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Table of content

Policies and logistics

COMPARATIVE ANALYSIS OF RESPONSIVE SUPPLY CHAIN STRATEGY IN GLOBAL COMPLEXITY MANUFACTURING INDUSTRIES

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ABSTRACT
This article presents a comparative analysis between American and Mexican manufacturing companies that is focused on the supply chain management, as well as how these companies have responded to the market. 254 manufacturing Mexican companies are compared with 559 companies reported by Roh et al. (2014) using data obtained through the International Manufacturing Strategy Survey. A structural equation model (SEM) that integrates 9 hypotheses is implemented, which relates 6 latent variables that fully integrate 20 observed variables validated through the partial least square technique. Also, the direct, indirect, and total effects among variables are obtained. The results indicate that there are some similarities and differences in the direct effect from relationships between latent variables, which may be mainly because the information and communications technologies have helped to integrate the supply chain, since the technologies implemented in the manufacturing processes have evolved and markets are increasingly globalized.

Keywords: supply chain, comparative analysis, maquiladora sector, manufacturing strategy.

1. INTRODUCTION

Cost associated with transportation of raw materials, handling of components, and the distribution system represent nearly 70% for some products, therefore, the supply chain (SC) is an area of opportunity for continuous improvement that allows companies to reduce cost and remain in the globalized and competitive market (Guo et al., 2018; Zhou et al., 2018). A supply chain is integrated by all direct or indirect activities and processes that are required in order to meet customers' requirements, where aspects associated with the raw materials supply, its processing in value-added product, and finally, with the distribution of products integration. Frequently, the recycling of the product is done at the end of its useful life (Wong and Ngai, 2019).

However, customers' requirements are constantly changing, consequently, the production orders change as well for the manufacturer, since more personalized products are required every day, which must be delivered in less time (Kisperska-Moron and de Haan, 2011).

Nevertheless, companies usually respond by improving SC strategies while providing a greater variety of products in less time, as well as presenting innovative features, where they need to share information with their customers in an agile way, in this sense, orders can be tracked in real time and a better support is offered after sales (Liu et al., 2019). Customers are essential for manufacturers because an appropriate information sharing with them will reduce risks in SC, as well as support the pull production systems by manufacturing only requested products (Boiko et al., 2019).

Furthermore, in a pull production system the quantity that is set to be produced is fundamental, which main benefits are associated with the small lot size, the low cost due to inventory management, the low cost due to obsolete raw materials, high inventory rotation, among others (Fowler et al., 2019). However, the most important aspect is that the manufacturer is assembling only products that are required by customers, therefore, the supply chain is going to be more agile among partners.

Similarly, it requires to be linked with the raw material suppliers as a principal requirement in the SC, which will not only be related with customers at the end. Also, manufacturers need to have a favorable information flow for reducing risks, sharing forecasts, as well as work plans to guarantee a supply process to avoid stoppages in production lines due to a lacking of raw materials (Shishodia et al., 2019).

However, these variables associated with customers and suppliers are external (Ayala et al., 2016), consequently, in order to guarantee the material flow, it is also necessary to analyze the production systems, such as, applied lean manufacturing tools that are included, for instance, kaizen, total quality management (Fowler et al., 2019), and the available manufacturing technology for the raw material transformation (Birasnav and Bienstock, 2019), among others.

In addition, the advanced manufacturing technology represents a computer-controlled or micro-electronics-based equipment used in the design, manufacture, or handling of a product (Jorge Luis et al., 2019). Currently, there are several taxonomies that are classifying the AMT as stand-alone, intermediate, and integrated system (Díaz-Reza et al., 2019), where a lot of them can be implemented in the supply chain and production processes, which provide agility, quality, and low cost to production (Koc and Bozdag, 2009).

According to previous paragraphs, several activities are required to guarantee a fast responsiveness to market, which is the most important aspect for manufacturers. In other words, a responsive SC strategy for a fast information, money, and material row flow is required. However, information sharing with customers and suppliers and a modern production process with adequate advanced manufacturing technology is required, where the principal problem is how they can be integrated in the SC.

1.1 Research problem and objective

Fortunately, there are several researches that are focused on integrating several tasks in the SC, which are aimed to have a fast response to market. For example, Wong et al. (2006) report a case study for responsiveness of volatile and seasonal supply chains, as special cloths; Bompard et al. (2007) analyze the impacts of price responsiveness on electricity markets, and how power supply must be fitted based on the demand; Rivera-Camino (2012) reports the most crucial individual and organizational drivers that enable a market responsiveness from an environmental point of view; Čiarnienė and Vienažindienė (2014) report the impact of the SC agility on responsiveness to market in the fashion industry, where a fast response is highly expected.

Moreover, Sardana et al. (2016) are focused on determining the impact of strategic alignment and responsiveness to market in the manufacturing firms performance, which indicate that a fast responsiveness must be part of strategies from the top management, because customers are always waiting for products on time, specially, Hum et al. (2018) indicate that companies invest a lot economical resources to get a high level in responsiveness, as a result, it is required to integrate a system to measure and control it.

Also, Fowler et al. (2019) indicate that responsiveness to market is one of the most relevant task for managers, which must be designed with push–pull supply chains along with multiple demand fulfillment, and recently, Ortega-Jimenez et al. (2020) indicate that advanced manufacturing technology must be reconfigurable to guarantee responsiveness to market through the SC.

In fact, a research that integrates several components or tools to guarantee a responsiveness to market is reported by Roh et al. (2014). Specifically, a structural equation model (SEM) was used to evaluate the relationship among the *Responsive supply chain strategy* (*RSCS*), *Information sharing with customers* (*ISC*), *Collaboration with suppliers* (*CSU*), *Advanced manufacturing technology* (*AMT*), *Pull production* (*PPR*), and *Responsiveness to market* (*RMA*), which are intertwined and validated with data from 559 manufacturing companies in different countries. Nonetheless, in six years the SC has been more integrated in the industrial sector, where the dependence between companies has been accentuated due to globalization, because information communications technologies have improved and facilitated a better integration into production systems, which are geographically distributed in different countries, therefore, it is essential to carry out a study that allows to identify the type of relationships that these variables have in their current conditions.

Particularly, in Mexico there are a lot of companies known as maquiladoras, which are subsidiary plants that have headquarters in other countries and are focused on assembling activities, taking advantage of free trade agreements, low labor costs, and closeness to the United States of America (Galván and García, 2018). Sometimes these industries have a duty and tariff-free that allow them to have access to raw materials from other countries in order to assemble, manufacture, or process them, and export the final product (García-Alcaraz et al., 2015).

According to the Mexican National Institute of Statistics and Geography (INEGI), nowadays, there are 5,115 maquiladoras (INEGI, 2019) established in Mexico, there are 1,421 maquiladoras in the northern of the country (27.78 percent), where 329 are established in Ciudad Juarez. Certainly, that industrial sector employs 305,313 direct workers and represent the most relevant economic sector.

As a matter of fact, these type of companies require special attention, because suppliers are established in one country, whereas the manufacturer is in Mexico and customers tend to be in another place; where a high technological level is provided and supply chains are very complex along with partners around the world.

For this reason, this paper is aimed to compare the findings reported by Roh et al. (2014) with the Mexican maquiladora sector in order to acknowledge the differences that can be presented from using a structural equation model, because that type of information will help managers to be focused on customers.

2. METHODOLOGY

Several tasks were performed to generate and validate the SEM proposed by Roh et al. (2014). This model proposes nine hypotheses from nine relationships among six latent variables. The hypotheses proposed are the following, where it is important to mention that readers interested in a theoretical justification about those relationships, should consider Roh et al. (2014):

H_1. *Responsive supply chain strategy* has a direct and positive effect on *Information sharing with Customers*.

H_2. *Responsive supply chain strategy* has a direct and positive effect on *Collaboration with suppliers*.

H_3. *Responsive supply chain strategy* has a direct and positive effect on *Advanced manufacturing technology*.

H_4. *Information sharing with customers* has a direct and positive effect on *Collaboration with suppliers*.

H_5. *Collaboration with suppliers* has a direct and positive effect on *Advanced manufacturing technology*.

H_6. *Information sharing with customers* has a direct and positive effect on *Pull production*.

H_7. *Collaboration with suppliers* has a direct and positive effect on *Pull production*.

H_8. *Advanced manufacturing technology* has a direct and positive effect on *Pull production*.

H_9. *Pull production* has a direct and positive effect on *Responsiveness to market*.

These hypotheses or relationships are illustrated in Figure 1 using the acronyms that were defined before.

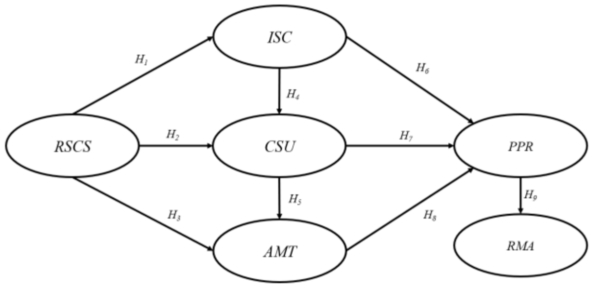

Figure 1. Proposed model

In order to validate and compare the model in different scenarios and time, the following steps were analyzed.

Survey design. Information is required for the SEM validation as well as to compare the models; the International Manufacturing Strategy Survey (IMSS) reported by (Roh et al., 2014) was used. The IMSS is adapted to the Mexican geographical context using three experts to review it; a copy is shown in (Roh et al., 2014), where each item integrating the six latent variables are listed and presented in the descriptive report.

Survey application. The IMSS is applied to Mexican maquiladora companies that belonged to the manufacturing sector from July to August 2018, which must be asnwered using a five-points Likert scale, where 1 indicates that the task is not done or not important, while 5 indicates that the task is always done or very important. Also, intermediate values, such as 2,3, and 4 are used for less important, kind of important, and important, respectively (Vonglao, 2017).

In the same way, an appointment is arranged with managers and engineers related to the supply chain, then a personal interview is done. If an interview is canceled three times, that case is not considered in the research.

Data registration and debugging. A database is created in the SPSS 24 ® software, which is widely used for data description as it is easy to work with (IBM, 2019). However, before registering the data from the survey, missing values are identified and replaced by the median, because a Likert scale is being used (Iacobucci et al., 2015). Also, outliers are identified by standardizing every item, where values over 4 are replaced by the median (Hoffman, 2019). Finally, uncommitted respondents are identified by estimating the standard deviation for every case or survey; if that value is under 0.5, it is not integrated in the analysis.

Description of the sample. The IMSS has a demographic section that is aimed to collect data from the participants, where some crosstabs are used to analyze the sample integration, such as gender, years of experience, industrial subsector, gender, among others.

Validation of latent variables. The latent variables in the model from Figure 1 are integrated by items, where Table 1 portrays the validation indexes that are used before they are integrated in the model (Kock, 2018):

Table 1. Validation indexes for latent variables

Index	Measuring	Best if
R2 and Adj. R2	Parametric predictive validity	>0.2
Composite reliability index (CRI) and Cronbach's Alpha (CAI)	internal and content validity	>0.7
Average variance extracted (AVE)	Convergent validity	>0.5
variance inflation factor (VIF)	collinearity	>5
Q2	Non-parametric predictive validity	~R^2

Significantly, it is essential to mention, that some validation indexes can be obtained in an iterative way, because sometimes by eliminating some items, they can be performed in a better way. Also, latent variables that fulfill the validity index are integrated in the SEM (Midiala et al., 2016).

Structural equation model

Before interpreting the SEM, some efficiency indexes are calculated, which are presented in Table 2 (Kock, 2019).

Table 2. Efficiency indexes for the SEM

Index	Measuring	Best if
Average path coefficient (APC)	Predictive validity	p<0.05

Average R-squared (ARS)	Predictive validity	$p<0.05$
Average adjusted R-squared (AARS)	Predictive validity	$p<0.05$
Average block VIF (AVIF)	Collinearity	<5
Average full collinearity VIF (AFVIF)	Collinearity	<5
Tenenhaus GoF (GoF)	Data fit to model	>0.36

Likewise, three types of effects are calculated in the SEM: the direct effects between the LV that represent the proposed hypotheses in Figure 1, the indirect effects that occur by moderating variables, which require two or more segments, and the total effects (sum of the direct and indirect effects)(García-Alcaraz et al., 2015; Villanueva-Ponce et al., 2015). Especially, for the direct effects, the size effect (SE) is calculated in each dependent variable, which is defined as the variance explained by independent latent variables, and the sum of the SE in a latent variable is the R^2 value (Schubring et al., 2016).

Furthermore, the SEM is evaluated through the partial least square technique integrated in the WarpPLS v.6® software, which is widely recommended for small samples with ordinal scale answers, as in this study (Kock, 2019).

3. RESULTS

After 3 months of applying the survey, 254 valid responses were obtained, where 68 correspond to women, while 168 to men. Further paragraphs and subsections are describing the main findings.

3.1 Description of the sample

Table 3 describes the sample, where it is observed that most respondents were engineers with 111 responses, followed by technicians with 80 responses. Also, the higher category in years of experience are the respondents with 2-5; this indicates that the data comes from reliable and committed participants.

Table 3. Years of experience and job position

Years of experience	Job position				Total
	M	E	S	T	
0 - <1	0	11	2	19	32
1 - <2	8	27	2	17	54
2 - <5	7	38	14	24	83
5 - <10	9	19	9	9	46
>10	4	16	8	11	39
Total	28	111	35	80	254

M= Manager; E=Engineer; S=Supervisor; T=Technician

Table 4 portrays the industrial sector as well as gender. Specifically, it is observed that 169 respondents were male, whereas 85 were female. Also, it is observed that the automotive sector was the most surveyed, followed by electric fabricants.

Table 4. Industrial sector and gender

Industrial sector	Gender		Total
	Female	Male	
Automotive	46	109	155
Electric	8	21	29
Medical	12	14	26
Machinery	8	10	18
Electronics	6	7	13
Aeronautics	2	5	7
Logistics	3	3	6
Total	85	169	254

3.2 Descriptive analysis of the items

Table 5 illustrates the descriptive analysis for the items in each latent variable, indicating the median and the interquartile range. It is observed that every item has a value over three but under four, indicating that they are relevant in the responsiveness to market.

Table 5. Latent variables/items analysis

Latent variable/items	Median	RI
Responsive supply chain strategy		
Wider product range	3.84	1.58
Offer new products frequently	3.72	1.7
Offer more innovative products	3.94	1.64
Information sharing with customers		
Data analysis, audit, and reporting	3.92	1.67
Access to catalogues	3.7	1.66
Order management and tracking	3.83	1.66
Content and knowledge management	3.76	1.58
Collaboration support services	3.92	1.57
Collaboration with suppliers		
The material inventory can be managed or held through a website by suppliers	3.52	1.84
Collaborative Planning, Forecasting, and Replenishment	3.73	1.7
Physical integration of the supplier into the plant	3.63	1.96
Advanced manufacturing technology		
Automated parts loading/unloading)	3.74	1.75
Automated guided vehicles, AGVs	3.31	1.86
Automated storage-retrieval systems, AS/RS	3.5	1.94
Pull production		
Undertaking actions to implement pull production (e.g., reducing batches, setup time, using Kanban systems, etc.) for the last 3 years	3.8	1.6

Planned effort to implement pull production (e.g. reducing batches, setup time, using Kanban systems, etc.) within next the next 3 years	3.95	1.66
Responsiveness to market		
Time to market	3.57	1.61
Delivery speed	3.73	1.71
Delivery dependability	3.92	1.62
Manufacturing lead time	3.71	1.6

3.3 Validation of latent variables

After debugging the dataset, Table 6 illustrates the results for the LV validation process, where it is observed that they comply with the expected values, because the R^2 and adjusted R^2 are over 0.2, which confirms the predictive validity, since the Composite reliability index and the Cronbach's alpha are over 0.7 that confirm the intern and composite validity, AVE is over 0.5, which demonstrates convergent validity, VIF is under 5, which indicates that there is a collinearity absence, and finally, Q^2 is similar to R^2, which indicates that there is non parametric predictive validity.

Table 6. Validation of latent variables

	RSCE	*ISC*	*CSU*	*AMT*	*PPR*	*RMA*
R^2		0.622	0.587	0.559	0.58	0.689
Adj. R2		0.621	0.583	0.556	0.575	0.688
CRI	0.933	0.948	0.917	0.908	0.953	0.942
CAI	0.893	0.931	0.864	0.846	0.901	0.918
AVE	0.823	0.784	0.787	0.768	0.91	0.802
VIF	3.009	3.754	3.224	2.366	3.339	3.469
Q^2		0.609	0.578	0.554	0.57	0.675

According to these values, all latent variables can be integrated in the SEM to be evaluated.

3.4 Structural equation model

Due that latent variables are adequate and fulfill the validation process, they are integrated in the SEM. Table 7 indicates the model fit index and quality indexes before its interpretation, whereas Figure 2 illustrates the evaluated model.

Table 7. Model fit and quality indexes

Index	Value	Best if
APC	0.449 (p<0.001)	p<0.05
ARS	0.607 (p<0.001)	p<0.05
AARS	0.605 (p<0.001)	p<0.05
AVIF	2.515	<5
AFVIF	3.194	<5
GoF	0.703	>0.36

According to those values, it is concluded that there is enough predictive validity, because the p-value associated to APC, ARS, and AARS is under 0.05; there are no problems associated to collinearity, because the AVIF and AFVIF are under 5, and finally, it is concluded that the data from the survey has an adequate fit to the model, because the GoF is over 0.36. In fact, considering findings in Table 7, the model is interpreted.

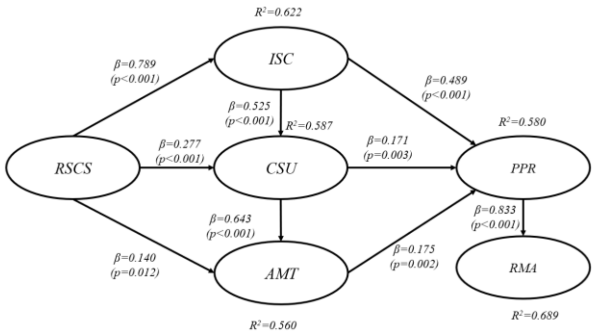

Figure1. Evaluated model

3.5 Direct effect in SEM

Figure 1 presents the evaluated model, where for each relationship there is a β value as well as a p-value for the statistical significance test. Also, each dependent latent variable indicates a value for R^2 as a measure for the variance explained by independent latent variables. In addition, direct effects allow to state conclusions about the hypotheses proposed in Figure 1, where according to the p-values, all the direct effects are statistically significant, which conclusions are as follow:

H_1. There is enough statistical evidence to declare that the *Responsive supply chain strategy* has a direct and positive effect on *Information sharing with Customers*, because when the first latent variable increases its standard deviation in one unit, the second variable increases in 0.789 units.

H_2. There is enough statistical evidence to declare that the *Responsive supply chain strategy* has a direct and positive effect on *Collaboration with suppliers,* because when first latent variable increases its standard deviation in one unit, the second variable increases in 0.277 units.

H_3. There is enough statistical evidence to declare that the *Responsive supply chain strategy* has a direct and positive effect on *Advanced manufacturing technology*, because when the first latent variable increases its standard deviation in one unit, the second variable increases in 0.140 units.

H_4. There is enough statistical evidence to declare that the *Information sharing with customers* has a direct and positive effect on *Collaboration with suppliers,* because when the first latent variable increases its standard deviation in one unit, the second variable increases in 0.525 units.

H_5. There is enough statistical evidence to declare that the *Collaboration with suppliers* has a direct and positive effect on *Advanced manufacturing technology,* because when the first latent variable increases its standard deviation in one unit, the second variable increases in 0.643 units.

H_6. There is enough statistical evidence to declare that the *Information sharing with customers* has a direct and positive effect on *Pull production,* because when the first latent variable increases its standard deviation in one unit, the second variable increases in 0.489 units.

H_7. There is enough statistical evidence to declare that the *Collaboration with suppliers* has a direct and positive effect on *Pull production,* because when the first latent variable increases its standard deviation in one unit, the second variable increases in 0.171 units.

H_8. There is enough statistical evidence to declare that *Advanced manufacturing technology* has a direct and positive effect on *Pull production,* because when first latent variable increases its standard deviation in one unit, the second variable increases in 0.175 units.

H_9. There is enough statistical evidence to declare that the *Pull production* has a direct and positive effect on *Responsiveness to market,* because when the first latent variable increases its standard deviation in one unit, the second variable increases in 0.833 units.

Specifically, Table 8 illustrates the direct effects obtained in the model proposed by authors using data from Mexican maquiladoras, where the direct effects obtained by Roh et al. (2014) through manufacturing companies around the world.

Table 8. Direct effects from both models

H_i	Hypotheses	Authors model	Roh et al. (2014)
H_1	*RSCS→ISC*	0.789	0.19
H_2	*RSCS→CSU*	0.277	0.23
H_3	*RSCS→AMT*	0.14	0.11
H_4	*ISC→CSU*	0.525	0.47
H_5	*CSU→AMT*	0.643	0.4
H_6	*ISC→PPR*	0.489	-0.06*
H_7	*CSU→PPR*	0.171	0.35
H_8	*AMT→PPR*	0.175	0.21
H_9	*PPR→RMA*	0.833	0.24

According to data in Table 8, some differences are observed. For instance, the relationship between *RSCS* and *ISC* is different in both models, because in the authors model that relationship is very high with β=0.789, while in Roh et al. (2014) is β=0.19, which represent an increment in 415.26%. Also, the relationship between *PPR* and *RMA* is highly different, because in the authors model it is indicated as β=0.833, whereas in Roh et al. (2014) is only β=0.24, which represent an increment in 347.08%. On one hand, the relationship between *ISC* and *PPR* in Roh et al. (2014) is statistically not significant, but on the other hand, in the authors model that relationships is significant. All other values seem to be similar.

3.6 Size effects

Table 9 shows the size effect for the R^2 decomposition in its components. This analysis is relevant, since it helps to identify the most critical relationships to explain a dependent variable. For example, *SCU* is explained in 0.587 (58.7%) by *RSCS* in 0.194 and by *ISC* in 0.393, which demonstrates that for *CSU* the most important variable is *ISC,* because is bigger. Another clear example is that *PPR* is explained in 0.580 by *ISC* in 0.358, by *CSU* in 0.116 and by *AMT* in 0.106, which indicates that for *PPR* the most essential variable is *ISC,* because it has the highest size effect.

Table 9. Effect size decomposition

To	From					R^2
	RSCS	*ISC*	*CSU*	*AMT*	*PPR*	
ISC	0.622					0.622
CSU	0.194	0.393				0.587
AMT	0.083		0.477			0.560
PPR		0.358	0.116	0.106		0.580
RMA					0.689	0.689

3.7 Sum of indirect effects in the authors model

Table 10 illustrates the indirect effect obtained in the authors model, and unfortunately, Roh et al. (2014) did not report this kind of relationships for a comparison. Nevertheless, it is fundamental to report that the values reported in the present research represent the sum of indirect effects, containing indirect effects with 2, 3, 4, and 5 segments. These relationships are important because a direct relationship between *RSCS*, *ISC*, *CSU,* and *AMT* with *RMA* (the independent variable) is not found, but this indirect effect allow to measure dependency among variables. Also, according to the p-value that is obtained, it is concluded that each indirect effect is statistically significant.

Table 10. Sum of indirect effects

To	From			
	RSCS	ISC	CSU	AMT
CSU	0.414*			
AMT	0.445*	0.338*		
PPR	0.606*	0.149*	0.113‡	
RMA	0.503*	0.529*	0.236*	0.146*

* p<0.001 ‡ p<0.005

3.8 Total effects

The sum of direct effects and the sum of indirect effects is called total effects, which are illustrated in Table 11. In fact, if two latent variables do not have indirect effects, then the direct and total effect are the same. Specifically, it is observed that the total effects are wide, and each value is statistically significant based on the p-value associated. In addition, it is relevant to mention that the direct effect between *PPR* and *RMA* is the biggest, as well as in the total effects' category, indicating that it is highest relationship.

Table 11. Total effect from the authors model

To	From				
	RSCS	ISC	CSU	AMT	PPR
ISC	0.789*				
CSU	0.692*	0.525*			
AMT	0.585*	0.338*	0.643*		
PPR	0.606*	0.638*	0.284*	0.175‡	
RMA	0.503*	0.529*	0.236*	0.146*	0.833*

* p<0.001 ‡ p=0.002

4. CONCLUSIONS

The direct effects between six latent variables analyzed by Roh et al. (2014) in 20 countries have been correlated to the Mexican maquiladora industry variables. Also, 9 relationships between the LV were compared in which several similarities have been found in the relationships between *RSCS→CSU, RSCS→AMT,* and *AMT→PPR.* However, some differences were found in the relationships between *RSCS→ISC, ISC→CSU, CSU→AMT, ISC→PPR, CSU→PPR*, and *PPR→RMA.*

For instance, regarding the similarity between *RSCS* and *CSU*, it is a result of the SC strategy that is still the same, and companies are trying to have a wide production range to fulfill the market demands, offer new or modified products with a high innovative level. Significantly, according to the SC management rules, a supplier is always integrated in the manufacturer's production process. Likewise, the relationship between *RSCS* and *AMT* is similar, because the production technologies are still used in the same innovation level.

Moreover, regarding the differences in some relationships; the direct effect between *RSCS* and *ISC* is 0.789 and 0.19, in the authors model and in Roh et al. (2014) respectively, which may be due to information systems for the information sharing with customers that have evolved in the last five years. Also, it can be because of the maquiladora industry nature, which is a subsidiary company that is established in another country, where it is depending completely on headquarters in other countries, which are the main customers for the maquiladora.

Finally, another significant difference between the models is seen in the relationship between *PPR* and *RMA*, which is because the maquiladoras only tend to respond to the headquarters with the production that is requested, therefore, only placed orders by their customers are produced.

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THE POST-DISASTER LOGISTICS IN MEXICO COMPARED TO THE REST OF THE WORLD

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ABSTRACT
The main purpose in humanitarian logistics is relieving the suffering of vulnerable people. Post-disaster logistics focuses on the efficient management to respond to the urgent needs from the affected people under emergency conditions. In the event of a disaster, the national and local civil protection structures and the international response structures can respond to the society needs. The objective of this paper is to present the situation of the post-disaster logistics in Mexico compared to the rest of the world. First, the post-disaster logistics is introduced; then, a description of the disaster management process is presented, including the disaster management cycle, the stakeholders in the relief operations and the international agreements; later, disaster logistics activities in Mexico and the rest of the world are explained, including official provisions and processes for disaster response in Mexico and other countries, and the international relief efforts of some organizations engaged in disaster management activities; and finally, a literature review on post-disaster logistics models is presented, providing advances and shortcomings.

Keywords: humanitarian logistics, disaster relief operations, disaster preparation phase, disaster response phase

1. INTRODUCTION

The logistics concept has evolved according to the challenges it has faced at different times, from the military art that studied the operations on the battlefield, to the set of control techniques and the management of flows of raw materials and products from the supply sources to the consumption points (Antún 1994).
Currently, important variations of logistics with different scopes are studied; two of them are commercial logistics and humanitarian logistics. Commercial logistics usually deals with factors like a specific number of suppliers, manufacturing sites, and predictable demand; all of them are unknown factors for humanitarian logistics.
Humanitarian and commercial logistics have common elements, such as planning and preparedness, design, procurement, transportation, inventory, warehousing, and distribution. All logistics operations must be designed in such a way that they make arrive the right goods to the right place and distribute them to the right people at the right time (Van Wassenhove 2006); but the main purpose of humanitarian logistics is relieving the suffering of vulnerable people (Thomas and Kopczak 2005).
The International Federation of Red Cross and Red Crescent Societies (IFRC 2019) defines ‘disaster’ as a sudden calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community’s or society’s ability to cope using its own resources.
The world has experienced several disasters with tremendous consequences, the humanitarian logistics applied to disasters has received increasing interest from researchers and practitioners just since 2004 when the Indian Ocean tsunami happened (Kóvacs and Spens 2007).
Disasters generate a massive demand for aid, including food, medicines, shelter, water and other resources, which makes logistics a critical element to carry out a successful relief operation (Safeer, Anbuudayasankar, Bulkumar and Ganesh 2014). Logistics is also the most expensive part of any disaster relief (Van Wassenhove 2006). Post-disaster logistics focuses on the efficient management to respond to the urgent needs from the affected people under emergency conditions (Sheu 2007).
The challenges faced during the relief efforts need improvements in the area of the humanitarian logistics and supply chain management, hence the scientific community has been developing models, methods and techniques inspired by different disaster scenarios (Gutjahr and Noltz 2016).
This paper is organized as follows: Section 2 presents the main characteristics of the disaster management process, including the disaster management cycle, the stakeholders in the relief operations and the international agreements; Section 3 provides an overview of the disaster logistics activities carried out in México and a group of selected countries, and the role of the humanitarian international organizations; Section 4 offers a review on disaster logistics models, providing advances and shortcomings; and the paper ends with conclusions and future work.

2. DISASTER MANAGEMENT PROCESS

The combination of hazards, vulnerability and inability to reduce the potential negative consequences of a risk results in a disaster (IFRC 2019). According to Van Wassenhove (2006), a disaster can be natural or man-made; according to their speed of onset, natural disasters can be classified as 'slow onset' disasters such as drought and famine, and 'sudden onset' disasters such as earthquakes and tsunamis. The occurrence of some of them are cyclical in nature such as hurricanes. Natural disasters represent only 3% of disaster relief operations (Van Wassenhove 2006).

2.1. The Disaster Management Cycle

Disaster relief efforts are characterized by considerable complexity and uncertainty, in order to address and implement better responses they need to be properly managed (Tomasini and Van Wassenhove 2009); the disaster management cycle is a process composed of several stages, the most commonly accepted are the following phases (Cozzolino 2012):

1. The *mitigation* phase: includes laws and mechanisms to reduce social vulnerability, mainly as a government responsibility.
2. The *preparation* phase: refers to operations that occur during the period before the disaster strikes. In this phase, the information and communication technology systems, the bases for collaboration and the physical network are developed.
3. The *response* phase: operations that are instantly implemented once a disaster strikes. In this phase the first 24 to 72 hours after the disaster are essential to help as many victims as possible. This phase has two main objectives, which can be seen as two sub-phases:
    - The immediate-response subphase: Time is crucial here. The emergency plans of regional actors come to action (Kóvacs and Spens 2007). Humanitarian organizations' first step is to send a first response team to determine the population affected, the level of damage, and what type of help they need and what kind of material are needed. This reaction should be extremely fast (Agostinho 2013).
    - The restore sub-phase: The objective is to restore in the shortest time the basic services and delivery of goods to the highest possible number of victims.
4. The *reconstruction* phase: operations in the aftermath of a disaster. It involves rehabilitation, and this phase aims to address the problem from a long-term perspective.

This paper is mainly focused on the preparedness and emergency response phases.

2.2. Stakeholders in the relief operations

In the event of a disaster, humanitarian relief operation management engages different kind of players, with their own purposes, mandates, interests, culture, capacity and logistics expertise (Balcik, Beamon, Krejci, Maramatsu and Ramírez 2010).

Kóvacs and Spens (2007) categorized the key players as follows: governments, the military, aid agencies, donors, non-governmental organizations, and private sector companies.

Governments are the activators of humanitarian logistics stream after a disaster strikes; they can authorize operations and mobilize resources. Without the authorization from the host government, no other player can operate in the disaster zone, except the national aid agencies and the military. Local governments are responsible for putting into place protocols and act to reduce the impact of disasters.

The military are a crucial actor since soldiers can provide primary assistance due to their high planning and logistics capabilities.

Aid agencies: are entities through which governments can attend the suffering caused by disasters.

Donors provide the bulk of funding for major relief activities. Donations can be in-cash and in-kind while logistics operations are performed.

Non-governmental organizations (NGOs) include different size organizations, some of them are temporary, being created just to address one particular crisis.

Private sector companies can play one or more of the following roles: as a donor by giving financial contributions; as a collector by gathering financial means from its customers, its employees and its suppliers to fund aid operations; and as a provider by offering its goods and services for free. Logistics service providers are excellent partners of humanitarian organizations through their logistics and supply chain management core capabilities.

2.3. International Agreements

An important role in the humanitarian relief process can be played by international collaboration agreements subscribed by governments or aid agencies. They let to put into place support protocols and take actions to assist when a disaster strikes and local capability cannot cope with the emergency.

One of the most important international agreement is the Sendai Framework for Disaster Risk Reduction.

According to the United Nations Office to Disaster Risk Reduction (UNDRR) (2019) the Sendai Framework is a 15-year, voluntary, non-binding agreement which recognizes that the State has the main role to reduce disaster risk, but that responsibility should be shared with other stakeholders: local government, private sector and other decision-makers. The framework outlines four priorities for action to prevent new and reduce existing disaster risks:

1. Understanding the disaster risk.

2. Strengthening the disaster risk governance to manage disaster risk.
3. Researching on disaster reductions for resilience.
4. Enhancing disaster preparedness for effective response, and to build back better in recovery, rehabilitation and reconstruction.

This agreement aims to achieve a substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries (UNDRR 2019).
The Framework was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan.

3. DISASTER LOGISTICS ACTIVITIES IN MEXICO AND THE REST OF THE WORLD

In the event of a disaster, national and local civil protection structures, and international response structures can respond. Each country has developed mechanisms and organizations, according to its experience, responsible for preparing tasks, mitigation risk, and providing assistance services to people, as a way for responding to its society needs. When a major disaster occurs, the local response capability is generally exceeded, giving way to obtaining international aid. Countries and donors who want to help look for 'the best way' to do it, which can be sending goods such as medicines, food, etc., or sending international search and rescue teams. The first 24 to 72 hours after the disaster are essential to help as many victims as possible.
A review of the official provisions and norms related to post-disaster logistics in Mexico and other countries (Japan, Chile, Spain and the United States) is presented below. Also information about the operations in disaster management and the role of the international organizations engaged in disaster management activities, are presented.

3.1. Official provisions and processes for disaster response in Mexico and other countries

Each country focuses its efforts on the disasters that frequently affect its territory, considering diverse actions for each stage of the disaster management, led by a national authority, and influenced by the sociocultural characteristics of the population. The actions have generally evolved according to its experience on disasters.
Despite many disasters have happened in México, the responsiveness from the government civil protection agencies has evolved slowly. The civil protection programs have arisen as a result of the disasters, and some events have evidenced a lack of protection from the government agencies to the affected population (Cienfuegos 2011).
In order to respond to emergencies, the Mexican government created the National Center for Disaster Prevention (CENAPRED), after the 1985 earthquake in Mexico City, with the support of the government of Japan and the Universidad Nacional Autónoma de México. CENAPRED is a Technical - Scientific center for disaster prevention responsible for conducting research, monitoring disturbing phenomena and spreading civil protection culture (CENAPRED 2018).
In 1986, the National Civil Protection System (SINAPROC) was created, which laid the foundations for coordinating efforts and gradually allowed the creation of emergency response plans (Cienfuegos 2011).
The Mexican emergency response plans consider the stages of civil protection, including actions of the authorities in ascending hierarchical order, starting from the community, the municipality, the state and the federal government; each of them has its own plan according to the main risks it faces (Jefatura de Gobierno 2014).
Annual human and material losses caused by natural disasters have high costs for the country, so the National Development Plan 2013-2018 establishes the need of strengthen prevention actions to reduce risks (Gobierno de la República 2014).
Preventive actions such as evacuation drills, technical studies, outreach campaigns, and development, updating and outreach of the risk atlases with different levels of access to information, are included in the Law of the Civil Protection System of Mexico City (Jefatura de Gobierno 2014).
In Japan, Chile, Spain and the United States, the emergency response plans are regionalized, established according to the main risks they face, and the population has a free access to them (BOSAI 2015, ONEMI 2019, Talavera 2013, FEMA 2019).
An important element for the development of emergency response plans is the risk atlas. In the United States the main ones are the Flood Hazard Maps (FEMA 2019); Chile has regional risk maps for different scenarios, end evacuation maps which include routes and safe areas (ONEMI 2019); in Japan, the risk maps are regional and include the probabilities of occurrence of each phenomenon (BOSAI 2015); and Spain has the national map of civil protection risks (Talavera 2013).
The Regulation of the Law of the Civil Protection System of Mexico City (Jefatura de Gobierno 2017) states the need of hazard and risk atlas, which must include an information system composed of georeferenced databases, cartographic information of hazards, vulnerability, and facilities exposed to risk, and risk maps.
The National Civil Protection Program 2013-2018 identified a vulnerability in the available information. The public policies must be based on the analysis of the National Risk Atlas, however it usually is outdated and its scale does not allow inquiries about the level of risks in a specific area (Secretaría de Gobernación 2014).
The early warning systems, coordinated by government agencies, are important tools to inform population about seismic, volcanic, meteorological and tsunami risks (Secretaría de Gobernación 2014).
When a large scale disaster strikes, the emergency must be addressed; immediate actions will be carried out such

as: identifying the type of risk and the affected area, cordoning security perimeters, controlling access and evacuation routes, orientating the population, opening temporary shelters, coordinating of assistance services, among others. If the capability of response is exceeded, higher instances of government must be involved. Figure 1 shows the process of disaster relief operations in Mexico.

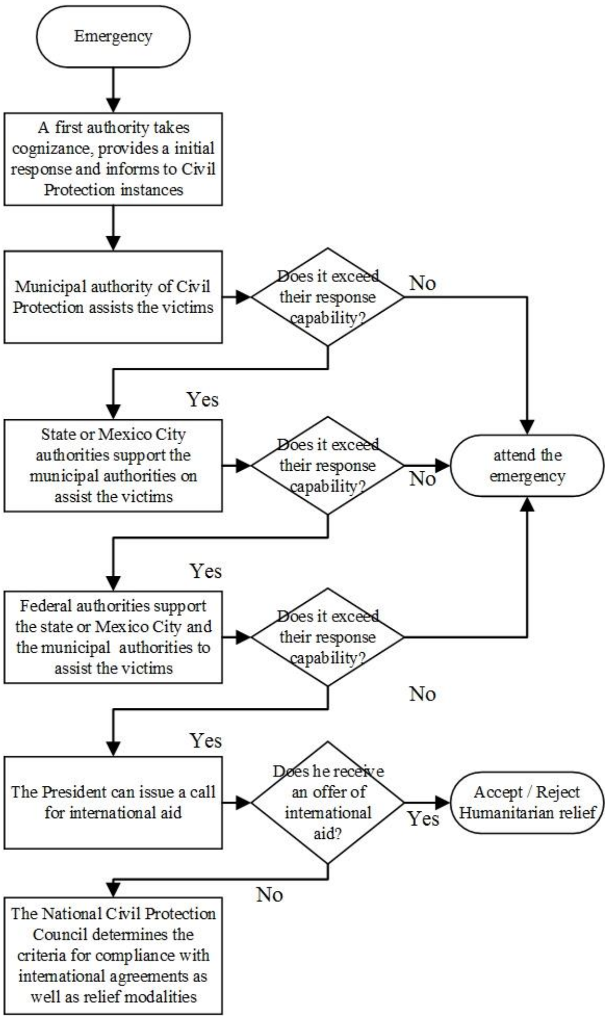

Figure 1: Process of disaster relief operations, based on Secretaría de Gobernación (2018)

The national authorities responsible for dealing with disasters are the following: SINAPROC in Mexico, the Office of the Cabinet / Minister for Disaster Management, in Japan; the DHS / FEMA, in the United States; the National Emergency Office of the Ministry of Interior (ONEMI), in Chile, and the National Civil Protection System, in Spain.

The Regulation of the Law of the Civil Protection System of Mexico City contemplates social and private participation in victim assistance activities, through voluntary groups, community brigades and accredited third parties (Jefatura de Gobierno 2017).

The army must provide relief in the event of a disaster, through DN III – E Plan, which can be carried out independently or jointly with other government agencies (SEDENA 2019). According to Cienfuegos (2011) this Plan responds to earthquakes, hurricanes, floods and fires, among others, through the deployment of specialized personnel, logistics and supply activities, and the coordination of air operations and damage assessment.

As a preventive measure during the hurricane season, engineering groups are deployed in Mexico City, Monterrey, Guadalajara and Valladolid; each one has personnel, material, tools, heavy machinery and a communal kitchen (Cienfuegos 2011).

Marine Plan respond to a disaster similarly as DN III-E Plan. Its action is focused on naval areas (coastal areas) and Mexico City, but can provide support if required in other regions (SEMAR 2019).

The National Civil Protection Program 2013-2018 (Secretaría de Gobernación 2014) identifies three main problems:

- The relationship with the organized civil society has been neglected despite its great potential; and the link of SINAPROC with national and international organizations, research centers and academic institutions has a limited exchange of knowledge on civil protection and risk management.
- The coordination in emergencies and disasters is limited by SINAPROC; there is a lack of records about the state of the national network of community brigades and voluntary groups, which difficult convene them in a situation of need, wasting human resources.
- Historically, disaster relief has been left to the army, minimizing the prevention and training actions by the government agencies and society, which implies a significant decrease in the capacity to respond, duplication of excessive efforts and expenses in reconstruction.

Some civil society organizations, which are not necessarily linked to government sponsorship, provide support in the event of disasters, both in search and rescue activities and in the collection and transfer of food to be distributed in the damaged areas. Mexican Red Cross and team ‘topos’ are some examples.

Being one of the countries that faces many natural disasters, Japan has become the reference country, with a budget oriented towards research and prevention, which seeks to develop innovative disaster management systems, promote the conservation of the national territory, improve weather forecasting technologies, and update communication and information technologies for disasters. One of the Japan’s mainstays is risk education, so its citizens know the general disaster procedures. Its emergency plans are specifically developed for the risks of each region and are constantly reviewed (BOSAI 2015).

In Chile, prevention is the key for saving lives, so it promotes the population educating for self-care through the “Prepared Chile” program, which carries out actions such as the strengthening of the Emergency and Early Warning System and the Civil Protection System. ONEMI assumes that the Disaster Risk Management is a process of continuous development, execution, monitoring and assessment, so it implements an 'Emergency Management System' in order to ensure a timely and effective response to emergencies (ONEMI 2019).

Spain has a structured Civil Protection System to deal with the disaster phases. They have strengthened the planning and emergency intervention; have standardized the actors' knowledge by means of training circuits to the personnel that acts in emergencies, for each specialty (Talavera 2013).

In the United States, the National Response Framework establishes a comprehensive, national and all-hazard approach to incident response. Strategic and operational planning prioritizes and identifies levels of performance and capacity requirements; it provides the standard for assessing capabilities and helps parties to know their functions (DHS 2019).

The FEMA Risk Analysis Division applies engineering, planning, and advanced technology to determine the potential risks of a natural event. Mobile emergency response provides support for telecommunications, logistics and self-sustaining operations through detachments that can be implemented immediately (FEMA 2019).

If an incident exceeds the ability of the Federal Emergency Management Agency, the Ministry of Homeland Security is authorized to activate the DHS Surge Capacity Force (SCF) to increase the federal disaster response. The SCF is composed of federal DHS employees and other agencies to help support response and recovery efforts. The program is administered by FEMA (DHS 2019).

3.2. Role of the international organizations

The international organizations develop activities, mainly in the preparedness and emergency response stages. Their main task is to facilitate the support work to national organizations by means the coordination of the procurement and delivery of international aid.

When a disaster occurs, people ask for help first to their own communities and governments and, secondly, to neighbouring countries and regional/international organizations. Three of the most important international organizations engaged in disaster relief activities are the following: United Nations, The International Federation of Red Cross and Red Crescent Societies and The Sphere Project.

United Nations (UN) is a multinational organization that is made up of agencies, funds and programs that address social problems; some of its entities play different roles providing humanitarian assistance, including the United Nations Development Program (UNDP), responsible for natural disaster mitigation and preparedness operations, and the World Food Program (WFP) (United Nations 2018).

The Office for the Coordination of Humanitarian Affairs (OCHA) is responsible for bringing humanitarian actors to intervene in emergencies, for mobilizing and coordinating effective humanitarian assistance and for collaborating with national and international agents to assist victims in case of catastrophe or emergency (OCHA 2018).

The Central Emergency Response Fund (CERF), managed by OCHA, allows humanitarian support of victims and receives voluntary donations to finance response actions worldwide. The UN Disaster Assistance Assessment and Coordination (UNDAC) team aims to provide reliable information and coordinate international assistance. This team usually stays in the affected area during the initial response phase up to three weeks in natural disasters. The international disaster response system consists of four components: personnel, methodology, procedures and equipment (OCHA 2018).

The Search and Rescue Operations Advisory Group (INSARAG) was created after the earthquakes in Mexico in 1985 and in Armenia in 1988, by the Urban Search & Rescue (USAR) teams. INSARAG contributes to the implementation of the International Strategy for Disaster Reduction (INSARAG 2015).

The international USAR teams act when the capacity of response of the affected country is exceeded and the national authorities accept the international relief; the assistance provided is based on the needs of the affected country and not on the availability of resources. International assistance is the third level of humanitarian assistance, which is requested for specialized tasks (INSARAG 2015).

INSARAG (2015) recognizes in the response framework of USAR teams that, search and rescue efforts start immediately after a large-scale disaster occurs; rescue efforts immediately begin by residents, complemented by local emergency services and then by local rescue teams, and continue by using of regional or national resources. The USAR international teams respond after a few days, following the official request for international assistance from the affected government. Each higher level of response considers an increase in rescue capacity and overall capacity, but it has to be integrated and support the already operating response. Work practices, technical language and information must be common and shared among all, in order to ensure the integration of the different levels of response (INSARAG 2015).

The five USAR components must be covered: administration, search, rescue, medical care and logistics. Many countries, international organizations and NGOs have prepared capacity that can be deployed in a very short time to assist in disaster. A country or organization may also decide to channel its support through UN agencies or NGOs (INSARAG 2015).

The International Federation of Red Cross and Red Crescent Societies (IFRC) groups 186 National Societies and its main mission is to provide humanitarian aid (Carrasco, Bará and Brunet 2011).

Two basic tools are required to provide disaster relief:

- Emergency Assistance Fund: constituted by 'preventive' donations that allow the necessary financial resources to activate the humanitarian response.
- Emergency Response Units (ERU): they are a modular system of rapid intervention in the event of a disaster, which can be at the disaster site within 72 hours.

Each ERU is prepared to act autonomously for at least one month and can remain in the field for up to four months. ERUs have well trained staff and previously identify and group the necessary material resources according to logistic criteria of rapid projection and deployment on the ground (Carrasco, Bará and Brunet 2011).
There are different types of ERU, depending on their activities in the field, which can be: basic health care, water and sanitation, mass sanitation, telecommunications, and logistics and distribution. Carrasco, Bará and Brunet (2011) point out that in the event of a disaster, the IFRC sends the Field Assessment Coordination Team (FACT), i.e., disaster management specialists deployed in the first 12 - 24 hours to the affected area, to assess the most pressing needs: shelters, water and sanitation, food and basic health care. The information on the needs in the field is centralized in the Relief Mobilization Table, which is sent to IFRC headquarters in Geneva, from which a call to National Societies and potential donors is launched. Simultaneously, the FACT determines what type of ERU is needed based on the magnitude of the disaster and its evolution, the needs of the victims, the ability of the Red Cross of the affected country, the lack of local resources to adequately deal with the disaster and the available resources from other agencies for the same event. Then the National Societies report their availability, and the final decision on the deployment is taken by the IFRC that will determine what type of ERU will move and the country responsible for the operation.
Once in the disaster place, the ERU contacts the National Society affected and, as far as possible, welcomes local volunteers to collaborate in its activities. The National Society that sponsors the ERU funds the travel expenses and salaries of the displaced specialized personnel, and is responsible for constituting the group, its previous training and ensuring that it has the required skills and expertise (Carrasco, Bará and Brunet 2011).
The IFRC logistics network has three regional logistics units (RLUs) to provide maximum global coverage, which are strategically located in the following places: Dubai, which covers Europe, the Middle East and Africa; Kuala Lumpur, to serve Asia and Australia; and Panama (the Pan-American Disaster Regional Unit), for the Americas (Carrasco, Bará and Brunet 2011).
Pre-positioning inventory of humanitarian items at strategical locations reduces lead time and obtains lower transportation costs. The network with pre-positioned inventories at regional locations allows to provide a faster response by air in the early days after a disaster strikes, where speed is a critical factor (Carrasco, Bará and Brunet 2011).
The Sphere Project Handbook is a collaborative effort between hundreds of Non-Governmental Organizations to stablish minimum humanitarian standards to be met in relief. The Sphere Handbook also states that agencies should provide aid impartially according to need but makes no mention of specific procedures (Sphere 2018). The implementation of the standards contained in the handbook is a decision of each organization but is generally considered as a reference by practitioners.

4. STATE OF THE ART ON MODELS FOR POST-DISASTER LOGISTICS

Mexico has several opportunity areas in post-disaster logistics. It is necessary to analyze whether certain actions can be successful for future emergency events in our country, taking account of the particularities of our territory and idiosyncrasy.
Disaster operations management provides techniques to prepare a community and reduce the severity of the damage caused by disasters. Even though governments and organizations use disaster management to try to reduce disaster's impacts, the decision-making process to support an emergency response is not an easy process; the unpredictability, magnitude, uncertainty and complexity of these events make difficult to develop efficient plans (Hoyos, Morales and Akhavan-Tabatabaei 2015). The stakeholders need to consider these issues and the available resources; humanitarian decision makers often make non-optimal decisions due to over-reliance on experience, over-confidence in their own unaided decision-making abilities, and the use of simple decision tools (Alem, Clark and Moreno 2016). The resulting poor decisions have attracted considerable research attention on disaster operations management, wich is reflected on the increasing number of research papers.
According to Altay and Green (2006) a better understanding of the specific characteristics of the events and their impact is still needed in order to develop pertinent models.
Several literature reviews have been carried out on mathematical models applied to Disaster and Humanitarian Logistics considering different approaches, as described below.
Caunhye, Nie and Pokharel (2012) separated the activities on field into pre-disaster and post-disasters operations, and classified the models into three main groups: facility location, relief distribution and affected people transportation, and other operations, including model types, decisions objectives and constraints.
De la Torre, Dolinskaya and Smilowitz (2012) focused on the Vehicles Routing Problem with different variations for the distribution of life-saving commodities to victims, classifying the models according to the problem characteristics and objectives.
Safeer, Anbuudayasankar, Bulkumar and Ganesh (2014) focused on objective functions and constraints for the

following models: transportation of affected people and relief distribution problems.

Hoyos, Morales and Akhavan-Tabatabaei (2015) focused on operations research models with stochastic component, applied to disaster operations management, using different solution techniques.

Özdamar and Ertem (2015) considered mathematical models for the post-disaster phases of response and recovery planning; they classified models in terms of their vehicle/network representations and their functionality, providing details on objectives, constrains and solution methods, and the use of information systems for humanitarian logistics.

Gutjahr and Nolz (2016) focused on quantitative decision-making approaches to humanitarian aid, using, deterministic or under uncertainty, multi-criteria optimization methods.

Boonmee, Arimura and Asada (2017) focused on the Facility Location Problems for humanitarian logistics, including deterministic, dynamic, stochastic and robust problems. They reviewed data modeling type, disaster type, decisions, objectives, constrains and solution methods.

A review of the state of the art, allows to identify key papers on post-disaster logistics, which are described below.

Wohlgemuth, Oloruntoba and Clausen (2012) addressed the Vehicle Routing Problem with dynamic Pick and Collect Scheduling based on a dynamic optimization model to avoid delays in the delivery of time-critical relief goods and increase equipment utilization, thereby saving lives and costs. A multi-stage mixed integer formulation was proposed, which is able to operate under variable demand and transport conditions, to find a set of minimum travel time routes starting and ending at a single depot and serving the demands of a range of locations, minimizing the number of vehicles used. This model considers a cluster strategy and a time dependent travel time approach as a way to incorporate dynamic changes. The model was tested in a business context of forwarding agencies. The authors suggested further research focused on the optimization of travel times and location clusters,and the refinement and testing of anticipation strategies for different travel times and locations.

Osguven and Ozbay (2013) addressed the Stochastic Inventory Control Problem to develop a realistic control model to implement efficient pre and post-disaster plans. A robust and efficient procurement system with an adequate off-line planning strategy and a careful on-line inventory management was proposed. The off-line model was formulated as a multi-commodity stochastic inventory management model in the context of humanitarian logistics, based on the Hungarian Inventory Control Model; a Normal distribution was considered for representing the stochastic nature of the consumption and delivery processes. The on-line strategy includes a real time management of the activities, obtaining real-time information through radio frequency devices, which was formulated as a neural network trained with the off-line model information. The models were tested with simulated data.

Charles, Lauras, Van Wassenhove and Dupont (2016) addressed the Distribution Network Design Problem based on a facility location model for humanitarian organizations, to identify the optimum number and location of warehouses on a regional scale to pre-positioning humanitarian resources at a strategic level. A mixed-integer linear programming formulation is proposed to minimize costs (transportation costs, fixed costs and variable costs). The model is based on scenarios, which allows a reliably forecast of demand using past data and future trends. As a future work, the authors underlined a discussion with different organizations to validate the results and applicability.

Alem, Clark and Moreno (2016) addressed the Distribution Network Flow problem based on a two stage stochastic network flow model under practical assumptions (dynamic multi-period relief operations, limited budgets, fleet sizing, etc.) to minimize the total cost of the procurement of emergency aid during a response and the prepositioning of emergency aid before a disaster strikes, focused on predictable disasters. They assumed that the location of relief centers and warehouses are well located beforehand, and focused on prepositioning, distribution and fleet decisions. Also, they included a model extension that considers risk management based on risk-aversion decisions. The model was tested with scenarios based on floods and landslides in Rio de Janeiro, Brazil. As a future work, the authors underlined to analyze the impact of a heterogeneous fleet, additional constrains and an extension to multistage stochastic models.

Pradhananga, Mutlu, Pokharel, Holguín-Veras and Seth (2016) addressed the Distribution Network Design problem based on a three-echelon network model to minimize the social cost (the sum of logistics cost and deprivation cost). A scenario-based two-stages stochastic programming formulation was proposed. Main contributions of this paper are a three-tier network structure with multiple supply point, a non-linear deprivation cost function, and the flexibility in purchasing and prepositioning decisions. The model was tested assuming a single commodity and different hurricane scenarios. The authors suggested further research considering different transportation modes and stablishing temporary distribution centers, in order to reduce the deprivation cost and increase de effectiveness of the distribution.

Das (2018) addressed the Facility Location Problem based on a multi-objective network model to select warehouse locations such that the maximum area is covered at the minimum distribution cost. An integer linear formulation is proposed to determine the location of a set of local warehouses and one regional warehouse. This model includes a hub-and-spoke network and, unlike other models, allows the interaction between different local warehouses to send and receive relief items. The model was tested assuming uniform relief demand and uniform distance between demand points, without considering weight factors in the objective function or parameters subject to uncertainty. For obtaining a robust model, the author suggested to consider different scenarios and incorporate uncertainty parameters.

Noham and Tzur (2018) addressed the Pre and Post-disaster Humanitarian Supply Chain Design Problem based on a two-echelon humanitarian supply chain of a single product to provide, as quickly as possible the greatest quantity of the supply that is stored in advance at the major warehouses. A mixed integer programming model is proposed to maximize the relief flow by time unit. This model includes facility location and inventory allocation decisions, and unlike other models, the practitioner's post-disaster decisions are included as a set of humanitarian constrains. The model was tested with randomly generated data as well as real data obtained from the Geophysical Institute of Israel. To extend the research, the authors suggested to relax the assumption of a centralized decision-making process.

Some authors have underlined that many parameters are unknown before a disaster, however the relief demand is a key parameter in disaster preparedness. Seven influencing factors of the relief demand have been identified by Das (2018): disaster characteristics, sociodemographic factors, emergency sheltering, ratio of victims, perception of hazards, social bonds, and income. Uncertainty is usually considered via scenario-based models, but Charles, Lauras, Van Wassenhove and Dupont (2016) consider that the research frequently use fictitious scenarios and data to compensate for the lack of realistic information, and underline that this approach is no longer sufficient to validate whether decision support systems can be successfully applied in the actual context of disaster relief. A better option is when the scenarios are defined by the country's emergency authorities, their evaluation is carried out by experts as part of the strategic plan for disaster preparedness and is updated as needed (Noham and Tzur 2018).

From the previously described papers, some features can be useful to generate a realistic model. Wohlgemuth, Oloruntoba and Clausen (2012) proposed a cluster strategy and a time dependent travel time approach to incorporate dynamic changes, which can be useful to improve the distribution of aid. The difficulty is that a good clusters generation requires a deep knowledge of the problem.

Osguven and Ozbay (2013) used an adaptive model to calculate the inventory level and proposed real-time information to feed the model through radio frequency, which allows to manage resources in a better way. Here it is necessary to try different technologies in disaster logistics environments.

Charles, Lauras, Van Wassenhove and Dupont (2016) proposed a methodology to define scenarios to get a reliably forecast of demand, using past disaster data and future trends; certainly. More realistic scenarios allow to obtain better solutions for the problems, however generating them without the right information or without a correct analysis can conduct to useless solutions.

Alem, Clark and Moreno (2016) consider risk management based on risk-averse decisions, which be able to guarantee the availability of the necessary products. The trouble is that having surplus in safety stocks can generate other problems on the resources management.

Pradhananga, Mutlu, Pokharel, Holguín-Veras and Seth (2016) included a non-linear deprivation cost function and the flexibility in the purchasing and prepositioning decisions, which allows to obtain more realistic solutions. They still must consider several commodities in the model.

Das (2018) proposed a hub-and-spoke network and allowed the interaction between different local warehouses. The possibility of mobilizing resources between the different warehouses could improve the coverage and availability of resources, but requires further analysis considering realistic scenarios.

Noham and Tzur (2018) included post-disaster decisions through a set of humanitarian constrains, taking into account the current logistics practice, which allows to obtain results with a better acceptance among practitioners. When a general consensus is not generated, their proposal cannot be implemented.

5. CONCLUSIONS AND FUTURE WORK

Natural disasters generate considerable economic and social effects in the population of different countries, which has motivated the development of a series of mechanisms and procedures to deal with them in a better way. Two important stakeholders are the national and local civil protection structures, responsible for preparing tasks, mitigating risk, and providing assistance services to people, as a way for responding to their society needs, and the international humanitarian organizations, as supporting elements when the capacity of the local agencies is exceeded.

Recent natural large scale disasters have captured the attention of the international scientific community, which has generated contributions in two main areas: the understanding and conceptualization of the problem, and the generation of models to optimize the use of available resources to improve the logistics.

Advanced countries on disaster management maintain strong links among authorities, research institutions and agencies in charge of emergencies; in Mexico needs to strengthen these links in order to generate promising advances.

Mexico has several opportunity areas in post-disaster logistics. It is necessary to obtain realistic models and solutions for post-disaster logistics, in order to improve the response in future disasters.

Information is crucial, so it is needed better-quality statistical information, updated risk atlases and free access to the databases.

Scientific advances such as those outlined in this paper can be useful to improve the logistics performance for disasters, however in Mexico the post-disaster logistics is more challenging due to the relationships among the stakeholders, the non-compliance with processes, and the lack of information.

Future work is needed, a deeper research for the development of models that allow us to consider the particularities of our territory and the idiosyncrasies of the population and agencies, in the process for obtaining better integrated and coordinated preparedness and response systems.

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QUALITATIVE ANALYSIS FOR THE ASSESSMENT OF RISK IN HUMANITARIAN LOGISTICS: A PRELIMINARY REVIEW

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ABSTRACT

Now researchers and experts pay special attention in natural disasters because of the effects caused on areas where these phenomena occur, therefore, they have developed methodologies to assess the risk of these events and to prevent people from them. These methodologies have been developed in order to reduce the impact of these events on people's health and properties, the socio-economic activities of the population and the environment. A natural event cannot be avoided, but its effect can be reduced by carrying out preventive activities and designing plans according to the needs of the vulnerable population. Nowadays, a variety of methodologies (qualitative, quantitative and hybrid) have been developed to assess the risk of different natural events, also how these events effect in humanitarian logistics. The objective of this document is to show literature about qualitative developments made to assess the risk of natural disasters, focused on hydrometeorological events in their prevention stage in humanitarian logistics.

Keywords: Risk assessment, Qualitative methods, Humanitarian logistics, Vulnerability

1. INTRODUCTION

For the development of this research it is important to define some terms for a better understanding. Disaster is "a serious disruption of the functioning of a society, causing widespread human, material or environmental losses that exceed the capacity of the affected society to deal with them using only their own resources" (Melching et al., 2006). People's concern about disasters is related to human death and the economic cost, which basically depends on the dangers and risk of the event. The danger is "a threatening event, or the probability of a potentially harmful phenomenon occurring within a given period of time and area" (Navia et al., 2018; Birkmann, 2006; Birkmann et al., 2013). The risk is defined as "expected losses (of lives, injuries, material damages and interrupted economic activity) due to a particular danger to a given area and reference period" (Melching et al., 2006; Smith et al., 2009); Vulnerability "is the degree of loss (from 0 to 100 percent) resulting from a potentially harmful phenomenon" (Melching et al., 2006; Jha et al., 2012; Rashed et al., 2003b). The hydrometeorological event is defined as "a hydrological and meteorological phenomenon that implies a transfer of energy and water between the earth and the lower atmosphere" (Chuan et al., 2018). These events include floods, tropical storms and droughts. The main causes are water, wind and climate change (Jayawardena, 2013). At this point, it is important to specify the impact of an event that can be measured taking into account the thresholds of human effect (death or injury), economic loss and environmental effect, then this event can be considered a disaster.

Thomas (2003) defined "humanitarian logistics as the process of planning, implementing and controlling in efficiencies, the storage of goods and material, from the point of origin to the disaster area, with the purpose of alleviating the suffering of disaster's victim". For Kopczak et al. (2005) Humanitarian Logistics is the planning, execution and control of the efficient and profitable flow and storage of material goods, as well as related information from the point of origin to the point of consumption, in order to alleviate the suffering of vulnerable people, greater detail is found in Kovács et al. (2007, 2009); Altay et al. (2006); Pettit et al. (2005); Van Wassenhove (2006); Lee et al. (2017); Thomas (2003); Cottrill (2002); Nisha de Silva (2001); Pettit et al. (2009), and Christopher et al. (2011) to mention a few works. In relation to the issue of supply chain and humanitarian logistics in disaster situations, McCormack et al. (2008) argue that interruptions in the supply chain may be caused by some elements within or outside the chain, in addition to considering a three-phase approach to the analysis of interruptions in the chain: i. Risk identification, ii. Risk assessment, and iii. Risk mitigation. Sheffi (2005) proposes possible modes of system failure once it is affected by a disruptive event: supply failure, demand failure, transport failure, installation failure, communication failure and violation of the load systems, some other works on this subject were found in the works written by Wagner et al. (2010), Christopher et al. (2003) and Barnes et al. (2005).

Behl et al. (2018) show in their deep literature review that the published papers using cases based on empirical validation, simulations and mathematical modeling. However, there are some fields, which have not had relevant importance like using qualitative approach.

Shafiq et al. (2019). Developed a qualitative study where they show that 94% of HO-LSCM (Humanitarian Organizations Logistics and Supply Chain Management) studies are based on qualitative research with theoretical frameworks, which have not been tested and HO (Humanitarian Organizations) has their own policies and procedures to operate in disaster situations. Therefore, they propose, “standardization is required to streamline the effectiveness and efficiency in logistics and supply chain functions”.

Mora-Ochomogo et al. (2016) concluded that few models include cultural or human resources matters as qualitative factors, which define the success of the supplies’ delivery in operative activities and those factors give more reality to the models. Also, they focus their work in Inventory Management during the disaster relief and they describe some of the special conditions which make it difficult to apply the classic inventory strategies, such as: time is crucial, non-repetitive inventories, no backlogging allowed, donations uncertainty, scarcity and surplus of resources in certain time, prioritization of goods needed according to the region, human resources variability and availability in the place, supplier development, expiration and obsolescence of the products, warehouse location, political and cultural matters. The objective of this document is to review some literature about qualitative developments made to assess the risk of hydrometeorological events in their stage of prevention of humanitarian logistics.
In addition, Whiting et al. (2009) mentioned that HO-LSCM operation cost could be around 25% more than a similar business supply chain management operation. As it was mentioned before by Mora-Ochomogo et al. (2016), the reasons of the high cost are the complexity and the factors involved on it such as: inherent uncertainty, limited local use of technology, human resource difficulties, and poor infrastructure (Antai et al., 2015).

Shafiq et al. (2019) in their work show that the researches about the HOLSC are mostly qualitative methodologies, which means that the generation of theories and frameworks, are used when particularly the information is insufficient, or the study is new in the field. Also, in their literature review from 73 studies reviewed, 68 studies were qualitative approach, only two studies quantitative approach, and the rest used both approaches (hybrid approach).

Behl et al. (2018) classified the publications found in different data bases from 2005 to 2017, they considered key words to select the papers and joined them in four groups: i. Optimization, Agility, Coordination, Collaboration; ii. Humanitarian Logistics, Humanitarian SCM, Humanitarian operations; iii. Risk, Resilience; iv. Disaster preparedness, Disaster relief, Disaster Management, Disaster relief operations. Figure 1 shows the percentage of each group.

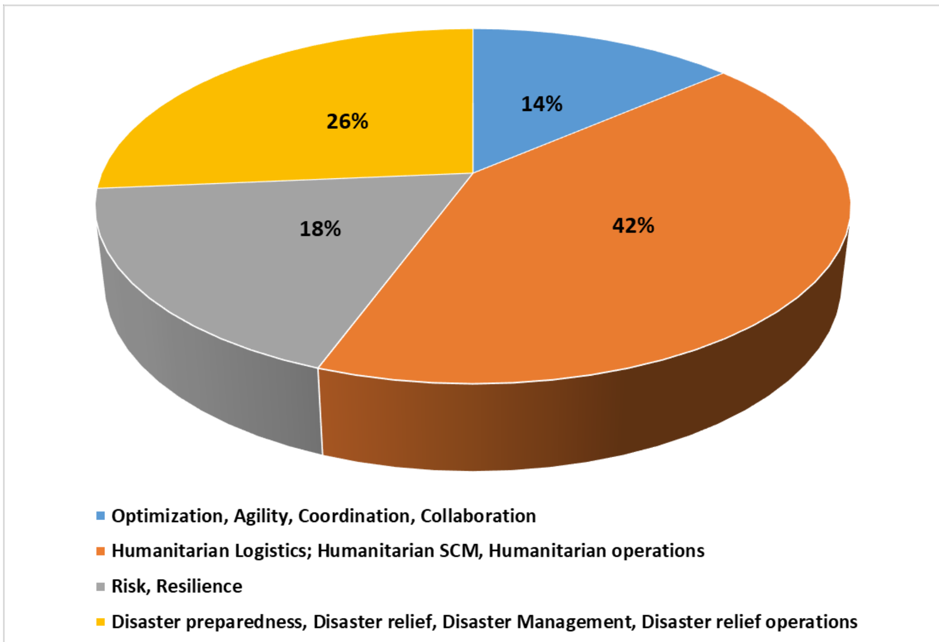

Figure 1. Source: Behl et al. (2018).

The documents related to Risk assessment and Resilience stage for a disaster have 18% of incidences, which proves the gap of this subject compared with the other fields in humanitarian logistics, also, it shows the opportunity area for new research in these subjects. The information presented in the last paragraph shows that developing new qualitative and quantitative approaches in these fields may help to the decision makers and the people to prevent the catastrophic effects of a disaster.

2. QUALITATIVE ANALYSIS FOR THE ASSESSMENT OF RISK

In the previous section it was defined risk by Melching et al. (2006), Smith et al. (2009); however, risk measurement depends on discipline, where it is assessed, in hazard research, risk is equal to the product of two or three factors, for example, Crichton (2002) describes the risk with three elements where each element is independent: hazard, exposure, and vulnerability. Other concepts consider the risk as a product of hazard and vulnerability (Wisner et al. 2004). Wisner et al. (2004) and Cannon (2000) comment that the risk in a specific area depends on their socioeconomic, cultural, and other attributes.

According to Melching et al. (2006), Risk assessment can be determined by the following steps: i) Estimation of the hazard (location, frequency and severity); ii) Estimation of the exposure (number of people, buildings, factories, etc. exposed to the hazard); iii) Estimation of the vulnerability of the elements at risk (expressed as percentage losses); iv) Product of hazard, exposure and vulnerability.

The risk assessment is a wide field of research as it was mentioned previously. Risk assessment in humanitarian logistics has been studied for more thirty years, different approaches have been developed to predict the risk magnitude, to prevent the people and decrease the effects of the events that they originate. This section describes from a qualitative point of view some of the models developed, because of vulnerability is considered in the models and it is complex to determine due to lack of information, however, some of these models have quantitative approach too, but that approach will not be part of this document.

Blaikie et al. (1994) and Wisner et al. (2004) developed a theoretical framework, which serves to analyze exposure to a natural hazard and vulnerability, this model is called Pressure and Release (PAR) Model and Access Model. This model gives details about how a disaster is recognized according to the phenomenon´s effects, also it considers relevant the causality of human vulnerability. Vulnerability is created by different factor such as: economic, demographic, and political process according to the access that population has to the resources; dynamic pressures (social, economic, and political activities in the area); specific locations (dangerous or out of law), deficiency preparedness to the disasters, and low-salary level, in general unsafe conditions for living. Wisner et al. (2004) assume that if two forces interact then a disaster occurs, it means vulnerability join forces with exposure. The risk is measured according to the magnitude gave by vulnerability level and exposure people amount in the area. However, these forces are difficult to measure with exactitude, that is why the model in this context is considered qualitative.

Davidson (1997) proposed a Disaster Risk Reduction Model, where vulnerability is integrated as a central factor to calculate the risk. In this model, Risk is calculated by the product of hazard, exposure, vulnerability, and adjustment capacity of the community. He proposes a framework to determine the disaster of the specific area under the last four factors as: i.“hazard is the probability or severity of an event”; ii. “exposure characterizes structure, population, and economy”, iii. “vulnerability encompasses physical, social, economic, and environmental aspects; and iv. “capacity and mitigation measures include physical planning, social capacity, economic capacity, and management”. The objective is to determine the community’s vulnerability to hazards, and help the actors in the community take accurate actions for decreasing the effects of a disasters.

Hewitt (1997) developed a Regions of Risk Model, where he considers vulnerability is the result of various factors: i. A hazard; ii. Vulnerability (features of a community or an individual); iii. Risk does not depend on hazard or vulnerability but they impact to the risk of hazard; iv. People’s adjustment capacities to a dangerous environmental, which depends on the social organization of a community or individuals’ capacity to respond to an extreme condition.

Hazards-of-Place (HOP) Model integrates biophysical and social characteristics as a causal process of hazards which considers vulnerability as the mixture of social vulnerability and a biophysical condition (potential exposure) in a specific area. Cutter et al. (2009) proposed an extended version of HOP, the model is called the disaster resilience of place (DROP) model, which was developed for natural hazard study. These models try to determine the vulnerability of a community or individuals to environmental hazards (Dewan, 2013).

The United Nations International Strategy for Disaster Reduction (UNISDR 2009a, 2009b) developed a framework for disaster risk reduction, where vulnerability, as in the previous models, is fundamental for determining the risk of the community. UNISDR (2009a) defines vulnerability by categories: physical, social, economic, and environmental. The framework shows phases to apply disaster risk reduction techniques considering vulnerability assessment, hazard identification, risk assessment, and the prevention activities. However, the approach does not explain the relation between vulnerability reduction and reduction of risk. But the contribution of this work is how the elements are involved to reduce the risk disaster. Figure 2 shows the relationship among the factors.

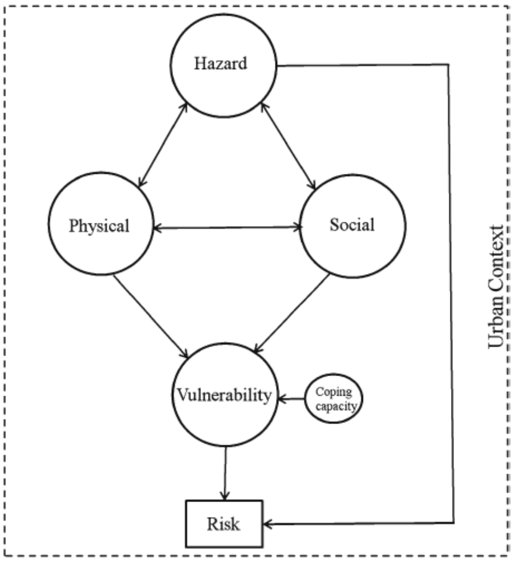

Figure 2. Schematic representation of conceptual framework. Source: Birkmann (2006).

Some conceptual models have been described until now, which involve vulnerability as a key of factor to determine the risk assessment for disasters in general. Below, some approaches for hydro-meteorological events will be describe where vulnerability is also considered an important factor of the models.

The conceptual Source-Pathway-Receptor-Consequence-Model (SPRC-Model) describes the flood risk. The conceptual framework shows a causal chain beginning from the meteorological and hydrological events in inland or at coasts, which are the 'sources'. The sources are released generating floods which are called 'pathways'. The 'receptors' are the elements at risk by physical impacts caused by the pathways, then it is possible to assess the effects of the physical impacts as 'consequences'. Schanze et al. (2006) say that "the chain links 'source', 'pathway' and 'receptor' refer to the physical process, whereas the assessment of the '(negative) consequence' is a matter of social values. After this description, factors are classified to determine the flood risk: flood hazard is determined by source' and 'pathway'; 'receptor', and '(negative) consequence', which defined the state of the vulnerability, where 'consequences' are defined by material losses and people capability to compensate the losses (Schanze et al. 2006). The next step of conceptual model is a quantitative approach to calculate the flood risk, which is not described in this document. Figure 3 shows the conceptual framework.

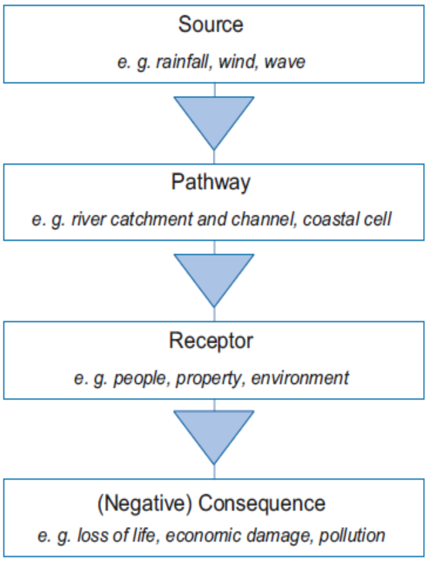

Figure 3. Conceptual Source-Pathway-Receptor-Consequence-Model (SPRC-Model). Source (Schanze et al., 2006).

It is important to mention that according to Quevauviller (2015) extreme hydrometeorological events can cause high impacts when they happen together, but if they occur independent their impacts may not be extreme. On the other hand, high impacts may result not dangerous events if the system exposure and vulnerability are high.

Eiser et al. (2012) present in their work a deep review about how people perceive and interpret risks and choose their actions based on their experiences and interpretations of the natural hazards. They say that the context of natural hazard considers vulnerability and social relationships. Also, they consider that it is very important how as individuals and as members of social networks interpret and react to the risk base on their experiences and understandings. Authors conclude that the literature is varied and extensive, but not enough to decrease the risk.

Lechowska (2018) considers in her work that risk perception is very important to assess of the perceived probability of hazard and the perceived probability of the consequences. Also, the issue of the underestimation of flood risk by the society is because of the lack of knowledge and information about the factors influencing in the perception of it. The paper shows that authors give different conclusions on features to determine the flood risk perception but it is still not enough.

The qualitative factors involved in the models, it is difficult to assess the risk, however, those factor let to the models are close to the reality, that is why researchers an experts want to determine those factors. In works developed by Greiving. (2006), Bloschl et al. (2013), Eckhardt et al. (2019), Jonkman et al. (2008), Messner et al. (2006), Zanuttigh et al. (2015), qualitative approaches are detailed to assess the risk of hydrometeorological events.

3. CONCLUSIONS

This document is focused on literature review about qualitative developments made to assess the risk of natural disasters, mainly on hydrometeorological events in the prevention stage of humanitarian logistics. However, some of those models also involve quantitative approach as a second step to assess the risk. Risk assessment has been studied in the last decades from different perspective according to research field, that is why the researches try to find the factors which can describe close to reality, and calculate the risk assessment to prevent the people. The authors consider different factors in the models, some of those factors are not easy to determine because of the lack of information or the qualitative characteristics on them, such as vulnerability, social relationship, risk perception, risk interpretation, risk understanding, economic, demographic, social, and political characteristics of the area, etc., but some of the authors agree that the vulnerability of the communities is a key to determine the risk assessment.

In humanitarian logistics to assess the risk is a basic step to plan strategies to help the people in areas that the disaster affects the normal activities. Also, based on the information presented by Behl et al. (2018), it is important developing new qualitative and quantitative approaches in these fields may help to the decision makers and the people to prevent the catastrophic effects of a disaster.

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Performance analysis

EFFECT OF GREEN ATTRIBUTES AND SOCIAL BENEFITS ON GREEN PROCESSES

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ABSTRACT
Environmental awareness is becoming a constant worldwide and the manufacturing industry is no exception so at this time more than a requirement, it has become an obligation to have a green manufacturing process focused on generating environmentally friendly products. Therefore, manufacturing industries worldwide are working on transforming their traditional manufacturing process to a green process, so this research presents a series of attributes that help identify and facilitate the steps to carry out the transformation of such processes and also proves that having a green process entails a series of social benefits, which are important today for the final consumer. This is done through a model of structural equations composed of four latent variables; green attributes before the production process, green attributes during the production process, green attributes after the production process and social benefits, variables that relate and validate each other. The results in the execution of the model indicate that the four variables are highly related and have a direct and positive impact between them.

Keywords: Green process, green attributes, social benefits, sustainability and suppliers.

1. INTRODUCTION

Social responsibility and pressure from customers, government regulations, and other interested parties (Cherrafi et al. 2018) have led organizations to consider integrating environmental thinking as part of their strategic business management (He, Luo, and Huang 2019) due to a growing concern for the environment, and industrial manufacturers that have previously been an important part of the growth of an economy and who are the source of new customers, products, and manufacturing processes have been forced to adopt this green integration as an integral part in the design, manufacturing, and distribution of their products (Rauch, Dallasega, and Matt 2016).
Therefore, one of the most common ways to integrate this green approach is to shift from traditional fabrication to green manufacturing. It is claimed that this change will drive growth, the economy, opportunities, social responsibility, and sustainability for industrial companies (Xie, Huo, and Zou 2019).
Thus, green process (GP) of products is a philosophy that seeks to improve the activities that involve the manufacture of a certain product, incorporating environmental attributes in the decisions associated with the design, manufacture, distribution, and all aspects of manufacturing a product, thus seeking to reduce the environmental impact (Zhao et al. 2016).
This research aims to generate a structural equation model (SEM) to determine the relationship between the different green attributes that can be used when determining whether a production process can be considered green or not, since the relationship, effectiveness and whether the use of attributes really facilitates the transformation of a traditional manufacturing process to a green one is unknown; It is also intended to determine whether the use of such attributes entails some social benefit for the Organization. SEM integrates four latent variables: *Green attributes before the production process (GABPP)*, *Green attributes during the production process (GADPP), Green attributes after the production process (GAAPP)*, and *Social benefits (SB)*. The above aim to quantitatively demonstrate the importance of using green attributes in the industry today, to quickly and easily assess whether it is green in a particular production process and indicating how the use of attributes can ensure social benefits in each organization.

2. LITERATURE REVIEW AND DEFINITION OF HYPOTHESIS

Transforming a traditional manufacturing process is not easy as companies do not know how to make that change easily and at low cost.
Here we will talk about the use of a series of green attributes, such as collaboration with green suppliers, ecobusiness, clean production processes, use of green technologies, recycling systems and eco-marketing, among many others (Seth, Rehman, and Shrivastava 2018).

1.1 Green attributes before the production process (GABPP)

The GABPP are those attributes that present in the environmental procurement management such as: green purchasing, ecological practices during purchasing activities, selection of green suppliers and a sustainable consumption of resources and inputs, dos Santos, Godoy, and Campos (2019); Alikhani, Torabi, and Altay (2019). Therefore, the GP will be a means to subject organizations in a process of green innovation and achieve environmental, social and economic objectives through it. Organizations that incorporate green practices into their operations have the advantage of being first in the market and therefore can offer higher prices for their green products and also enter new local markets. (Gupta and Barua 2017). Recent research indicates that companies' competitive position and environmental performance are greatly affected by green sourcing practices and collaboration with green suppliers. (Mendoza Fong et al. 2017).

It is also desired that for the GP to be successful it must take into account the perspectives of the products, processes and distribution. At the process level, the use and conservation of natural resources should be considered (Cherrafi et al. 2018), in terms of product and distribution, an eco-business must be implemented that is positively correlated with environmental performance and the lower ecological impact of a GP process (Fang and Zhang 2018).

1.2 Green attributes during the production process (GADPP)

The GADPP are those attributes that are presented in the environment of the GP system refers mainly to multiple types of elements that make up the production system, which can be engulfed in the use of green manufacturing technology, the use of green manufacturing process and the environmental impact on the use of resources Zhang et al. (2019); Aboelmaged (2018).

However, the initial integration of the GABPPs is important as they seek to implement a GP in a gradual and more detailed way, as they will work from suppliers to make a procurement of raw materials green (Mendoza-Fong et al. 2019).

In addition to suppliers, the organization seeks to adopt joint strategies for the simultaneous reduction of waste emissions to the environment and the minimization of damage to the environment, but with the condition of whether and only if they develop new products in a GP (Severo, Guimarães, and Dorion 2017).

Once the supplier is involved, the aim is to generate a clean GP that generates products that consume a minimum of material and energy, alternating input materials, reducing unwanted outputs and converting them into inputs for recycling (Das, Rukhsana, and Chatterjee 2019). At the same time, tools such as the Total Quality Management (TQM) philosophy, which makes it easier to determine measures and management plans to improve green product quality, reduce costs and promote environmental productivity, will be used. (Li et al. 2018). Based on the above, the first working hypothesis is defined:

H1: Green attributes before the production process (GABPP) have a direct and positive effect on green attributes during the production process (GADPP), in a GP.

1.3 Green attributes after the production process (GAAPP)

The GAAPP are those attributes that are based on the structure of the system of ecological distribution and life cycle of the product and will value aspects such as it; design, logistics, service, recycling and reuse in the delivery of the green product to an end customer and that will be key areas of the industry and even more for the GP, Adamson-Small et al. (2017); Zhu and He (2017).

However, as mentioned above, the involvement of suppliers in the design and implementation of a GP process is of high importance since the supplier and the green procurement, denotes certain stages of the product life cycle and manufacturing activities, in addition to having a positive impact on market performance and marketing of ecological products or eco-business. (Dangelico, Pujari, and Pontrandolfo 2017). In the same way, supplier involvement from the beginning of the GP will help by minimizing or preferably eliminating the negative effects of procurement operations and improving environmental practices. (dos Santos, Godoy, and Campos 2019). Based on the above, the second working hypothesis is defined:

H2: Green attributes before the production process (GABPP) have a direct and positive effect on green attributes after the production process (GAAPP) in a GP.

Not only should we focus on the importance of procurement and supplier, but also we have to consider processes, distribution and reverse logistics, which is also of utmost importance in the transformation of a typical process to a GP, since in order to implement a successful and functional GP requires certain environmental attributes to improve the design of the processes and product (Hong et al. 2017), attributes such as; reducing and minimizing emissions and damage to the environment, sustainable product and process objectives (Liu, Zhu, and Seuring 2017), a recycling system and, of course, ecological marketing that converts consumers' ecological awareness into real purchasing behavior, thus making it easier to monitor the product's life cycle and reverse logistics. Based on the above, the third working hypothesis is defined:

H3: Green attributes during the production process (GADPP) have a direct and positive effect on green attributes after the production process (GAAPP) in a GP.

1.4 Social Benefits (SB)

The focus on the development of green products applied in the manufacturing industry will aim mainly at reducing the environmental impacts of products (Singh et al. 2018). However, it must not only consider the environmental impact, but must be based on a threefold end result that includes the environment, the economy, and social responsibility (Li et al. 2017). Having green manufacturing is essential for any organization that wants to remain in force and having competitive advantages over its rivals (Salem and Deif 2017).

Organizations must obtain environmental social benefits as they play a crucial role in maintaining the brand, image, their product; before their consumers and this is done through the creation of environmentally conscious consumers who consume more and more green products (Hong and Guo 2019).

At the same time, social benefits in organizations will maximize the image of industrial production by empowering public and government awareness (Gao, Xiao, Wei, et al. 2018) that such a GP organization has a green marketing that meets the needs of its customers and consumers and minimizes damage to the environment. Based on the above, the fourth working hypothesis is defined:

H4: Green attributes after the production process (GAAPP) have a direct and positive effect on the social benefits (SB) obtained with GP.

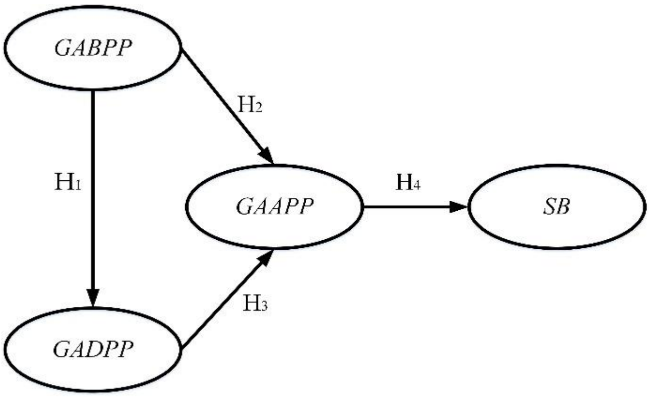

Figure 1: Hypotheses

2. METHODOLOGY

Below is a brief description of the methodology carried out in the development of this research work.

2.1 Literatura Review

At this point a search and review of the most recent and highly related research on the implementation, transformation or design of GM processes is carried out. In order to find those attributes most used and important and mentioned when assessing how green is a manufacturing process, we also identified those social benefits that most impact when having a GM process. Table 1 shows the identified and categorized attributes and benefits.

2.2 Survey development, implementation and capture

Based on the review of developed literature, a survey is designed, with the purpose of collecting information from the industrial sector for the analysis and validation of the proposed hypotheses. The survey consists of two sections, the first section includes a series of demographic questions, which serve to know specific data such as; gender, industrial sector, branch of the survey respondents' company. Section two consisted of the items (questions) described in Table 1 and which were assessed using a Likert scale where one meant; never or not important and five always or very important. The survey is applied in the Mexican manufacturing industry bordering the United States of America and focused on personnel highly related and involved with GM. The surveys achieved were captured in a database built on the statistical software SPSS 24 ®, and widely used in statistical analysis of large samples, where the rows represent the answers to each of the questions and the columns represent the survey questions.

Table 1: Items

GABPP (Yu, Yang, and Chang 2018; Ghadimi, Dargi, and Heavey 2017; Hamdan and Cheaitou 2017)
1. Environmental collaboration with suppliers. 2. Eco-business models. 3. There are programs for the use and conservation of natural resources. 4. Green procurement practices.
GADPP (Marimin et al. 2018; He et al. 2018; Saad, Nazzal, and Darras 2019; Seth, Rehman, and Shrivastava 2018)
1. Reduction of emissions to the environment. 2.There is a clean production process. 3. Damage to the environment is minimized. 4. Use of TQM
GAAPP (Gao, Xiao, Cao, et al. 2018; He, Luo, and Huang 2019; Sellitto et al. 2019)
1. Reverse logistics. 2. Recycling system. 3. Ecological marketing. 4. Product life cycle management.
SB (Severo, Guimarães, and Dorion 2017; Hong and Guo 2019; Madani and Rasti-Barzoki 2017)
1. Green image before society. 2. Better compliance with government regulations. 3. Governmental and social recognition. 4. Enhanced acceptance of products by society.

2.3 Statistical validation

The information obtained from the four variables has to be validated and for which the following indices are used, the Average Variance Extracted (AVE), to test the convergent validity and where you want to obtain values greater than 0.5. Also, the indexes R^2, R^2 adjusted and Q^2 are used, which test the predictive validity, the R^2 have a parametric approach and the Q^2, a non-parametric approach. Likewise, the Cronbach Alpha and composite reliability index are used to test internal reliability and latent variables and to obtain values higher than 0.7, and finally the Full collinearity VFI index is used to check collinearity, where values lower than 5 are intended.

2.4 Characterization of the sample

The sample is characterized with the purpose of knowing important data of the participants of this research, data such as the gender and department to which these participants belong, with these two data the tendency in the sample is identified.

2.5 Model execution

The model defined in Figure 1 is executed in WarpPLS 6.0 ® Software, specialized in structural equations and based on minimum partial tables. The models of structural equations are currently widely used in environmental research as in the research developed by Abu Seman et al. (2019); Wang et al. (2018). The software uses different indices to validate the model, first analyzes an Average path coefficient (APC), Average R-squared (ARS) and Average adjusted R-squared (AARS) indices that present a p value to determine their statistical significance and it can be determined that the model has sufficient predictive validity and that the dependence between the latent variables analyzed there is an average different from zero, since they are statistically significant with a 95% confidence level.

Likewise, it checks that there is no collinearity between the latent variables and it can be observed that the Average block VIF index (AVIF) and the Average full collinearity VIF index (AFVIF) must be below 3.3. And finally, the Tenenhaus GoF index (GoF) and an acceptable value higher than 0.36 are tested.

Finally, three types of effects will be measured: direct, indirect and total. Direct effects are represented by arrows that connect directly to two latent variables, indirect effects are represented by routes with two segments and total effects is the sum of the most indirect direct effects.

Tests of statistical significance are done at a 95% confidence level, testing the null hypothesis: $\beta i = 0$, versus the alternative hypothesis: $\beta i \neq 0$.

3. RESULTS

The results based on the methodology defined above are presented below.

3.1 Sample Characterization

With a 4-month application, a total of 559 questionnaire responses were obtained, of which 369 were answered by the male staff 369 (66.01%) and the other 190 (33.99%) were answered by female staff. Of the total participants, 250 (44.72%) were answered by engineering and production personnel, see Figure 2.

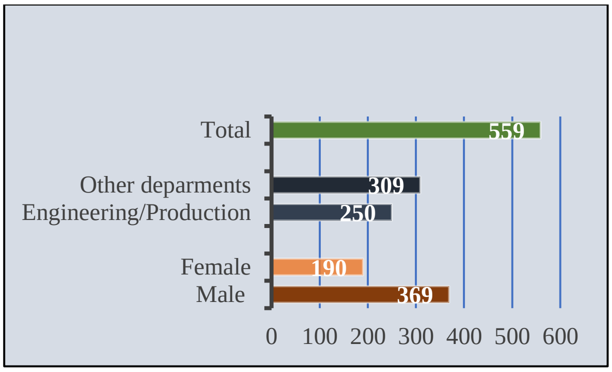

Figure 2: Demographic data

3.2 Validation of latent variables

Table 2 presents the values obtained from each of the latent variables presented in Figure 1, as well as each of the indices that are part of the validation of the latent variables presents values within the parameters defined in the methodology, so it can be said that the latent variables have convergent validity, parametric and non-parametric predictive validity. In addition to internal reliability and latent variables do not present problems of collinearity.

Table 2: Validation rates

Coefficients	*GABPP*	*GADPP*	*GAAPP*	*SB*
R^2		0.472	0.612	0.387
Adjusted R^2		0.471	.610	0.386
Composite Reliability	0.908	0.881	0.904	0.940
Cronbach´s Alpha	0.864	0.820	0.858	0.915
AVE	0.712	0.649	0.701	0.798
Full Collinearity VIF	2.535	2.381	2.687	1.864
Q2		0.473	0.611	0.387

3.3 Final model

The results obtained from the execution of the model are illustrated in Figure 3, where the arrows represent the relationship between two latent variables, one can observe a beta value (β) and a p value that is used for tests of statistical significance at 95%. Likewise, a value of R^2 can be observed in the dependent variables, which serves to determine the amount of variance that is explained by each independent variable.

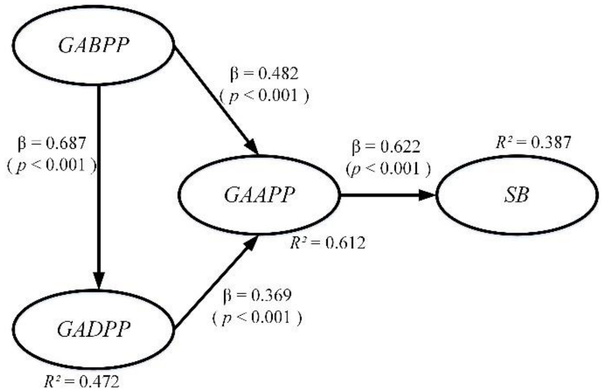

Figure 3: Final Model

In Table 3, the efficiency indices of the model can be appreciated and it can be observed that based on what is described in the methodology section, all the indices of the model have sufficient statistical significance, a predictive validity, there is no collinearity in it.

Table 3: Efficiency Rates

Average path coefficient (APC) =0.540 P<0.001
Average R-squared (ARS) =0.490, P<0.001
Average adjusted R-squared (AARS) =0.489, P<0.001
Average block VIF (AVIF) =1.875, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF) =2.367, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF) =0.592, small >= 0.1, medium >= 0.25, large >= 0.36

3.4 Direct effects

The assumptions are tested through the implementation of the model, and the interpretation and significance of each of the four assumptions defined in section two is presented below.

H_1: There is enough statistical evidence to state that *Green attributes before the production process (GABPP)* have a direct and positive effect on *Green attributes during the production process (GADPP),* because when the first variable increases its standard deviation by one, the second one increases by 0.687 units.

H_2: There is enough statistical evidence to state that *Green attributes before the production process (GABPP)* have a direct and positive effect on *Green attributes after the production process (GAAPP),* because when the first variable increases by one its standard deviation, the second increases by 0.482 units.

H_3: There is enough statistical evidence to state that *Green attributes during the production process (GADPP)* have a direct and positive effect on *Green attributes after the production process (GAAPP),* because when the first variable increases by one its standard deviation, the second increases by 0.369 units.

H_4: There is enough statistical evidence to state that *Green attributes after the production process (GAAPP)* have a direct and positive effect on *Social benefits (SB),* because when the first variable increases by one its standard deviation, the second increases by 0.622 units.

3.5 Sum of indirect and total effects

Table 4 shows the sum of indirect effects, which were three and both in two segments. For example, the latent variable GABPP has an indirect effect of two segments on the latent variable GAAPP and this effect is 0.254 and is given through the mediating variable GADPP.

Table 4: Sum of Indirect Effects

	From	
To	*GABPP*	*GADPP*
GAAPP	0.254 (P<0.001) ES = 0.186	
BS	0.458 (P<0.001) ES = 0.268	0.230 (P<0.001) ES = 0.142

The sum of total effects is presented in Table 5 and represents the sum of direct effects and indirect effects, where three are equal to the value β presented in Figure 3, indicating that these three effects do not have an indirect effect.

And an example would be the total effect of GABPP on the latent variable GADPP is 0.687, the same value as the direct effect (β in Figure 3).

Table 5: Sum of total effects

Total Effects			
	From		
To	*GABPP*	*GADPP*	*GAAPP*
GADPP	0.687 (P<0.001) ES = 0.472		
GAAPP	0.736 (P<0.001) ES = 0.540	0.369 (P<0.001) ES = 0.258	
BS	0.458 (P<0.001) ES = 0.268	0.230 (P<0.001) ES = 0.142	0.622 (P<0.001) ES = 0.387

CONCLUSIONS

Based on the results obtained, it is concluded that monitoring the transformation of a GP can be performed using attributes before, during and after the manufacturing process, as it is a fast, effective and simple way, which also ensures the achievement of social benefits, such as acceptance by customers and society in general.

First of all, it can be noted that GABPP are transcendental and of utmost importance in order to have GADPP and this is verified through the H1, in addition to the fact that Yu, Yang, and Chang (2018); Mendoza-Fong et al. (2019) denote the importance of the involvement of suppliers from the beginning of a GP because in order to have a successful GP from the beginning, it is necessary to involve the person responsible for the supply of green raw materials to the process, in order to have green product outputs.

It is also possible to mention that in order to have a GAAPP you have to previously have GABPP and GADPP and this is verified through the H_2 and H_3, due to the fact that nowadays it is not viable to have a green provisioning a GP and not have a green distribution. (Rehman, Seth, and Shrivastava 2016), reverse logistics and of course a recognition of the brand and the product as green because when integrating environmental awareness to a GP it necessarily involves all processes and participants in the successful satisfaction of our green consumers and further reduce the environmental impact of products and processes in the course. Already having a GP before, during and after it, it is important to note that this GP has benefits, economic, processes and quality, but also having GP guarantees social benefits and these are verified with the H_4, because already having an environmental collaboration with suppliers, a clean production, an eco-business and an ecological marketing, your product will have a social acceptance, government and an image that catalogues it as a green product and friendly to the environment, leading to better acceptance and consumption of it. (Zhang et al. 2019).

Finally, it can be concluded that green innovation in manufacturing processes tends to be effective and possible to implement using attributes, and that more benefit can be obtained than in other ecological practices.

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COLLABORATION IN THE SUPPLY CHAIN AND ITS EFFECT ON FINANCIAL PERFORMANCE

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1. INTRODUCTION

A supply chain (SC) is a network of organizations that participate through several connections in different type of processes and activities that generate values known as products and services delivered to a final consumer (Christopher, 2016). There are several functions performed in the SC, such as the acquisition of raw materials, the transformation of materials into semi-finished and finished products, as well as their distribution to final customers (Novais, Maqueira, & Ortiz-Bas, 2019). The information sharing (IS) is required to integrate the SC, because in order to achieve its efficiency, it is expected that the SC members work together in the material management, information and financial flow (Bian, Shang, & Zhang, 2016). Also, the practice of making strategic and operational information available to other partners in the SC depends on the IS, which is considered a fundamental way to promote collaboration or optimize the performance of the entire SC (Dominguez, Cannella, & Framinan, 2014).

Furthermore, the collaboration in the SC denotes two or more independent companies that are organized together to design and structure the operations of the SC (Cao & Zhang, 2011). Particularly, companies that work collaboratively may obtain greater resources, recognition, and rewards when they face competition due to limited resources (Liao, Hu, & Ding, 2017). It may also produce benefits for its members, for example, reducing risks, accessing complementary resources, and reducing exchange costs (Narayanan, Narasimhan, & Schoenherr, 2015). The collaboration of the SC can present two different relationships: (1) vertical, which is between a supplier and a customer, whereas (2) the horizontal is between companies from the same level; even among competitors (Raweewan & Ferrell, 2018). In addition, with congruent objectives, both suppliers and customers are intrinsically motivated to adopt cooperative behaviors, such as constructive communication, mutual support, adaptation, as well as a high level of commitment (Jap & Anderson, 2003).

The principal goal for a SC is to improve its performance and fulfill the customer expectations, therefore, measures and performance metrics are needed to value its effectiveness and efficiency (Reddy. K, Rao. A, & L, 2019). In fact, performance measurement can be defined as the process of quantitatively and/or qualitatively evaluating the effectiveness and efficiency of a business activity or processes (Reddy. K et al., 2019). Specially, this type of performance is affected by partners and information sharing that is defined as the practice of making strategic and operational information available to other SC partners, which is considered as an essential way to promote collaboration and consequently, optimize performance (Dominguez et al., 2014). The general benefits from evaluating performance include evaluating and monitoring progress, highlighting achievements, improving understanding of key processes, identifying potential problems, and providing information on possible improvement tasks in the future, among others (Ahi & Searcy, 2015).

Moreover, in the literature review, structural equation models in which the SC performance is measured can be found. For instance, it is measured by the effect of national and international logistics policies (Avelar-Sosa, García-Alcaraz, Vergara-Villegas, Maldonado-Macías, & Alor-Hernández, 2015), where Reddy. K et al. (2019) report a literature review associated to the mean metrics. In Q. Zhang and Cao (2018), a second-order structural equation model (SEM) is presented in which the variables for information sharing, Goal Congruence and Decision synchroare grouped into a variable called collective and inter-organizational systems. The results showed when there is a lack of collaborative culture, collaboration in the SC is likely to decrease, and the collaborative advantage will adversely be affected. In addition, the collaborative culture helps companies overwhelmingly overcome the benefits of individual companies. Cao and Zhang (2011), measure the relationship that these same variables have between the competitive advantage, as well as between the performance of companies; with a moderating variable (company size), this, through a second order SEM. The results indicate that collaboration in the SC improves the collaborative advantage, which has a final influence on the performance of the company, where the collaborative advantage is an intermediate variable that allows SC partners to achieve synergies and create superior performance. Liao et al. (2017) analyzed the relationship of the collaborative innovation in the SC between the capabilities of the SC, the competitive advantage, and the performance of the SC in Taiwan industries, which was done through a SEM, where the results showed that the relationships between the innovation of value from the collaboration of the SC, the capacity of the SC, and the competitive advantage can have a positive impact on each other, as well as that the capacity of the SC is a complete mediator. In addition, SC levels have some moderating effects on these relationships. Y. Li (2014) reports a model in which the effects of social resources on promoting the practice of sharing information were examined, therefore, improving the company's performance. The relationships were analyzed through a SEM, where statistical results reveal that each dimension of the social capital has different type of effects on the information sharing as well as performance; relational capital and cognitive capital have significant positive influences on the information sharing.

However, the principal problem is that the effect of *Goal Congruence, Decision synchro, and Information Sharing* on the *Supply Chain Performance* in the maquiladora industry of northern Mexico has not been measured. In that sense, the objective of this research is to measure the effect that three independent latent variables (*Goal Congruence*, *Information Sharing*, and *Decision synchro*) have on the *Supply Chain Performance* in the maquiladora industry sector of northern Mexico. In order to carry on this task, a model is proposed which is presented in Figure 1, where six hypotheses are established; each one is represented by an arrow. Figure 1 also shows the results of the model that is already evaluated.

Finally, the rest of the article is distributed as follows: in section 1, the latent variables are presented, where the six hypotheses are proposed, in section 2 the methodology is described, section 3 presents the results obtained, while section 4 describes the conclusions and industrial implications.

2. LITERATURE REVIEW AND HYPOTHESES

2.1 Goal congruence

Goal congruence is the degree to which the associated companies jointly participate in the achievement of an objective (Samaddar, Nargundkar, & Daley, 2006). Collaboration is working with other members to accomplish tasks and achieve shared goals. Specially, it is a recursive process, in which two or more people or organizations work together: more than simply the intersection of goals in common, as it has been seen in cooperative enterprises, but as a deep and collective determination to achieve a common goal (Liao et al., 2017). It is the process where the company acknowledges if its own objectives are achieved by accomplishing the objectives of the SC, also it indicates the degree of agreement of objectives between the partners from the SC (Q. Zhang & Cao, 2018). In the spirit of true congruence of objectives, companies believe that, in case of disparity, their objectives can be achieved as a direct result of working towards the objectives of the SC (Q. Zhang & Cao, 2018). That is why, the Goal congruence variable is evaluated with the following items:

- The firm and supply chain partners have an agreement on the supply chain goals.
- The firm and supply chain partners have an agreement on the importance of collaboration across the supply chain.
- The firm and supply chain partners have an agreement on the importance of improvements that benefit the supply chain.
- The firm and supply chain partners agree that the firm goals can be achieved through working toward the supply chain goals.
- The firm and supply chain partners jointly design collaboration and implementation plans to achieve the supply chain goals.

2.2 Information sharing

As a matter of fact, the success of any product depends on the attitude of customers towards that product; it is important that companies achieve customer satisfaction by having efficient and effective supply chains (Ramanathan, 2014). This may be possible through collaboration between SC partners. In addition, companies collaborate by working on mutual goals, developing processes or products together, sharing the cost of investments, mitigating risks, or sharing information (de Leeuw, 2009). There are many types of information that can be shared in an SC, such as production and transportation cost, demands, and orders. In general, the more information available, the greater the space for negotiation and cooperation (Huang, Hung, & Ho, 2017), the deeper the level of information sharing, the greater the benefits, risks, and costs that can also be associated (G. Li, 2005). The information sharing is not only considered positive, because revealing too much information will reduce relational rents by empowering customers and allowing them to reduce supplier margins or exclude some of their SC providers altogether (Wang, Pfohl, Berbner, & Keck, 2016). Similarly, IS can also be used by suppliers to get more power over their customers in order to achieve an advanced position in the SC (Wang et al., 2016). Therefore, in the present paper the following items are included to evaluate the Information sharing variable:

- The firm and supply chain partners exchange relevant information.
- The firm and supply chain partners exchange timely information.
- The firm and supply chain partners exchange accurate information.
- The firm and supply chain partners exchange complete information.

- The firm and supply chain partners exchange confidential information.
- There is an exchange of information between the supply chain department and another department.

Likewise, in situations where there is congruence of objectives, companies will share strategic information to achieve mutually beneficial objectives, since exchange routines of knowledge are a source of competitive advantage (Dyer & Singh, 1998). In the absence of common goals, companies will not have any incentive to participate in the inter-organizational information sharing (Samaddar et al., 2006). The effective information sharing can strengthen cooperation and alleviate conflicts of objectives. In terms of supplier selection, purchasing companies should not only consider the cost, quality, and delivery time, but also make an effort to understand the corporation objectives and the supplier reliability, since the conflicts of dysfunctional objectives and the opportunistic behavior diminishes the willingness to share information, as well as compromise the longevity of relationships (Wang et al., 2016). Therefore, in order to measure the relationship that *Goal congruence* has on *Information sharing*, the following hypothesis is proposed:

H_1: *Goal congruence* has a direct and positive effect on *Information Sharing.*

2.3 Decision synchronization

Synchronization of decisions refers to the process by in which SC partners organize decisions in planning and operations that optimize the benefits of SC (Q. Zhang & Cao, 2018). There are several key management decisions about the SC, for example, strategy planning, demand management, production scheduling, purchasing, inventory replenishment, order placement, order delivery, and distribution management (Q. Zhang & Cao, 2018). Planning decisions are required to determine the most efficient and effective way to use the company's resources to achieve a specific set of objectives (Cao & Zhang, 2011). Also, planning together is used to align the collaborative partner and to make operational decisions, including replenishment of inventory, order placement, and delivery of orders (Cao & Zhang, 2011). In this paper, the following items are used to evaluate the *Decision synchro* variable:

- The firm and supply chain partners jointly plan promotional events.
- The firm and supply chain partners jointly develop demand forecasts.
- The firm and supply chain partners jointly manage inventory.
- The firm and supply chain partners jointly plan product assortment.
- The firm and supply chain partners jointly work on solutions for the company.

Furthermore, goal congruence on inter-organizational cooperation is often framed as a facilitator for the creation of value for organizations involved in the relationship (Barringer & Harrison, 2000). The concept of congruence presents the notion that collaboration in the SC needs a certain degree of understanding, as well as a mutual agreement between certain attributes, values, beliefs, and business practices of the organization (Cao & Zhang, 2013). In a successful inter-organizational collaboration, individuals invest resources to create bonds that transcend individual exchanges by creating a network of collective bonds (Cuevas, Julkunen, & Gabrielsson, 2015).

In addition, working along in the decision-making process with SC partners is necessary for intra-organizational operations, as well as for the development of long-term plans, for example, a company and its SC partners could take decisions together on demand forecasting to establish and jointly share common objectives throughout the SC (Pradabwong, Braziotis, Pawar, & Tannock, 2015). Therefore, the following hypothesis can be proposed:

H_2: *Goal Congruence* has a direct and positive effect on *Decision Synchro.*

In the same way, collaborative relationships transform the way of doing business in an SC; companies have evolved from cooperation (information sharing to improve internal business processes) to collaboration (execution of some business processes to improve profits and reduce costs together) (Rodriguez Rodriguez, 2008). Also, the information that members of a SC spontaneously exchange through their normal daily collaborative relationships could work as a platform, in order to develop a deeper insight into the type of CS that the innovation process requires (Liao et al., 2017). In other words, the amount of information provided by a SC can be inferred through collaborative relationships to improve the effectiveness of the SC capacity (Liao et al., 2017).

In general, information can be shared horizontally (to the information sharing between competitors at the same level) and/or vertically (indicates that SC partners at different levels share information with each other), in addition, a combination of vertical and horizontal information sharing can effectively increase the SC performance as partners strive to increase the profits of the entire SC (Wei, Zhao, & Hou, 2019). In that sense, the following hypothesis can be established:

H_3: *Information Sharing* has a direct and positive effect on the *Decision Synchro.*

2.4 Supply chain performance

The SC performance is considered as the ability of the chain to deliver products in the right place, at an agreed time, with the best possible logistics costs (H. Zhang & Okoroafo, 2015). In other words, it is the ability that any SC has to understand the customer needs, which are associated with the product availability, timely deliveries, and adequate inventory levels (Avelar-Sosa, García-Alcaraz, & Maldonado-Macías, 2019). Nowadays, the competitive business environment, the SC performance is one of the most critical problems in several industries, the measurement of the SC performance is essential for the efficient SC management (Balfaqih, Nopiah, Saibani, & Al-Nory, 2016). There are two ways to measure the SC performance; (1) in terms of the level of customer satisfaction and (2) for the incurred costs (Lihong, 2012). In fact, evaluating the SC performance is a complex task, partly, because it is a cross-cutting process that involves several actors that cooperate to achieve logistical and strategic objectives, where these type of evaluations become particularly relevant in situations where supply chains are considered a crucial factor or a key to achieve success (Lihong, 2012). The performance function must be carefully chosen to take an appropriate decision on how to organize the supply chain, therefore, it will be more flexible and reliable (Martínez, Lizárraga, Cavazos, Salais, & Saucedo, 2018).

The Supply chain performance variable is evaluated by the following items:

- Deliveries to customers are completed and on time.
- Customers are completely satisfied, there are no complains.
- SC performances are continuously improving.
- The cycle time from suppliers to the customer delivery is low.
- It is focused on cost reduction.
- The SC performance allows the financial flow.
- The SC is visible.
- Level of product customization.
- SC synergy.

The Goal congruence among the members of the SC is the extent to which the members of the SC perceive that their own objectives are accomplished along with the fulfillment of the SC objectives (Cao & Zhang, 2013). Specifically, companies that collaborate with their customers and suppliers can generate several benefits, including the reduction of creating new products as well as manufacturing times (Christopher, 2005). Similarly, companies and their SC members who work collaboratively in opening communication and sharing resources, risks, and rewards should enjoy the mutual benefits (Pradabwong et al., 2015). Therefore, building relationships between companies instead of working individually can lead to a competitive advantage, resulting in an improvement in the organizational performance (Cao & Zhang, 2011). In that sense, the following hypothesis can be proposed:

H_4: *Goal Congruence* has a direct and positive effect on the *Supply Chain Performance.*

Moreover, information sharing generates benefits for companies, such as reducing inventories and costs, better monitoring and optimized capacity utilization (Lotfi, Mukhtar, Sahran, & Zadeh, 2013), higher sales and a better understanding of demand (Kaipia, 2006). In addition, IS also includes performance criteria, such as production quality data, early completion date, and production capacities among partners (G. Li, 2005). IS helps reduce the whip effect in exchanging information with the client, it also helps reduce delivery times (Pamulety & Pillai, 2011). In that sense, the following hypothesis can be presented:

H_5: *Information Sharing* has a direct and positive effect on the *Supply Chain Performance.*

As it was previously mentioned, synchronization of decisions is defined as the process in which the SC partners coordinate activities in the planning and operations of the SC to optimize the benefits from the SC (Simatupang & Sridharan, 2005). Among these activities, working together in the development of demand forecasts, inventory management, solutions, among others is required. Consequently, forecasting and demand planning are essential factors for the successful implementation of a SC management strategy; collaborative forecasting is a way in which the entire SC participates in demand decisions that will boost its activity (Helms Marilyn, 2000). A better forecast helps to increase supplier deliver rates, improve stock levels, and reduce reserve stock (Rodriguez Rodriguez, 2008). Participation in the forecasting process requires the dependence of the SC partners to provide detailed, accurate, and timely information on demand (Rodriguez Rodriguez, 2008). The level of precision and efficiency where this type of demand communicates throughout the chain is directly connected to the levels of inventory and customer service (Helms Marilyn, 2000). In the same way, SC members must decide the quantity of products and type of products to be supplied or delivered to customers. In that sense, Umpfenbach, Dalkiran, Chinnam, and Murat (2018) define assortment as the set of products that a manufacturer builds and offers to its customers. The objective of assortment planning is to identify a type of assortment that maximizes sales, profits or gross margin while satisfying numerous limitations, including budget, shelf space, and capacity (Kök, Fisher, & Vaidyanathan, 2009). Therefore, the following hypothesis can be presented:

H_6: *Decision synchro* has a direct and positive effect on the *Supply Chain Performance.*

The hypotheses proposed are shown in Figure 1.

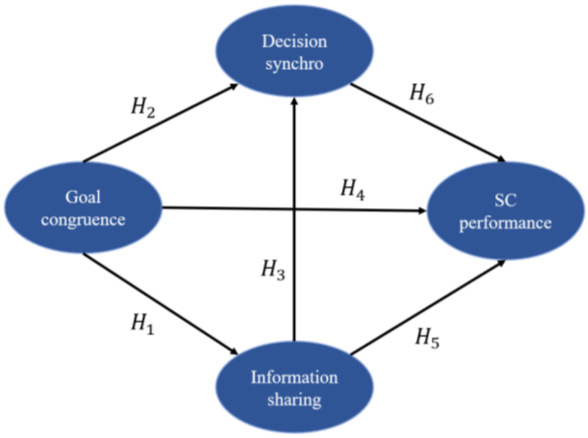

Figure 1. Proposed model

3. METHODOLOGY

In order to carry out this research, some activities were performed as it is described below:

As a first step, a questionnaire is done based on a literature review that was carried out in different databases such as: Sciencedirect, springer, scopus searching for relevant supply chain information about the latent variables in the model. In fact, within that literature review, a questionnaire prepared by Cao and Zhang (2011) was found to assess the impact of the supply chain collaboration on the competitive advantage as well as the companies' performance, which was used to conduct this research. In the same way, an independent variable called supply chain performance was created with 9 items that were obtained from the literature review. As a second step, the questionnaire was applied in the maquiladora industry of northern Mexico, specifically in Ciudad Juarez. In addition, it was applied through face-to-face interviews with each of the participant; they were selected by stratification.

Furthermore, the third step is to input the information and create a database in SPSS 21® to debug it, which is done by calculating the standard deviation of each of the questionnaires to identify uncommitted participants; if the value is under 0.5, the questionnaire is not considered (Adhikary, 2016; Arnab, 2017). Next, the missing data is identified (Leys, Ley, Klein, Bernard, & Licata, 2013), and if the total is over 10% of the data, the questionnaire is eliminated, otherwise, the missing values are replaced by the median (Hair, Black, Babin, & Anderson, 2010). Finally, extreme values are identified by standardizing the items; if the absolute value is more than four (Schubert, Zimek, & Kriegel, 2014; Wu et al., 2013), it is replaced by the median. As a fourth step, the validation of the questionnaire is done, where the following indexes are used (Ned Kock, 2019): R^2, Adjusted R^2, Q^2, Cronbach's alpha index and the composite reliability index, the average variance extracted (AVE), and the variance inflation factor (VIF).

In the same way, once the variables of the questionnaire are validated, they are integrated to the structural equation model (SEM), which is executed in the WarpPLS 6.0® software. Before interpreting the results of the model, its efficiency indexes are analyzed, where a 95% confidence level is used for its estimation. The indexes are the following (N. Kock, 2018): average path coefficient (APC), Average R-Squared (ARS) with a 95% hypothesis test, Adjusted Average R Squared (AARS), variance inflation factor (VIF) Average block variance inflation factor (AFVIF) with acceptable values under 5, and Goodness of Fit (GoF) with acceptable values over 0.36. Once the model is validated, the analysis of the effects involved in the model is proceed; these are the direct, indirect, and total effects.

4. RESULTS

The results obtained from this research are presented below.

4.1 Descriptive analysis of the sample

From the application of the questionnaires, a sample of 143 answers was obtained, which is divided into the different industrial sectors (automotive, electrical, among others).

4.2 Validation of latent variables

Table 1 portrays each of the validation indexes of each latent variable. It is observed that there is enough predictive validity from a parametric point of view, since the R-squared and Adjusted R-squared indexes are over 0.5, in the same way, there is enough reliability, both compound and internal consistency, since, for each of the variables, the composite reliability and Cronbach Alpha indexes are more than 0.7. Similarly, there are no collinearity problems, since the VIF index is under 3.3 in all variables. Finally, there is enough non-parametric predictive validity, since the Q-squared values are greater than 0.5 and similar to the R-squared. Therefore, it is concluded that the relevant relationships can be described along with the latent variables that are shown in the model.

Table 1. Validation of latent variables

	SC Performance	Information sharing	Goal congruence	Decision synchro
R-squared	0.585	0.592		0.566
Adj. R-squared	0.576	0.589		0.559
Composite reliability	0.922	0.920	0.890	0.910
Cronbach Alpha	0.904	0.895	0.834	0.877
Avg. Var. Extrac.	0.567	0.658	0.669	0.670
Full collin. VIF	2.339	2.631	3.244	2.379
Q-squared	0.591	0.593		0.567

4.3 Structural equation model.

Table 2 shows the model fit and quality indexes, based on the results from the APC, ARS, and AARS indexes, which value is P < 0.001, where is concluded that the model has enough predictive validity. According to the values under 3.3 from the AVIF and AFVIF indexes, it is concluded that the model is free of collinearity problems between variables. Finally, according to the GoF = 0.610, it is concluded that the model has an appropriate fit. Therefore, the relevant assertions regarding the direct, indirect, and total effects can be established.

Table 2. Model fit and quality index

Index	Value	P-value
Average path coefficient (APC)	0.400	p < 0.001
Average R-squared (ARS)	0.581	p < 0.001
Average adjusted R-squared (AARS)	0.575	p < 0.001
Average block VIF (AVIF)	2.624	
Average full collinearity VIF (AFVIF)	2.648	
Tenenhaus GoF (GoF)	0.610	

4.3.1 Direct effects

Figure 2 shows the model evaluated, within the Figure 3 different values can be observed on the arrow, the β value, which is the direct effect that occurs between two latent variables, the p-value, which shows the statistical validity of that direct relationship between the two variables, and finally, the R^2 value is shown, which is the participation of the variance explained by the independent variable. In addition, below the independent variable, the total of R^2 is presented, which is the sum of all the shares of the independent variables on the dependent variable. In Figure 2 five of the six hypotheses proposed are statistically significant, since their p-value is under the significance level of 0.05; the value at which the hypotheses were proposed. It can be concluded that, for example, in H_1, the *Goal congruence* variable has a direct and positive effect on the *Information sharing* with a value of β = 0.769, since when the *Goal congruence* increases its standard deviation in one unit the *Information sharing* increases in 0.769 units. Likewise, the *Goal congruence* explains in a R^2 = 0.592 of the *Information sharing* variance. The same applies to the other four hypotheses. However, the H_5 hypothesis is not statistically significant, since the p-value is more than 0.05, which is marked with an arrow with a dotted red line.

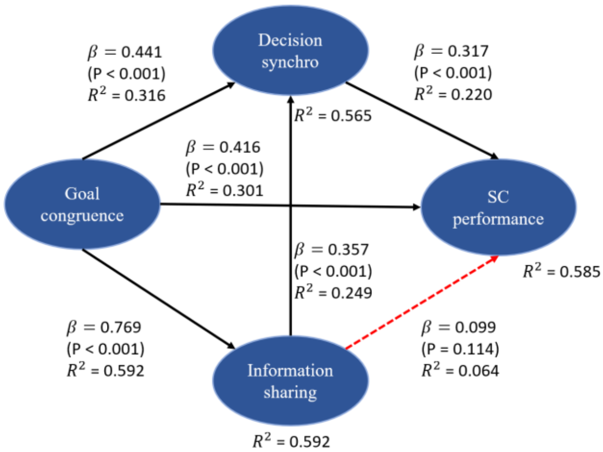

Figure 2: Evaluated model

4.3.2 Indirect effects

Table 3 presents the indirect effects between the latent variables, as it was previously mentioned, the indirect effects occur between two variables through one or more mediating variables. For instance, there is a direct effect from the *Goal congruence* variable on the *SC performance*, but there are also two indirect effects from two arrow segments, as well as an indirect effect from three arrow segments that has a value of β = 0.303, which represents a size effect (SE) = 0.219, in other words, it represents the value of the variance explained indirectly. Similarly, in the *Information sharing* variable on the *SC performance*, there is an indirect effect through the *Decision synchro* variable with a value of β = 0.113, and a SE = 0.073, in this case, the indirect effect between these two variables is statistically significant, that is, *Information sharing* has a relationship with the *SC performance*, only that, in this model, it is shown through the *Decision synchro* variable. It is important to mention that the p-value is also mentioned in Table 3 for each of the indirect effects, which indicates that the three indirect effects presented in the model are statistically significant.

Table 3. Indirect effects

From	To	Beta	SE	P-value
Goal Congruence	Decision synchro	0.275	0.197	p< 0.001
Goal Congruence	Supply Chain Performance	0.303	0.219	p < 0.001
Information Sharing	Supply Chain Performance	0.113	0.073	p = 0.026

4.3.3 Total effects

Finally, Table 4 illustrates the total effects that are presented in the model from Figure 2. It is observed that the effects with the highest value are those provided by the *Goal congruence* variable on the three dependent variables: *Information sharing* (β = 0.769, SE = 0.592), *SC performance* (β = 0.179, ES = 0.520), and *Decision synchro* (β = 716, SE = 0.513), which makes it the most fundamental variable in the model, since it is the one that contributes the most directly to the variance.

Table 4. Total effects

From	To	Beta	SE	P-value
Goal Congruence	Information Sharing	0.769	0.592	$p < 0.001$
Goal Congruence	Decision synchro	0.716	0.513	$p < 0.001$
Goal Congruence	SC Performance	0.719	0.520	$p < 0.001$
Information Sharing	Decision synchro	0.357	0.249	$p < 0.001$
Information Sharing	Supply Chain Performance	0.212	0.137	$p = 0.004$
Decision synchro	Supply Chain Performance	0.317	0.220	$p < 0.001$

6. CONCLUSIONS

According to the results obtained, it can be concluded that the *SC performance* is directly affected in a positive way by the *Goal Congruence*, since there must be an agreement on the objectives as well as on the importance of collaboration. Also, the importance of improvements by the company and partners, it is essential, since plans are designed together by the company and partners. In the same way, a synchronization of decision makers among partners is important, in order to take decisions together such as, the planning of promotional events, making the demanding of forecasts, managing the inventory and variety of products, as well as work together on possible solutions.

Additionally, the *Information sharing* does not have a direct effect on the *SC performance*, but it is a crucial activity in performance, since information must be shared among partners to take decisions together, as well as guarantee that the performance is positively affected.

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DEVELOPMENT OF A FORECAST, INVENTORY MANAGEMENT AND TRANSPORTATION STRATEGY, TO IMPROVE EFFECTIVENESS IN THE E-COMMERCE CHANNEL, FOR A LEADING WINE AND ALCOHOLIC BEVERAGES COMPANY, IN MÉXICO CITY

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1. ABSTRACT

The E-commerce channel in the retail market represents transcendental challenges in the strategy logistics placement, to manage through the supply chain, products in a short time, with a low cost, and a rich mix of value for the costumer. Structural growth in terms of markets and digital infrastructure grows vertiginously. In Mexico, costumers are aware of their omnichannel, with more than 20% annual growth in digital sales and 90% smartphone penetration (Rodríguez, M 2017). Mexico is emerging as one of the fastest growing countries in the region in online retail sales (Emarketer, 2018). Given that the market is committed to more digital purchases through e-commerce channels, the wine and alcoholic beverages industry begins the path towards digital sales platforms, which stimulates research and analysis into new models and logistics strategies in these channels. A strategy development project for forecasts, inventories and transport in the e-commerce channel was carried out in a leading company of alcoholic beverages and wines in Mexico City, with the robustness that Mexico City can involve in distribution and routing issues. The company has a recent e-commerce channel, which did not have a logistic control strategy, therefore, a sales forecast was carried out, an inventory system and a transport system were created with information of sales data for 2016, 2017 and 2018 of various products marketed by the company in the e-commerce channel, that were eligible. First it was carried out was a seasonal adjustment so that through this an optimal forecast was made with the seasonal factor and with the use of dynamic tables. Then a warehouse system was made using the EOQ model, they were used in pivot tables and data segmentation. At the end, a transport route was made taking an average of the location of the stores in municipalities. With these averages, a saving method was used to see that two vans are needed to distribute everything. Based on the analyzed data, it was possible to build a feasible proposal that seeks to minimize current logistics costs, and that will allow the company to have greater competitive advantages.

Keywords: Logistics, efficiency, E-commerce, forecast model, transportation strategy.

2. INTRODUCTION

In today's markets, where the optimal cost of the product, customer service and the speed of delivery thereof, play an extrapolated extended role in the manufacturing and services industry, logistics strategies act as vital tools in efficiency indicators , and in the strategic and tactical processes of the companies, accelerating the growth towards new markets, and allowing to explore alliances and future growth in e-markets with support in the e-commerce, which allows to help to scale up to modern business structures (joong -kun cho et al. 2008), impact logistics services and boost the transaction channel (steinfield and whitten 1999; swaminathan et al. 1999; Hoffman et al. 1995).

The logistics chains of all sectors present incremental challenges in the construction of these strategies; a supply chain with a hectic competitive market is the alcoholic beverage market. Within the best-performing global alcoholic beverage markets, Mexico has a high growth in the world, due to a combination of legally drinking-age populations and healthy economies, which are expected to continue for the next 5 years. After India, Mexico expects a market leadership of 4.5% (IWSR, Drinks market analysis, 2009), and with the empowerment of E-commerce in the retail market in these emerging markets, transcendental challenges are expected in the placement strategy of products in a short time, as well as logistics strategies for generating inventories and reliable forecasts, which allow developing strong strategies of e-commerce strategys, rather than simple sales routes (Euromonitor 2018).

The company's challenge is that E-commerce represents its sales channel in which it ventured most recently. The company has many years of experience in both wholesale and retail sales. However, they had few experience in e-commerce sales, much less has developed a logistics control strategy. A model totally focused on this sales e-channel must be proposed.

With all the particular characteristics, it has, the objective of this paper is to develop a conceptual and practical logistic model of forecasts, inventory management and transport strategy in the E-commerce market under the use of real company data, which allows recognizing the importance of logistics strategies in the current e-competitive environments, distinguishing the relevance of undertaking more effective relationship strategies between customers and supply chain, as part of the development of highly changing and sustainable systems, such as inventory management and forecasting processes, in emerging chains of e-commerce.

The model has been built for the year 2019 in three phases: in the first phase, it was analyzed through tools such as linear regression, single and double exponential smoothing, and mobile forecasts, traceability and data mobility patterns from three previous years In order to determine the forecast method that suits the behavior of the data. In order to prepare the forecast, the behavior of the data of products sold was analyzed, considering the subunits per unit sold. Since the variation of data is show to be high under linear regression methods, the seasonal factor method was used when noticing the fluctuations. With this, it was also possible to obtain, through dynamic tables, non-seasonal demand, and with the help of a linear regression, generate the 12-month forecast, under verification through DAM and MAPE, which gave low values on the possible error of the forecast.

In the second phase, the inventory model was developed under the EOQ model, based on the demand for products from the previous year, to obtain the optimal order quantity for the next re-order, minimizing costs for product maintenance. With phases 1 and 2 optimized, phase three of establishing the optimal transport model was carried out, using the center of gravity method, obtaining the locations by coordinates of the delivery points by municipalities, and using the average volume values of sales, thus generating a database with distances and route savings, considering multimodal transport restrictions such as vehicle capacities, and cargo volume.

If a forecasting and transportation strategy is complicated for sales data from off-line channels, for sales data from an emerging channel such as e-commerce, it can become even more challenging. Because there is few evidences of general rules or models of behavior, and therefore the significant opportunities for developing models and strategies in this channel are still being studied.

3. MATERIALS AND METHODS

Sales data for 2016, 2017 and 2018 of various products marketed by the company in the e-commerce channel, were eligible. It was considered by strategy to analyze the database of historical sales information, by several quantitative methods of time series. It started from the base tools of moving averages and exponential smoothing, even more complex methods of decomposition with linear regression, by least squares. The process of choosing the method was taken by evaluating, on the one hand, the error that each forecast produced through the calculation of its mean absolute deviation (DAM) and the percentage of average absolute error (MAPE). On the other hand, decomposing the time series into its seasonal factors. It is relevant to note that the analysis of these projections was done by grouping by category or product families, since the behavior of an individual article is random, even if the group has stable characteristics.

With respect to the inventory management strategy, based on the information provided on annual costs per inventory maintenance SKU, and the estimation of the cost that this sales channel implies issuing a new inventory supply order, developed with the help of spreadsheets, a template that for each SKU yields both the economic order quantity (EOQ) and the reorder point at which said order must be issued with a service level of 95%. This template yields relevant data for inventory management, such as the calculation of annual average stock per SKU, and the optimal number of orders for said SKU that must be made during the year.

Finally, in the transportation strategy, the design of an optimal route for the distribution of products in Mexico City is resolved, applying the savings method, since it is a method that allows the necessary restrictions to be included, as it is in this case the capacity of the selected vehicle, in addition to throwing a solution quite close to the optimal one. It should be noted that, for the estimation of the savings, the coordinates of the average points of location of each of the municipalities were used as a reference, and the average volume per municipality to be filled, obtaining with this data the efficiency of the capacity of load and the maximum distance traveled.

4. RESULTS AND DISCUSSION

3.1. Forecast

To prepare the forecast, it is decided to use the data of products sold (table 1) considering the subunits per unit sold and the sub-units sold separately, as well as considering the behavior of sales within each year 2016, 2017 and 2018 (table 2). It was decided to create a dynamic table for the analysis of sales by month and year, in addition to having used data segmentation to evaluate the sales of type of products. In this way, it is easily possible to take the sales data in the table and only be able to do the seasonal factor with a product and change the data in the table and change the forecast data depending on the product.

Using the monthly summed sales of the years 2017 and 2018, the average, seasonal factor can be obtained later, so that the monthly demand can be non-seasonally adjusted, then the slope and secant of the line is calculated to create the forecast with a simple linear regression of the next 12 months (which would be the year 2019), finally the values obtained are multiplied by the seasonal factor and generate the forecast. It was determined that it was the best method through the DAM and MAPE, both giving rather low values on the possible error in the forecast.

Table 1: Performance of sales in the years 2016, 2017 and 2018 of the cognac products

Sales MONTH	Year 2016	2017	2018
1	-	20	53
2	1	5	38
3	-	10	19
4	-	8	23
5	5	12	41
6	4	82	105
7	4	12	49
8	5	15	17
9	3	21	32
10	4	28	47
11	27	105	117
12	35	56	134
		Units	

Table 2: Forecast of the 12 months of the year 2019 of the cognac product in the "Forecast" column. Reference. Table created by the project, based on the data provided by the company

Month	Liner Regression	Forecast
25	80.41	67.15
26	83.35	41.00
27	86.28	28.62
28	89.22	31.64
29	92.15	55.87
30	95.09	203.41
31	98.03	68.40
32	100.96	36.96
33	103.90	62.99
34	106.83	91.66
35	109.77	278.77
36	112.71	244.97
	Total	1211.44

DAM: Maintenance Analysis Data MAPE: Mean Absolute Percentage Error Reference Table created by the project, based on the data provided by the company

Slope	2.94
Intercept	7.01
DAM	12.54
MAPE	1.30%

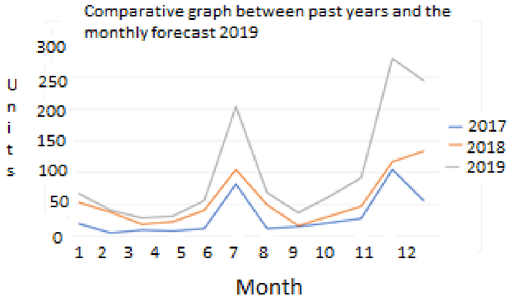

Figure 1: Comparative graph of sales for 2017, 2018 vs sales forecast for the 2019 months of the cognac product.

3.2. Inventory

Was selected the EOQ method to determine that the point at which the costs for ordering a product and the costs for keeping it in inventory are the same. This method takes into account the demand of 2018, the cost of maintaining the inventory, the cost of ordering the product. By considering these factors, the optimum quantity of the order for the next re-order is obtained as a result, minimizing the costs for product maintenance (table 3 y 4).

Table 3: Product sold of the product wky J. walker red

Sum of Total Sales per Product	Storage Cost (%)		
		0.2	
Month	126.03	171.66	
1	182	2	10
2	15	2	2
3	179	1	8
4	15	269	46
5	39	40	66
6	266	53	338
7	192	254	21
8	414	5	15
9	365	1	44
10	593	16	114
11	634	243	414
12	459	31	233
Total General	3353	917	1311
		Units	

Table 4: Product calculations wky J. walker red. Reference Table created by the project, based on the data provided by the company

Standard deviation	205.50

Level of service	0.95	
Z	1.64	
B (Security Inventory)	338.02	
Average Inventory	617.44	
Level of service	1.00	Units
Final average Inventory	426.75	
Anual Cost of Inventory Maintenance	85.35	
Orders in a Year	19.00	
Annual Cost of Order	2248.84	

Oder Cost ($)	$118.36
Storage Cost (H)	$25.21
EOQ	177.45

Z = Number of standard deviations for a specific service probability. EOQ = Economic order quantity

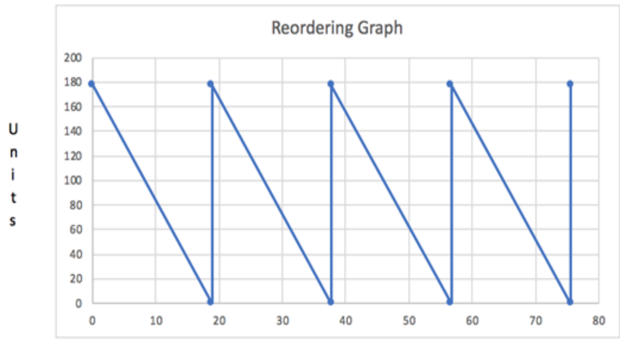

Figure 2: Product reorder graphic wky J. walker red

3.3. Transport

Was decided that first we must obtain the locations by coordinates of the delivery points by municipalities, then each one is calculated the average of coordinates to be able to use it as references of coordinates by municipalities. As for the quantities, how many places are reached per municipality, the company is multiplied by an average of its volume and multiplied by the number of points per municipality and, therefore, the quantities are obtained.

Having the board with the coordinates and quantities per municipality plus the coordinates of the ecommerce, it is possible to make a table of distances and route savings, the restrictions are placed according to the capabilities of the vehicle FORD LOBO 2019 whose maximum distance is 627 km (density and the weight of the alcohol that influences gasoline was not counted) and a maximum volume of 13,730,067 cm^3.

It began to observe with the formula of maximizing which is the route with the most savings in distances and it showed that the route with the most savings would be from Ecommerce - Álvaro Obregón - La Magdalena Contreras - Ecommerce (figure 1), it’s noticed that is still lacked as 10,000,000 cm3 to reach a capacity limit and much more for the distance, so possible routes were added to reach the limit of the restriction that was a van from the Ecommerce - Álvaro Obregón - La Magdalena Contreras - Tlalpan - Benito Juárez - Miguel Hidalgo - Iztacalco - E-commerce (figure 2) because there the capacity was reached and with 722,243 cm3 left over. Because of this, it’s necessary to use a second truck and began to see which was the most cost-saving route of an unresolved route and it could be observed that it was Ecommerce - Azcapotzalco - Cuauhtémoc - Ecommerce, but as with the one truck, it can still be added more routes for the truck to reach more locals and be able to complete the routes adding the missing ones and the route of the truck two was Ecommerce - Azcapotzalco - Cuauhtémoc - Tláhuac - Xochimilco - Milpa Alta - Ecommerce.

In the end it was achieved an efficiency of 69% in terms of capacity and 1% in maximum distance, since it could never take advantage of the entire journey that the truck can make, because it reaches a distance of 627.2 km and as efficiency it was very low even so counting the weights or any other factor, can not go up so much.

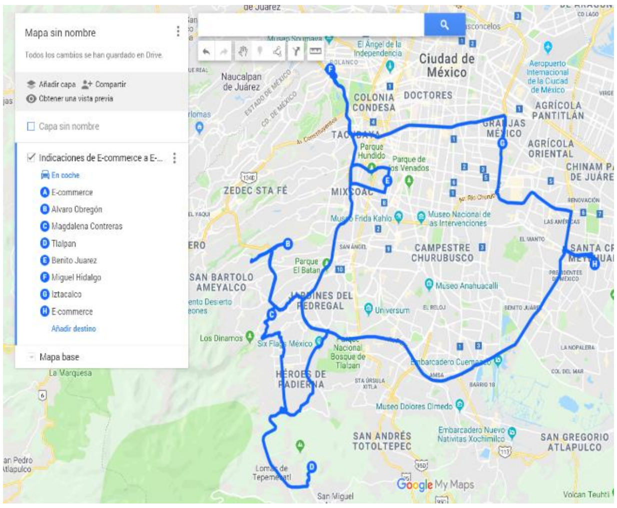

Figure 3: The route for the first van that goes from the Ecommerce - Álvaro Obregón - La Magdalena Contreras - Tlalpan - Benito Juárez - Miguel Hidalgo - Iztacalco - E-commerce

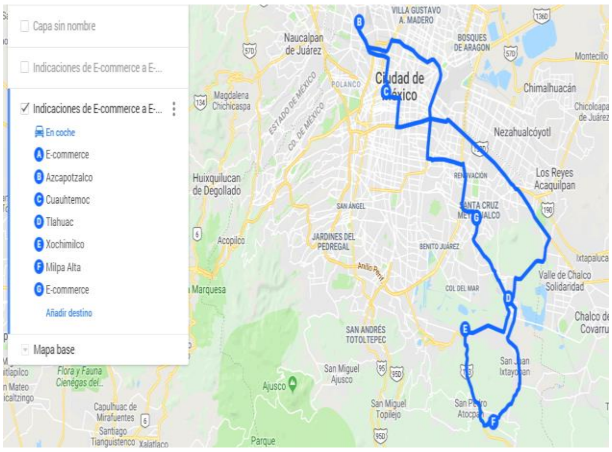

Figure 4: The route for the second van that goes from Ecommerce - Álvaro Obregón - La Magdalena Contreras - Tlalpan - Benito Juárez - Miguel Hidalgo - Iztacalco - E-commerce.

5. CONCLUSION

If a forecasting and transportation strategy is complicated for sales data from traditional channels, for sales data from an emerging channel such as e-commerce it can become even more challenging.

It was possible to fulfill all the main objective, since it was possible to generate a good forecasting system with dynamic tables and graphs that makes it more didactic and where it can shows that sales are more stable since 2017 (Ecommerce helped), it was possible to generate an inventory system for any product in an easy way and make a transport route with an efficiency above 50% in terms of the capacity it can have. In the end, a program has been generated that allows forecasting and inventory, in an easy way with the help of the Excel program.

The e-commerce channel for the company is relatively recent, so there is currently no proven model. The behavior analyzed reflects an exponential growth in the demand for products through this channel.

It is a comprehensive strategy that includes sales projects, inventory management and route optimization (at least locally). Based on the data analyzed, a feasible proposal can be built that seeks to minimize current logistics costs, and that allow the company to have greater competitive advantages for the satisfaction of this increasingly growing and demanding environment.

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Urban transport

COMPLEX NETWORKS ANALYSIS: MEXICO'S CITY METRO SYSTEM

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ABSTRACT

The metro system from Mexico City has previously been analyzed, but only by parts, specific case studies to some stations (transfer, transit or terminals) or metro lines (individually) and not to the entire system as such. This study is important since it will give us information about the system that is not yet known, it will help us to correctly identify risks to minimize them, as well as delays in the lines, make improvements to the system, have an adequate planning, establish different policies to improve and satisfy the system needs. Tools such as simulation will be used to create scenarios and search for alternatives for improvement in the system. This paper uses different techniques such as Complex Networks Methodology, Statistics and Simulation.

Keywords: transport system, Complex Networks

1. INTRODUCTION

The Mexico City Metro, also known as Metro de la Ciudad de México, is the second largest metro system in America. The subway authority Sistema de Transporte Colectivo (STC) operates the metro with funding support from Mexico's federal district (DF), the Transport and Communications Ministry (SCT) and the Mexico City government.

The system comprises 12 lines that span 225 km and cover 195 stations (115 underground, 55 at-grade and 25 elevated) with 48 transfer stations which are distributed within Mexico City and part of the State of Mexico.

The Metro of Mexico City has a total of 384 convoys, of which 285 are in operation and 99 out of service for the following reasons: 33 for lack of spare parts, 20 for being in reserve, 17 for maintenance, 15 by general review, 7 by revision of breakdowns, 5 by work of modernization, and one more by special works and another by reprofiling of wheels.

Figure 1 México City Metro System

2. PROBLEM

There are not easy solutions for Mexico City's congestion nightmare. Now the largest city in North America, Mexico City's metro area population is nearly double the size of the Los Angeles metro area. Mexico City saw its population grow from 13 million in 1980 to nearly 22 million in 2019. Population growth and urban sprawl are creating problems. Residents and visitors alike can see firsthand that Mexico City is the world's most congested city and it is worst at rush hours.

People in Mexico City rely heavily on cars for commuting. There are nearly 5 million vehicles registered in Mexico City and another 5.1 million registered in the surrounding state of Estado de Mexico. Many residents also drive cars in Mexico City that are registered in other states. Residents have also registered nearly 350,000 motorcycles. The resulting traffic, at times, can be infuriating. On average, residents of Mexico's capital city spend 227 hours stuck in traffic. Even non-drivers feel the effects of the traffic in the form of air pollution.

The government has proposed measures to further restrict car use, but without major new investments in public transportation infrastructure and public security, these restrictions may just push commuters to use Uber or taxis during restricted days. Mexico City currently operates a rapid transit bus system (Metrobus) with dedicated lanes that runs along Insurgentes Avenue and other principal avenues. The city also runs an expansive subway system that runs 285 trains over nearly 225 km. But with an estimated 5.5 million passengers on a system designed to accommodate 4.5 million passengers, Mexico City's subway is one of the world's most crowded. One study found it as the second most congested subway system in the world just behind New Delhi, India, with up to six passengers crammed into every square meter of train during rush hours. Both the Metrobus and Metro are oversaturated and unappealing options during commuting hours. These systems simply do not have the capacity to move the city's full population of commuters and are disconnected from many peripheral neighborhoods.

The subway system has its main problems due to factors such as the elements´ wear of the gear change, which has been caused by natural wear, cracks or fractures in lines with greater age, as well as lack of lubrication in rails and settlements differentials caused by the settlements of the subsoil of the city.

The Metro reported different problems: Technical, Operational, Social and Financial problems. The technical problems are those related to the operation of the network such as the control system, braking system, door opening system, capacity of the wagons, lack of spare parts, among others, most of these problems are due to lack of maintenance. Other problems are found in the operation of the system, which are those related to the rules and policies with which the Metro operates, such as the number of trains operating per schedule, action policies within the platforms, such as safety measures, evacuation, action measures in case of mishaps such as earthquakes, fires, terrorist attacks, among others. Another type of problem is the social problem, which is associated with people such as the flow of passengers, crowds, violence inside and outside the wagons, street vendors, among others. Finally, we find the financial or budgetary problems, since the Metro does not have enough money to maintain, buy spare parts of trains, rehabilitation of trains that are out of circulation or put in circulation new trains.

Therefore, the next questions are made: which are the most likely failure stations? how will faults propagate to other lines? How is the network connectivity? which are the alternative routes in case of failures?

So, we will focus this analysis with Complex Networks to identify the stations that have the most important problems and its vulnerability, and we will create different scenarios from which we will have the simulation of the whole system and how it works with the different scenarios.

3. METHODOLOGY

For the methodology we will follow the next steps.

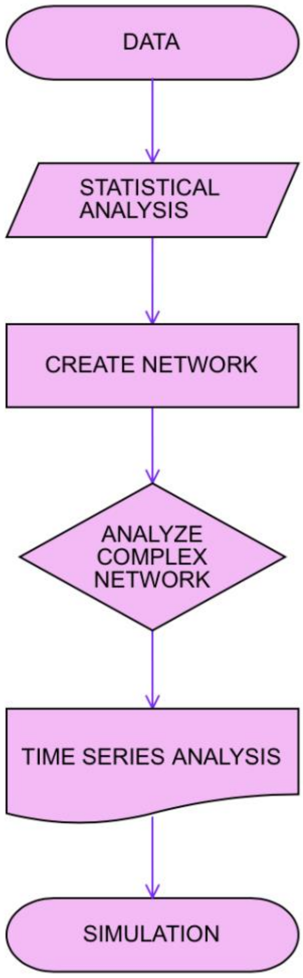

Figure 2 Steps Methodology

For this study we focused on the analysis of the metro as a whole system, to identify it as a first approach.

1. Data Acquisition

This step is maybe one of the most difficult steps because we need to look up for all the data that are relevant for the study.

2. Statistical Analysis

So, with this information the second step was to analyze the data with basic statistical techniques.

3. Network Creation

We can create the network in different ways, the most common is with the adjacency matrix. An adjacency matrix is a square matrix used to represent a finite graph or network.

4. Analysis of Complex Network

Once the network is obtained, we used the methodology of complex networks, specially to analyze the topology or structure of the networks, for example, the clustering, the closeness, betweenness, assortativity, and more metrics of complex networks. Also, we can have the degree distribution of the networks and a good approach of the network's behavior. With all the metrics and the degree distribution we can classify the networks into one of the different networks model (Random Networks, Small World Networks and Scale-free Networks).

5. Time Series Analysis

The fifth step consists in translate the information to time series, so we did a decomposition of time series into the three components series (Seasonal, Trend and Random), we obtained the ACF (Auto Correlation Function), PACF (Partial Auto Correlation Function). In this step we also can create time series models like ARIMA (Autoregressive Integrated Moving Average) models to do some forecast of the data.

6. Simulation

For the simulation process we will build different scenarios of the network to analyze the different structures and the vulnerability, so we can compare which network is better. We can have different scenarios for example what happens if we delete one node or an edge.

4. RESULTS

For the statistical analysis, we used the R software, which is an open source programming language and software environment for statistical computing and graphics. For this work, we used specific R software packages, such as, igraph, networks, tkrplot, sand, sna, forecast, TimeSeries, TSA and others. Software allows us to generate graphs/networks, compute different network metrics like clustering or transitivity, different centrality metrics, plot networks, create mathematical models, forecast data and more functions. Also, we used a BI (Business Intelligence) software that allow us to have some data preparation just like an ETL (Extract, Transform, Load) process and to create reports and visualization of our data.

According to the methodology, at the first step we have the data of the number of passengers by station and trimester: from the first trimester from 2011 to the first trimester of 2019.

Computing basic statistics: First, we analyze the number of passengers per line, to have the ranking of the lines with more passengers.

Table 1 Number of Passengers per Line

Line	Passengers	%
Line 2	2,399,777,835	17.87%
Line 1	2,128,428,724	15.85%
Line 3	1,944,304,705	14.47%
Line B	1,313,948,094	9.78%
Line 8	1,129,922,146	8.41%
Line 9	952,297,672	7.09%
Line 5	882,986,511	6.57%
Line 7	828,596,887	6.17%
Line A	794,763,580	5.92%
Line 12	592,338,103	4.41%
Line 4	249,863,002	1.86%
Line 6	215,006,325	1.60%
Total	13,432,233,584	100.00%

Then, we analyze the number of passengers per station to also have a ranking of the station with the highest numbers of passengers.

Table 2 Top 10 Number of Passengers per Station

Line	Station	Passengers
Line 3	Indios Verdes	345,139,908
Line 2	Cuatro Caminos	344,277,759
Line A	Pantitlán A	300,460,361
Line 5	Pantitlán 5	267,067,692
Line 8	Constitución de 1917	259,450,656
Line 2	Tasqueña	259,221,934
Line 9	Pantitlán 9	254,180,021
Line 1	Observatorio	218,684,664
Line 3	Universidad	217,461,690
Line 2	Zócalo	204,023,284

From table 2 we can see that the station Indios Verdes is the most crowded, but we also can notice that Pantitlán is a hub so, the cumulative number of passengers is higher than at Indios Verdes. This is important because this means that we need to have special attention in this station.

We continue with the methodology and we need to create a network. So, we have the structure of the metro system, characterize these data as an adjacency matrix. In this case, the nodes represent the stations and the edges represent the connections through the line. The next figure shows the structure of the system as a complex network.

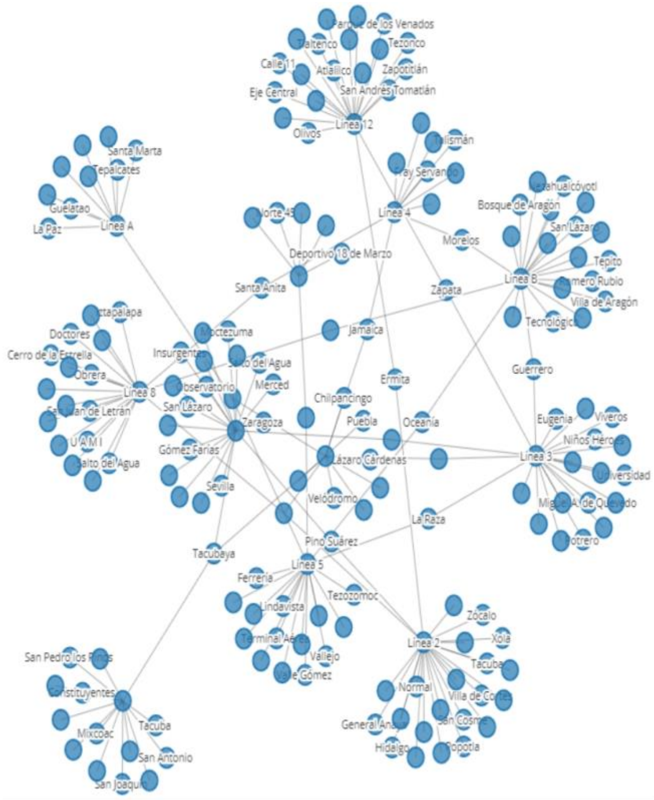

Figure 3 Metro Complex Network

Now, we have the system characterized as a complex network so now we can compute the different complex networks metrics to study the topological structure of our network.

Table 3 Complex network metrics

Results	Total
Nodes	195
Edges	220
Max. Degree	4
Min. Degree	1
Mean Degree	2.25641
Diameter	39
Mean Distance	12.94618
Cliques	4
Density	0.011631
Assortativity	0.245905
Global Clustering	0.056962
Mean Local Clustering	0.017304
Closeness Centrality	0.059484
Degree Centrality	0.008988
Betweenness Centrality	0.144816

The minimum degree corresponds to 1 and it makes sense because they are the terminal stations, the maximum degree is 4 that corresponds to stations like Pantitlán, meanwhile the average grade is 2.25, which tells us that there are very few stations that are transfer.

On the other hand, the density is important, it tells how connected the network is, the real systems modeled with networks, in general, are not very dense, due to the cost of the links. The network has a density of 0.011 which indicates that the connectivity within the network is very low and poor.

Another metric that we use in this analysis is the mean distance, which is the average of the distances between all pair of nodes, so we expect that the networks have a low average distance, which has to do with the small world property, but in this case we have a mean distance of 12.94 that is quit high in comparison with the number of nodes and edges.

In addition to the metrics that are listed above, we are interested in studying the topology of the network so clustering is important and, we start with the global clustering, it means what the tendency of the network is to form triangles or to be transitive, so, the global clustering is very low (it is 0.056), so it has a low tendency to form triangles. While, if we look at the mean local clustering, it is very similar to the global clustering but in this case, it is lower (0.017) so we can say that there is no tendency to form small groups, that is, they remain in the whole group.

On the other hand, the betweenness centrality, helps us to identify how important a node is within a network, computing how many short paths pass through the node in question, so we compute the average of the intermediate centrality of each case and we obtained a value of 0.144, the network has a very low betweenness centrality. The closeness centrality focuses on computing the shortest paths of each node to all other nodes in the network, we have that the closeness is relatively high. If we talk about the correlation of nodes, we have the coefficient of assortativity that gives us values between -1 and 1, therefore we can say if a network is assortative or dissortative, so, our network has a value of 0.24 with this we can say that it is assortative.

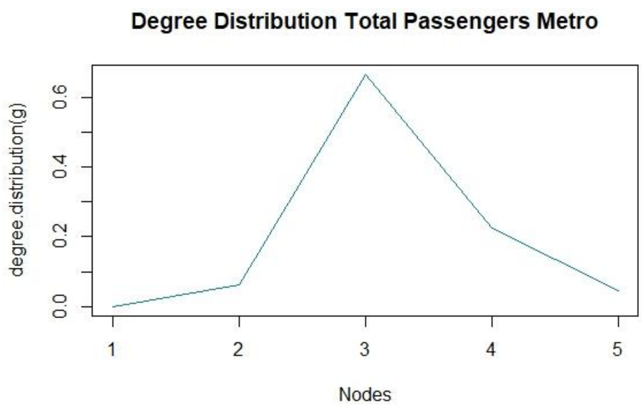

Figure 4 Degree Distribution Total Passengers Metro

We can observe that the distribution of degree seems to be binomial.

With all these results we can analyze and compare the behavior of the different stations and lines, in addition, we could analyze the topology of the whole system, which concludes the type of network model is and what specific characteristics and properties they share.

The next step is to perform the time series analysis, so first we organize and sort our date by the date (the most recent date and the end). Then we plot our time series just as the example of figure 5, where we plot the 12 lines as a time series.

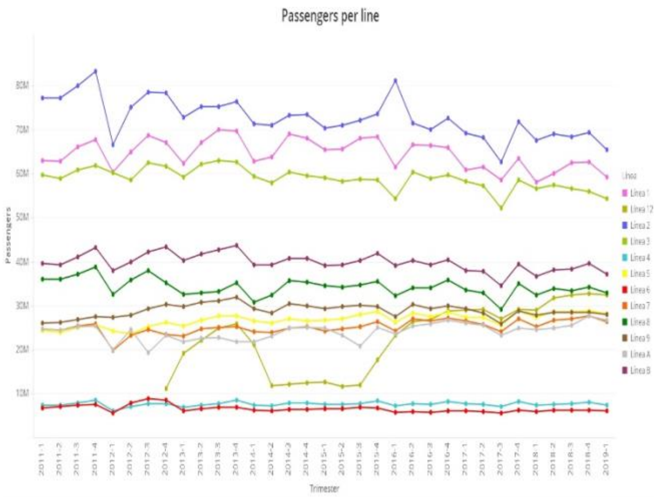

Figure 5 Time Series Passengers per Line

We can see that there are some lines that have the same behavior; for example, the lines 1, 2 and 3, and we can make clusters with the lines that have the same patterns. We have a strange behavior in the line 12 because it was open by the end of October 2012 then the part of the line was close due to technical problems.

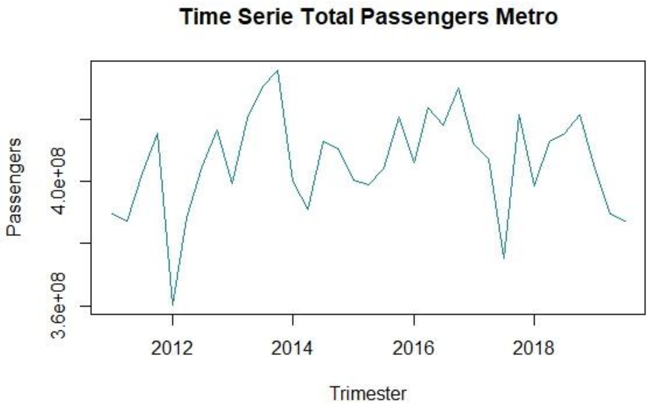

Figure 6 Time Series Total Passengers

On figure 6 we have the time series of all the passengers and the next step is to analyze the time series.

We use the time series decomposition that is a mathematical procedure that transforms a time series into a multiple different time series. The original time series is often split into 3 component series:

- Seasonal: patterns that repeat with a fixed period.
- Trend: The underlaying trend of the metrics.
- Random: also call “noise”, “irregular” or “remainder”, this is the residuals of the original time series after the seasonal and trend series are removed.

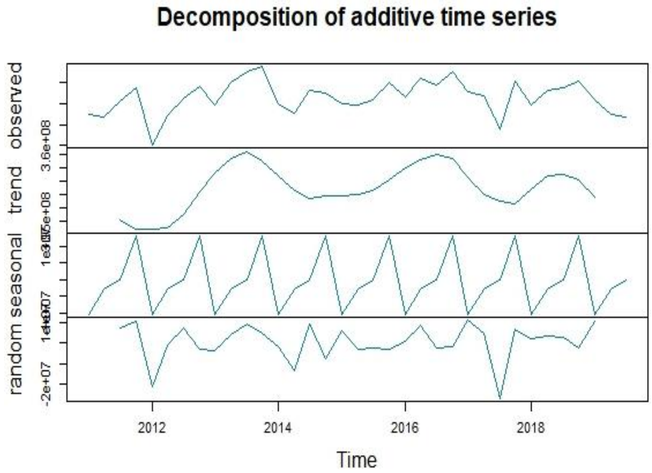

Figure 7 Decomposition Total Passengers Metro

To continue with our analysis, we use the ACF (Auto-Correlation Function) that gives values of autocorrelation of any series with its lagged values. We plot these values along with the confidence. We have an ACF plot. In simple terms, it describes how well the present value of the series is related with its past values. A time series can have components like trend, seasonality, cyclic and residual. ACF considers all these components while finding correlations hence it’s a complete auto-correlation plot.

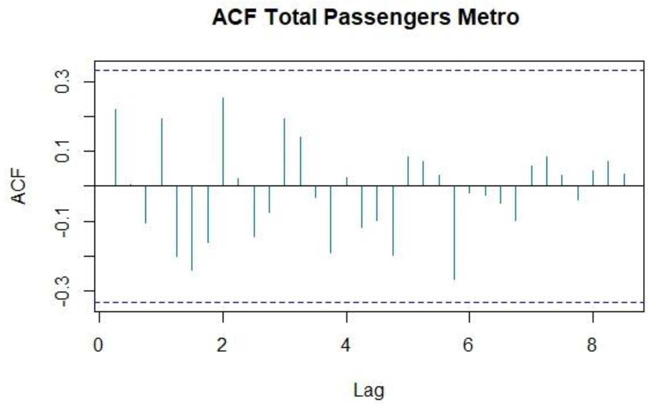

Figure 8 ACF Total Passengers Metro

We also used the PACF (Partial Auto-Correlation Function). Basically, instead of finding correlations of present with lags like ACF, it finds correlation of the residuals (which remains after removing the effects which are already explained by the earlier lag(s)) with the next lag value hence ‘partial’ and not ‘complete’ as we remove already found variations before we find the next correlation. So, if there is any hidden information in the residual which can be modeled by the next lag, we might get a good correlation and we will keep that next lag as a feature while modeling. Remember while modeling we do not want to keep too many features which are correlated as that can create multicollinearity issues. Hence, we need to retain only the relevant features.

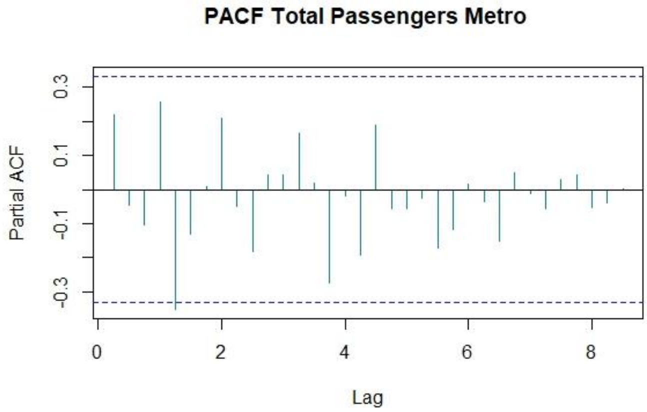

Figure 9 Total Passengers Metro

The ACF and PACF plots are more common used to obtain the values of p and q to feed into the ARIMA model.

All these analyses are important because it show us which are the patterns, seasonality and trend that the passengers follow throughout the time.

For the simulation scenarios two even more scenarios were proposed and were constructed depending on the problem that the network has to face. The first scenario is when we delete Pantitlán (the four stations of the lines 1,5,9, A and it´s connections) station that is one of the most important because of the number of passengers and the connections. The second scenario is when we delete the station with the lowest number of passengers that in this case is Tlaltenco.

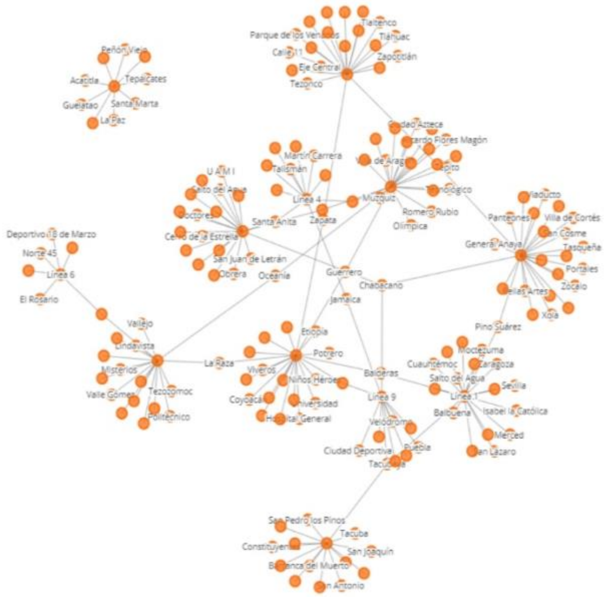

Figure 10 Scenario 1

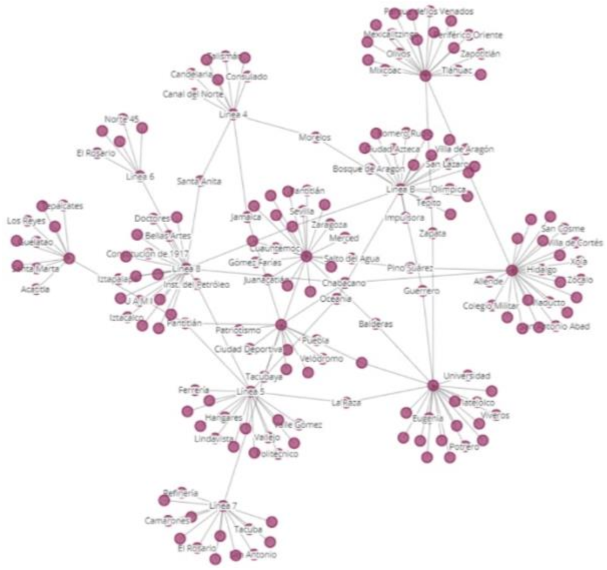

Figure 11 Scenario 2

On the scenario 1 there is a community (all the line A) that is completely disconnected from the whole system and in the case of the scenario 2 we only delete one station and this station is the last one of the line 12 so the only problem here is that the terminal station Tláhuac is completely disconnected from the system.

According with the methodology, we compute the different complex network metrics for both scenarios and then we analyze and compare the results with the original network.

Table 4 Results Scenarios

Results	Total	Scenario 1	Scenario 2
Nodes	195	191	194
Edges	220	212	218
Max. Degree	4	4	4
Min. Degree	1	1	0
Mean Degree	2.25641	2.219895	2.268041
Diameter	39	39	37
Mean Distance	12.94618	28.40568	14.30458
Cliques	4	3	4
Density	0.011631	0.01168366	0.01175151
Assortativity	0.245905	0.1842668	0.24273
Global Clustering	0.056962	0.02006689	0.05538462
Mean Local Clustering	0.017304	0.00571429	0.01657459
Closeness Centrality	0.059484	0.02111135	0.05236912
Degree Centrality	0.008988	0.00936897	0.00897388
Betweenness Centrality	0.144816	0.1533715	0.1566145

Comparing the three-network metrics, we find that the maximum degree is the same but the minimum degree on the scenario 2 is 0 because we delete the node that is the only connection with the terminal Tláhuac, so Tláhuac had 1 degree and when we delete Tlaltenco, Tláhuac remains alone. The mean degree is almost the same, in the case of the diameter on the scenario 2 there is a difference of 2 nodes so is a smaller size, but where we find the greatest difference is on the mean distance because on the scenario 1 it increases a lot so this tell us that Pantitlán station is important in our system and if we delete this station our connectivity decrease so we cannot remove or change this station. On the other hand, the centrality metrics does not change so much, so the scenarios remain with almost the same characteristics of the original network.

We also plot the degree distribution of the scenarios 1 and 2.

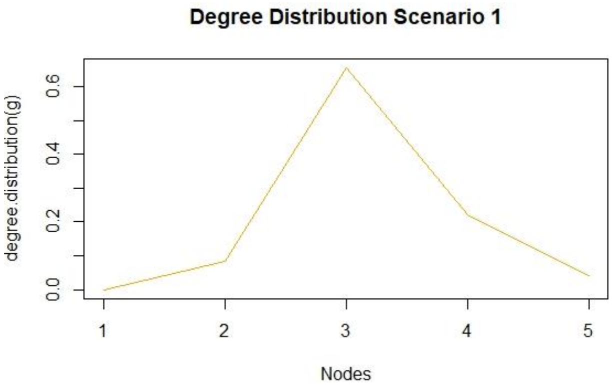

Figure 12 Degree Distribution Scenario 1

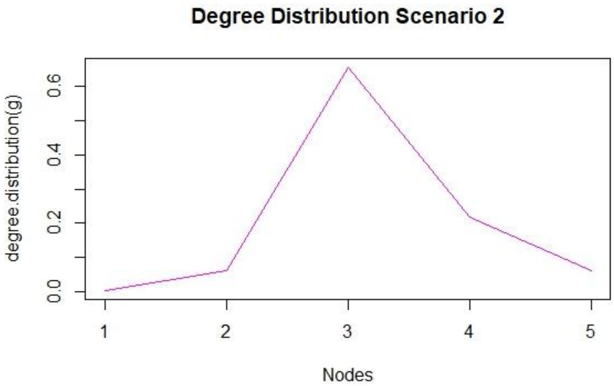

Figure 13 Degree Distribution Scenario 2

Both plots follow a binomial distribution just like the original network.

5. CONCLUSIONS

From the simulation scenarios we can conclude that if we delete a node (station) that is one of the more crowded stations or if it is one of the stations with important connections like transfer stations our network will suffer a big disruption, so the network will lose connectivity, robustness and efficiency and we will have bottlenecks in some lines or stations. In the case we delete a node (stations) that is not so important when we talk about the number of passenger and its connection with other stations or lines, if we delete this station will not have a great impact because the network will continue working also not as with the connectivity, efficiency and robustness as the original one but not as bad as if we delete an important node.

We conclude that the degree distribution of the network follows a Binomial Distribution, and in this case the network follows a Random Network Model because of the binomial distribution on the degree, The mean distance is high (tends to p ~ log *N*), the clustering is low (tends to k/N), where k is the average degree of the nodes.

In random networks, the neighbors of a certain node are chosen at random, so there is no correlation between the degree of neighboring nodes. Finally, these networks are more robust to targeted attacks, but at the same time they are vulnerable to internal errors.

After the time series analysis, we concluded that there is no evidence of a growing trend in the number of passengers and we could find some patterns in the seasonal cycles. It is difficult to find the behavior patterns in a macro level. Then, for the next steps, we will do the same analysis but in a medium and micro levels.

We will use the same methodology on the stations and lines that are more crowded to find and implement real solutions for this complex system. Also, the simulation will help us to create different scenarios to improve the way the metro works. In a future work we will focus on the application of the methodology that we proposed and on the implementation of a simulation-optimization solution to improve the efficiency of the metro system. Also for future work, it would be important to analyze the Plan Maestro del Metro for 2018-2030 because there are proposed different actions to improve the metro system such as new lines, extend actual lines and a maintenance program can be simulated and compared them with the actual network, and we can also propose different actions to improve the metro service.

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LOCATION OF MASSIVE BIKE-PARKING IN MEXICO CITY WITH THE USE OF GIS AND INTEGER PROGRAMMING

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ABSTRACT
This paper proposed a model based on integer programming and GIS to make a decision on where to build five parking lots for bicycles in Mexico City, with the aim of promoting the use of the bicycle and thus positively impacting the mobility of the city as well as reducing the use of motorized transports which generate pollution and road congestion. Therefore it is required that the five bike-parking lots in conjunction with the infrastructure already built, maximize the population benefited. Places were chosen within the Mexico City which had a large number of trips according to the ODS 2017, to meet the greatest use, the population that are less than five kilometers away from other services will be taken into account as they can be schools, shops, corporations, metro, metrobus or bus stations known as "Intermodal Transfer Centers" (CETRAM), in order to carry out this model it is necessary to obtain information from the population as well as geographic data of the surrounding services to the places where it can build these bike-parking lots, this information is obtained through the National Institute of Statistics and Geography (INEGI), to process the information it will be through the Geographical Information Systems in particular the QGis software is used. Once the information is obtained and processed , an entire programming model is generated whose objective is to maximize the population around of the bike-parking lots. Finally the solution that has five bike-parking lots along with the three bike-parking lots already built, covers 37 % of the population, 47 % of the CETRAM of Mexico City.

Keywords: bikes, mobility localization, parking lots

1. INTRODUCTION
In Mexico City, 34.56 million trips are made one day during the week, it is estimated that 70% of cars in homes can circulate daily, based on the results of the Origin Destination Survey (ODS) of 2017 (INEGI, 2017) . In addition, the percentage of trips made by bicycle is 3% in contrast to 30% of trips made by own car and 47% representing trips by minibus or collective transport, This shows that the city has a problem of mobility .The United Nations Organization on its page (ONU-Habitat, 2019) mentions that when investing in road infrastructure that promotes the use of the car or some other motorized transport, people choose to use such transport so that in the future more infrastructure will be required generating a cycle due to this it is recommended to promote the use of bicycle and other non-motorized vehicles in addition to affordable and accessible transport.

The bicycle is considered as a means of transport that helps mobility and does not pollute for this reason, cities and different international organizations make efforts to promote the use of the bicycle, these are classified into three types: programs, which refers to changes in the law, promotion of bicycle activities and public policies, for example: in Germany reforms to the road code are currently being proposed, to make cycling more attractive and safe. The second is the creation and maintenance of road infrastructure for bicycle use, for example: In the case of Colombia, it has made a large investment in bike lanes, only Bogotá has 2,513 km, finally, there is the creation of infrastructure other than the bike lanes, such as investment in public bicycles, bike-parking among others as an example is the country of Argentina, in Buenos Aires there is a public bicycle program. (Ríos R., 2015). In the case of Mexico there are both programs and infrastructure, for example, the city of Guadalajara has designated streets where the maximum speed is 30 km per hour, The National Autonomous University of Mexico (UNAM) has a loan service of bicycles for students and workers of the university, Mexico City has the "ECOBICI" project which is a public bicycle system, since its creation in February 2010 it has grown to 400%, it has one hundred thousand users and covers 35 km^2 around forty-three colonies of the city. It also exist the "Muevete en bici" program which promotes the recreational use of the bicycle, finally has a safe bike-parking program called "Biciestacionamientos Masivos" this program has three bike-parking spaces with space for about 1000 bicycles .

The bike-parks can be of various shapes and sizes and obey different purposes, (City Of Toronto, 2005) classify as follows the bike-parking: short-term bicycle parking and long-term bicycle parking, the first is for public use may be covered or uncovered and do not protect bicycles from theft or vandalism for example bike-parking in form of or inverted are the most common, they are to park bicycles for a short period of time; the long-term parking they have controlled access, they are generally in a closed and secure space, it is assumed that they have the purpose of parking the bicycle for a long period of time. An example is the massive bike-parking in Mexico City or the bike-parking of the Groningen station in Holland. This is the largest in the world. It was built in 2007 with space to park four thousand bicycles, currently the bike-parking lot has a space for twelve thousand five hundred bicycles. Therefore they can be small or very large, with access to all public or restricted access roofed or not, they can have technology to store bicycles, among other features, and all those features are designed so that bike-parking lots have an impact positive for this requires a design, a plan and a decision-making as mentioned (Saris infraestructure, 2019) or (Garcia Palomares , Gutierrez, & Latorre, 2012). Therefore, it is necessary to apply the operations research to solve the decision making of where to place a bike-parking lot with the objective that promotes the use of the bicycle for this purpose, a location problem can be solved: the location problems go back to scientists like Fermat and Torricelli among others. The Fermat-Weber problem seeks to locate a distribution center to minimize transportation costs. In the case of this problem, it can be considered as maximal covering location problem (MCLP), this type of model was first presented by Revelle and Church in 1974 (CHURCH, 1974). The model has been widely used for example Fazel Zarady, Davari and Haddad use the model to locate and place three different types of patrols to maximize the coverage of an area (Fazel Zarandi, et al. 2013). In this work we seek to maximize the population benefited by building 5 bike-parking spaces in Mexico City with characteristics similar to those built in the city project “Mass biciestacionamientos” once obtained the solution will analyze the possible services that are found around as are shops, schools, hospitals, factories offices and corporate.

2. DESCRIPTION OF THE PROBLEM

The use of the bicycle in Mexico City is limited according to the 2017 origin and destination survey (ODS) (INEGI, 2017) and in the city only 3% of the trips are made by bicycle one of the reasons why the use of the bicycle is small is the one that causes the theft of these, only in recent months according to the data of the attorney general's office on average steal 5 bikes a day (Estrada A.E, 2019). That is why infrastructure is required to deal with the problem.

In 2014, the first bike parking lot was created at the modal transfer center (CETRAM by its acronym in Spanish), with a capacity of 400 bicycles. With the objective of creating infrastructure that promotes the use of the bicycle, in addition to intermodal transport. There are currently 3 massive bike-parking lots with an average space of 350 semi-massive bike-parking bicycles with space for 100 bicycles. According to information from the Ministry of the Environment, it is planned to build 2 massive bike-parking lots and 1 semi-massive bike-parking lot. (Sedema, 2019). The "Biciestacionamiento masivo" project in Mexico City has advantages such as: being a safe place to leave the bicycle since it has access only to previously registered people and has a surveillance system; promotes intermodal transport; in addition, although Mexico City is not currently suffering from bicycle parking problems like other cities in the world, massive bike-parking has been shown to control the saturation of bicycles on public roads.

Therefore, if the Massive Bike-parking program has shown success in promoting the use of the bicycle, however, more bike-parking spaces of this type are required, since currently only 24% live within five kilometers of one of the 3 bike-parking lots according to the analysis of the data obtained in (INEGI, 2010). In addition these must be located in strategic points, so that it encourages the use of the bicycle this implies a great problem, as indicated (M. Ahmadi, 2012) y (Samani, 2018) in their respective they locate a public parking lot, to solve the problem MDC multi-criteria decision models were used, also (Saris infraestructure, 2019) They mentions that the place must be chosen in an appropriate manner, for which an analysis is required.

An adequate decision making will avoid situations like the case presented by the newspaper (Bahena, 2017), in the bicycle parking lot located in the “La race” subway which is not being 100% used, while the semi-massive bicycle parking of "Periferico Oriente" (in Spanish name have a saturation problem since you have 80 bicycle racks according to the (INEGI, 2017) survey are carried out around 3472 bicycle trips.

3. METHODOLOGY

First, a collection of information was made from sources such as the Survey origin and destination of the metropolitan area of 2017 (INEGI, 2017), the population census of the year 2010 (INEGI, 2010) With the information obtained, the analysis of the information was carried out through the QGIS software, with this analysis the districts in which more bicycle trips are made are made on a weekday, with that information twenty-seven points were considered as alternatives (include the 3 bike-parking lots already built) to build the bike-parking.

Considering the average time that a person travels by bicycle is 20 minutes and if the average speed of four kilometers per hour. It is expected that a bike-parking lot has an area of influence of five kilometers, a circle is drawn with that radius with a center in each alternative, the population living in that area is counted, schools, shopping centers, offices, are also counted corporate, commerce and CETRAMS, in order to analyze what kind of population can be benefited with the construction of the service and compare the population currently benefited with the one that will benefit once the solution is implemented. CETRAMS are important because if there is a bike-parking near a CETRAM, the use of intermodal travel is promoted, a multimodal trip consists of a trip that in segments of this can reach different types of transport for example a person can take the subway get to a station enter the bike-parking take the bike and continue the trip to get to the office.

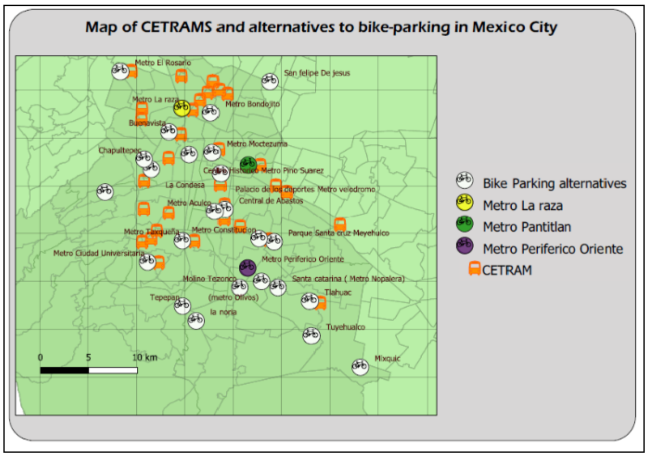

Figure 1: Map of CETRAM and alternatives

4. MODEL

The objective will be that the five chosen Bi-parking lots benefit the maximum of the population in addition to the three already built

4.1. Decision Variable

The decision variables will be x_i binary variables 1 if the i bike-parking is constructed and zero in otherwise

$$x_i = \begin{cases} 1 \\ 0 \end{cases}$$

4.2. Objective function

The objective will be that the five chosen Bike-parking lots benefit the maximum of the population in addition to the three already built

$$\max Z = \sum_{i=1}^{27} c_i x_i \tag{1}$$

4.3. Restrictions

The first restriction is for only five parking bikes to be built. The second restriction is so that at least trhee bike parking lots are built exactly in a CETRAM (The race-bike parking lots; La raza , Pantitlan y Periferico Oriente are not taken into account because those already built).

$$\sum_{i=1}^{27} x_i = 8 \tag{2}$$

$$\sum_{i=1, i\neq 21,24,26}^{27} a_i x_i \geq 3 \tag{3}$$

The restrictions four to ten represent the fact that there should only be at least one parking bike by town.

$$x_9 + x_{14} + x_{17} \leq 1 \quad Coyoacan \tag{4}$$

$$x_6 + x_{10} + x_{13} \leq 1 \quad Cuahutemoc \tag{5}$$

$$x_{19} + x_{24} \leq 1 \quad Gustavo\ A.\ \ Madero \tag{6}$$

$$x_{11} + x_{12} \leq 1 \quad Iztacalco \tag{7}$$

$$x_{14} + x_{16} + x_{18} + x_{21} + x_{25} + x_{26} \leq 1 \quad Iztapalapa \tag{8}$$

$$x_5 + x_7 + x_{14} + x_{17} + x_{21} \leq 1 \quad Tlahuac \tag{9}$$

$$x_1 + x_{15} \leq 1 \quad Xochimilco \tag{10}$$

The restriction, eleven and twelve and is that of bike parking lots already built.

$$x_{21} = 1 \quad Periferico\ \ Oriente \tag{11}$$

$$x_{24} = 1 \quad La\ \ Raza \tag{12}$$

$$x_{26} = 1 \quad Pantitlan \tag{13}$$

5. COMPUTATIONAL EXPERIMENTATION

A mix linear integer programming model was developed and solved whit the lingo software (LINDO SYSTEMS.Inc, 2019)

The solution should be built bike-parking in: La Condesa, Metro el Rosario, Central de Abastos, Metro Moctezuma, and Metro CU.

Table 1: Results of solution within the area of influence

Results of solution within the area of influence		
Type criterion	Number	Percentage
Commerce	30049	42%
Health services	3517	34%
professional and scientific services	15966	24%
information services	1060	31%
Schools	8609	37%
Recreational services	1431	37%
banking and financial services	2425	33%
Manufacturing industry	9689	43%
post office and storage	400	44%
Corporate	45	21%
Construction	1126	29%
Total Population	8796254	37%
CETRAM	79	46%

The solution shows us that bike-parking should be built in: Buenavista, Central de Abastos, Palacio de los deportes, Metro Moctezuma, Taxqueña In addition to those already built: La raza, Pantitlan y Periferico Oriente.

With the solution it has a population of 8,796,254 people benefited.

In addition to the population benefited by a proximity analysis, the services that are within the service area can be analyzed. This analysis (table 1) offers a broader picture of what type of population will benefit as the reasons for using the bicycle can vary, for example, a user can use the bicycle to go to the mall or his destination is the workplace. The reason for travel directly influences the use of the bike-parking lot because the two-station parking is expected to have long-term characteristics.

On the map it can see that the bike-parking lots of Moctezuma,Palacio de los deportes, and Pantitlan have an area in common. In addition, part of the western area is not covered, while the table shows that professional and corporate services are covered only around 20%.

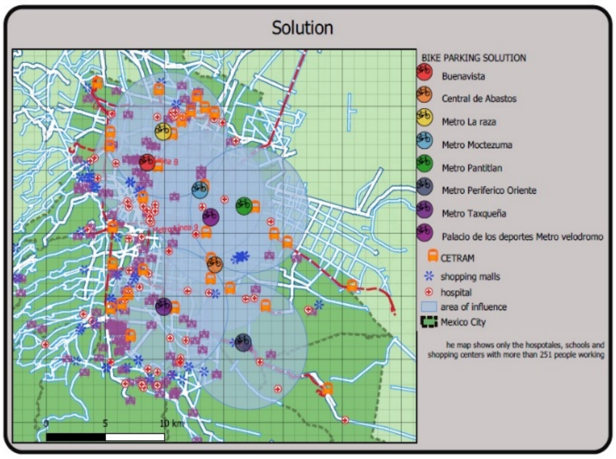

Figure 2: Map City of Mexico influence area of solution

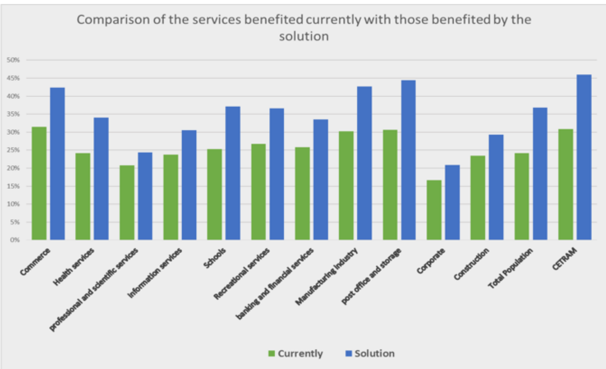

Figure 3: Comparative graph of solution 1 and 2: Own Elaboration

Finally, Figure 4 shows a graph that compares the percentages of the services of the current situation with the solution found. Among the highlights are; the increase in coverage in stores, which goes from 31% to 41%, the manufacturing industry which is covered by 30 % and with the proposed solution increases to 43% and finally the CETRAM of 31% at 46% this last one of the most important services since a bike-parking in a CETRAM encourages multimodal transport.

6. CONCLUSIONS

Geographic information systems are of great support when processing information since without this, estimates should have been made to calculate populations in addition to other data such as the number of shops, schools, hospitals, among others. They are also a tool that allows you to present the results in a graphical way. This makes it easier to understand which services are near a two-station. and in this way you can also understand what kind of population benefits.

With respect to the solution that having 8 bike-parking spaces considering the already trhee built, there is a service coverage of less than 50%, for example, only 46\% of the modal transfer centers are covered. Only 21% of corporate would have access to the bike-parking service.

We also note that the bike-parking lots of Pantitlan, Moctezuma and Palacio de los Deportes have a service area in common so the model must be readjusted so that the area of intersection is minimal.

And within the objective which benefits the largest number of population of 31% of the potentially benefited population the solution gives a total of 37% of potentially benefited population.

APPENDIX

Figures

- Figure 1: Map of CETRAM and alternatives
- Figure 2: Map City of Mexico influence area of solution
- Figure 3: Comparative graph of solution 1 and 2: Own Elaboration

Tables

- Table 1: Results of solution within the area of influence

Ecuations

- (1) Function Objetive of model
- (2) Restriction of number of bike-parking will construct
- (3) Restriction of model for locate A CETRAM
- (4) Restriction of town hall
- (5) Restriction of town hall
- (6) Restriction of town hall
- (7) Restriction of town hall
- (8) Restriction of town hall
- (9) Restriction of town hall
- (10) Restriction of town hall
- (11 Bike-parking lot of Periferico oriente
- (12) Bike-parking lot of La raza
- (13) Bike-parking lot of Pantitlan

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DATA VISUALIZATION TO FORECAST WITHDRAWALS IN A BIKE-SHARING SYSTEM: MEXICO CITY CASE

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ABSTRACT

In this paper we predict the overall withdrawal of ecobicis for a given day. The principal problem adressed was the lack of data available to understand certain behavior related to the ecobici´s demand at some time of the day. However, with the information available in the ecobici´s website we were capable to adjust a time series model that help us forecast the total withdrawals in the short time, this can be used to estimate the overall demand of ecobicis for a given hour in the day in order to identify the time of the day when the ecobici's demand is greater than the availability. The principal motivation of our analysis is to predict the demand of each ecobici´s station, so this model is a benchmark for future analysis.

Keywords: ecobici system, withdrawals, time series.

1. INTRODUCTION

Ecobici is a mobility system of the México´s city that started operations in February of 2010. The ecobici´s system consists that through a cheap membership you can use a bike offered by the service and get around over México city. Once you take a bike, you can use it for at most 45 minutes (if not, you must pay an extra charge), and at the end of your travel you must put down the bike in some station. The service and the number of users continue growing, since it started operations, because it has provided an alternative way to move around Mexico city and thus avoid the delay that happens in other mobility systems, such as traffic during crowed hours, for example. As a mobility alternative and the upgrowing number of users have occasioned that in certain hours of the day the demand of bikes is greater that the number of bikes available in some stations or that some stations are saturated and a user can´t put down the bike in that stations, causing the frustration of some users and some extra costs for relocating bikes from saturated stations to the empty ones.

As said above, it is important that the ecobici´s system known with anticipation the expected demand of bikes through the day, and thus, make strategies that can afford the demand and shortage of the stations. This is the reason why in this paper we propose a first model that help us to forecast the ecobici´s aggregated demand for all the stations in one specific day. In section 2 we talk about the available data and show some figures that help us to understand in deeper the problem. In section 3 we talk about the obtained time series model and present some results. Finally, in section 4 we talk about some conclusions and future work.

2. DATA AVAILABLE

The data used in this work is public and can be obtained in the ecobici's system website (see references). This data is reported monthly since February 2010 to June 2019 and consists of the following variables:

- *Genero_Usuario*: this is a nominal variable that takes the value M if the user is male and F if is female.
- *Edad_Usuario*: this is a numeric variable that reports the age of the user.
- *Bici*: this is a nominal variable that defines an id for the bikes.
- *Ciclo__Estacion_Retiro*: this is a nominal variable that defines an id for the station where a bike was taken.
- *Fecha_Retiro*: this is a nominal variable that reports the date when a bike was taken. This variable is reported as month/day/year.
- *Hora_Retiro*: this is a numeric variable that reports the time in which a bike was take. This variable is reported as hour:minute:second.
- *Ciclo_Estacion_Arribo*: this is a nominal variable that defines an id for the station where a bike was leaved.
- *Fecha_Arribo*: this is a nominal variable that reports the date when a bike was leaved. This variable is reported as month/day/year.
- *Hora_Arribo*: this is a numeric variable that reports the time in which a bike was leaved. This variable is reported as hour:minute:second.

2.1 Data visualization

In the ecobici's website it is possible to consult at the moment the number of bikes per station, this information could be useless to the users because they don´t know if some minutes after their query they would have a chance to withdrawal a bike from a particular station. In Figure 1 we show the information displayed in the website of the number of bikes per station when a query is done. The green circles represent the stations with more than 5 bikes, the orange circles represent the stations with less than 5 bikes, the red circles represent the stations with no bikes, and finally the grey circles represent closed stations.

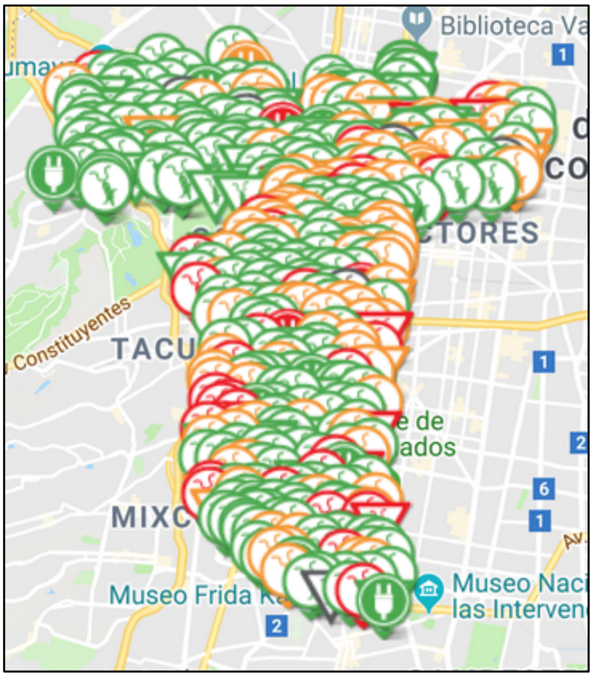

Figure 1: Bikes availability per station

So we start our analysis by monitoring the behavior of the aggregate number of bikes per stations in a given month by time intervals of 15 minutes, in particular we choose January 2018. In Figure 2.1 we illustrate the number of aggregate bikes withdrawals at time intervals 6:00 to 6:15, 9:00 to 9:15 and 18:00 to 18:15 respectively, also in figure 2.2 we illustrate the number of aggregate bikes arrivals at time intervals 6:00 to 6:15, 9:00 to 9:15 and 18:00 to 18:15 respectively. In both cases, each circle represents a station, while each number represents the station id. The size of each circle indicates the number of aggregated withdrawals or arrivals, according each case, while the color is assigned according to the station id. As we expect, these figures give us evidence about the dependency of the demand of bikes and the hour of the day. For example, if we compare the time interval 6:00 to 6:15 with 9:00 to 9:15 we can see a lot of more mobility in the second one. Also, if we compare the retreats and arrivals for interval 9:00 to 9:15 we can observe that the circles of color yellow and pink are greater in Figure 2.2 than in Figure 2.1, this give us evidence that the destiny of many users is closer to this stations, in contrast, if now we compare time intervals from 18:00 to 18:15 we can observe that the yellow and pink circles are bigger in Figure 1 than in Figure 2, so we observe the inverse scenario. This last example shows us that also the geographic zone can influence in the demand of bikes, for example, if some stations are closer to offices, the employees that use ecobicis as a mobility option would concentrate their arrivals in this stations by at the time they got to work, and at the end of the workday they are going to withdrawal bikes for a near station too.

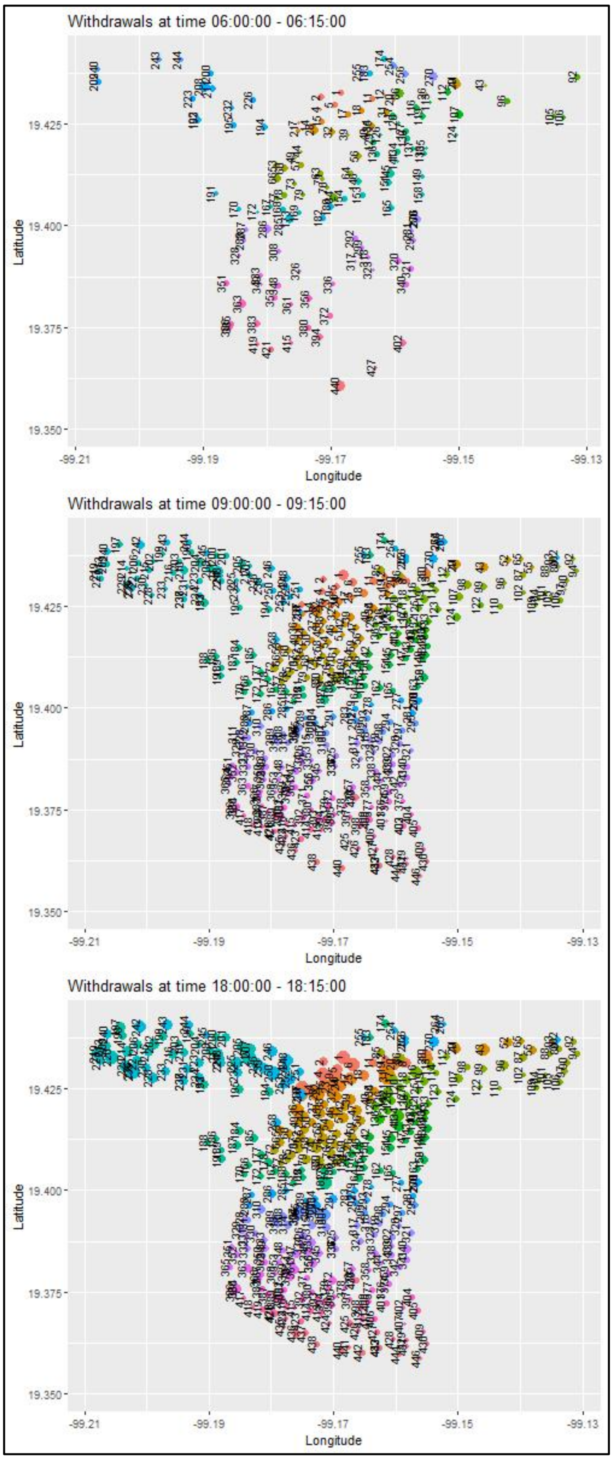

Figure 2.1: Aggregated retreats at January 2018

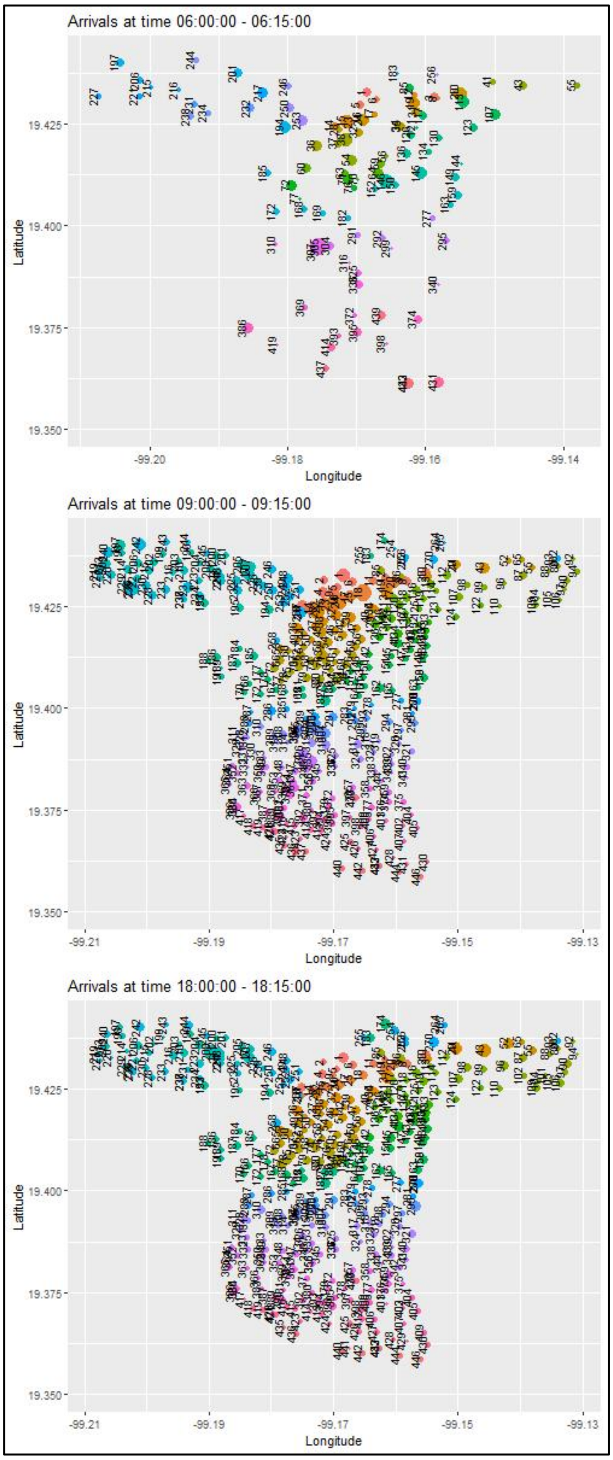

Figure 2.2: Aggregated arrivals January 2018

Once we explore the aggregate retreats by station in some time intervals, we continue our analysis exploring the number of arrivals and withdrawals per month, we aggregated the information per time intervals of 5 minutes, for example, in the time interval from 5:00 to 5:05 of each day of January 2018, we aggregate the number of arrivals and withdrawals of all of the days. In Figure 3 we show the aggregate arrivals and withdrawals for January, May and December 2018, we can notice that the shape of this graphs is very similar (also for the other months don´t showed), and it even seems that the aggregate arrivals and withdrawals have a similar behavior that depends strongly on time, for example, for time intervals from 7:00 to 10:00, 14:00 to 16:00 and 18:00 to 19:30 we observe an increase in arrivals and withdrawals. It is interesting to notice that in Mexico´s City these time intervals match with the start of workday, the break time and the end of the workday, respectively. Hence, we have evidence to believe that the demand of ecobicis is highly correlated with the working times.

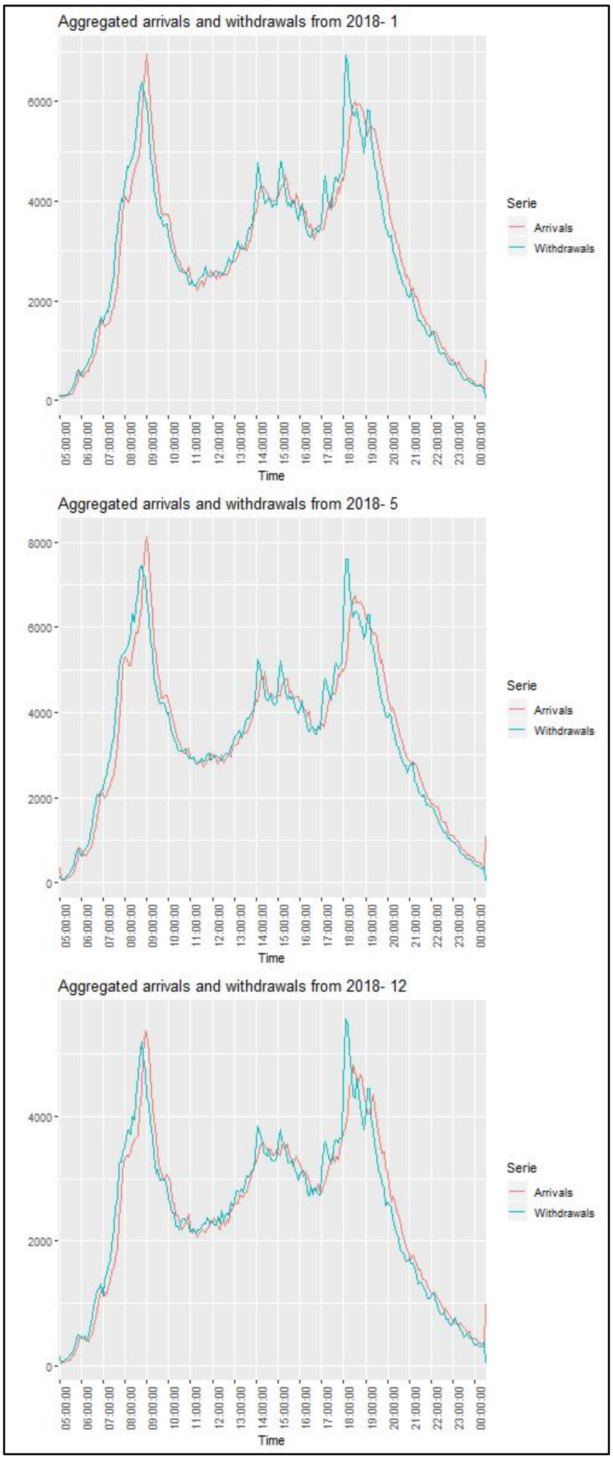

Figure 2.3: Aggregated arrivals and withdrawals

After we explore the aggregate arrivals and withdrawals, we consider analyze this quantities in a disaggregated way and we find out that in working days (Monday to Friday) the number of arrivals and withdrawals maintain the same shape as the aggregated versions, this is illustrated in Figure 2.4 for three random working days selected from 2018.

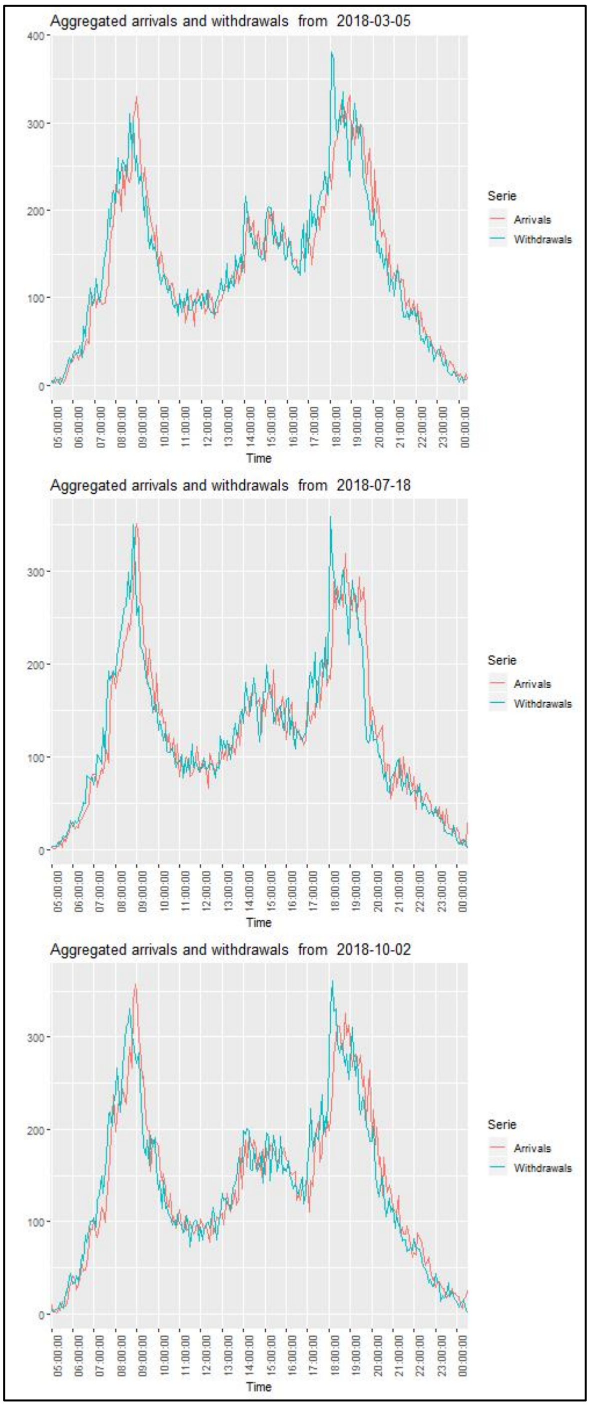

Figure 2.4: Arrivals and withdrawals by day

3. TIME SERIES ANALYSIS

Once we explore de available data, we propose to adjust a time series model to forecast the aggregated withdrawals. We decided to work with the aggregated series first of all because we think that although the daily series are similar in shape it is more difficult that a model adjusted to a particular daily data can be used to predict the withdrawals of each day of the year. Instead of that, we prefer a model that give us accurate aggregate predictions and then try to distribute the forecasted quantity among the days of the month. In second, because if we have de need of adjust a model for each month of the year, it is easier to adjust 12 models than adjust one model for each day of the year. Finally, as we will talk later, for future works it is convenient for us to forecast the aggregate withdrawals.

3.1. Model obtained

To obtain our model we worked with January of 2018 data, and followed the next steps:

1. We transformed the time series by taking natural logarithm.
2. We take some differences and stational differences to the logarithm series to remove the trend and some stational behavior that was present.
3. We use some statistical criterions to identify the model that best suited to our transformed time series.
4. After choosing a model, we make some forecast to the aggregate withdrawals of February of 2018.

Now we illustrate the above steps as well as our results. To stabilize the trend and the variance of the withdrawals series, we used the first difference of the logarithm transformation, then we notice a seasonal pattern in the series so we also take a stational difference of order 3. Then when we try to identify and adjust the model, we notice that the increase of withdrawals in the time period from 5:30 to 6:00, and the pronounced decrease from 23:00 to 00:30 generated great outliers in the series of errors for almost all models proposed, these outliers were a little tricky, because if we removed them the series of errors was so correlated that the Ljung-Box (see appendix) test failed, so this was a signal that our prediction bands were erroneous. To overcome this problem, we adjust our model to the data belonging to time interval from 06:00 to 23:00. In Figure 3.1 we show the resulting time series after taking natural logarithm and differences, the "Withdrawals" series are the series resulting from take natural logarithm and one difference, the "dif" series are the series resulting from take natural logarithm, one no seasonal difference and one seasonal difference of order 3.

Once we bounded the time interval and propose a data transformation, we use the autocorrelogram (ACF) and partial autocorrelogram (PACF) to identify model candidates. The great correlation at lags 3, 6 and 9 of the PACF suggest a seasonal component AR(3), also the great correlation at lags 1 and 2 suggest a non-seasonal component AR(2). The great correlation at lags 3,6 and 9 of the ACF suggest a seasonal MA(3) component, and the great correlation at lag 1 suggest a non-seasonal

MA(1) component. After we observed the ACF and PACF we try many combinations of the suggested seasonal and non-seasonal components to fit the model, in Table 1 we report the models that best fitted the data.

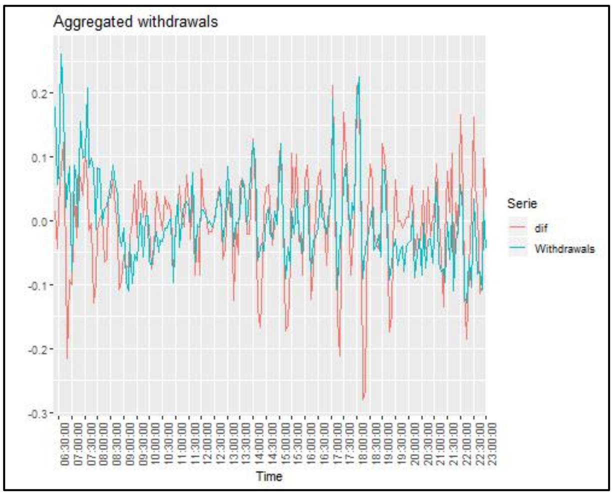

Figure 3.1: Transformed series

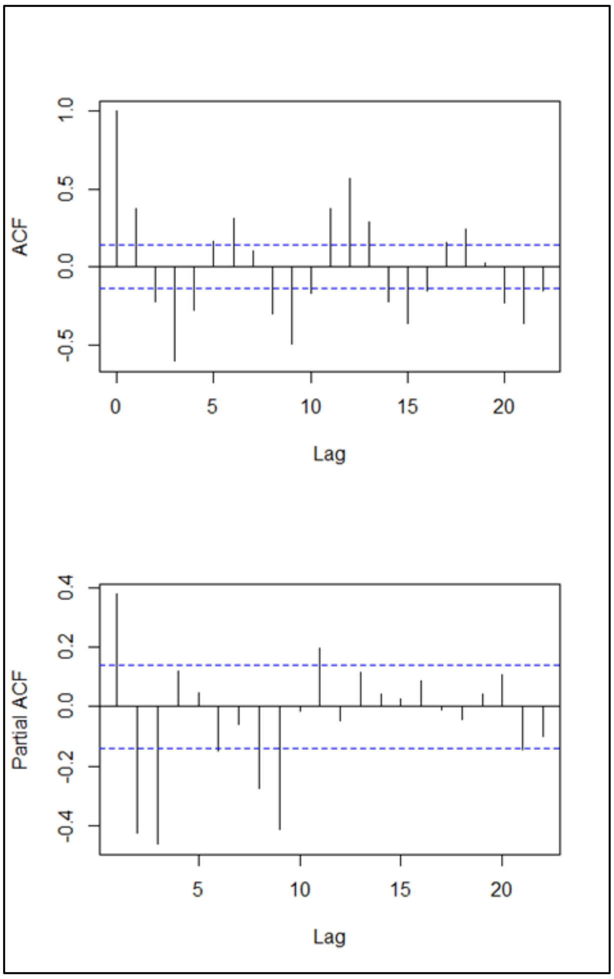

Figure 3.2: ACF and PACF

Table 1: Models comparison

ARIMA (2,1,0)(3,0,0)[3]	
Coefficients	ar1=0.41 ar2=0.01 sar1=0.17 sar2=0.07 sar3=-0.12
AIC	-594.15
L-B Test	p-value=0.2084
ARIMA (2,1,0)(3,1,0)[3]	
Coefficients	ar1=0.20 ar2=0.09 sar1=-0.72 sar2=-0.46 sar3=-0.56
AIC	-613.84
L-B Test	p-value=0.84
ARIMA (1,1,0)(3,1,0)[3]	
Coefficients	ar1=0.22 sar1=-0.7 sar2=-0.44 sar3=-0.55
AIC	-614.13
L-B Test	p-value=0.79
ARIMA (1,1,0)(3,0,0)[3]	
Coefficients	ar1=0.41 sar1=0.17 sar2=0.33 sar3=-0.12
AIC	-596.13
L-B Test	p-value=0.229

Comparing the AIC statistic (Akaike 1974) and by looking for a parsimonious model we decided to choice an ARIMA (1,1,0)(3,1,0)[3] model, which respective residuals are showed in Figure 3.3, the Ljung-Box test (Ljung and Box 1978) associated to the residuals of our chosen model has a p-value 0.79 so we can accept the statistical hypothesis that the residuals are not correlated. Note that the histogram of the residuals seem to be normal, so if we visualize the qq-plot of the residuals as in Figure 3.4, and we perform the Shapiro-Wilk test (Shapiro and Wilk 1965), we got a p-value equal to 0.84, so we can accept the statistical hypothesis that the residuals are generated by a normal distribution. In summary, the residuals can been seen as independent realizations of normal distribution with constant variance.

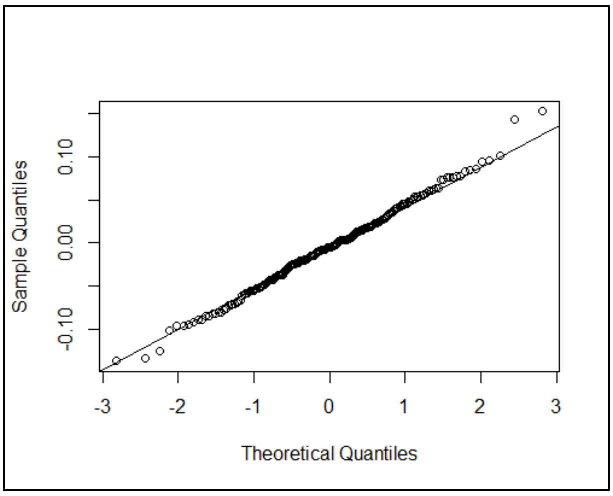

Figure 3.3: Residuals Q-Q Plot

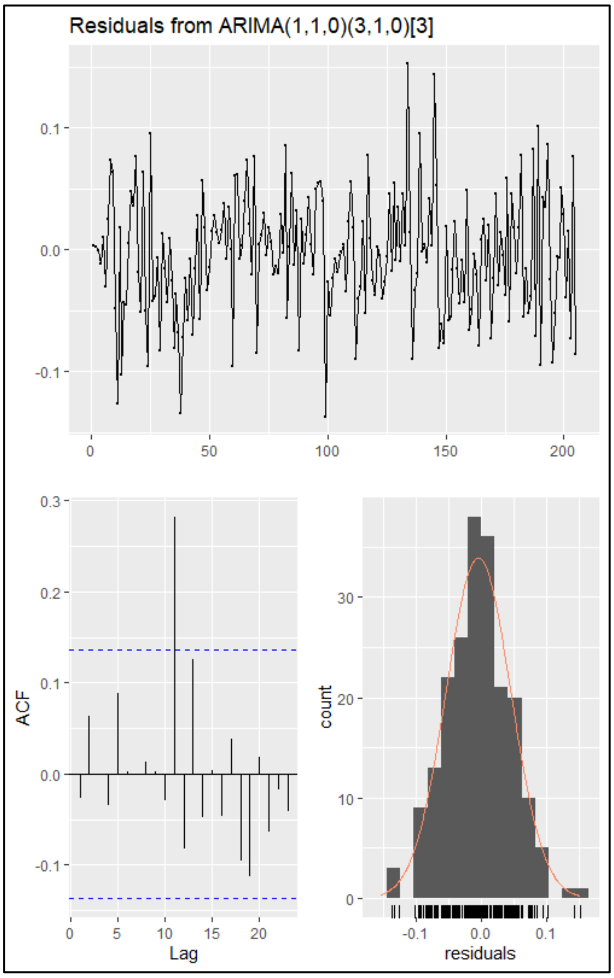

Figure 3.4: Model residuals

Once we proved that our model is adequate to fit the January data, we also used it to fit the data of all the other months of 2018, in general we got good results. In Figure 3.5 we show the fitted series for our January data of the ARIMA(1,1,0)(3,1,0)$_{[3]}$ model obtained, we also show the one-step forecast of our model applied to May and November data, the red series refers to the fitted values, while the black series refers to the observed data.

Finally, to complete our analysis we got some forecast of our model, in Figures 3.5.1 we show the forecast of our model and the original data series for January, May and November of 2018 for time interval from 10:00 to 10:45, we also show confidence intervals at 85% and 95%. In Figure 3.5.2 and 3.5.3 we also show the original and predicted series and confidence intervals from January, May and November from time intervals 13:20 to 14:05 and 20:00 to 20:45 respectively. More details about seasonal ARIMA models can be found in Box and Jenkins (1970).

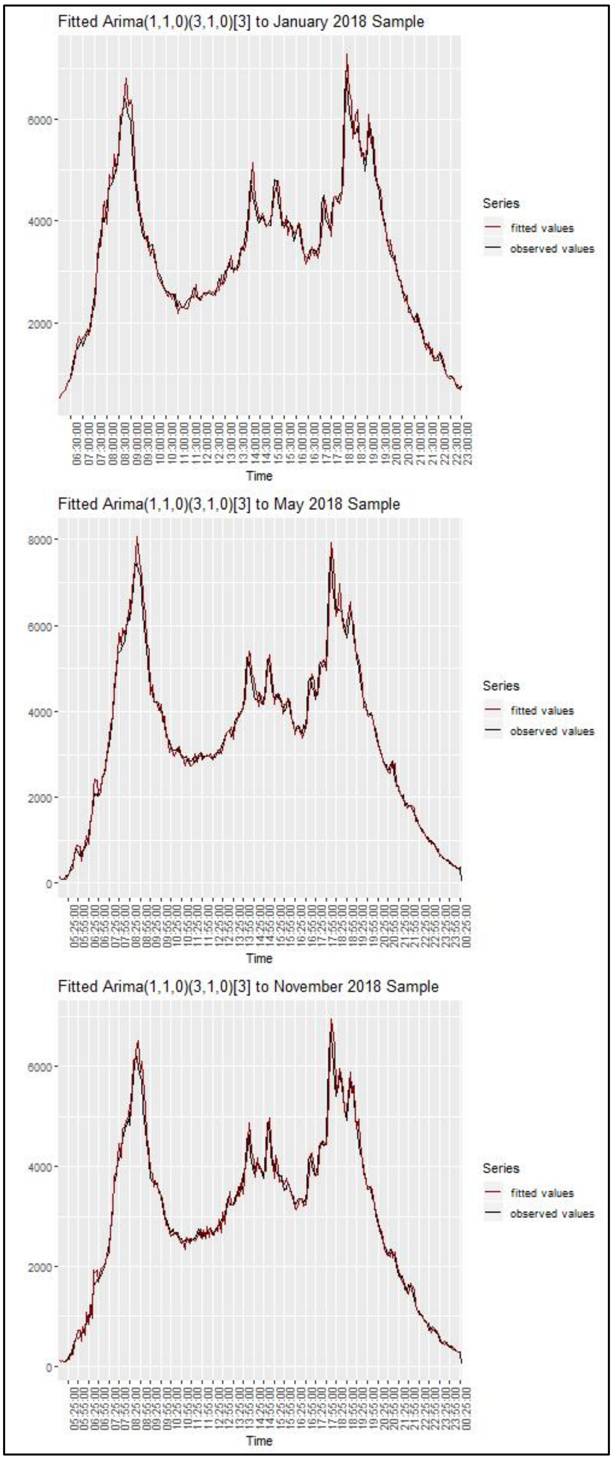

Figure 3.5: Fitted model

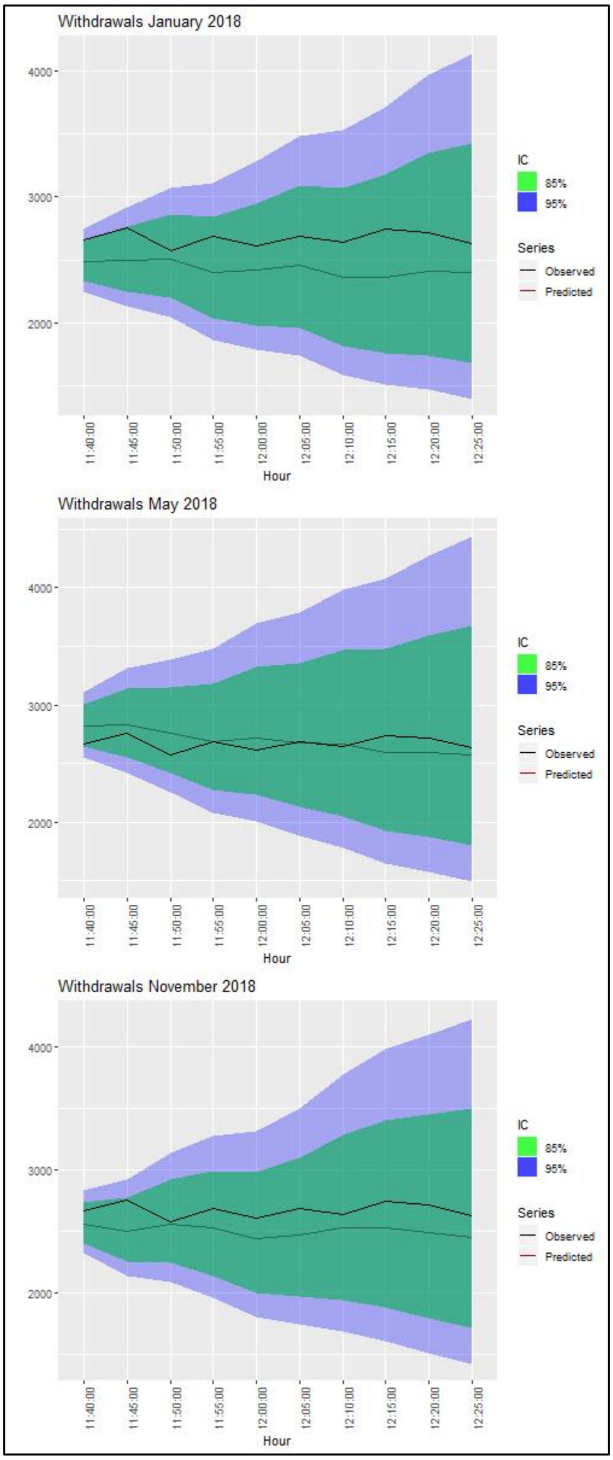

Figure 3.5.1: Fitted model

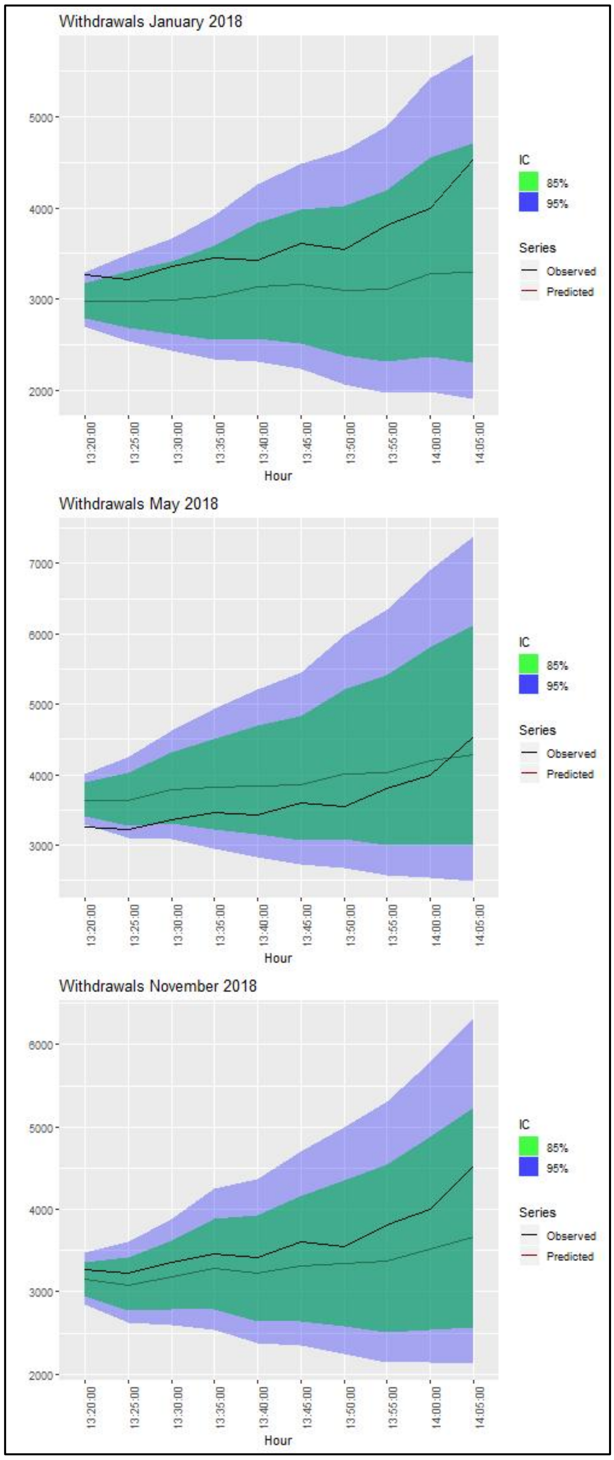

Figure 3.5.2: Fitted model

4. CONCLUCIONS

To estimate the demand of ecobicis we focused in estimate the aggregate number of withdrawals in time intervals of 5 minutes. These quantities can be visualized as a surplus or deficit of bikes if we subtract the overall quantity of bikes that all the stations could store. The predictions that we showed can help us to estimate the number of withdrawals in the short term, also we showed some time intervals of 45 minutes with confidence intervals at 85% and 95%.

It is important to mention that the withdrawals behavior depends on the time of the day as well as on the geo-localization of the stations. Also, the behavior observed appears to be present in each month and each day of the usual working days of Mexico´s City.

As a benchmark the model presented seems to fits adequately the withdrawals series, however, we believe that the model can be more robust if we incorporate some geospatial information related to the surroundings of the stations, for example incorporate the information related to offices, schools, hospitals, etc. Also we can try

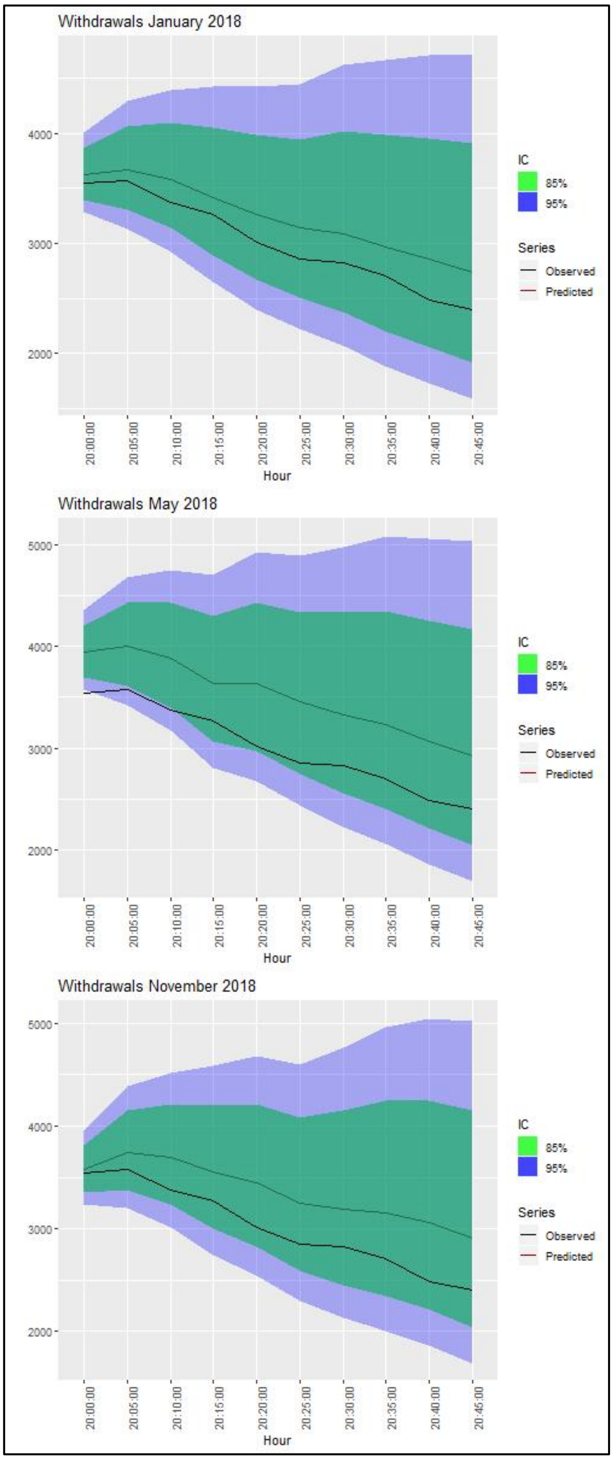

Figure 3.5.3: Fitted model

to incorporate some covariables, a natural choice is to incorporate the aggregate number of arrivals, but due to its great similitude to the number of withdrawals we don´t know yet if it adds some useful information. Hence, as future analysis we will try to make more robust our model by exploring the points mentioned before, and also find and add more sources of information as covariables, this last point can be a little difficult because we must find information that is reported and stored through the hours and days.

Another point in which we are still working is how to predict the individual number of withdrawals of each station through the predicted aggregate. We have though to search for graph structures among the stations and investigate if these structures change during the day, so we could estimate the number of withdrawals that each component of the graph demands conditioned in the overall aggregate withdrawals.

As a final comment, all our results were obtained with the statistical software R (R Core Team, 2019). The data manipulation was addressed whit the tydiverse package (Hadley Wickham 2017), the figures were obtained in ggplot2 package (H Wickham 2016) and our predictions with the forecast package (Hyndman, Athanasopoulos, Bergmeir, Caceres, Chhay, O'Hara-Wild, Petropoulos, Razbash, Wang, Yasmeen, 2019).

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THE REGULATION SCHEME OF THE PASSENGERS PUBLIC TRANSPORT SYSTEM BASED ON CONTRACT THEORY

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ABSTRACT
The purpose of this work is to model regulation scheme for the performance of an urban passenger public transport system. The aim is that the regulator has at his disposal the elements to define which scheme of regulation is more convenient to be implemented. The previous is based on the theory of regulation for the system of public transport, that includes the analysis of the interests of the economical actors: users, concessioner and regulator. The effect of the regulation from the variation of utility functions and social welfare. There are two mechanisms of regulation that are specifically characterized: 1) contract of higher cost, in which there are no incentives for efficiency. 2) Fix priced contract. It considers high incentives in order to have an efficient enterprise in terms of cost of production. The aim of these mechanisms is to guide the concessionaire´s behaviour with the purpose of reducing his production costs to prompt him to have a more efficient company.

Key words: Regulation, regulation´s model, efficiency, incentives.

1. INTRODUCTION

The regulation of the transport market consists of introducing legal barriers that allow the control of the economic actors in order to establish the optimum level of efficiency and social welfare, through a regulatory authority. Passenger transport is a public service and should therefore must be controlled by such an authority, which must monitor the production and distribution of it in such a way that it is offered efficiently. On the other hand, there are certain situations in which some kind of public intervention is desirable (De Rus and Nombela, 2003): 1) when competition is desirable, but there are problems so that it occurs effectively, 2) when competition between firms actually occurs, but with a degree that does not make it socially desirable and social welfare may be improved with some regulation on firms and 3) when there is difficulty for more than one operator, but also socially it is not interesting that there is more than one company. These considerations lead to the conclusion that regulation based on public intervention is necessary in public transport systems. There are several models for achieving this. Based on the relationship between the operators and the regulatory authority regarding the presentation of initiatives to change the service, there are four models of regulation to offer the services (Lecler, 2002): *direct production of services*, where the authority is who is responsible for providing the service; delegated management, operators are entrusted at the request of the authority, whether it is a closed market or monopoly; *free competition* is characterized by the null intervention of the authority in the provision of the service, the service providers have all the freedom to direct the services as they wish, it is a free market and *regulated systems* where the public authority establishes the quality of the service and defines economic instruments (contracts, concessions), this model allows controlled competition in the public transport system. The regulated system model, as discussed in this paper, is subdivided into four schemes: a) *the regulation schemes*, in the case of monopoly (Train, 1991) that are known as return rate regulation schemes, b) *the incentives based on Contract Theory* (Laffont and Tirole, 1993 and Laffont and Martimort, 2004) for a competitive market, c) *by pricing* (Button and Verhof, 1998) and d) the scheme called *Competitive Tendering* (Finn and Nelson, 2002), for certain characteristics of local infrastructure. In the case of the incentive scheme based on contract theory, two regulatory mechanisms are established: higher-cost and fixed-price, which are the ones that are characterized below.

In the case of the model used, the behavior of the actors is characterized at three levels.

a) Firstly, the regulator proceeds to implement a regulation scheme based on the production cost information and the market demand. The company decides if it improves its level of efficiency according to the proposed incentives. Given the level of efficiency chosen by the company, the regulator verifies whether it maximizes social welfare. If so, it maintains the initial contract. If the company decides not to improve its efficiency, it will be subject to the alternative regulation scheme established by the regulator.

b) Once the level of efficiency has been chosen, the company establishes the combination of production factors and implicitly the rate that applies to the user. Depending on the latter, the regulator provides an efficiency improvement incentive and the level of social benefit is re-evaluated.

c) Finally, in the third level, the user reacts to the rate that the regulator and the company have agreed either by increasing or decreasing the number of trips. If the social benefit does not deteriorate, the scheme can be maintained. Otherwise, the scheme is again evaluated with a new combination of production factors.

The levels described above are characterized in a partial equilibrium model in which the company is first characterized from a production function to which the level of transport services required is associated. This function considers factors of production, such as labor force, material and energy, soft capital (e.g. office equipment) and mobile equipment (e.g. company cars used by staff).

Subsequently, the function of production costs is established, which attempts to minimize from two regulatory schemes: higher-cost and fixed-price and thereby obtain maximum utility for the company; the latter depends additionally on the fee collection fee, production costs and the level of labor efficiency. Secondly, the regulator (public entity) is explicitly characterized and the user is implicitly in the objective function of the former. To this end, a social welfare function is defined, which includes the utility of the consumers, the costs of the producer and the amounts of incentives provided by the regulator. In this way, the objective of the regulator is to maximize consumer and producer surpluses, which reflects the incentive granted by the regulator to the company for its efficiency indirectly, so that the user will benefit once the optimal price (lower rate) and a better level of service have been found. The analysis tool (solvable model) allows the optimal combination of production factors to be estimated so that the user, the company and the regulator obtain great utility and therefore a maximum social benefit. The following is a succinct description of the partially balanced model developed, the details can be consulted in Nájera (2008) and Sánchez (2006).

2. THE ANALYTICAL MODEL

2.1. The producer

Transportation production (Nash, 1982; Small, 1992) requires combining inputs to achieve technically efficient production levels based on the relationship of technology

$$Y = f(L, M, I, K; t) \tag{1}$$

Where Y is the maximum amount of transport (number of trips) that, with a certain amount of inputs, can be generated for each unit of time taken as a reference while the functional form $f(\cdot)$ represents the existing technology. In other words, the production function (1) indicates that to produce a certain amount of transport services Y it is necessary to use mobile equipment and infrastructure (K), for example the number of units and the number of lanes; (I) soft capital, this item refers to everything that consists of equipment and office supplies; (M) refers to the set of factors (energy) that allows the operation of the units and all machinery and equipment, such as: fuel, spare parts, tires and other additives that allow the movement of the units; (L) represents the level of employment contracted by the producer and is usually measured as the total number of workers in a company at a given time (directors, operators, mechanics, office staff, and all who provide support). Finally, (t) is a trend because it is of great interest to know the growth rate (r) which is described in more detail below.

The production process is based on technology, costs and benefits are based on two performance variables: the capacity that in turn is directly associated with the level of demand (y_i) and indirectly at the service level (z_i). From the Cobb-Douglas constant elasticity production function, the production function is established for this study, expressed as follows:

$$Y_i = \beta_0 y_i^{b_1} (1 + \mathrm{r})^{t_i} \tag{2}$$

Which can be expressed alternatively as:

$$\ln(Y_i) = b_0 + b_1 \, ln y_i + b_2 t_i \tag{3}$$

Where $b_0 = \ln \beta_0$ and $b_2 = \ln(1 + r)$. This expression is a reduced way to represent a process of adjustment between capacity and service level. Where y_i it is the demand that is defined based on the consumer's choice, which allows you to decide how much you want to consume, t is a trend in the demand function.

2.2. Cost function

In the construction of this function, the effects generated by the lack of information between the company and the regulator are considered. It is assumed that the company has full knowledge of labor efficiency while the regulator does not (asymmetric information) (Baron, 1984).

In fact, the licensees know to what extent the movement of the users affects the quality of the service, especially in periods of maximum demand, since during this period the operators of the units perform several tasks at the same time that they are difficult to control: sell tickets, monitor the rise and fall of users, take care of the bus space. On the other hand, the company also has knowledge of the quality of capital, that is, the rolling stock (state and maintenance requirements) and the structure and state of the network. This implies: 1) that it is quite difficult to estimate labor efficiency (worker) when there are many contracted operators, 2) labor inefficiency affects production, which leads to a difference between what is observed and the strength of effective work.

Considering this information problem, the labor force observed by the regulatory authority (L^*) can be explained as the relationship between the really required force (L), to efficiently produce at the level (Y) and a level of inefficiency associated with an effort of the same operator to decrease it, that is:

$$L^* = L \exp(\theta - e) \tag{4}$$

Where θ is a parameter called "work inefficiency" and its values for the purpose of this work are: 1 if you decide to be efficient and 0 if not. On the other hand, e represents the level of efficiency that the operator performs to try to reduce the effect of the inefficiency factors, whose values proposed for this analysis are 70%, 85% and 100%. It can be noted that in equation (4) L^* converges to L when labor inefficiency is compensated by the operator's effort to reduce it.

Considering that the operator reflects a behavior with respect to the minimum cost for each level of effort, the operation cost function can represent the technological process. The cost function assumed by the company is presented below:

$$C = w_L L^* + w_M M + w_I I \quad (5)$$

where, w_L, w_M and w_I are price factors: labor, soft material and investment, respectively. In this way the company's program is to operate minimizing production costs and with a minimum of necessary staff. This allows to determine the parameters from the production function, the level of efficiency and the activity of reducing costs. It is achieved through a structural estimate of the cost operation; is a structural estimate in the sense that the method considers the effects of the obligations of the regulated company. This will assess the difference between the current situation and the optimal regulation schemes, in terms of efficiency, company costs and social welfare.

Firstly, the contractual arrangement is defined, in this case the operator chooses the minimum cost and the optimal combination of production factors, this leads to a conditional cost function at a certain level of efficiency, note that the associated cost function depends on the price factors.

Substituting equation (4) in (5) allows you to define:

$$C = w_L L\, exp(\theta - e) + w_M M + w_I I \quad (6)$$

In this expression when $exp(\theta - e) > 1$, the operator minimizes the cost, considering a higher labor cost.

Secondly, the operator optimization program is resolved, considering the following stages:

1) showing that the level of efficiency depends on the type of incentive provided by the system of regulatory obligations; 2) describing how the contractual environment affects the cost and allocation function of the combination of production factors.

As production is based on technology, the *cost function of Cobb-Douglas* is easy to manage, if a description of the technology is sufficiently accurate for the intended purpose. Under this assumption the cost function (minimum expense associated by the company) is:

$$C = \beta_0 \exp[\beta_L(\theta - e)]\, w_L^{\beta_L}\, w_M^{\beta_M}\, w_I^{\beta_I}\, Y^{\beta_Y}\, K^{\beta_K} \quad (7)$$

Remembering that it guarantees first degree homogeneity $\beta_L + \beta_M + \beta_I + \beta_Y + \beta_K = 1$

Given that the first order condition (minimize costs from efficiency) is:

$$\psi'(\mathrm{e}) = -\rho \left(\frac{\partial C}{\partial e}\right) = \rho \beta_L C \quad (8)$$

Where $\psi'(e)$ is the cost of not being efficient, ρ is a proportionality factor; under the fixed-price regime, the marginal efficiency cost savings are proportional to the cost level and increase with β_L which is the elasticity of the cost of efficiency with respect to the labor factor. On the other hand, under the higher-cost regime this is not relevant.

Now considering the cost of efficiency, as follows:

$$\psi(\mathrm{e}) = \exp(\alpha e) - 1 \text{ con } \alpha > 0 \quad (9)$$

Where the function $\psi(\mathrm{e})$ is the cost for the effort to be efficient (Gagnepain, 2002, 2005).

If $\psi'(0) = 0$ and combining equations (7), (8) and (9) the optimum level of effort is:

$$e^* = [\ln(\beta_L \beta_0) + \beta_L \theta + \beta_L lnw_L + \beta_M lnw_M + \beta_I lnw_I + \beta_Y \ln Y + \beta_K lnK - \ln \alpha]/(\alpha + \beta_L) \quad (10)$$

The level of effort is a function that is directly proportional to the inefficiency parameter θ, at the level of performance Y in relation to the input prices of the factors w_L, w_M and w_I; with respect to α is a decreasing function in the technological parameter of the internal cost function. Finally, the cost function to be estimated is obtained from the replacement of the optimal effort (10) in the cost function (6).

Under the *higher-cost* regime the contract does not require a certain level of effort and its *cost function* is given by:

$$lnC = ln\beta_0 + \beta_L(\theta - e) + \beta_L lnw_L + \beta_M lnw_M + \beta_I lnw_I + \beta_Y \ln Y + \beta_K lnK \quad (11)$$

For the *fixed-price* regime it is:

$$lnC = \beta_0' + \xi(\beta_L(\theta - e) + \beta_L lnw_L + \beta_M lnw_M + \beta_I lnw_I + \beta_Y \ln Y + \beta_K lnK) \quad (12)$$

With $\xi = \alpha/(\alpha + \beta_L)$ and $\beta_0' = ln\beta_0 + \beta_L(ln\alpha - ln\beta_L - ln\beta_0)/(\alpha + \beta_L)$, taking into account that α increase the parameter ξ up to 1 and with it the fixed-price cost function converges to the higher-cost function. In this way, the difference between the types of contracts is:

$$\ln C_{/FP} - \ln C_{/CP} = \frac{\beta_L}{\alpha + \beta_L}\left\{\ln\left(\frac{\alpha}{\beta_0 \beta_L}\right) - \ln \tilde{C}\right\} \quad (13)$$

Where

$$ln\tilde{C} = \beta_L(\theta - e) + \beta_L lnw_L + \beta_M lnw_M + \beta_I lnw_I + \beta_Y \ln Y + \beta_K lnK + \beta_L \theta \quad (14)$$

In summary, the function of operation cost to be estimated is:

$$lnC = \rho(\beta_0' + \xi(\beta_L(\theta - e) + \beta_L lnw_L + \beta_M lnw_M + \beta_I lnw_I + \beta_Y \ln Y + \beta_K lnK)) + (1 - \rho)(ln\beta_0 + \beta_L(\theta - e) + \beta_L lnw_L + \beta_M lnw_M + \beta_I lnw_I + \beta_Y \ln Y + \beta_K lnK) = C(Y, K, w, \theta, \rho / \beta) \quad (15)$$

Considering ρ as variable, that when $\rho = 1$ it is obtained a fixed price contract and when $\rho = 0$ a higher-cost contract is given.

2.3. Regulator

2.3.1. The utility function of the regulator

The local public authority (Chang, 1997), is responsible for the organization of the service in its territory; in particular, it imposes the price level (rate) of transport (p), the level of capacity (y) and choose the regulation scheme (Dalen, 1996), which is defined by the payment of the government cost for the two types of contracts:
For the *higher-cost* regime, the public authority receives the commercial revenue $R(y)$ and pays the total operational cost (C) of the company and a monetary transfer (t_0). The remuneration of the company is given by (t):

$$t = t_0 + C(Y, K, w, e, \theta / \beta) \quad (16)$$

Regarding equation (16) the company is not a risk for this reason, the company has no incentive to produce effectively. For this, the level of utility is defined:

$$U = t_0 - \psi(e) \quad (17)$$

Where the function $\psi(e)$ is the cost for the effort to be efficient (Gagnepain, 2002, 2005).

The second type of regime by *fixed price*, all risks, costs and profits of the operator are affected. The company's compensation is:

$$t = t_0 \quad (18)$$

This contract is a very high incentive scheme, to produce an optimal effort and reduce costs, the utility of the company is:

$$U = t_0 + p(y)y - C(Y, K, w, e, \theta/\beta) - \psi(e) \quad (19)$$

Remembering that ρ is a variable, that when $\rho = 1$ you have a fixed price contract and when $\rho = 0$ a higher-cost contract is given. Now you have the profitability of the company under two regulatory schemes:

$$t = t_0 + (1 - \rho)C(Y, K, w, e, \theta/\beta)$$

$$U = t_0 + \rho\big(p(y)y - C(Y, K, w, e, \theta/\beta)\big) - \psi(e) \quad (20)$$

This fits in the environment where the operator makes decisions, that is, to determine the level of efforts to have the minimum cost and input factor amounts required to run the network system.
On the other hand, the price and the level of performance is established by the contractual rules, the regulator determines the level of cost that reduces the activity by solving the program defined as:

$$\max_e U = t_0 + \rho\big(p(y)y - C(Y, K, w, e, \theta/\beta)\big) - \psi(e), \quad \rho \epsilon \{0, 1\} \quad (21)$$

From the previous expression under the fixed-price regime, the optimum effort level is such that the marginal disutility of the effort $\psi'(e)$ is equal to the marginal cost

$$\psi'(e) = -\rho(\partial C / \partial e) \quad (22)$$

Under a higher-cost regime, the level of effort is optimal if it is $\psi'(e) = 0$.

2.3.2. Benefit Assessment

The need for economic regulation in the mode of transport is sometimes derived from its technological production characteristics, as already mentioned. Two criteria are defined to compare the benefits of the proposed regulatory schemes with respect to the current situation: consumer surplus and demand elasticities. It is assumed that the regulator maximizes social welfare (integrated by the welfare of government, companies and users). First, monetary distortions are evaluated, that is, the costs of public funds are estimated in each scheme. This estimate serves as a reference to compare the current situation with the optimal regulation schemes. Once the cost structure, the elasticity of the demand, the level of efficiency and the price function must be specified, the regulator's behavior must be specified, that is, the optimum performance level and the lowest service cost are chosen with a specific financial restriction.
The regulation program for the two schemes (higher-cost and fixed-price) is:

$$\max_y W(y) = S(y) - R(y) - (1 + \lambda)(\psi(e) + C(Y, e, \theta)) \quad (23)$$

Subject to
$$Y = \phi(y)$$

Where $\phi(y)$ is the function of population density.

For areas where the *higher-cost* rules, consumer surplus is given by:

$$V(y) = S(y) - R(y) + (1 + \lambda)R(y) \quad (24)$$

Where the surplus $S(y)$ is derived from the demand function and the $R(y)$ return is obtained from the average cost product and the level of demand. The parameter λ measures the tax distortion, that is, the cost of public funds. This monetary distortion is due to the collection of local taxes or at the same time it can be expressed in

the incentive to the company. The social monetary cost is equal to $(1+\lambda)$ and $(1+\lambda)R(y)$ is the reduction caused by the tax.
In urban areas where the *fixed-price* contract governs, the consumer surplus is:

$$V(y) = S(y) - R(y) \quad (25)$$

Operators are given a transfer that allows them to balance the budget and provides them with monetary support as a cost incentive, which reduces activities (the day).
Of the associated first-order conditions for the maximization of well-being, the optimal price corresponds to the Ramsey equation (Laffont and Tirole, 1993), that is:

$$\frac{p(y)-\phi'(y)C_Y}{p(y)} = -\frac{\lambda}{1+\lambda}\frac{\partial p(y)}{\partial y}\frac{y}{p(y)} \quad (26)$$

The left side (the Lerner index) is inversely proportional to the elasticity of demand and the costs of public funds. As for equation (26), what is necessary to know is the cost of public funds, but it can be solved to obtain the estimate of λ for each network. It is worth mentioning that these estimates are partial, due to some assumptions. In particular, the estimate is conditional under the hypothesis of maximization of welfare.
The structure incorporated is asymmetric information parameters with the principle of the dichotomous price incentive (Laffont and Tirole, 1993, pp. 178), which means that Ramsey's formula applies for complete or incomplete information. Therefore, the estimation of the cost of public funds depends only on the observed price levels and the estimated values of the marginal cost and the elasticity of demand.
According to Ramsey's relationship, when the taxation involves less distortion, that is, when λ is close to zero, the distance between prices and the marginal cost is reduced, otherwise, that the budget deficit is easily covered for the taxation.
On the other hand, if the local cost of public funds is high, the price tends to the price of the monopoly where subsidies are expensive for society. Then the company's deficit is partially covered by the commercial revenue.
Optimal scenarios are presented as a reference to make an assessment of the current state.
A first contract. *The regulator is perfectly informed of the efficiency level of the network operator.* Assume that the regulator receives commercial revenues *R(.)* and pays ex-post *C(.)* cost operation. The utility of the operator is:

$$U = t - \psi(e) \quad (27)$$

Now the regulator takes the cost of public funds previously estimated to make comparisons of optimal and current contracts.
A second contract. *It is defined by the price level* $p(y^s)$ *and a transfer*. However, given the situation of the monopoly and the selection of a rate, a level of performance corresponds.

Equation (27) defines a level of transfer with respect to a level of effort (e^s). Optimization of the expected social welfare maximization, defined in the interval $[\underline{\theta}, \overline{\theta}]$, is obtained,

$$\underset{\theta}{E}\, W = \underset{\theta}{E}\{S(y) + \lambda R(y) - (1+\lambda)(\psi(e) + C(Y, e, \theta)) - \lambda U\} \quad (28)$$

With respect to y and e, under three conditions: 1) the capacity condition $Y = \phi(y)$; 2) the principle of individual rationality $U \geq 0$, meaning that the operator is endowed with at least a level of utility as high as they could get it outside and 3) a written incentive compatibility condition such as

$$U'(\theta) = -\psi(e^s) \quad (29)$$

that is, to have the incentive, the operator must provide the same gain as if he provides less efficiency. Also, the first order condition associated with the maximization of well-being, including Ramsey's formula (26) defines to y^s and e^s. In addition, in the optimal solution, the reduction of the marginal cost is equal to the marginal disutility of the effort, since less distortion is obtained to limit the surplus of the yield.

$$\frac{\partial C(\phi(y^s), e^s, \theta)}{\partial e} = -\psi'(e^s) - \frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\psi''(e^s) \quad (30)$$

CONCLUSIONS
Several studies have shown, from different perspectives, that public intervention in the passenger transport service is essential to reduce distortions of this market and improve the quality of the service to the user. A model was formulated where any regulation based on incentives, which is implemented by the regulator, leads to a better situation than the current one for both the company and the users. To reach this conclusion, an analytical tool based on regulation theory through contracts and microeconomic theory was used. This tool allows to characterize the mechanisms of regulation of contract of greater-cost in which there are no incentives for efficiency and fixed-price contract that considers using incentives for the company to be efficient. It should also be mentioned that in the model you can add or remove as many variables as required due to the characteristics of the study area.

Finally, the model used is as general as possible for the case of regulation by contracts and incentives since it involves the three actors (government, company and user) and considers the regulatory processes that imply market recognition, as an efficient mechanism in the allocation of resources, as well as the importance of incentives to the companies that most strive to provide a more efficient and quality service to society.

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ON-STREET LOADING AND UNLOADING PARKING INITIATIVES FOR TWO DIFFERENT AREAS IN MEXICO CITY

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ABSTRACT
Mexican cities lack policies for on-street loading/unloading parking, which generates several problems. First, a review of the Urban Freight Transport initiatives, implemented around the world, which could contribute to solve some loading/unloading parking problems in Mexican cities, is presented. Then, relevant areas for the implementation of on-street parking policies are identified, for two representative areas of Mexico City. For each selected area, the quantity of required parking spaces and the percentage of the total space that they represent is explained.

Keywords: Urban Freight Transport, freight transport policies, on-street loading/unloading parking.

1. INTRODUCTION

Urban freight transport (UFT) has a great importance for the cities, since it provides the commodities that are daily used by the population to carry out their activities, and the raw materials for the industry. The UFT has a valuable contribution to the economy of a city, however as a city is bigger the movements of UFT are more complex producing an inefficient operation and several problems (OECD 2003).
UFT in Mexico faces several problems, as congestion, high logistics costs, long service times, accidents, pollution, lack of parking spaces for loading/unloading activities and limited infrastructure for freight vehicles. Then, it is important to propose policies and regulation to improve the UFT in Mexico. However, usually the policies are restrictive, without an assessment and selection process, or information and studies to validate its applicability (OECD 2003).
In supply chains, the parking of freight vehicles is a fundamental activity of the UFT, which allows the loading/unloading of the transported goods and has a direct impact on the deliveries cost and time; the lack of spaces contributes to increase congestion and emissions problems (Holguín-Veras et al. 2015).
The objective of this work is to present an initial study of the freight service activity (FSA) in two different areas of Mexico City, which allows the identification of parking space needs for freight and service transport, useful for the application of improvement initiatives.
This paper is divided as follows: in Section 1 an introduction to urban freight transport and its importance are given; in Section 2, a literature review on UFT initiatives and parking requirement calculation is presented.
Section 3 shows the methodology used for estimating parking spaces, including the data requirements and the analysis. The selection of the study areas and the calculation of the parking spaces are also described. In Section 4, the application of the methodology for two areas is presented and results are exposed.
Finally, in Section 5 the conclusions, recommendations and future work are given.

2. LITERATURE REVIEW

2.1. Urban Freight Transport Initiatives

Many initiatives that seek to improve Urban freight transport (UFT) have been implemented in cities of different countries around the world such as USA, England, France, Colombia, Sweden, among others. The selection of the best initiative depends on the problem characteristics and the pursued objective. The initiatives are classified in eight major groups (Holguín-Veras et al. 2015):

1. Infrastructure management
2. Management of loading parking areas
3. Vehicle-related strategies
4. Traffic management
5. Pricing, incentives and taxation
6. Logistics management
7. Freight demand/land use management
8. Stakeholder engagement

Lozano et al, (2006) stated that one of the main problems of the UFT in the Mexican cities is the lack of on-street loading/unloading parking, mainly for those delivery/pickup vehicles that serve small businesses. This deficiency causes congestion, insecurity, road reductions due to double-parking and impacts on pedestrians' safety and city dynamics (GIZ 2006).

Regarding this problem, the following nine initiatives were identified. Below is presented the description of these taken from Holguín-Veras et al. 2015:

1. Freight Parking and Loading Zones: The adjustment of the existing street design and loading areas to accommodate current and future traffic and truck volumes. The strategies on parking places and loading zones focus on designating and enforcing curbside parking, reallocating curb space, revising signaling, and identifying potential freight traffic parking locations.
2. Loading and Parking Restrictions. The implementation of parking and loading/unloading restrictions, parking ban on residential streets, and other time-related parking restrictions.
3. Peak-Hour Clearways. The prohibition, by means signaling, of parking and standing vehicles during peak hours on corridors.
4. Vehicle Parking Reservation Systems. The implementation of a system to allow drivers to schedule or reserve curbside parking space.
5. Enhanced Building Codes. The design of off-street parking and loading facilities in urban center buildings, and of parking lots in and at the fringe of metropolitan areas.
6. Timesharing of Parking Spaces. The scheduling of the use of parking spaces among specific carriers and the coordination of the pick-up and delivery timing among freight carriers, shippers and receivers, and in some cases between freight and passenger vehicles.
7. Upgrade Parking Areas and Loading Docks. The redesign of docks to meet the geometric space needs of current and future trucks, and to provide adequate parking.
8. Improved Staging Areas. The development or improvement of on-site off-street areas at businesses or other facilities in order to conduct loading, unloading or other freight-related activities.
9. Truck Stops/Parking Outside of Metropolitan Areas. The construction or installation of truck stops/parking facilities outside the metropolitan area.

According to Holguín-Veras et al. (2015), in a decision-making process on transportation, virtually every decision or a recommended course of action can result in predictable and unpredictable, intended and unintended, immediate and long-term, positive and negative impacts. In most cases, the complex issues that metropolitan areas face have no perfect solutions, then transportation decision-makers have to accept trade-offs that require a proper understanding of the problem, and such trade-offs are identified while evaluating and selecting the solution alternatives. Then, the evaluation and selection process of the policies and regulations, and the data requirements for their application, are needed (Holguín-Veras et al. 2015).

2.2. Calculation of parking requirements

Currently, there are two types of techniques for estimate the Freight Trip Generation (FTG), land use based models and econometric models.

Holguín-Veras et al. (2017) stated that different metrics could be used to measure the transportation activity at a given establishment. The term freight service activity (FSA) refers to all the activities related to freight and service.

There are different metrics for FSA, which are defined by Holguín-Veras et al. 2017, as follows:

- Freight Generation (FG) is the amount of freight typically measured in units of weight and is composed of Freight Attraction (FA) and Freight Production (FP).
- Freight Trip Generation (FTG) is the number of freight vehicle trips generated by a commercial establishment and is composed of Freight Trip Attraction (FTA) and Freight Trip Production (FTP).
- Service Trip Generation (STG) is the number of service trips generated by a commercial establishment and is composed of Service Trip Attraction (STA) and Service Trip Production (STP).

Land use has been used for determining freight generation, identifying two separate aspects: (1) how land use at the establishment level influences FTG; and (2) how freight activity and land use interact with each other at the system level (Holguín-Veras et al. 2012).

This models faced difficulties such as lack of uniformity in the definition of land use classes. Land use classes typically group a number of highly heterogeneous industry sectors hence when an FTG rate is calculated as a function of a land use variable, the analyst assumes that FTG depends on business size, but this is not the case for a sizable number of industry sectors, when FTG rates based on land use classes that group industry sectors that do not share similar FG and FTG patterns (Holguín-Veras et al. 2012).

Econometric techniques such as the used by Sánchez-Díaz, Holguin-Veras, and Wang (2014) can be used to estimate two sets of models; one which considers traditional independent variables such as employment and another establishment attributes, and the other where spatial variables such as proximity to similar businesses and large population centers are considered (Holguín-Veras et al. 2017).

Applying economic-based models leads to a better forecasts of FSA due to the use of employment, which correctly measures the intensity of the use of space, these models express FSA as a statistical function of employment (Holguín-Veras et al. 2017).

The amounts of freight consumed at an establishment constitute the inputs and outputs of an economic process.

Then employment and the industry sector are better predictors of FSA than variables like square footage and land use, which denotes little about the activity taking place at the establishment (Holguín-Veras et al. 2017).
Also, the econometric models for the calculus of FSA can be used for estimating the need of freight and service parking spaces, using sets of data on establishments' industry sectors, and their numbers of employees (Holguín-Veras et al. 2017).
The role of transportation policy is to ensure that public resources are allocated in a way that maximizes economic welfare. The allocation of public resources such as curb space, must consider the needs of all the users.

3. METHODOLOGY

The methodology used for this work is describe below.

3.1. Selection of the Urban Freight Transport Policies

For the initiative selection, several factors must be considered: advantages/disadvantages, type of regulation and information required for the implementation. The initiatives of management of loading parking areas were chosen in this work due to they could contribute to solve one of the main problems in Mexico cities for UFT.

3.2. Analysis Technique Selection

An extensive literature review on generation of Urban Freight Transport information, let to the selection of the Holguín-Veras et al. (2017) technique due to its applicability to the Mexican cities.
This technique uses the following input variables: type of establishment, number of employees and a sampling of trips, which allows characterizing the activity of freight and service vehicles in an urban area.

3.3. Data Collection

The data used for this work includes: number of establishments, industrial sectors and number (in ranges) of employees, for the selected metropolitan areas. The information is obtained from several sources.

3.4. Data Analysis

A classification of the industrial sectors is conducted, resulting into two groups, as proposed by Holguín-Veras et al. (2017) and Taniguchi et al. (2018). The Freight Intensive Sectors (FIS) are the industrial sectors whose production or consumption of freight is an indispensable component of their economic activity. The Service Intensive Sectors (SIS) are industrial sectors where the provision of services is their main activity. The activity of the freight vehicles differs markedly between these two groups.
The economic data about the number of establishments and employment provide a good way to get a sense of the real dimension of the FSA (Holguín-Veras et al. 2017).
The obtained data consider a two-digit classification for the type of establishment and the average number of employment in each range; these data are available in (DENUE-INEGI 2018).

3.5. Selection of two urban areas in Mexico City

The study areas where selected because they highlight in the following variables: business density, industrial sectors with freight generation and quantity of small establishments with employment range 1-5. The information was obtained from INEGI (2015) and DENUE-INEGI (2018). Heat maps allows to identify the areas with a higher density of establishments, and two of them were chosen.

3.6. Computing the number of parking spaces

The number of parking spaces needed for each selected area was obtained following the technic by Holguín-Veras et al. (2017), which let to estimate the total number of deliveries generated in an area.
The calculation of the parking needs requires first, the freight trip generation. Equations 1 and 2, linear and non-linear respectively, are used for estimating freight trip attraction. In this work, the ∝ and β parameters obtained for New York City by Holguín-Veras et al. (2017) are used.

$$\mathrm{FTA_i} = \propto + \beta \mathrm{E_i} \quad (1)$$

$$\mathrm{FTA_i} = \propto^* * \mathrm{E_i^{\beta}} \quad (2)$$

Then, equations 3 and 4, linear and non-linear respectively, are used for estimating freight trip production according the type of establishment.

$$FTP_i = \propto + \beta E_i \quad (3)$$

$$FTP_i = \propto^* * E_i^{\beta} \quad (4)$$

Afterwards, the number of service trips attracted per day is estimated by means equation 5 and equation 6, linear and non-linear respectively, per establishment type.

$$STA_i = \propto + \beta E_i \quad (5)$$

$$STA_i = \propto^* * E_i^{\beta} \quad (6)$$

Then, three facts need to be considered for the parking space calculation (Holguín-Veras et al. 2017):

1. Percentage of FTG that takes place during the peak hour.
2. Percentage of service trips distribution during normal office hours.
3. Occupation of parking space for each one of the previous percentages (time gap).

3.7. Analysis

The obtained information was analyzed and some recommendation for initiatives on-street loading/unloading parking are given.

4. CASE STUDY

The data analysis allows to identify the areas or corridors with high number of Urban Freight Transport activities, making suitable industrial sectors groups and obtaining the average number of employees per establishment. This information is needed for the estimation of on street parking spaces.

4.1. Selected initiative

Figure 1 shows the process for the determination of the best initiatives. The on-street loading / unloading parking management initiatives were chosen because: they focus on one of the most important problems faced by the UFT in Mexico; they are regulated by the government; they do not require a large amount of information; and they are easily applicable.

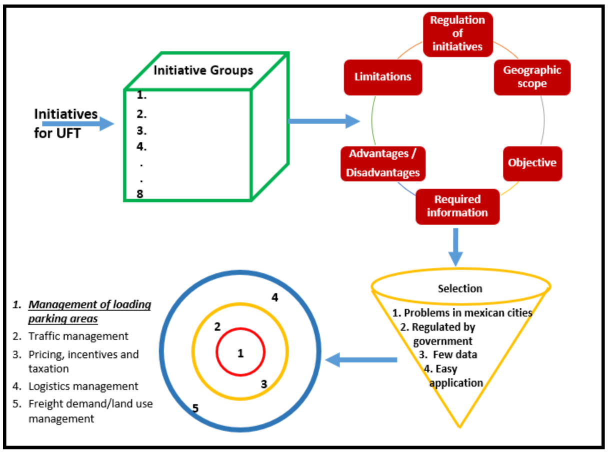

Figure 1. Process for the determinations of initiatives

4.2. Analysis for the selection of two urban areas in Mexico City

The selection of the two urban areas was performed using data on the establishments´ location in the Metropolitan Zone of the Valley of Mexico (MZVM). Heat maps were created to recognize the relevant areas, those with a high establishments' concentration. Down town is the most relevant area, but some restrictions for freight transport are currently applied there. Then, other two relevant areas were chosen: in Benito Juárez and Coyoacán municipalities.

Afterwards, a heat map for each area was created, in order to delineate the most important part, that with the highest establishment density. The selected areas in Benito Juárez and Coyoacán are presented in Fig. 2 and Fig. 3, respectively.

For Benito Juárez, the most relevant area is located near to the World Trade Center, but many of its establishments are big (with over 10 employees), then the second most relevant area was chosen; it contains two markets surrounded by many small establishments.

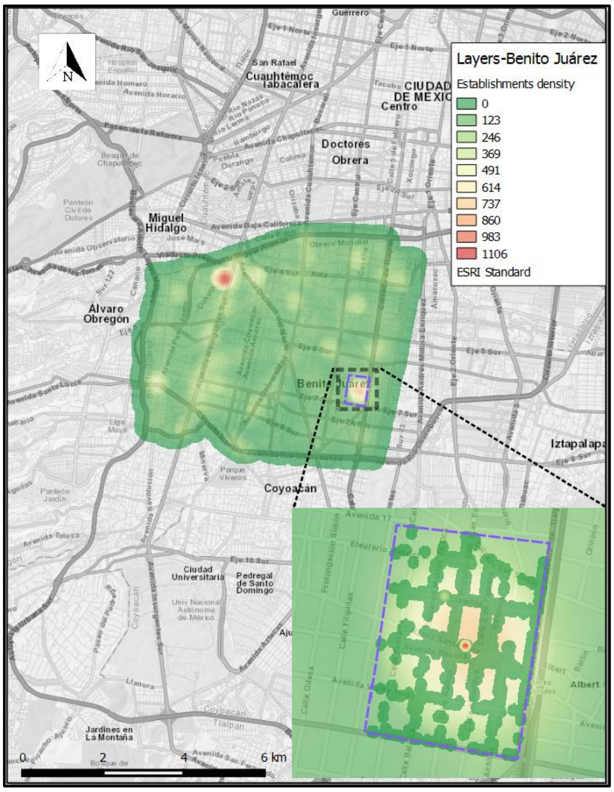

Figure 2. Benito Juárez area

For Coyoacán, the most relevant area is a tourist side located in its center, which contains different types of establishment and a traditional market.

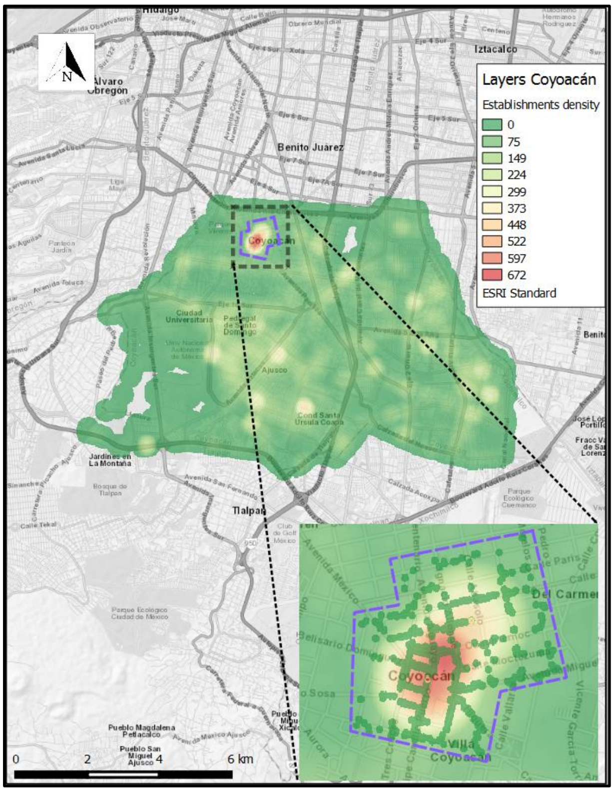

Figure 3. Coyoacán area

The FIS and SIS industrial sectors for Mexico is shown in Table 1 and Table 2, according to the data contained in DENUE-INEGI (2017).

Table 1: Classification of industrial sectors FIS

CODE	FREIGHT INTENSIVE SECTORS (FIS)
11	Agriculture, Forestry, Fishing and Hunting
21	Mining
22	Utilities (electricity, gas and water supply)
23	Construction
31-33	Manufacturing
43	Wholesale Trade
46	Retail Trade
48-49	Transportation and Warehousing
72	Accommodation and Food Services

Table 2: Classification of industrial sectors SIS

CODE	SERVICE INTENSIVE SECTORS (SIS)
51	Information
52	Finance and Insurance
53	Real Estate Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Administrative and Support and Waste Management and Remediation Services
61	Educational Services
62	Health Care and Social Assistance
71	Arts, Entertainment, and Recreation
81	Other Services (except Public Administration)
93	Public Administration

Table 3 and Table 4 show a summary of the data analysis for the selected areas, where the percentage of establishments with a range of employment from 1 to 5 varies from 82.1% to 89.2%; the most relevant sector is retail trade. With these data, the FSA calculations were conducted.

The classification of the industrial sectors allowed a preliminary qualitative identification of the type of vehicle that could be used by each industrial sector class. For each class, the percentage of establishments and the number of employees was obtained. Among the FIS, four sector classes stood out in the selected areas: manufacturing industry, wholesale trade, retail trade, and accommodation and food.

Table 3: Number and percentage of establishments per sector in Benito Juárez area

AREA	BENITO JUÁREZ			
Code	Establishment		Employment	
	No	PC	No	PC
Freight Intensive Sectors (FIS)				
23	2	0.19%	6	0.09%
31-33	36	3.38%	108	1.62%
43	24	2.25%	72	1.08%
46	634	59.47%	1,902	28.48%
48-49	3	0.28%	9	0.13%
72	98	9.19%	294	4.40%
Sub-Total FIS	**797**	**74.77%**	**2,391**	**35.80%**
Service Intensive Sectors (SIS)				
51	2	0.19%	6	0.09%
52	13	1.22%	39	0.58%
53	3	0.28%	9	0.13%
54	3	0.28%	9	0.13%
56	11	1.03%	33	0.49%
61	1	0.09%	3	0.04%
62	24	2.25%	72	1.08%
71	7	0.66%	21	0.31%
81	88	8.26%	264	3.95%
93	2	0.19%	6	0.09%
Sub-Total SIS	**154**	**14.45%**	**462**	**6.92%**
Grand Total	**1,066**	**89.2%**	**6,678**	**42.7%**

Table 4: Number and percentage of establishments per sector in Coyoacán area

AREA	COYOACÁN			
Code	Establishment		Employment	
	No	PC	No	PC
Freight Intensive Sectors (FIS)				
23	4	0.31%	12	0.12%
31-33	74	5.70%	222	2.24%
43	4	0.31%	12	0.12%
46	652	50.19%	1,956	19.78%
48-49	0	0.00%	0	0.00%
72	128	9.85%	384	3.88%
Sub-Total FIS	**862**	**66.36%**	**2,586**	**26.15%**
Service Intensive Sectors (SIS)				
51	1	0.08%	3	0.03%
52	17	1.31%	51	0.52%
53	11	0.85%	33	0.33%
54	24	1.85%	72	0.73%
56	10	0.77%	30	0.30%
61	17	1.31%	51	0.52%
62	26	2.00%	78	0.79%
71	8	0.62%	24	0.24%
81	86	6.62%	258	2.61%
93	4	0.31%	12	0.12%
Sub-Total SIS	**204**	**15.70%**	**612**	**6.19%**
Grand Total	**1,299**	**82.1%**	**9,890**	**32.3%**

4.3. Computing the number of parking spaces

The calculation of parking spaces was done according section 3.6; the results for each area are shown below.

4.3.1. Parking spaces requirement in Benito Juarez area

As shown in Tables 5 to Table 8, the estimated value for the total FTG is between 2,924.32 (2,456.62 + 467.71 linear model) and 3,474.83 (1,952.29 + 1522.55 non-linear model), and the estimated value for the total STA is between 272.72 (linear model) and 363.8 (non-linear model) as shown in Table 9 and Table 10.

Table 5: Calculation of delivery trips in Benito Juárez area, through the linear model

BENITO JUÁREZ					
LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	DLV Received/Day
23	3	2	2.168	0.059	4.69
31 -33	3	36	1.144	0.096	51.6
43	3	24	3.910	0.079	99.5
46	3	634	2.871	0.117	2042.8
48	3	3	11.291		33.9
72	3	98	2.081	0.069	224.22
					2456.6
FTA (1 delivery = 1 vehicle trip)					**2456.6**

Table 6: Calculation of delivery trips in Benito Juárez area, through the non-linear model

BENITO JUÁREZ					
NON-LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	DLV Received /Day
23	3	2	1.574	0.280	4.28
31 -33	3	36	0.870	0.495	53.95
43	3	24	1.182	0.538	51.23
46	3	634	1.592	0.431	1620.58
48	3	3	3.154	0.448	15.48
72	3	98	1.449	0.342	206.76
					1952.29
FTA (1 delivery = 1 vehicle trip)					**1952.29**

Table 7: Calculation of shipment trips in Benito Juárez area, through the linear model

BENITO JUÁREZ					
LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	SHPT Out/Day
23	3	2		0.091	0.55
31 -33	3	36	5.441	0.065	202.90
43	3	24	6.021		144.50
46	3	634		0.279	530.66
48	3	3	7.667		23.00
72	3	98		0.115	33.81
					935.42
FTP (2 shipments = 1 vehicle trip)					**467.71**

Table 8: Calculation of shipment trips in Benito Juárez area, through the non-linear model

BENITO JUÁREZ					
NON-LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	SHPT Out/Day
23	3	2	0.378	0.639	1.53
31 -33	3	36	1.946	0.446	114.35
43	3	24	6.286		150.86
46	3	634	1.854	0.702	2541.78
48	3	3	1.717	0.413	8.11
72	3	98	1.468	0.421	228.47
					3045.10
FTP (2 shipments = 1 vehicle trip)					**1522.55**

Table 9: Calculation of service trips in Benito Juárez area, through the linear model

BENITO JUÁREZ					
LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	Svc Trips /Day
23	3	2		3.92E-03	0.02
31 -33	3	36	0.251		9.04
43	3	24	0.266		6.38
46	3	634	0.248		157.2
48	3	3		9.25E-03	0.08
51	3	2	0.804		1.61
52	3	13	0.428	3.22E-04	5.58
53	3	3		9.15E-04	0.01
54	3	3		1.10E-03	0.01
56	3	11	0.393		4.32
61	3	1		2.77E-03	0.01
62	3	24	1.126		27.02
71	3	7	0.879		6.15
72	3	98		0.017	5.00
81	3	88	0.571		50.3
					272.7
STA (1 service call = 1 vehicle trip)					**272.7**

Given that, this is the first estimation of a starting work on this topic, and the required data have a general form, the following assumptions were considered:

1. Due to the lack of information about the peak hour in the areas, but knowing that most of the freight transportation usually have a schedule from 9:00 am to 6:00 pm for deliveries to small establishments in the Mexican cities, we consider that the freight trips are normally distributed during this period.
2. Similarly, for the service trips it is considered they are uniformly distributed during the office hours, from 9:00 am to 6:00 pm. Then 11.1% is performed each hour of a regular business day.
3. Delivery and service vehicles occupy the parking space for 0.5 hour and 1.5 hours, respectively (Holguín-Veras et al., 2017).

Table 10: Calculation of service trips in Benito Juárez area, through the non-linear model

BENITO JUÁREZ					
NON-LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	Svc Trips /Day
23	3	2	0.326		0.65
31 -33	3	36	0.259		9.32
43	3	24	0.302		7.25
46	3	634	0.254		161.0
48	3	3	0.003	1.278	0.04
51	3	2	0.887		1.77
52	3	13	0.897		11.66
53	3	3	0.012	0.567	0.07
54	3	3	0.884		2.65
56	3	11	0.46		5.06
61	3	1	0.021	0.592	0.04
62	3	24	1.689		40.54
71	3	7	1.22		8.54
72	3	98	0.64		62.72
81	3	88	0.596		52.45
					363.8
STA (1 service call = 1 vehicle trip)					**363.8**

Then, the parking space calculation indicates that for the study area in Benito Juárez, 254 spaces are required to cover the freight transport demand, as shown in Table 11.

Table 11: Calculation of the parking space required in Benito Juárez area

BENITO JUÁREZ					
Activity	Daily total	Peak hour as % of total	Vehicles / hour	Parking time	Parking spaces
Freight	3474.8	11.11%	386.1	0.5	193.0
Service	363.8	11.11%	40.4	1.5	60.6
Total	3838.6		426.5		253.7

4.3.2. Parking spaces requirement in Coyoacán area

As shown in Tables 12 to Table 15, the estimated value for the total FTG is between 3,041.61 (2,525.54 + 516.06 linear model) and 3,652.45 (2,064.65 + 1587.80 non-linear model), and the estimated value for the total STA is between 285.60 (linear model) and 417.02 (non-linear model) as shown in Table 16 and Table 17.
The parking space calculation indicates that for the study area in Coyoacán, 272 spaces are required to cover the freight transport demand, as shown in Table 18.

Table 12: Calculation of delivery trips in Coyoacán area, through the linear model

COYOACÁN					
LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	DLV Received /Day
23	3	2	2.168	0.059	9.4
31 -33	3	36	1.144	0.096	106.0
43	3	24	3.910	0.079	16.6
46	3	634	2.871	0.117	2100.7
72	3	98	2.081	0.069	292.9
					2525.5
FTA (1 delivery = 1 vehicle trip)					**2525.5**

Table 13: Calculation of delivery trips in Coyoacán area, through the non-linear model

COYOACÁN					
NON-LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	DLV Received /Day
23	3	2	1.574	0.280	8.6
31 -33	3	36	0.870	0.495	110.9
43	3	24	1.182	0.538	8.5
46	3	634	1.592	0.431	1666.6
72	3	98	1.449	0.342	270.6
					2064.7
FTA (1 delivery = 1 vehicle trip)					**2064.7**

Table 14: Calculation of shipment trips in Coyoacán area, through the linear model

COYOACÁN					
LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	SHPT Out/Day
23	3	4		0.091	1.1
31 -33	3	74	5.441	0.065	417.1
43	3	4	6.021		24.1
46	3	652		0.279	545.7
72	3	128		0.115	44.2
					1032.1
FTP (2 shipments = 1 vehicle trip)					**516.1**

Table 15: Calculation of shipment trips in Coyoacán area, through the non-linear model

COYOACÁN					
NON-LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	SHPT Out/Day
23	3	4	0.378	0.639	3.1
31 -33	3	74	1.946	0.446	235.1
43	3	4	6.286		25.1
46	3	652	1.854	0.702	2613.9
72	3	128	1.468	0.421	298.4
					3175.6
FTP (2 shipments = 1 vehicle trip)					**1587.8**

Table 16: Calculation of service trips in Coyoacán area, through the linear model

COYOACÁN					
LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	Svc Trips /Day
23	3	4		3.92E-03	0.05
31 -33	3	74	0.251		18.6
43	3	4	0.266		1.1
46	3	652	0.248		161.7
51	3	1	0.804		0.8
52	3	17	0.428	3.22E-04	7.3
53	3	11		9.15E-04	0.03
54	3	24		1.10E-03	0.1
56	3	10	0.393		3.9
61	3	17		2.77E-03	0.1
62	3	26	1.126		29.3
71	3	8	0.879		7.0
72	3	128		0.017	6.5
81	3	86	0.571		49.1
					285.6
STA (1 service call = 1 vehicle trip)					**285.6**

Table 17: Calculation of service trips in Coyoacán area, through the non-linear model

COYOACÁN					
NON-LINEAR MODEL					
CODE	Avg Empl	No Est	α	β	Svc Trips /Day
23	3	4	0.326		1.3
31 -33	3	74	0.259		19.2
43	3	4	0.302		1.2
46	3	652	0.254		165.6
51	3	1	0.887		0.9
52	3	17	0.897		15.2
53	3	11	0.012	0.567	0.2
54	3	24	0.884		21.2
56	3	10	0.46		4.6
61	3	17	0.021	0.592	0.7
62	3	26	1.689		43.9
71	3	8	1.22		9.8
72	3	128	0.64		81.9
81	3	86	0.596		51.3
					417.0
STA (1 service call = 1 vehicle trip)					**417.0**

Table 18: Calculation of parking space required in Coyoacán area

COYOACÁN					
Activity	Daily total	Peak hour as % of total	Vehicles/hour	Parking time	Parking spaces
Freight	3652.5	11.11%	405.8	0.5	202.9
Service	417.0	11.11%	46.3	1.5	69.5
Total	4069.5		452.1		272.4

4.4. On-street parking availability

The parking space demand was calculated, but it is necessary to determine the on-street parking supply in each study area, i.e., the existing parking space for the vehicles serving the establishments. This supply was obtained measuring the streets lengths on each area; in the case of streets with double parking space (corresponding to each sidewalk) the length was multiplied by two.

In some parts of the road parking is prohibited, such as in front of house entrances, sites with hydrants, pedestrian crossings and ramps for disabled people. Then, for the Coyoacán area, the on-street parking space is 30% of the street lengths, which corresponds to 6,843 meters; and for Benito Juárez area, the on-street parking space is 25% of the street lengths, which corresponds to 3,180 meters.

Usually, four types of vehicles are mostly used to deliver to small establishments, which are the following.

- Vans and pick-ups: they can have different dimensions from 5.4 to 7 meters long, and require an additional space of 1.5 meters for opening the doors and freight handling, then the average required length for this type of vehicle is 7.7 meters.
- Light trucks: they can have a great diversity of dimensions, depending on the type of box and the usage they have; then an average length of 7.5 meters is considered plus 1.5 meters for the doors opening and freight handling, resulting in a required length of 9 meters.
- Trucks with two or three axes (C2 and C3): according to (SCT 2017) the maximum length of these vehicles is 12.5 meters, however their dimensions also differ according to their purpose, then an average required length of 12 meters is considered, including the space for freight handling.

Then, considering the length of the vehicles and the on-street parking space supply, in each area, the results are shown in Tables 19 to Table 21.

Table 19: Calculation of the required length for Vans and pick-ups

VANS - PICK-UPS		
AREA	Benito Juárez	Coyoacán
Total parking space / hour	254	272
% vehicles used	40	40
No parking spaces	102	109
Avg. length per vehicle (m)	7.7	7.7
Total length needed (m)	**782**	**838**

Table 20: Calculation of the required length for light trucks

LIGHT TRUCKS		
AREA	Benito Juárez	Coyoacán
Total parking space / hour	254	272
% vehicles used	35	35
No parking spaces	89	95
Avg. length per vehicle (m)	9	9
Total length needed (m)	**800**	**857**

Table 21: Calculation of the required length for Trucks with two or three axes (C2 and C3)

C2 - C3		
AREA	Benito Juárez	Coyoacán
Total parking space / hour	254	272
% vehicles used	25	25
No parking spaces	64	68
Avg. length per vehicle (m)	12	12
Total length needed (m)	**762**	**816**

The required length for each study area, is shown in Table 22; the first length is the result of the space required according to the type of vehicle and the second one corresponds to a length standardization which considers the maximum space required for parking the vehicles, this standardization allows the use of any type of FSA vehicle. Although the length standardization implies about a 30% increase on the space requirements, it could also minimize negative externalities such as the time, emission and congestion caused by the search of a suitable parking space.

Table 22: Calculation of the total required length

TOTAL PARKING SPACE NEEDED		
AREA	Benito Juárez	Coyoacán
Vans - pick-ups	782	838
Light Trucks	800	857
C2 - C3	762	816
Total length needed (m)	2,344	2,511
Total standardized length needed (m)	**3,048**	**3,264**

For Benito Juárez area, 254 parking spaces are needed, which implies a need of 3,048 meters according with the standardization, this space requirement corresponds to a 95.85% of the total parking space in the area.

For Coyoacán area, 272 parking spaces are required, which implies a need of 3,264 meters according with the standardization, this space requirement corresponds to a 47.69% of the total parking space in the area.

Based on these results, the space required for both areas is high, especially for the Benito Juárez area, since practically all the available space would have to be used for freight and service vehicles, which is not feasible.

Therefore, on-street parking space is not enough for UFT in both study areas, then additional parking initiatives must be studied.

5. CONCLUSIONS AND FUTURE WORK

Counting with the parking spaces needed for satisfying the demand of freight transport is difficult due to the lack of regulation and the sharing of the public space.

As the parking spaces supply is lower than the demand, this on-street parking initiative is not enough, and other initiatives must be considered for solving the parking problem for freight vehicles.

Nevertheless, the needed parking space estimation let to observe the impact that freight transport has on the city logistics, and how if it´s improved the externalities caused by it can be minimized

Questions resulting from the analysis are about the accuracy of the methodologies regarding FSA and the possibility of applying on-street loading/ unloading parking management initiatives.

Further studies should obtain better estimations of freight trips, which must use data on the type of vehicles used, the number of employees, the occupation time per vehicle, the peak hours and the available curb-parking space. Such data can allow obtain the corresponding alpha and beta parameters for each sector.

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PUBLIC TRANSPORT CASE: ROUTE 36: DIAGNOSIS OF TAXQUEÑA MODAL TRANSFER CENTER-PUENTE DE VAQUERITOS

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ABSTRACT
This article develops an operational analysis and diagnosis of bus route number 36 in Mexico City. This route runs from the Taxqueña modal transfer center to Puente de Vaqueritos, travelling in both directions. This analysis provides information about on-road stops, demand at each stop together with the idling and greenhouse gas emissions it produces.
This research is aimed at supplying information about the operation of a route that will give an insight into how improvements can be made to lower the negative impacts it entails.
Keywords: environmental impact, idling, emissions, reduction.

1. INTRODUCTION

Public transport is of great importance for the cities, as it gives inhabitants the means to be able to carry out their daily activities; however all too often this is not taken into account when public policy is drawn up, resulting in an operation that is non-optimal and has repercussions in a variety of problems and areas of opportunity.
The impact of transport is so wide ranging, from the economy to the environment; two factors that are particularly linked at a time when there is increasing global concern about the environmental impact and economic consequences of transport. For this reason, we need to develop strategies that not only improve the operation of public transport, but also help to lower its environmental impact. For all of the above, the objective of this research is to diagnose the operation and environmental impact of an urban public transport route in southern Mexico City.
This article was developed as follows: section one is an introduction and talks about the importance of public transport while section two explains our methodology, such as data analysis, problem determination and diagnosis.
Section three gives the results obtained by the methodology and the conclusions of the work presented in this article are presented in section four.

1.1. Public Transport

There has always been a need for the movement of goods and people. In the past land transport was dependent on the use of animals and humans, however with the development of the steam engine and internal combustion engine, new forms of transport were developed. Thus, the industrial revolution saw the arrival of the railroad for the transport people and goods, followed by the internal combustion engine in the twentieth century. The means of transport is extraordinarily relevant for society because they enable the movement of goods and people, achieving a social integration that favors economic development.
Their daily activities require people to move between and within cities; for a variety of reasons (work, study, leisure, exercise and shopping) and, depending on their level of income, they travel by foot or using some mode of transport, all of which implies a large number of trips and routes; therefore, their journeys dpend on several variables, such as the following: origin and destination of the trip; frequency; schedules; as well as mode and cost of transport, etc.
We often use different means of transport in our daily lives, from public transport (trains and buses) to private vehicles such as cars, motorcycles and bicycles.
Transport requires infrastructure, such as roads and the place where a specific vehicle operates (in the case of automobiles, the infrastructure would be the road or route) and an energy source (fuels or a system of pedals and chains).
Mobility generates connection links and transport is an organizational process with very specific characteristics that enables people and goods to move from one place to another. Thus urban transport is not an end itself and its efficiency depends on its contribution to the fulfillment of the relations of production and social reproduction (García, 2014).
The importance of public transport for a city resides in it meeting most of its social functions, so the approach needs to be more efficient and favorable (Urrutia, 1981). In economic terms, it enables the reproduction of the labor force through mass movement and generates productivity for the city. (Henry, 1985)
Urbanistically it has effects on the dimension and socio-spatial configuration of the city while on a cultural level, it enables social relations other than those strictly that are productive and generates spaces where the citizen can represent and imagine the city and others. (García, 1996)
Given the multiple implications of public transport for the city and its inhabitants, it is deemed to be a matter of public interest and so should be regulated by laws and public policies that facilitate its control and proper operation. Mobility requirements are so significant for our daily activities that it is necessary to understand how collective public transport systems are part of the

mechanism that drives city economies, as is the case of Mexico City.

1.2. Public Transport's Place in the World

Public transport is a crucial engine of economic and social development, providing opportunities and enabling economies to be more competitive. Transport infrastructure connects people with jobs, education and health services; enabling the supply of goods and services throughout the world; and making it possible for people to interact and generate the know-how and solutions that foster long-term growth.
This sector is crucial for lowering poverty, boosting prosperity and achieving sustainable development goals, making public transport one of the core critical challenges in worldwide development, such as:

- Climate change: transport represents approximately 64% of world oil consumption, 27% of all energy use and 23% of CO_2 emissions relating to energy use in the world. With the rates of motorization increasing, the environmental impact of the sector is expected to grow dramatically.
- Rapid urbanization and motorization: cities will host some 5.400 million inhabitants by 2050, which is equivalent to 2/3 of the projected world population. The number of vehicles on the road will double to reach 2 billion by 2050.
- Accessibility and affordability: it is estimated that one billion people in low-income countries do not yet have access to an all-weather road. In many cities, time lost by traffic congestion erodes prosperity. High transport costs lower the disposable income of the poor who often lack reliable and affordable public transport.
- Road safety: more than 1.25 million people die and up to 50 million are injured on the world's roads every year. Low- and middle-income countries account for 90% of deaths, although they only own half of the world's motor vehicles.
- Air pollution: pollution from motorized road transport has been associated with a wide range of health conditions, including cardiovascular and pulmonary diseases. Each year, almost 185,000 deaths can be directly attributed to the pollution of vehicles.

As the developing world rapidly urbanizes, there is an opportunity to build safer, cleaner, more efficient and accessible transport systems that will lower traffic congestion and pollution, facilitate access to jobs and reduce energy consumption in transport. In medium-sized emerging cities, where most new urban dwellers will live, urban planners can design inclusive and sustainable transport systems from the start, overcoming more polluting and costly means of transport. In older or larger cities, technology and big data are helping to better map travel patterns and needs, engaging citizens and improving the quality and efficiency of transport solutions. (Bank, 2018).

1.3. Public Transport in Mexico

In Mexico, the process of urban and population growth is the main agent of demand for transport systems, creating the need of an efficient adaptation that meets the needs for urban mobility.
Similarly, despite the large investments and actions of the different areas of government in Mexico, the transport systems in most cities are not suitable to meet the growing demand for travel. This shortcoming is particularly evident in the huge daily levels of traffic congestion. The main causes of traffic congestion are the excessive use of low capacity vehicles and an insufficient framework of integrated urban transport policies and programs; all of which results in huge costs from time lost, expenses for the health services and low productivity, accompanied by an increasing demand for space for roads and parking. Although there has been some success in dealing with the problem of air pollution, there are other aspects that have not received enough attention, such as energy consumption, low level of service and the expansion of cities (Manuel, 2012).
In the case of Mexico City, despite the bad press public transport has had, it can be said that considering the prices and the rates charged (which are the lowest of the OECD by far), the system operates quite efficiently if one considers that there is no comparison of the number of people who drive every day in the cities studied. The biggest problem with the public transport system in Mexico City is the lack of coordination of actions between the different elements of the system and between the different municipalities. The absence of a universal ticket contributes to the lack of integration of the system through interconnectors.

1.4. Factors that Contribute to the Level of Emissions Produced by Public Transport

On analyzing the generation of pollutants by public transport, we were able to identify the following contributing factors:

- Road infrastructure: The current planning of the road infrastructure is not sufficient to respond to the overwhelming volumes of vehicles using it and causing traffic congestion.
- Traffic congestion: Due to the number of vehicles in the Metropolitan Area of the Valley of Mexico, there are times when the saturation of the road infrastructure is inevitable, which creates moments of motor acceleration and deceleration, thus generating pollutant gases.
- Traffic lights: In some cases, the lack of synchronization of the traffic lights creates bottlenecks.
- Road Culture: The lack of road culture on the part of public transport operators, pedestrians and private transport has an influence on the flow of vehicles.

- Road blockages: Due to the lack of the road culture, private transport users block public transport routes, causing unnecessary stops.
- Driving cycles: A driving cycle is defined as acceleration, deceleration, idling and the time when the car is stationary; all of which generates different percentages of emissions depending on the point in the cycle the vehicle is at.
- Idling: Idling or empty times are when the engine continues to run and travel at low speeds, from 0 to 40 km / h. This point of the cycle is the one that causes the most pollutants.

2. LITERATURE REVIEW

2.1. Motor Vehicle Emissions

Radian says that motor vehicle emissions are made up by a large number of pollutants from many different processes. The ones that are most frequently considered are exhaust emissions, resulting from combustion of fuel. These types of emissions include: total organic gases (TOG), carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), particulate material (PM), toxic air gases

In addition to exhaust emissions, vehicles have a wide variety of evaporative emission processes, limited to TOG emissions, that include:

- Hot soak: Vaporization of fuel in the feed system due to the retained heat of the engine after the engine is turned off.
- Running losses: These are emissions caused by fuel leaks, as liquid or vapor, which are presented while the engine is running.
- Refueling: what constitute evaporative emissions displaced from the fuel tank of the vehicle during recharging. These can occur while the vehicle is at rest and in
- Diurnal: Represent gasoline that vaporizes due to the heat of the engine and exhaust system during normal operation. These emissions are due to the increase in ambient temperature caused by the vehicle exhaust system or by the heat reflected on the road surface.
- Resting losses: These evaporative emissions are different from the others, as they happen when the engine is not running, being the result of natural permeation that occurs from the fuel delivery system while not operating under ambient conditions. (Radian, 1997).

There are additional sources of particulate matter (PM) from motor vehicles, of which the biggest source is the dust kicked up on the road, which is the dust collected on the tires of the vehicle and suspended in the air due to turbulence caused by movement. Dust emissions are generally handled as an area source in emission inventories. Other PM sources not originating in the exhaust include wear and tear on tires and brakes. In general, these sources are insignificant when compared to exhausts and raised dust and, therefore, are sometimes omitted from emission inventories (USEPA, 1992).

The basic equation used to estimate emissions from motor vehicles involves vehicular activity data and an emission factor.

$$Ep = KRV \times FEp \quad (1)$$

Where:

Ep = Total pollutant emissions p

KRV = Kilometers traveled by the vehicle

FEp = Pollutant emission factor p

For motor vehicles, activity data refers to the kilometers traveled by the vehicle (KRV), while emission factors are expressed in units of grams of pollutant per KRV. KRVs represent the total distance traveled by a population of vehicles in a certain period. It is preferable for KRV to be estimated from models of transport or by counting the vehicles in circulation.

In some cases, however, KRVs must be calculated using fuel consumption statistics. The basic estimation equation given above is applicable for most gaseous pollutants and particles. For other contaminants, such as SOx and lead, emissions are calculated using a fuel balance, with the assumption that all the sulfur or lead contained in the fuel is emitted (Wark and Warner, 2007).

Emission factors for different pollutants are identified using models. The reason for this is that emissions from motor vehicles are much more complex and dynamic than those from other types of emission sources. For example, changes in the characteristics of the fuel; vehicle operating speeds; emission control technology; ambient temperature and altitude can all affect emission factors. In order to incorporate these and other factors, we generally use an emission factor model that includes the effects of numerous parameters (Murillo, 2015).

For the purpose of this paper, the calculation of greenhouse gas emissions was performed using the format provided by the Mexican Association of Automotive Distributors (AMDA) as the information required for the calculations, as stated in the literature review, is not available.

2.2. Data collection methodologies

Mobility surveys provide information about the movement of people in a geographical area and are mainly relevant for entities responsible for the planning of transport infrastructure and services but are also useful for decision making about the use of the territory and social policies. These surveys have two relevant characteristics that should be taken into account when interpreting the results:

- The information they reveal is given by the respondents.
- They are a statistical sample of a universe of larger units.

Demand for transport services has characteristics that clearly differentiate it from the demand for other goods and services (Ortúzar and Willumsen, 1994). Usually, travel is not a need in itself but is required to perform a localized activity in space and time. For example, the levels of traffic congestion in urban areas are normally highest first thing in the morning and in the late afternoon. It is also possible to detect, in the context of travel, seasonal components in the behavior of demand. This dynamic and spatial characteristic of demand is fundamentally justified by the very nature of economic activity.
The main components of a mobility survey are: the origin-destination household survey, which describes the journeys of household members; origin and destination intercept survey where users are intercepted at some point on their journey, capacity studies where vehicle and passengers are counted at a given place over a certain period of time and complementary information, such as land use and value, employment and other destination indicators, level of service offered by the different modes of transport (capacity, frequency and travel time) as well as travel time and the operating costs of cars (Ortuzar, 2016).
Its important to mention that the methodology presented in this paper was developed for the master's thesis entitled “Passenger transport in the Metropolitan Area of the Valley of Mexico (ZMVM) and its environmental impact. Case Route 36: Taxqueña modal transfer center - Puente de Vaqueritos.

3. METHODOLOGY

The methodology used in this paper is as follows:

3.1. Selection of Case Study

The case study was chosen by analyzing the information presented in the Origin-Destination Survey of the Metropolitan Area of the Valley of Mexico 2017 (INEGI, 2017), which determined that one of the areas that generates trips is the political subdivision of Xochimilco and their destination is the political subdivision of Coyoacán. The fact that a lot of public transport users depart from or arrive at the Taxqueña modal transfer center located in the Coyoacan political subdivision played a part in the selection of the case study.
Thus, the aforementioned Route 36 was selected and specifically the branch that goes from the Taxqueña modal transfer center to Puente de Vaqueritos. This route also has interconnectivity with three political subdivisions in the Metropolitan Area of the Valley of Mexico, Coyoacán, Tlalpan and Xochimilco, as it runs along a primary avenue, Miramontes, and crosses a variety of roads, avenues and secondary streets.

3.2. Data Collection

A first approach for data collection was to hold a series of interviews with the management, operators and users of the route. As the quantitative data was collected, we also observed several impact factors, resulting in a qualitive data collection.
For the quantitative data collection, the speed, type of stop, stop coordination, and the number of users per stop were determined as the variables of interest, because with this data it is possible to calculate the percentages by types of stops that are made, the length of time for each stop, the number of people that use each stop, and the percentage of idling that the units present.
Said data collection was carried out from Monday to Sunday in three different schedules, considered to be peak hours. These schedules were determined based on the origin and destination survey and through talks with the route's checkers and operators, which indicated that the busiest and most crowded schedules are: from 7:00 a.m. to 9:00 a.m. 2:00 p.m. to 4:00 p.m. and 6:00 p.m. to 8:00 p.m.
For recording the stop type variables and the number of users, the form shown in Figure 1 was used, which was filled out by hand using the nomenclature given in Table 1.
We used the Oruxmaps software for geographic coordinates, speeds, time at stops and kilometers and this enabled us to display geographic maps and save their characteristics in.gpx and KML format. Said software was configured so that the geolocation points of the tracks were saved every second, in coordination with GPS Test software that measures the accuracy of the gps measurements, thus giving us the greatest possible precision.

Table 1: Stop Indexation

Type of stop	INDEX
Official stop	PE
Traffic stop	C
Traffic light stop	S
Unofficial stop	X

DATE: ________ APLICATOR: ________

ROUTE NAME ________

START TIME: ________ END TIME ________

STOP NUMBERS	DEMAND ASCENT	DEMAND DESCENT	STOP NUMBERS	DEMAND ASCENS	DEMAND DESCENT
1			36		
2			37		
3			38		
4			39		
5			40		
6			41		
7			42		
8			43		
9			44		

Figure 1: Data collection form

3.3. Data treatment

The first step in the data treatment was to capture the information recorded in the sampling format in Microsoft

Excel, the second step was saving the data generated by means of Oruxmaps, dividing them into folders for each day.
In the third step, the gps data was converted in the Route converter software to obtain the attribute table of each track (observation), which is saved in.csv format for its handling.
At this point of data processing we have two independent tables for each track, so it is necessary to join them for the creation of a single table for both tracks.
Once we have the joint table, it is possible to analyze the data.

3.4. Data analysis

The data analysis was carried out in Microsoft Excel, where the number of stops performed, units, types of stops, travel time and the percentage of the journey when the unit was idling were determined.
Direct emissions of greenhouse gases and compounds were also calculated.

4. RESULTS

The analysis of the data permitted us to make qualitative and quantitative diagnoses of the route and these are presented below.

4.1. Qualitive diagnosis

The qualitive diagnosis allowed a clear visualization of the factors that contribute to the problem presented by the route.

4.1.1. Traffic lights and signs

Route 36: Taxqueña modal transfer center-Puente de Vaqueritos covers 8.0079875 km from its origin to its destination (Puente de Vaqueritos), making its path through Axis East one, Canal de Miramontes, which has two types of traffic lights: vehicular traffic lights, intended to regulate the transit of vehicles at intersections, and approach lights and simple traffic lights that inform, generally preventively, about a particular traffic situation (pedestrian crossing, schools). It is important to mention that these traffic lights are correctly synchronized. In the same way, it has signage for both transport and pedestrians and specifically for public transport.

Each type of sign is:

- For transport:
  - No parking
  - Junction with intersections
  - Maximum permitted speed
- For pedestrians:
  - Pedestrian crossing
  - School crossing
  - No jay walking
- For public transport:
  - Prohibition of stops
  - Location of stops

4.1.2. Types of users

The users of the route use it to get to their places of work (usually located in the business and industrial parts of the city) and as a means of transport to return to their homes. The road along which it transits has many junctions, so users also use it as a way to get to the point where they can transfer to another route or direction. Likewise, as this road has a large number of commercial areas, it has become a destination point for work and recreation. There are also a lot of schools on the periphery of the road that also generate both outbound and inbound trips and, as the route departs from and arrives at a modal transfer center, the range of users is varied.

4.1.3. Infrastructure

As regards the public transport infrastructure, there is a bus stop on the road, although it is not specific for the route in question and has mostly fallen into disuse because the points of greatest demand are not the points where that bus stops were located.
As the road travels through a primary road which has junctions with high traffic inflows, it is possible to observe that the points with the most traffic congestion are exactly at the junctions with five key roads. It is worth mentioning that the traffic lights at these points have been properly established and synchronized, so the traffic congestion is not due to this factor.
It is important to emphasize that the public transport does not have an exclusive lane for its operation, which generates another factor of direct impact that affects not only its operation but the emissions it generates.

4.1.4. Problem

It´s important to note that although there are official stops most users do not use them, resulting in stops at any point along the way, even at intersections with some of the other roads and in some cases, boarding and alighting is not performed in the far-right or left lanes.
The users also ask to board and alight wherever they like without taking into account whether the unit has just made a stop a few meters before; there are even times when the unit is stopped because of traffic congestion and / or traffic lights, when the user could board or alight, but they do not, causing the unit make another stop, unnecessarily.
In addition, users do not respect the signs governing boarding and alighting s and sometimes they do so while the unit in motion.
As for problems caused by third parties, which is how we shall refer to private transport and pedestrians, in the case of private transport it is possible to observe that, because there is no exclusive lane for public transport, the extreme right or left lane, which is generally used for the ascent and descent of passengers, is used by private cars

for parking, despite this being a primary road, causing the route operators to have to make unnecessary maneuvers that can lead to accidents.
Moreover, because of the numerous junctions on these roads, private transport uses the far-right lane to turn, causing traffic congestion in that lane.
In the second case, that is, pedestrians, there is a clear lack of respect for signaling and traffic lights, as they cross the streets randomly, regardless of whether there are pedestrian bridges or pedestrian crossings, often making the units stop to let them past.

4.2. Quantitative diagnosis

The quantitative diagnosis enables us to observe how the route actually operates and where there might be areas of opportunity.

4.2.1. Stops

A total of 1234 stops were made during 42 trips, of which 155 correspond to official stops, 288 to traffic lights, 220 to traffic congestion and 571 to unofficial stops, with an average of 59 stops per round trip which corresponds to the percentages given in Figure 2. Figure 3 shows the distribution of stops exclusively for the ascent and descent of passengers. This indicates that most of the ascents and descents are made at unofficial stops, implying that there are numerous of points where the unit is driving slowing and then accelerating again.
Table 2 gives the average and deviation per type of stop.

Table 2: Average and deviations per type of stop

Type of stop	Average	Standard deviation
PE	9	±2
S	14	±4
C	11	±6
X	29	±9

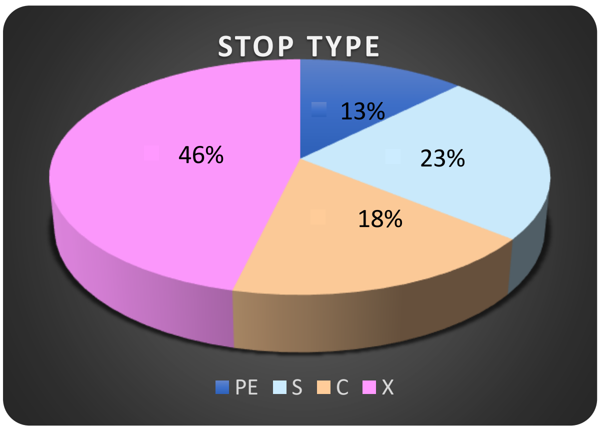

Figure 2: Type of stop in percentages

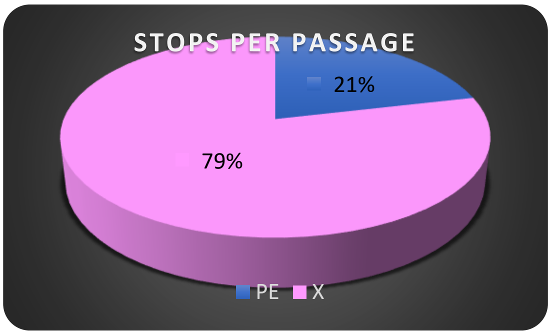

Figure 3: Percentage of stops per passenger

It is possible to observe that the percentage of stops at traffic lights is higher than stops due to traffic congestion because traffic congestion and the recurrent stops requested by users force the operator to stop the vehicle at the limit of the traffic light change which increases them considerably.
The stops made according to type and geographical position are given in Figure 4, where we observe that the unofficial stops are recurrent and at consecutive points.

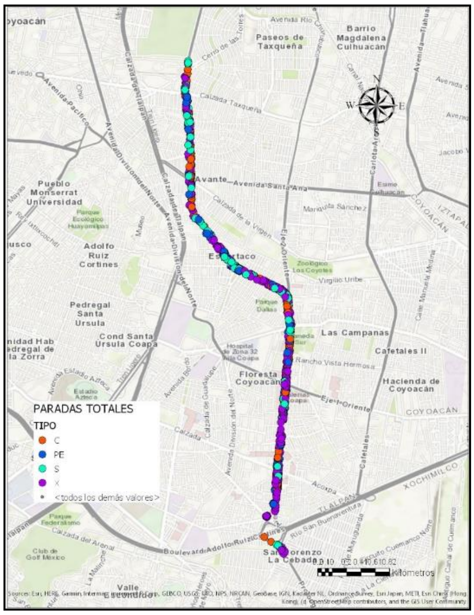

Figure 4: Stops on the route

4.2.2. Users

The route has a total of 2215 people as passenger inflow with an average of 53 people per trip, without considering the number of people boarding at the modal transfer center.

4.2.3. Speed and travel time

The trip is made in an average of 32 minutes with a minimum of 17 minutes and a maximum of 1 hour. Its average speed is 15.5483841 km / h, with a minimum speed of 8.7 km / h and a maximum of 27.55 km / h; which are within the range considered to be idling and is equivalent to 92.6587364% of the time of the total distance.

4.2.4. Emissions of greenhouse gases and compounds

The emissions were determined using data obtained from sample interviews with the 50 bus drivers that provide the service every day about their daily fuel consumption. This information was given in monetary units, as it was necessary to determine the cost associated with the fuel; using the following:

- Average fuel consumption in monetary units is $ 1513.
- Cost per liter of natural gas is $ 8 (Energía C. R., 2019).

Subsequently, we did the calculations given in Table 3, on which basis it is possible to calculate the emissions.

Table 3: Fuel Consumption

Daily fuel consumption ($)	Daily fuel consumption (L)	Liters per year
1,513	189.125	3,451,531.25

We used the format provided by the Mexican Association of Automotive Distributors (AMDA) for the calculation of emissions. Said format aims to guide the techniques and formulas for the application of methodologies for the calculation of the emissions of greenhouse compounds, derived from the consumption and oxidation of fuels in internal combustion engines in mobile sources, as stipulated in Article 5, Fraction II.
The calculation of emissions for Route 36 is given in Table 4 and Figure 5.

Table 4: Direct emissions of Greenhouse gases and compounds

Fuel	Annual consumption (L)	Emission factor		
		CO_2 (ton/MJ)	CH_4 (kg/MJ)	N_2O (kg/MJ)
Natural gas	3,451,531.25	0.0000693	0.000025	0.000008

Calorific value (MJ/bl)	Annual emissions			Emisiones anuales (tCO_2eq)
	CO_2	CH_4	N_2O	
5122	7705.878	77.837	235.735	8,019.451

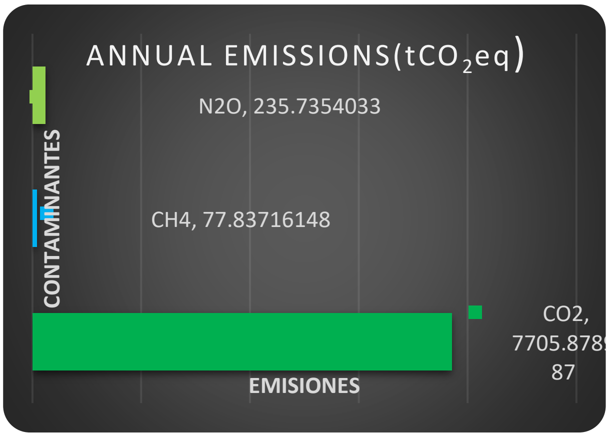

Figure 5: Greenhouse gases direct emissions and compounds

5. CONCLUSIONS

This analysis shows us that there are several factors that impact directly on the operation of a public transport system, from the education of users to the infrastructure itself and that their solution requires changes in behavior and for proper policies to be implemented.
The idling caused by these factors has a direct impact on the environment and health, so a reduction in idling will lower not only fuel consumption but also, consequently, the generation of greenhouse gas emissions.
It´s important to mention that this will not only lower environmental impacts but also help with the economic and operational issues that are important for the management of the route.
The importance of these studies lies in being able to achieve sustainable public transport, that considers the environmental impact and the needs of the users.
For future study, we believe that the minimization of emissions through the minimization of idling should be considered, performing spatial statistical analysis to determine the points with the highest influx of users and proposing official stops that would lower idling emissions, fuel consumption and its associated costs.

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DESIGN OF A TOOL TO ALERT MOTORISTS ABOUT THE CONDITIONS OF FLOODED ROADS

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ABSTRACT

This article describes the design of an automatic Internet of Things (IoT) alert and real-time measurement of the level of water accumulated by floods. A flood can obstruct major roads; as is the case in Mexico City, where every year during the rainy season floods cause road chaos, paralyze public and private transport and damage material resources. The proposed sensor system is complemented by an application for mobile devices, through which users can be notified about the water levels on the roads, to avoid traveling through risk areas. The application will create a synergy between the different users, by notifying the types of vehicles (cars, vans or buses) that, depending on their height, are able to pass through the flooded area, preventing said vehicles from suffering mechanical damage, being partially immersed or dragged by the current. On the other hand, users may decide to use their vehicle to travel or choose another transport system to reach their destination. These measures will help to reduce the saturation of roads and allow emergency vehicles such as ambulances to reach their destination faster.

Keywords: IoT technology, flood contingency plan, optimization, smart cities.

1. INTRODUCTION

Flooding in cities is one of the most frequent natural hazards and one of the most disruptive in terms of mobility and logistics, which means that hundreds or thousands of people and products cannot reach their destinations and remain stranded for hours.

In Mexico City, because of climate change, atmospheric phenomena have increased their intensity, frequency and duration. Because of this situation, in 2011 a decree was passed enacting the law on mitigation and adaptation to climate change and sustainable development (Asamblea Legislativa del Distrito Federal, 2011). It has been empirically estimated that Mexico City's deep drains cannot drain off at a rate higher than 40 mm/h and any higher rate may cause flooding (Landa, 2008), so contingency plans for rain and floods must be dynamic and adaptable to the circumstances presented by this phenomenon. This paper proposes a real-time monitoring system that includes users and enables them to anticipate the threats caused by road flooding and keep abreast of changes in water levels on the roads.

1.1. Background

Mexico City, like other countries in Latin America and the Caribbean, is affected by extreme weather events. In the Dominican Republic, Ecuador and Bolivia there have been increased floods. These countries have implemented an Early Warning System (SAT) consisting of four elements: 1) knowledge of the risks they face, 2) systematic observation, 3) communication and alert, dissemination of warnings to people at risk; and 4) preparedness and response measures to generate public awareness and readiness to act. In these countries, the existence of a planning and response mechanism to deal with floods has been evident, to move from a disaster approach to a comprehensive risk perspective. However, there is still a gap between technical forecasting / monitoring and community communication / response (Del Granado, 2016).

In Barranquilla, there is a high risk of death and material losses associated with flash floods in the city streets (Cama-Pinto, 2016). So a wireless sensor network was designed to monitor flash floods, through the wireless architecture or sensor network WSN (Wireless Sensor network) to monitor real-time atmospheric parameters that influence the water levels, detecting the danger of flash floods caused by sudden and heavy rainfall in a short period of time.

The flash flood early warning (FFEW) has drawn worldwide attention for its outstanding practicality and economic efficiency. Developing countries have built several operational FFEW systems adapted to certain regions with specific input data. FEW systems involve long-term and real-time flash flood warnings. Long-term warnings predict the risk of flash flood disasters on a long timescale. Real-time warnings forecast the probability of flash flooding over a short timescale, such as a day or a few hours, and are commonly used in emergency situations (Li, 2018).

In China, research into real-time flash flood warnings on the FFEW system uses computational methods for real-time warning indicators, improving the data sources used for warnings and the automation of real-time warning systems.

1.2. Early flood detection in Mexico City

The Mexico City government currently has two tools for warning and informing the population during the rainy season about how to avoid flooding and to protect their families. These tools are:

- Early meteorological warning, a tool developed by Civil Defense (Protección Civil, 2017). The alert helps citizens to have at least 15 minutes of advantage warning to take preventive actions for the greater safety to their family and property.
- Rainstorm warning signals, this tool can be found on the website of the Mexico City Water System (Sacmex) shows a list of the 16 municipalities indicating the intensity of the rainfall (Atlas de riesgo, 2019).

1.3. Internet of Things (IoT)

The Internet of Things (IoT) refers to those objects, animals, plants, humans and, in general, "things" that have an internet connection anytime and anywhere. Technically, it consists of the integration and interconnection of a set of sensors and microcontrollers with objects over a wireless network. Because of the increasing availability of Internet access and connection, the adoption of IoT is also increasingly feasible. Moreover, the low costs allow an easy integration of sensors in various environments, which implies that every object can be a source of data and information.

The IoT phenomenon has opened up around us, giving life to everyday objects that are interconnected thanks to the Network and that constitute inexhaustible sources of information. For this, it has been necessary to combine three phenomena that enable users to the use IoT. First of all, the growing miniaturization of computer components, making it easy to connect virtually anything, from anywhere, at any time.

Secondly, overcoming the limitation of mobile telephony infrastructure and lastly, the proliferation of applications and services that put the large amount of information created from the IoT into use.

With the IoT, small sensors are integrated into real-world objects and provide information on virtually everything that can be measured. In this way, we are increasingly interconnected, and people and objects can interact completely differently. Today there are one billion Internet users, 4,000 million people with mobile phones and an endless list of objects (cars, appliances, cameras, etc.) connected to the Internet in one way or another. "Intelligent" environments are built around this and are capable of analyzing, diagnosing and executing functions, eliminating possible human errors (FIB, 2011).

2. LITERATURE REVIEW

The research focuses on two technological aspects: the implementation of IoT and the use of a specific application for the identification and early notification of flooding on certain roads. For the use of IoT, authors like González (2017) explain how so-called Smart Cities are a field where there is extensive use of IoT through devices that collect the greatest amount of data to facilitate the life of the inhabitants. There is also Smart Traffic, which consists of giving real-time information about the traffic and proposing alternative routes.

Nowadays there are some flood detectors, mainly for domestic use, on the market (retrieved from Tunstall, 2019), (retrieved from Fibaro, 2019), but there are some others with wider uses, as (retrieved from LoRa and LoRaWA, 2019). There is also a site (FLOOD NETWORK, Building the UK's biggest network of flood sensors, 2019) where they explain what they offer: "Our low-cost wireless sensors harness the power of the Internet of Things to give you updates about waterways, culverts, rivers, ditches and even groundwater. They're battery powered and connect wirelessly to a gateway which sends the data back to our system using the Internet. A web map visualises your waterways and their levels at https://map.flood.network".

It is important to mention that all these devices use IoT. So, based on this information, what this paper proposes is an ultrasonic device that detects the level of water, whose operation consists of emitting an ultrasonic sound through one of its transducers, and waiting for the sound to bounce of any object that is present with a second transducer picking up the echo. The sensor can detect objects, distance or level at a minimum range of 2 cm to a maximum of 400 cm. It can be used, for example, for different types of projects such as proximity alarms, measuring water levels of a water tank or any other object that stores some kind of liquid. This sensor, created by the authors, is currently in the experimental phase.

3. METHODOLOGY

The methodology used for this research is as follows:

3.1 Information gathering

According to UNAM researcher, Ramón Domínguez (2000), in his study whose title translates as "Floods in Mexico City. Problem and Solution Alternatives", the problem of flooding occurs mainly on roads that are below the Western Intercept Drain, where the collectors have lost gradient; this is from the Periférico to Avenida de los Insurgentes. This study analyzes the problem of flooding in the Valley of Mexico, based on a historical perspective that, in essence, shows that the problem has been recurring since the time of the Aztecs, for which a solution has always been sought that does not involve stopping the growth of urbanization in the valley. But it is also true that the "solutions" have never been preventive, but have been developed following catastrophic floods. On the other hand, the Mexico City Water System (Sacmex, 2017) together with the authorities of Mexico City have identified 48 neighborhoods and 136 points of high risk of flooding when there are heavy rains that exceed the capacity of the sewer system. These points are mainly concentrated in the Iztapalapa and Gustavo A. Madero municipalities, where the 18 high-risk flood neighborhoods are concentrated. But there are also critical points in Miguel Hidalgo, Álvaro Obregón, Azcapotzalco, Magdalena Contreras and Benito Juárez.

For his part, Omar Diaz (2019), in his interview with Bernardo Carmona, general director of the Mexico City

Water System, highlights the areas where there is a high probability of flooding in the different municipalities of Mexico City, namely: Iztapalapa 640, Gustavo A. Madero 402, Cuauhtémoc 298, Venustiano Carranza 290, Iztacalco 218, Coyoacán 198, Azcapotzalco 168 and Tláhuac 15. These numbers represent areas per municipality.

3.2 The identification of the problem

The problem was identified through the analysis of the information collected, considering the following:

- There are areas that have recurring problems irrespective of how much rain falls. This is because of the unevenness of the area and / or the concentration of large quantities of garbage that prevent rainwater from flowing freely through the drainage.
- Affected roads: this occurs when there is flooding that, depending on the area, ranges from moderate to intense.
- Material damage such as: lifting of the asphalt pavement, potholes, partial or total damage to cars, among other things.
- Total or partial blockage of roads derived from: broken-down cars and high water levels during flooding.
- Emergency vehicles being blocked as the result of road paralysis.

3.3 Proposed solution

While analyzing the problems caused by floods and waterlogging in various roads in Mexico City, an alternative solution emerged. This solution consists of the integration of IoT technologies to monitor in real time the level of water on some of the roads on a route and determining whether or not the cars, depending on their size, will be able to pass through it without the risk of being stranded in the attempt. This solution is complemented by an application for mobile devices that allows the user to know the status of monitored roads by indicating the level of water so that vehicles can circulate, in addition to having a signal that shows water levels. Currently the Mexico City Water System (SACMEX) has implemented an intensity signal for each city municipality (Figure 1) that warns the population about the general situation of the different districts, however, it does not indicate the level of flooding on the affected roads and, above all, does not issue recommendations on the type of vehicles that can circulate along the road, as with the current proposal. These types of recommendations are very important as they will enable users to decide in advance on the route that they should choose to arrive safely at their destination; not block the roads where only taller vehicles, such as buses, cargo transport or emergency vehicles, such as ambulances, are allowed; and, when necessary, to choose an alternative means of transport (bus, Metro or Metrobús) to avoid the unnecessary congestion of roads.

3.4 Simulation

The proposed solution is supported by simulation in SIMIO software, where values are assigned to the different variables, such as: type of vehicle (car, van and bus) in relation to its height, original road, alternative road available, fault in the system (flooding of the road) and probability of a successful crossing for each type of vehicle (Figure. 2).

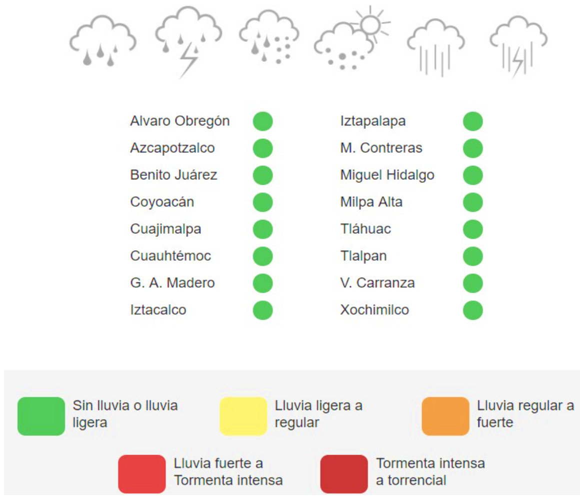

Figure 1. Rainfall warning signal. Source: SACMEX, (2019).

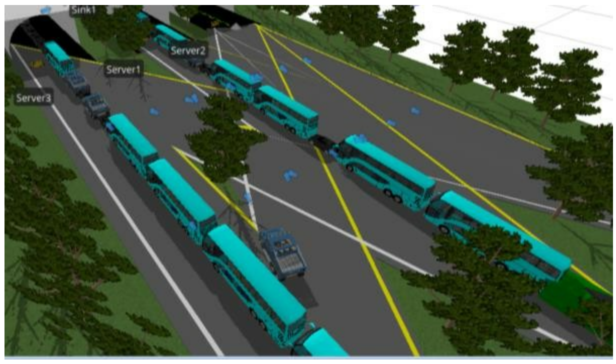

Figure 2. Simulation of road flooding. Source: the authors.

Figure 3 shows the flow of vehicles on the roads without the presence of any fault in the system (floods).

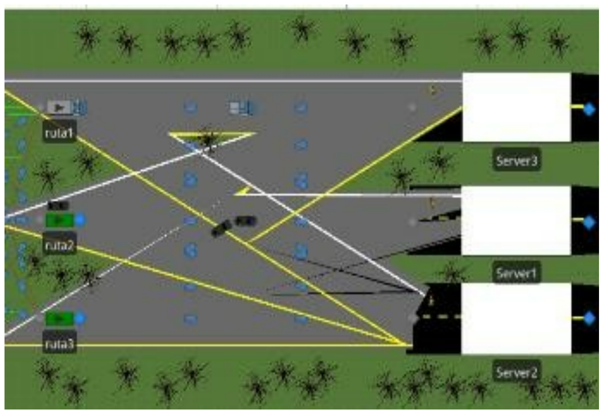

Figure 3. Vehicle flow without flooding. Source: the authors.

The simulation also finds the saturation of the roads when there is a fault in the system (floods). Figure 3 shows how, by having an alternative road (maintained in good conditions), the vehicle flow increases but does not stagnate as on the flooded roads. This is because the various vehicles choose the alternate route in advance in order to avoid being stranded in traffic caused by floods. From the results obtained from the simulation, we conclude that real-time monitoring of the level of flood water and giving timely information to motorists makes it possible to reduce the number of vehicles left stranded and obstructing the affected roads.

4. DESIGN OF THE DEVICE

The proposed monitoring system consists of a set of devices connected through a Wi-Fi network with a database, where each device sends the corresponding information about the monitored variable (water level in this case, as shown in figure 4).

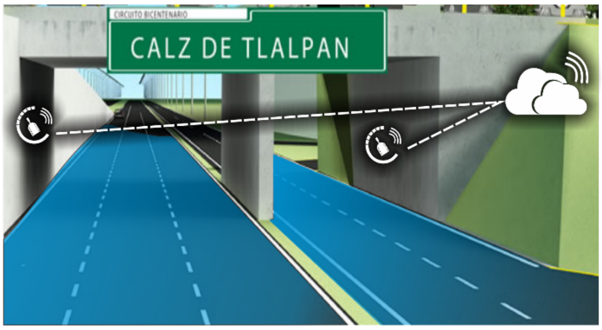

Figure 4. Wi-Fi network devices. Source: the authors.

The system receives the data, verifies the value of the variable and associates it with a high, medium or low water level. This system is based on an ESP chip that enables connection to existing WiFi networks and is easy to program on the Arduino platform, free software that facilitates the creation of electronic prototypes.
Development cards based on the Arduino programming platform can support many elements, such as different types of sensors, thanks to their ports composed of pins that can be programmatically configured as inputs or outputs, making it possible to capture information about the environment through different types of sensors.

The proposed monitoring system works as follows:

1. The ESP chip connects to a Wi-Fi network.
2. Through serial communication, the ESP chip collects the information about the variable coming from an ultrasonic sensor (as illustrated in the figure 5).
3. The information collected is verified in the chip through specific structures that ensure the accuracy of the data. If the measured values do not match the expected data, a new sampling is performed to avoid errors.
4. The data collected through the sensors are sent and stored in a database on the "cloud" (external database servers) as shown in figure 6. This data is updated in real time throughout the event, this way it is possible to know if water levels are rising or falling.

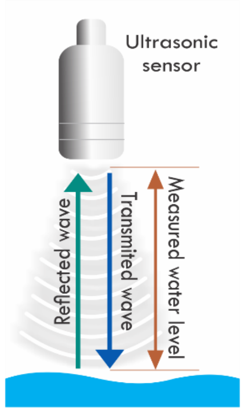

Figure 5. Ultrasonic sensor data acquisition. Source: the authors

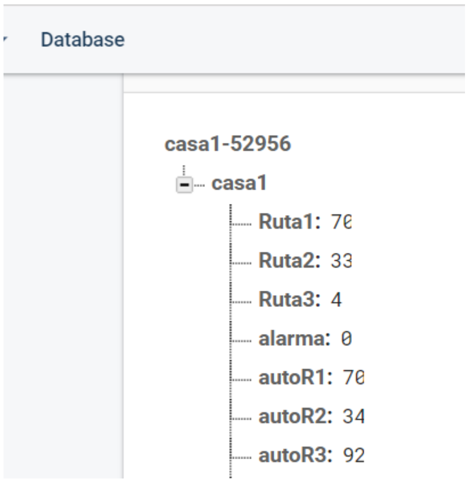

Figure 6. Database with stored data. Source: the authors.

The application for mobile devices accesses the information stored in the database, interprets it and displays a value corresponding to the probability of a vehicle being able to cross a flooded street or avenue, as shown in figure 7.

Figure 7. Probability, interpreted by WebApp, of a vehicle being able to cross a flooded street. Source: the authors

The proposed system is conceptualized, in its simplest form, as a set of sensors that collect data and communicate it to a microcontroller that processes the data and sends it to a database via Wi-Fi, then to be retrieved and interpreted by an application for mobile devices for the users to use, as shown in figure 8.

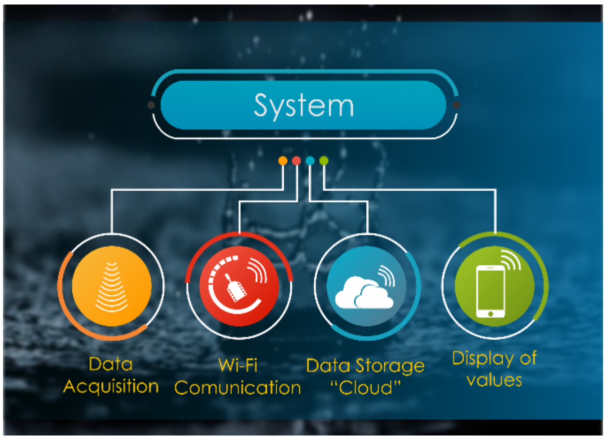

Figure 8. Proposed system in its simplest form. Source: the authors.

5. RAIN MONITOR

Rain Monitor is an app developed by students from the systems engineering postgraduate unit, aimed at contributing to the mitigation of the effects and consequences caused by flooding on the different roads of Mexico City.

The proposed device collects information on the level of water accumulated in the streets, this water level is acquired through an ultrasonic sensor which transduces the energy received by means of ultrasonic waves and transmits them to the microcontroller in the form of digital pulses. For its part, the microcontroller receives the signal, processes it and emits the results to the ESP microcontroller via serial communication. Then, the ESP microcontroller sends the data via internet to a database hosted on the "cloud" (databases hosted on external data servers).

The rain monitor is a WebApp responsible for recovering the data stored in the cloud database and presenting them in numerical (probability) and graphic form. This WebApp makes it possible to know the flood levels on the different routes so users can select the route with the optimal water levels for their type of vehicle.

5.1. App features

The main feature of this application is that it is not designed as a native application, that is, it is not developed for a particular operating system, instead, the application is based on a WepApp where a web page is basically adapted so "Responsive", that means attached to any type of screen of the different mobile devices.

The different advantages of that WebApp include:

- Display on any operating system: it has no problem adapting to iOS, Android, among others.
- It does not need to be installed from App stores, such as Google Play Store or Apple App Store. That means a saving, as the direct link through a Web Approximately is free.
- Development time is also shorter.

Figure 9 and figure 10 show the WebApp developed for mobile device screens and PC desktop screens respectively. The graphs shown indicate the probability of success for a vehicle crossing a street or avenue with a level of flooding.

Figure 9. View of mobile device screen. Source: the authors.

Figure 10. PC desktop view. Source: the authors.

6. CONCLUSIONS

The design and application of tools that permit the real-time monitoring of areas affected by floods is important for determining the scope of the emergency, reducing material losses and adjusting an action plan to take another route or means of transport.

The increasing use of technology based on the internet of things or "IoT" allows us to interconnect many elements. This interconnection seeks to create the connection between the real world and the virtual world, whose purpose is to integrate the parts of a system. In the case of cities, these technologies can improve the quality of life of its inhabitants through an efficient and responsible management of their resources, enabling them to face future challenges. In this paper, the design and implementation of applications based on IoT tools that allow the real-time monitoring of flood-affected areas are important for determining the scale of the emergency, reducing material losses and adjusting an action plan for taking another route or means of transport.

In the future work we plan to make an analysis of networks that let users know the routes that are not saturated for reaching their destination. On the other hand, it is advisable to perform a risk analysis to determine the hazards as well as the present and emerging risks that can be subsequently evaluated, quantified and even modeled, to finally conclude with the implementation of control and mitigation plans aimed at safeguarding the well-being of the population.

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Planning and scheduling

EXACT PLANNING FOR AN INSTITUTIONAL SOCCER SCHEDULING PROBLEM WITH TIME WINDOWS

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ABSTRACT
This work presents a solution for an institutional Soccer Scheduling Problem, which defines a planning process based on four stages: 1) a round-robin match assignment 2) a balanced home-visitor selection, 3) the construction of a time schedule, and 4) a referee designation. The goal of this approach follows two purposes: automate the planning and optimize the computation time of the process. The proposal is supported with a mathematical model based on the Sports Scheduling and the Traveling Salesman Problems, solved through a software application developed in Java with LINDO API to get optimal solutions for instances of maximum size 14, including cases with a non-pair number of teams through a parity adjustment process. The application solves test instances in an average time of 248 milliseconds (99.9% of time saving with regard to the 60 minutes of manual calculation), which demonstrates the advantage of application of the proposal in planning stages.

Keywords: planning, optimization, sports scheduling problem, soccer scheduling problem.

1. INTRODUCTION

Scheduling is a common problematic when a sporting event is organized, due to many restrictions that must be considered to satisfy different objectives related to planning. For example, a round-robin assignation with local-foreign constrains in where the teams must play in different locations in different days each week during a season, which increases the complexity to build a working plan. In case of professional football soccer is not the exception, because there are a wide variety of management schemes and cases of study where additional restrictions are considered, such as TV Broadcasting rights and sponsors, where a sponsors are a decision factor about dates and hours when a football soccer game is performed, giving to the sport a business coverage and generating economic benefits for all participants.

For this reasons, some works have approached the soccer planning using mathematical optimization, needed to establish the basis to create computational algorithms to build solutions in a reasonable time. For example, in Ribeiro (2013), is presented a bi-criteria approach to get a planning for the Brazilian league that computes solutions in 40 minutes. This approach is based on the Sports Schedule Problem proposed by McAllon (2010), in which the number of matches are minimized and number of broadcast transmissions are maximized, satisfying the objectives 45 minutes; in some cases such as in Duran (2012), formulations aggregate an objective function in which maximizes the economic profit of ticket sales, this is approached in a few seconds. These formulations have in common the construction of solvers based on the constraint satisfaction process.

At this point, some approaches have included constraint satisfaction for the soccer scheduling, including linear programming and exact algorithms to compute optimal solutions through optimization software. The most common strategies consist of decomposition techniques, needed to support their results.

For instance, in Bartsch (2006) is applied a branch and bound technique to satisfy the planning of Austrian and Germany leagues, executing solvers in 30 minutes. In (Della Croce and Oliveri 2006) the scheduling problem for the Italian league is approached in 25 minutes using a stage decomposition technique, while in (Fiallos 2010; Goosens 2009; Duran 2017) soccer scheduling formulations are approached in few seconds using integer programming for the Chilean and Honduran leagues and the CONMEBOL (Confederación de futbol de América del Sur) respectively.

These cases of study reveal the advantages of use of exact approaches to support a planning stage in professional leagues, in whole cases, other complementary organisms such as player associations and arbitration committees are required. This introduces an availability constraint that makes it difficult for participants to hold work meetings to establish the planning. For this reason, organization process of a sport event is performed in phases and a planning in stages, which increases the schedule time used to organize and manage all resources, common problems in professional leagues that constitute object of study of the present work.

2. THE SPORTS LEAGUE SCHEDULING PROBLEM

A general task to organize a sport contest consists of generate the matches between the teams, being the most common used the round robin system. It makes feasible assignations for n teams in $n/2$ periods as seen in Table 1. The formulation includes four additional restrictions:

1. There are n teams and each team face with the remaining teams only once.
2. The season has n-1 weeks (W).
3. Each team faces one game per week during the season.
4. There are $n/2$ periods (P) where in each week is scheduled only one match.

Table 1: The Sports League Scheduling problem

W \ P	w_1	w_2	w_3	w_4	w_5	w_6	w_7
p_1	1 vs 2	1 vs 3	5 vs 8	4 vs 7	4 vs 8	2 vs 6	3 vs 5
p_2	3 vs 4	2 vs 8	1 vs 4	6 vs 8	2 vs 5	1 vs 7	6 vs 7
p_3	5 vs 6	4 vs 6	2 vs 7	1 vs 5	3 vs 7	3 vs 8	1 vs 8
p_4	7 vs 8	5 vs 7	3 vs 6	2 vs 3	1 vs 6	4 vs 5	2 vs 4

This overview for the problem was defined in (McAlloon 2010) as the Sports League Schedule Problem. Table 1 represents the planning as a bi-dimensional scheduling with rows and columns of size $P \times W$, establishing the rows for the periods and the columns for the weeks.

The scheme defines that a team that is assigned to a period can not appear more than two times, while in each week a team can be programmed only once. It includes a global constrain that establishes that a match defined as a pair (team i vs team j) occurs only once. The scheme approached and solved with integer programming.

However, a disadvantage for this allocation is observed in the distribution of the teams at the cells, where the team i faces the most of the confrontations in the host role, giving as a result a set of partially ordered pairs (i vs j, where $i < j$) and giving a not balanced scheme in the home-away roles. In the same way, periods are scheduled according to just one schedule horizon (confrontations are scheduled in a unique day), leaving aside the notion of parallelism for schedules in several days or sports facilities.

Additionally, the round-robin assignation is observed as a single-category problem, where allocation in groups of teams is not permitted, giving also the task of referee assignment to another planning committee. These characteristics are common in the most of the sports and soccer scheduling approaches reported in literature.

3. THE INSTITUTIONAL LEAGUE SCHEDULING PROBLEM

The UMAR (Universidad del Mar) soccer contest is attended each biannual period following an organization scheme based on five phases: 1) the registration of the tournament, teams and players, 2) the weekly scheduling, 3) the weekly tracking of the competition, 4) the registration of weekly statistics and the ranking, and 5) the schedule of the finals, these phases are described in (Delgado 2019). The championship is programmed each week (k) using a determined and finite number of days (pd) of a weekly day set D, as a result of a restricted space to develop it (the campus Puerto Escondido of the Universidad del Mar has only one physical installation, adaptable to practice football soccer, basketball and volleyball). The tournament is performed in a set C of m categories or groups of teams with size N_c, where N_c can be a pair or non-pair number of teams for each category c. If all categories have the same number of teams (N_c values are equivalent) a single round robin is computed with $N_c - 1$ games, otherwise an adjusted double round-robin for all categories is programmed. The adjusted double round robin defines the schedule for all categories with smallest number of teams of any category, which is scheduled with regard to the category with the most number of teams, it introduces a value n_c that corresponds to the maximum number of teams of all categories. An example of double round robin is shown in Table 2.

Table 2: The UMAR Soccer Scheduling Problem

W	D	P	Time windows	Match	Referee team
w_1	d_1	p_1	19:15-19:45	1F vs 2F	1M
		p_2	19:45-20:15	1M vs 5M	2M
		p_3	20:15-20:45	2M vs 3M	5M
	d_2	p_4	19:15-19:45	3F vs 4F	4M
		p_5	19:45-20:15	4M vs 6M	7M
w_2	d_1	p_1	19:15-19:45	3F vs 1F	4M
		p_2	19:45-20:15	2M vs 4M	7M
		p_3	20:15-20:45	7M vs 1M	2M
	d_2	p_4	19:15-19:45	4F vs 2F	6M
		p_5	19:45-20:15	6M vs 3M	5M
w_3	d_1	p_1	19:15-19:45	2F vs 3F	2M
		p_2	19:45-20:15	4M vs 7M	5M
		p_3	20:15-20:45	2M vs 5M	7M
	d_2	p_4	19:15-19:45	1F vs 4F	6M
		p_5	19:45-20:15	1M vs 6M	3M
w_4	d_1	p_1	19:15-19:45	2F vs 1F	1M
		p_2	19:45-20:15	2M vs 1M	3M
		p_3	20:15-20:45	7M vs 3M	2M
	d_2	p_4	19:15-19:45	4F vs 3F	5M
		p_5	19:45-20:15	6M vs 5M	4M
w_5	d_1	p_1	19:15-19:45	1F vs 3F	5M
		p_2	19:45-20:15	5M vs 4M	2M
		p_3	20:15-20:45	2M vs 7M	4M
	d_2	p_4	19:15-19:45	2F vs 4F	3M
		p_5	19:45-20:15	1M vs 3M	6M
w_6	d_1	p_1	19:15-19:45	3F vs 2F	6M
		p_2	19:45-20:15	6M vs 2M	3M
		p_3	20:15-20:45	4M vs 3M	2M
	d_2	p_4	19:15-19:45	4F vs 1F	7M
		p_5	19:45-20:15	7M vs 5M	1M
w_7	d_1	p_1	19:15-19:45	NA	NA
		p_2	19:45-20:15	1M vs 4M	3M
		p_3	20:15-20:45	3M vs 5M	1M
	d_2	p_4	19:15-19:45	NA	NA
		p_5	19:45-20:15	6M vs 7V	2M

The schedule of Table 2 shows a UMAR soccer contest with two categories: male (*M*) and female (*F*) like two different groups with different cardinality. With this description, example establishes m = 2 with a female category with four teams $N_F = 4$ (1*F*, 2*F*, 3*F*, 4*F*) and the male category with seven teams $N_M = 7$ (1*M*, 2*M*, 3*M*, 4*M*, 5*M*, 6*M*, 7*M*). Table 2 observes also that in the matches of the female category (*F*) all teams have two confrontations between them, finishing the round robin in the week six. In contrast with male category (*M*) in which only a single round robin is executed (it occurs because n_M = 7). For this reason, the scheduled confrontations of the female category in the week appear with the “NA” label (games of this category end before). When the number of teams N_c for any category $c \in C$ is a non-pair value, the input N_C is adjusted with the addition of a fictitious team, leaving at rest to the team that faces it each week and extending the number of weeks to N_c weeks, according to the single or double round robin performed. This process that is named parity adjustment.

With these elements, the global formulation of the problem to set a planning, consists of four stages: 1) the solution of the related round-robin for each category, 2) the balanced home-visitor allocation for the teams, 3) the construction of a calendar schedule, and 4) a designation for a referee for each confrontation, stages that are designed as a part of a software tool, which uses a mathematical formulation to lead an automatic planning for the tournament.

4. MATHEMATICAL FORMULATION

Mathematical formulation of the UMAR soccer scheduling problem is defined according the next input elements:

C	Is the set of categories (groups of teams) that are scheduled.
N_C	Is the number of teams for each category *C*.
k	Is the number weeks, established to schedule the confrontations. It is dependent to the N_C value where $k = N_C - 1$.
pd	Is the constant parameter of playing days for all weeks.
ss	Is the starting time parameter in which the weekly confrontations starts in all schedule days.
pt	Is the playing time parameter, a constant duration for the confrontations.
x_{ijk}^m	Is an integer variable with a value of 1 if the game (*i* vs *j*) is assigned in the week *k* for the category *m*, 0 value in otherwise. Where $i=1,2,\ldots,N_C$, $j=1,2,\ldots,N_C$, $m=1,2,\ldots,\lvert C\rvert$
t_{ih}	Is an integer variable used to establish the horary time windows. It has a value 1 if the time window is active for the team *i* in the *h* schedule, 0 value in otherwise.

These sets, parameters and variables are needed to establish a fair allocation, which is calculated in iterative form for each week *k* until the round robin is finished according the number n_c of teams. Solution is built following the four stages, getting a fair assignation to generate the semiannual scheduling for the soccer championship.

4.1. Stage 1. The double round-robin assignation

The match assignment uses the basis of the sports league scheduling problem, given *n* teams a pair (*i* vs *j*) is selected in each week *k* for each category. This selection is used to define the objective function of the problem according to the equation (1).

$$\min z = \left(\sum_{m=1}^{|C|} \left(\sum_{k=1}^{N_m-1} \sum_{i=1}^{N_m} \sum_{\substack{j=1 \\ j\neq i}}^{N_m} c_{ij} x_{ijk}^m + \sum_{i=1}^{N_m} M x_{iik}^m \right) \right) \tag{1}$$

Where the minimum value obtained by the *z* value is n_c, setting all the c_{ij} values in one, giving to all teams the same possibility to be chosen. It approaches the problem according to (Cook 1971, Gomes 1998) as a constraint satisfaction problem. The objective function of equation (1) includes also a sum of a number $M \to \infty$, required to avoid that a team *i* will be scheduled against himself. This function is satisfied through three types of elemental constrains, defined in equations (2), (3) y (4), which defines the feasible solution space for the problem.

$$\sum_{i=1}^{N_m} x_{ijk}^m = 1, \quad j=1,2,\ldots,n;\ i \neq j;\ k=1,2,\ldots,n-1; \quad m = 1,2,\ldots,\lvert C\rvert \tag{2}$$

$$\sum_{j=1}^{N_m} x_{ijk}^m = 1, \quad i=1,2,\ldots,n;\ i \neq j;\ k=1,2,\ldots,n-1; \quad m = 1,2,\ldots,\lvert C\rvert \tag{3}$$

$$x_{ijk}^m - x_{jik}^m = 0,\ i = 1,2,\ldots,n;\ j=1,2,\ldots,n;\ i\neq j;\ k=1,2,\ldots,n-1,\ m = 1,2,\ldots,\lvert C\rvert \tag{4}$$

These restrictions define a route-based assignation with a set $R = \{(i,j) \cup (j,i) | i = 1,2,\ldots,N_C,\ j = 1,2,\ldots,N_C;\ i \neq j\}$ of size $2n_C$ (parity), similar to the Traveling Salesman Problem (TSP) described in (Bellman 1962). Where equation (2) corresponds to the output flow for one *i*-th node or team faces the *j* team (named as supply or host team constrains), while constrain (3) ensures that just one team *j* is programmed against the *i*-th team or node (demand or foreign team constraints). At the same time equation (4) ensures that a feasible subtour of size two is formed. When the set *R* is formed, objective coefficients c_{ij} are penalized adding them the *M* value according to the selected x_{ijk}^m variables in each iteration *k*, according to equation (5).

$$c_{ij} = \left(M + c_{ij}\right) x_{ijk}^m \tag{5}$$

This penalty ensures that the *z* values are influenced in the selection of the x_{ijk}^m variables, discarded them in future scenarios according to the rule “who does not know his history is destined to repeat it”. This rule introduces a behavior defined in terms of a Markov's decision process (Bellman 1957). The mathematical model is used to generate a double round robin for all categories, which is adjusted in the next stage according to the required balanced home-away assignment.

4.2. The balanced home-visitor match programming

Once computed the double round-robin of the stage 1, it can be used to obtain a balanced assignation for the home-foreign role. It can be performed using the symmetry property of the related TSP representation, where a solution matrix SLP_C is introduced. The SLP_C is a squared matrix that represents the game allocation pairs (i vs j) per each category C, each pair is filling in each iteration with the k value. This matrix is initialized in zeros values as shown in Figure 1. In this case, two solution matrixes for two categories are represented (3-*a* shows the female category F with N_F=4, while 3-*b* represents the initial matrix for the male category (M) given $N_M = 7$.

a)

$$SCP_F = \begin{bmatrix} - & 0 & 0 & 0 \\ 0 & - & 0 & 0 \\ 0 & 0 & - & 0 \\ 0 & 0 & 0 & - \end{bmatrix}$$

b)

$$SCP_V = \begin{bmatrix} - & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & - & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & - & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & - & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & - & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & - & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & - \end{bmatrix}$$

Figure 1: Solution matrix for the round-robin UMAR soccer scheduling problem

The Markovian process described in stage 1 makes that each element of the matrix SLP_C changes according to the k-th value of the week, and reflecting it through the symmetry, which means that an arc (i, j) is equivalent to the arc (j, i), as a result of the double-round robin. Figure 2 shows an example of this symmetric matrix, used to permit a balanced selection.

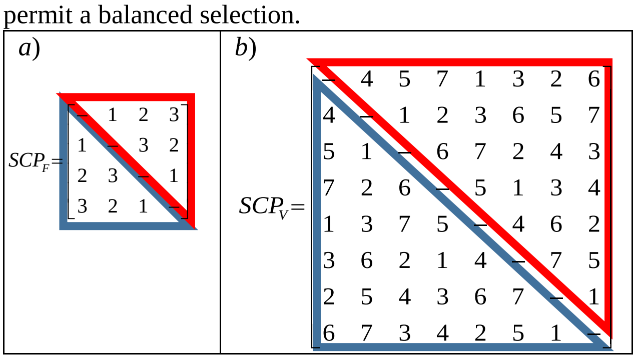
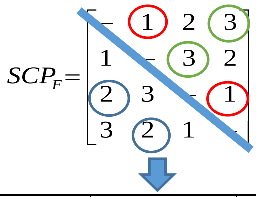


Figure 2: A home-away balanced assignment (white-color clothes) of the UMAR soccer scheduling problem

When the superior triangular matrix is used, the home team has preference to set the ordered pair (i, j), while a selection in the inferior triangular matrix obtains a pair (j, i) giving preference to the foreign team. This assignation is used in the UMAR soccer contest to design the white (host) and color (foreign) clothes that teams must wear in each week, exchanging the selection between both triangular matrixes for each value k. For example, schedule of Figure 2-*a*) is shown in Figure 3.



k=1		k=2		k=3	
Home	Away	Home	Away	Home	Away
1	2	3	1	1	4
3	4	4	2	2	3

Figure 3: A fair home-visitor assignment for the UMAR soccer scheduling problem

Stages 1 and 2 are used as a partial solution, needed to create the calendar schedule, in which an assignation of the day and the hour is made for all games. It defines the basis to establish a calendar for the event in next stage.

4.3. Stage 3. The time windows based calendar scheduling

The schedule assignment for this stage is based on the time tabling scheme defined in (D. Werra 1985), where a scheduling is defined like a time windows problem. The time tabling scheme is added to the mathematical formulation of the UMAR soccer scheduling problem with the t_{ih} time windows variables, joining all teams (N) of all categories in a tableau with a defined number of time windows $h=\sum_{m=1}^{|C|}\left\lfloor N_m/2 \right\rfloor$ where matches are scheduled.

Thus, the tableau is defined with the t_{ih} integer variables taken from the partial solution of the stages 1 and 2 (the SLP_C matrix where $x_{ijk}^{m}=1$) to set them in 1 at each time window h without overlapping a pair (i, j) in the week k. For instance, a tableau scheme defined for the matrixes of Figure 2 is shown in the time tabling scheme of the Table 3.

Table 3: The time tabling scheme for the UMAR soccer scheduling problem

C	*N*	Time Windows *h*				
		1	2	3	4	5
F	1	1	0	0	0	0
	2	1	0	0	0	0
	3	0	0	1	0	0
	4	0	0	1	0	0
V	1	0	1	0	0	0
	2	0	1	0	0	0
	3	0	0	0	1	0
	4	0	0	0	1	0
	5	0	0	0	0	1
	6	0	0	0	0	1
	7	0	0	0	0	0

The time tabling scheme of Table 3 involves the addition of constrains (6) and (7) to ensure that the time tabling satisfies feasibility conditions for the problem.

$$\sum_{i=1}^{n} x_{ijk}^{m} t_{ih} = 2 \qquad j=1, 2, \ldots, n;\ i \neq j;\ h=1, 2, \ldots, \frac{n}{2}; \quad k=1,2,\ldots,n-1;\ m = 1,2,\ldots,|C| \tag{6}$$

$$\sum_{j=1}^{n} x_{ijk}^{m} t_{ih} \leq 1 \qquad i=1, 2, \ldots, n;\ i \neq j;\ h=1,2,\ldots, \frac{n}{2}; \quad k=1,2,\ldots,n-1;\ m = 1,2,\ldots,|C| \tag{7}$$

Here, equation (6) ensures that an allocation in the time tabling scheme satisfy the round-robin assignment obtained in stages 1 and 2; while equation (7) permits an assignment of until one team for each row, allowing the zero value cases that corresponds to the team that is programmed against the fictitious team, where the parity for non-pair cases is adjusted. It reveals the dependence of this stage on the stages 1 and 2, because the time tabling allocation is executed offline with regard to the round robin system. For this reason, stage 3 is approached using a FIFO (First In, First Out) structure. This structure is processed in cyclic form according to the FIFO philosophy, making a designation for each game or pair (i, j) in the respective cell of the time tabling scheme (the t_{ih} and the t_{jh} cells). It means that a team that starts the championship being programmed in the first time window (h=1) will be play again in this time window before $\lfloor h/2 \rfloor$ weeks, following the related queuing process.

At the same time, a playing day for each match uses the time tabling scheme to divide the time windows h between the pd value, defining a proportional number of matches in each day (d_i, i=1,2,3,4,5,6,7 for each weekly day) and giving preference to the initial days of the week. When an assignation is done in a day and a time window, a playing itinerary $[st, et]_{d_i}$ is created, establishing the start time and the finish time for each game on the day d_i. So, the stage 3 ends with the weekly itineraries of the tournament and leaves to the stage 4 the last task of referee designation.

4.4. Stage 4. The referee designation

Referee designation uses the partial solution of stage 3 to identify the teams that were programmed in a determined day d_i or the team that is at rest every week when n_c is non-pair. The UMAR soccer meeting is designed so that all teams have an authority role as a formative part of discipline habits. For this reason, a referee is proposed by each team of a given category (usually the male category in the UMAR contest).

The referee selection is made in deterministic way following three rules: the first consists that a referee can not judge the match of his team; the second rule considers that a referee can be assigned on the day d when his team is scheduled; and the third rule establishes that if referees are not available in a determined day d, selection is performed through a frequency table with the accumulated number of arbitrations for all teams. In this case, the team with the least number of arbitrations must present a referee to preserve the fair play. So, this referee designation finishes the phases of automation of the planning (of phase 2) for the UMAR soccer tournament. The remaining phases are detailed in (Delgado 2019), where competition is organized with the use of a spreadsheet to store and register all statistics, executing a manual planning in 60 minutes in average each week. This spreadsheet was used in eight times and it will be used to demonstrate the viability of this proposal in terms of automation and optimization.

5. ARCHITECTURE OF SOLUTION

The solution of the UMAR soccer scheduling problem is performed following the architecture of the Figure 4 in a software application. This architecture starts with the definition of the input instances set (storaged in the file SCP_IN.txt). It contains all data of the teams registered in the contest, organized according to the semester school term when they were carried out, introducing the configuration parameters and sets described in this work.

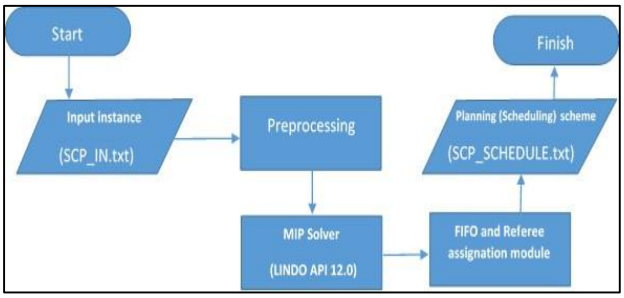


Figure 4: Architecture of solution

This data is read in the preprocessing module and loaded into a data structure, which transforms the information of the SCP_IN.txt file in an input set for the solver LINDO API 12.0 (LINDO API 2018). Once that the input set for LINDO API is generated, it is sent to LINDO API to get the optimal solution of the described round robin (stages 1 and 2). Then, the a dataset is returned with the first partial solution, which is taken by the FIFO Calendar and Referee designation module to generate the biannual planning itinerary, which is storaged in the SCP_SCHEDULE.txt file and presenting the scheduling as a planning.

5.1. The input instance set

The input instance set is formed by the SCP_IN.txt file, which is structured in the next section scheme that contains the input information of the problem:

Section header	Description
PROBLEM_TYPE	Defines the type of the problem, it can accept a 'SCP' or 'TSP' value.
CATEGORY_TEAMS	Defines the number of categories, groups of

	participating teams in the current contest.
N_TEAMS	Defines the number of teams for each category defined in the section "CATEGORY_TEAMS:", separated for whitespaces.
PLAYING_DAYS	Defines the number of days (*pd*) of the week set (*D*) when the games are scheduled in the format: (`d M Tu W Th Fr Sa Su`), establishing a 1 value if a determined day is used to schedule matches, zero in otherwise.
PLAYING_TIME	Defines the constant duration of each game.
START_SCHEDULE	Defines the start schedule (*ss*) time for all days of the week.
REFEREE	Defines the category that is used to the referee designation.
DESCRIPTION_ TEAMS	Includes a description of the teams, organized by category. It defines an *id_category* as header, followed by a second level header *id_team* and the *team_name* parameters.
EOF	An identifier of end of file to stop the reading procedure.

The mentioned input file is shown in Figure 5, and it can be opened using any text editor.

```
PROBLEM_TYPE: SCP
CATEGORY_TEAMS: 2
N_TEAMS: 5 8
PLAYING_DAYS: 2 0 0 1 1 0 0 0
PLAYING_TIME: 30
START_SCHEDULE: 1155
REFEREE: 2
DESCRIPTION_TEAMS:
1        FEMENIL
         1 MULATAS
         2 ENFERMERIA 425 B
         3 ENFERMERIA 225
         4 GALÁCTICAS
         5 LOBAS DEL DESIERTO
2        VARONIL
         1 LOS AVENGERS
         2 LOS PERRUCHAS
         3 PITUFOS 4: LA RESURRECCIÓN
         4 GALAXY
         5 GALÁCTICOS
         6 BIOLOGÍA
         7 LOS TREMENDOS
         8 WOLFS F.C.
EOF
```

Figure 5: The input file SCP_IN

This file contains all input parameters to define an input set required by the MIP (Mixed Integer Problem) Solver of LINDO API, which computes optimal solutions for the round robin of the stages 1 and 2.

5.2. The Preprocessing module: an intermediate representation of the problem

Math approach for the problem uses a support API (Application Programming Interface) of LINDO software (LINDO SYSTEMS 2018), an API designed to develop software applications on high-level programming languages, in which LINDO can be incorporated to compute linear and no linear models using exact methods.

To use the algorithms, an intermediate representation named "sparse matrix" is required. It is used by the API to compute through a MIP solver (included in LINDO API) as an integer solution as an integer problem. To exemplify the form of a sparse matrix is needed to set the general form of an integer programming model, which is defined as follows:

$$\text{Optimize } z = Cx$$
$$\text{Subject to}$$
$$Ax \{ \leq, =, \geq \} b$$
$$x \geq 0, \text{ integer}$$

Where z is the objective value (maximum or minimum), C is a cost-utility vector according to the objective function, x is the decision variables vector, A is the matrix of technological coefficients of the model, and b is the resources vector. In the preprocessing module, the sparse matrix representation is created and used to reduce the complexity of the matrix A through the omission of the zero values, defining a formatted input for the MIP solver.

The matrix A is commonly the main element of complexity in the expansion of an integer model because its dimension is defined by the number of variables (nN) and the number of constrains (nM). The omission of the zero values permits the reduction of the worst case for the matrix A since $O(n^2)$ until $O(ln)$ for a problem with size n, where l represents the number of elements of the matrix A with non-zero values (nNZ). For example in the next integer model:

$$\begin{aligned} &\text{Maximize } z = 20x_1 + 30x_2 \\ &\text{subject to} \\ &\quad x_1 + 2x_2 \leq 120 \\ &\quad x_1 \leq 160 \\ &\quad x_2 \leq 50 \\ &\quad x_1, x_2 \geq 0, \text{ integer} \end{aligned}$$

This model generates the next vectors and matrixes:

$$C = [20, 30] \qquad x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \qquad A = \begin{bmatrix} 1 & 2 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad b = \begin{bmatrix} 120 \\ 160 \\ 50 \end{bmatrix}$$

The sparse matrix uses a linear vector named *adA* in which all elements non zeros are copied for each column of the matrix A. This process is adapted to any input instance through the equations (8), (9) and (10) where n is the size of the problem for the category m.

$$nN = n^2 \tag{8}$$

$$nM = 2n + \frac{n(n-1)}{2} \tag{9}$$

$$nNZ = 2n^2 + n(n-1) \tag{10}$$

The obtained *adA* vector of the matrix *A* corresponds to

$$adA = [1,1,2,1]$$

The sparse matrix requires also of two auxiliary vectors *anRowX* and *anBegCol* that manages the memory using the references of row and column with regard to the matrix *A* and the vector *adA* respectively. Where *anRowX* references to the row of the matrix *A* for all the non-zero values, adding at the end the number of non-zeros (*nNZ* value). In the same way, the *anBegCol* references to the position element of the vector *adA* where a column of the matrix *A* starts. So, in the described example, a vector *adA* defined with an index scheme as follows:

adA	1	1	2	1
Position	1	2	3	4

It defines the *anRowX* and *anBegCol* vectors as follows:

$$anRowX = [1,2,1,3,4],\ anBegCol = [1,3]$$

The vectors *C* and *b* of the general integer problem are defined as *adC* and *adB*, following the nomenclature of variables defined by LINDO API, whole definition is taken from the example source code ex_lp1.java (Java is used like the high level language programming) to invoke the MIP solver. The solver returns a solution for the round robin of the stages 1 and 2, used by the FIFO and the Referee designation modules that implements the algorithms described in stages 3 and 4 to produce the biannual planning.

5.3. The planning scheme (Scheduling output)

Once that the scheduling is completed, results are written in a plain-text file named SCP_SCHEDULE.txt as the shown in Figure 6.

```
Input: SCP_IN_1314B.txt
Category     Week     Day     Match     Home     Away     StartSchedule  EndSchedule     Refe
-----------------------------------------------------------------------------------------------
FEMALE        1        1        1        1        5           1155          1185          3
MALE          1        1        2        1        2           1185          1215          4
MALE          1        1        3        3        4           1215          1245          1
FEMALE        1        2        1        2        3           1155          1185          6
MALE          1        2        2        5        6           1185          1215          5
MALE          1        2        3        7        8           1215          1245          1C
MALE          1        3        1        9        11          1155          1185          9
MALE          1        3        2        10       12          1185          1215          11
FEMALE        2        1        1        4        3           1155          1185          5
MALE          2        1        2        5        1           1185          1215          3
MALE          2        1        3        11       10          1215          1245          1
FEMALE        2        2        1        2        1           1155          1185          4
MALE          2        2        2        4        2           1185          1215          9
MALE          2        2        3        9        3           1215          1245          3
MALE          2        3        1        7        6           1155          1185          12
MALE          2        3        2        12       8           1185          1215          7
FEMALE        3        1        1        1        4           1155          1185          7
MALE          3        1        2        7        10          1185          1215          11
MALE          3        1        3        11       12          1215          1245          1
FEMALE        3        2        1        2        5           1155          1185          9
MALE          3        2        2        1        3           1185          1215          2
MALE          3        2        3        2        9           1215          1245          3
MALE          3        3        1        4        5           1155          1185          8
MALE          3        3        2        6        8           1185          1215          5
FEMALE        4        1        1        5        3           1155          1185          6
```

Figure 6: An overview of the SCP_SCHEDULE.txt.

This file contains all details of the scheduling, including category, week, day, match, host team, foreign team, start and end schedules and the referee team in each game, finishing the planning and providing to the organizing committee a biannual calendar that can be broadcasted before the championship starts.

6. EXPERIMENTS AND RESULTS

The proposed approached was tested using the historic databases of the contests, which include a set of eight instances of competition calendars between 2013 and 2018, according to the semiannual scholar calendar. The solver was developed in Java 8 using the Integrated Development Environment (IDE) Eclipse Photon (version 4.8), with the support of LINDO API 12.0. Tests were executed in a MacBook pro computer A1708 model, with eight gigabytes in RAM memory under the operative system Mac OS X High Sierra. The proposal was tested in stages according to the definition of the problem. For this reason, the first test focused on the computation of optimal values for the round-robin (stages 1 and 2), giving the results of Table 4.

Table 4: Solution of the round-robin (stages 1 and 2) of inputs instances of the UMAR soccer championship.

Instance	*pd*	*C*	Size (N_C)	Computation time (Milliseconds)	Optimal solution
2013-2014B	3	*F*	5	78	6.0*
		V	12	328	12.0
2013-2014V	3	*F*	6	46	6.0
		V	8	124	8.0
2014-2015A	3	*F*	3	16	4.0*
		V	11	266	12.0
2014-2015B	4	*F*	5	31	6.0*
		V	12	298	12.0
2017-2018A	4	*F*	6	46	6.0
		V	11	358	12.0*
2017-2018B	4	*F*	8	78	8.0
		V	14	421	14.0
2018-2019A	4	*F*	8	63	8.0
		V	14	422	14.0
2018-2019B	3	*F*	8	78	8.0
		V	10	248	10.0

* Instances where parity adjustment is applied.

Results of Table 4 reveals the fast time in when an optimal solution is computed (248 milliseconds in average), giving place to the second test, which consists of verifying the balanced home-visitor assignment. To validate this module, the second test was performed only with the most recent instances named 2018-2019A and 2018-2019B (and two of the biggest instances in the test dataset). Results of this test are shown in Tables 5 and 6.

Table 5: Results of fair assignation of the UMAR soccer competition (stage 2), case 2018-2019A.

C	N	Home (White dress)	Away (Color dress)
F	1	4	3
	2	4	3
	3	3	4
	4	3	4
	5	3	4
	6	4	3
	7	4	3
	8	3	4
M	1	7	6
	2	6	7
	3	6	7
	4	7	6
	5	7	6
	6	6	7
	7	7	6
	8	6	7
	9	6	7
	10	6	7
	11	7	6
	12	7	6
	13	6	7
	14	7	6

Table 6: Results of the fair assignation of the UMAR soccer competition (stage 2), case 2018-2019B.

C	N	Home (White dress)	Away (Color dress)
F	1	4	3
	2	4	3
	3	3	4
	4	3	4
	5	3	4
	6	4	3
	7	4	3
	8	3	4
M	1	5	4
	2	4	5
	3	5	4
	4	5	4
	5	4	5
	6	4	5
	7	4	5
	8	5	4
	9	5	4
	10	4	5

Tables 5 and 6 show a balanced assignation in which the teams faces their matches approximately the 50% both local and visitor places, obtaining with this a fair assignation for the white and color clothes in the UMAR soccer tournament. The last test consists of the evaluation of the assignation for the stage 3, taking the accumulative frequencies in all the t_{ih} time windows over the instances 2018-2018A and 2018-2019B, results that are displayed in Tables 7 and 8.

Table 7: Allocation tests in the time tabling scheme (stage 3) for the UMAR soccer contest (2018-2019A).

C	N	Schedule										
		d_1				d_2				d_3		
		h_1	h_2	h_3	h_4	h_5	h_6	h_7	h_8	h_9	h_{10}	h_{11}
F	1	2	2	0	0	2	0	0	0	1	0	0
	2	0	2	0	0	3	0	0	0	2	0	0
	3	4	1	0	0	0	0	0	0	2	0	0
	4	0	2	0	0	4	0	0	0	1	0	0
	5	4	0	0	0	2	0	0	0	1	0	0
	6	0	1	0	0	3	0	0	0	3	0	0
	7	2	4	0	0	0	0	0	0	1	0	0
	8	2	2	0	0	0	0	0	0	3	0	0
M	1	0	0	2	2	0	2	2	2	0	1	2
	2	0	0	1	2	0	2	2	2	0	2	2
	3	0	0	2	0	0	2	3	3	0	1	2
	4	0	0	1	3	0	0	2	1	0	4	2
	5	0	0	0	1	0	1	1	3	0	2	5
	6	0	0	2	2	0	2	3	2	0	2	0
	7	0	0	3	3	0	0	3	1	0	2	1
	8	0	0	1	3	0	1	2	1	0	3	2
	9	0	0	2	3	0	1	0	4	0	3	0
	10	0	0	2	3	0	4	0	2	0	0	2
	11	0	0	2	0	0	4	0	3	0	1	3
	12	0	0	2	1	0	2	4	0	0	3	1
	13	0	0	4	1	0	3	3	1	0	0	1
	14	0	0	2	2	0	2	1	1	0	2	3

Table 8: Allocation tests in the time tabling scheme (stage 3) for the UMAR soccer contest (2018-2019B).

C	N	Schedule								
		d_1					d_2			
		h_1	h_2	h_3	h_4	h_5	h_6	h_7	h_8	h_9
F	1	2	2	0	0	0	2	1	0	0
	2	0	3	0	0	0	1	3	0	0
	3	4	0	0	0	0	2	1	0	0
	4	0	2	0	0	0	4	1	0	0
	5	4	0	0	0	0	2	1	0	0
	6	0	1	0	0	0	3	3	0	0
	7	2	4	0	0	0	0	1	0	0
	8	2	2	0	0	0	0	3	0	0
V	1	0	0	2	2	2	0	0	2	1
	2	0	0	2	1	2	0	0	2	2
	3	0	0	1	1	1	0	0	2	4
	4	0	0	2	3	1	0	0	2	1
	5	0	0	4	1	2	0	0	0	2
	6	0	0	0	1	4	0	0	2	2
	7	0	0	3	1	3	0	0	1	1
	8	0	0	2	1	0	0	0	4	2
	9	0	0	2	5	0	0	0	0	2
	10	0	0	0	2	3	0	0	3	1

Tables 7 and 8 reveal that there are some time windows that are left without assignations by the FIFO approach, overloading in contrast other time windows with a greater number of assignations. It reveals that a load balancing should be applied in this part of the solver so that a fair allocation of time windows prevails. However, it is acceptable in terms of computation time, since a justice schedule that includes day and hour to satisfy all team demands, increased the manual computation time reported in (Delgado, 2019) from 40 to 60 minutes in average each week. Reason why a load balancing is a good alternative

7. DISCUSSION

Even when it is possible to compute a solution for the UMAR Soccer Scheduling Problem in a reasonable time using LINDO API and Java, the application has a dimensionality limitation related with the construction of the model. Reason why, the maximum size allowed to compute solutions without the parity condition is 15. This is a consequence of the constrained license of the LINDO API software, which supports until 300 continue variables, 30 integer variables and 150 constrains according to the website of LINDO API (LINDO SYSTEMS, 2019). This fact limits the maximum size of the round robin of the stages 1 and 2, which with a size of 16 (teams) reaches 256 variables (*nN* parameter) and 152 constrains (*nM* value), being this the reason why the maximum size that the application computes optimal solutions without the condition of parity adjustment is 15.

However, this value and the restrictions of feasible subtours of equations (2), (3) and (4), lead the solution to infeasibility with regard to the objective function. It occurs because in non-pair cases, the objective value $z \to \infty$ as a consequence of the Markovian decision process described in equation (5), which represents a barrier to the objective of minimization. This is the reason why in literature only pair cases are boarded.

This situation was corrected with the adjust of parity, but the due to the dimensionality limitation, the maximum size permitted under these conditions by the solver is 14, being enough until now to compute optimal solutions for the 100% of the available input instances for the problem. Tests of fair allocation in stage 2 prove a correct assignment with a balanced 50-50 percent of the white – color cloth selection, which reveals that this module of the application is also feasible and optimal to be implanted. On the other hand, allocationsal in stage 3 over the t_{ik} time windows obtains a coverage of 79% in the male category (according Tables 7 and 8), while in the male category reaches a coverage of 87% and 88% respectively. It reveals an opportunity line to improve this percentages, complemented with the load balancing procedure to be implemented. With these suggestions, the coverage will increase towards the expected 100% (all teams are allocated in all time windows), getting a balanced distribution for the tabling scheme.

Although there were limitations with the number of variables and constrains, the approach shows an efficient time of calculus solving the set of eight instances in a total time of 2.9 seconds. In the same way as in each particular instance, the average time is reduced from 60 to 0.0041 minutes, saving the 99.9% of computation time with regard of the manual solution and prove a good performance as the related works.

8. CONCLUSIONS AND FUTURE WORKS

This work focused in a proposal of automation based on mathematical model and a solver developed like a software application to support the planning process as a part of organization process of an institutional sport event, focused on two main objectives: automation and optimization in the manual way in which the soccer competition is carried out.

The planning process was defined as a problem that was approached through integer programming and the data structures required to develop the software application, giving an optimized semiannual planning proposal before the tournament starts. Even though, schedule could be subject to last minute changes due to administrative reasons external to the formulation, leaving the decision of changes in this propose to the organizing committee.

Another advantage of the proposed methodology consists of the introduction of the explicit parallelism, which can be observed in schedules for many days. It can be expanded by the addition of other parallelism conditions like many stadiums (more physical installations). This notion of parallelism will make the proposal adaptable to other leagues.

Feasibility and optimality for the methodology were proved. However, the restricted license of the optimization software represents a difficult to expand the problem towards these environments. Reason why the use of other optimization software as CPLEX, AMPL or GAMS can be used to compare with LINDO API. Or in case of not having an unrestricted license, problems greater of size 15 (teams) can be approached using heuristic approaches to get more coverage, consider the possible expansion of the proposed approach towards a professional league.

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SOLUTION OF A PURCHASING SCHEDULING PROBLEM WITH CONSTRAINED FUNDS THROUGH A GENETIC ALGORITHM BASED ON THE PARETIAN APPROACH

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ABSTRACT

This work presents the Genetic Algorithm (GA) as solver for the Purcharsing Scheduling Problem (PSP) to probe the most efficient solvers, according to the common solution building topologies: route construction and grouping. In this way, the proposed GA of this work approaches in a simple GA (P-SGA) and a grouping GA (P-GGA), two versions of GA that approach multiobjective optimization based on the Pareto principle to satisfy two simultaneous objectives: maximization of satisfied demand and minimization of purchasing costs. Heuristic rules and representation schemes lead the two versions towards feasible solutions, which according to experimental results demonstrate that P-SGA obtains the 90% of effectiveness, while the P-GGA obtains 98%, higher values than the 86% obtained with the previous path build ant approaches. This approach reveals the best kind of solver that can be applied to PSP in terms of feasibility, optimality and reliability to be implanted in purchasing planning systems.

Keywords: Purchasing Scheduling Problem, Multi Objective Optimization, Simple Genetic Algorithm, Grouping Genetic Algorithm.

1. INTRODUCTION

The purchase and marketing of goods is an essential activity for many producers and commercial companies. This process consists of check availability, distribution and occupied space of items in physical facilities according to stocks, reorder levels and the market conditions subject to demands of customers to make the decision to supply items periodically in the inventory. For this reason, decision to buy requires an optimal use of the economic resources, needed to increase utilities of business. In this way, the Purchasing Scheduling Problem (PSP) introduces an approach to automate a purchasing planning when the described conditions are variable. PSP, is defined in (Delgado 2014) as a bi-objective graph-based problem that solves the maximization of demand satisfaction and the minimization of purchasing costs. The problem is solved in a first approach through an ant colony system (ACS) algorithm, which permits to build feasible solutions for the problem. Even with the proposal defined, the need to improve solutions and the multiobjective nature bring a second version in Delgado (2015), which performs a Paretian approach over the ant colony optimization algorithm, improving the basic design of the ACS and proving the bi-objective feasibility with a classical path building algorithm. However, optimal solutions of PSP according to opportunity areas to explore in the solution space (observed in Delgado 2015), define a new need to improve the heuristic PSP solvers, which are able to incorporate grouping algorithms in the search of best solutions.

Additionally, an industrial PSP formulation carries out additional constrains such as penalties to influence a schedule with a subset of desired elements, according to quality factors in cases where preferences are a decision factor (Baker 1987; Booker 1982), critical supply times in public management scenarios (Cámara de Diputados del H. Congreso de la Union 2011), negotiations in economical lots of orders (Gen 1997), categorization of products to be purchased (Fisher 1997), and availability of physical spaces at warehouse facilities (De Jong 1975) when stock must be supplied. For these reasons as a constrains, an appropriated selection goods to be supplied in the inventory becomes in a complex task, where a suitable scheduling can determines the efficiency of a purchasing plan, which is desirable to optimize economical resources in the companies according to the supply chain.

2. THE PURCHASING SCHEDULING PROBLEM

The Purchasing Scheduling Problem (PSP) is defined from an industrial inventory database, in which a catalog of products is defined. This catalog can be approached in terms of a weighted graph $G=(V,E)$, where $V=\{P\cup S\}$ consists of a set of *n* products (*P*) and *m* suppliers (*S*). The set $E=P\times S$ is formed by pairs (*p*, *s*), where $p\in P$ and $s\in S$. Each pair has a cost c_{ps} to purchase a product *p* from any *s* supplier. Formulation can be showed as a network flow design of Figure 1.

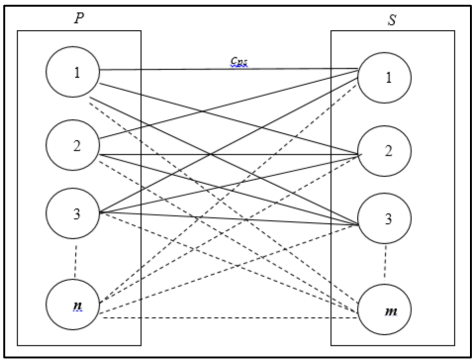

Figure 1: The graph-based PSP

The purchasing process is performed through orders $P_k \in P$ (or demands), where k represents an actor (purchaser) with a number n_k of products to be satisfied with an available fund a_k. In this form, the current description of PSP requires the optimization of two related objectives: maximization selected products for each order P_k and minimization of purchasing costs c_{ps} in an inventory cycle. Relation between objectives in a purchasing schedule focus the nature of this definition as a multi-objective problem, where the simultaneous satisfaction of the two objectives is needed, introducing for this calculus based on Pareto optimization.

3. THE PARETIAN APPROACH

Development of efficient algorithms for multivariate and multi-objective problems is a challenge, according with (De Jong 1985), because of the computation of optimal solutions for multi-objective problems represents an element of intractability when large-scale instances are solved. As a consequence, optimal solution of MOP is not possible to compute because MOP is represented by a set of objectives in conflict. For this reason, computation of solutions in a MOP consists of establish the set Pareto front $PS = \{s_1 , s_2 ,.., s_m\}$ with s_m solution vectors of the problem, where feasibility of solutions is given in terms of dominance and efficiency of Pareto.

Dominance is defined in bi-objective problems according to analysis of objectives in pairs. It establishes that objective $s_j \in PS$ dominates a vector $s_j' \in PS$ if and only if $s_j \leq s_j', \forall j \in \{1,..., p\}$, with at least one index j for which the inequality is strict (denoted by $s_j \prec s_j'$). Efficiency of Pareto defines a feasible solution s_j, for which there does is no other solution s_j' such as $z(s_j) \prec z(s_j')$. It implies that s_j is a non-dominated solution (or Pareto optimal). PSP implies the solution of two objectives based on warehouse operations, in which these represent opposite decisions. It defines a multi-objective scene of PSP in terms of a graph-based problem, needed to compute efficient solutions for the related MOP in PSP.

Exists in optimization some problems based on routes construction as a solution approach, which are defined in terms of network flow such as transportation, assignation, the traveling salesman problem and the vehicle routing problem for instance. These problems follows the architecture of Figure 1, used to solve PSP in (Delgado 2014, Delgado 2015) with ant colony approaches. Both approaches were used because of literature reveals the best results in many problems with this configuration.

However, results of ant approaches still have a bias with regard to the optimal values (or the best solutions), establishing the next hypothesis: “path build approaches are not the most viable to solve PSP”. Reason why, it is developed in this work a solver based on a clustering approach, in which the genetic algorithm is often the best alternative to solve this type of problems. Development of solvers often starts with a problem formulation, which directs the stages of their construction in terms of optimization.

4. MATHEMATICAL FORMULATION OF PSP

PSP is presented in mathematical approach according the next data elements:

P	is the set of products in an inventory catalog with n products.
O_k	is the set of products to be purchased in an order k with n_k products, where $P_k \in P$.
S	is the set of suppliers in the product catalog with m suppliers.
k	is the number of orders in each inventory cycle. $k = 1,2,\ldots, s$.
c_{ij}	is the cost to purchase a product i from a supplier j.
a_k	represents the available funds for each order k.
x_{ijk}	is an binary variable, equal to one if a product i is assigned to the supplier j in the order k, zero in otherwise.

Objectives of PSP are defined through of normalized objective values in the domain [0,1] according to the utility principle proposed for MOP proposed in (De Kok 1997; Eshelman 1991; Falkenauer 1996; Garey 1969). It is established in expression (1), which follows a decomposition strategy, where MOP is solved in terms of a global objective, presented in equation (1).

$$\text{maximize } z = \sum_{i=1}^{n} \frac{f_i(x)}{n} \quad (1)$$

For this reason, objectives must be normalized and transformed according to the global objective (it is needed only if some objective f_i may represent a minimization objective function). The current description of PSP defines two objectives: the first objective represents the maximization of satisfied demands (f_1) in terms of the uniform assignation of each item, while the second objective (f_2) represents the minimization of costs expressed also uniformly with regard to the total costs of purchase orders. Objectives of PSP are presented in equations (2) and (3).

$$\max\ f_1 = \frac{1}{\sum_{k=1}^{s} n_k} \sum_{k=1}^{s}\sum_{i=1}^{n_k}\sum_{j=1}^{m} x_{ijk} \tag{2}$$

$$\min\ f_2 = 1 - \frac{1}{\sum_{i=1}^{n_k}\sum_{j=1}^{m} c_{ij}} \sum_{k=1}^{s}\sum_{i=1}^{n_k}\sum_{j=1}^{m} c_{ij}x_{ijk} \tag{3}$$

The f_1 and f_2 values of expressions (2) and (3) are normalized according to the features of orders in each inventory cycle. Due to normalization of f_i values follows the decomposition strategy, and with the assignation of products as a priority of PSP. Minimization of costs is focused in the same way, through the normalization of costs with regard to all funds required to satisfy the orders. This objective is changed to its negative equivalent according to (Dantzig, 1990), this minimization value is subtracted to the maximum value of the maximization objective (whole maximum value is 1) to define the conflictive objectives. The f_1 and f_2 coefficients define of equations (2) and (3) establish the domain of the *z* value, when the *z* value between 0 and 1, where 1 represents that an optimal solution of the problem is reached, given a lower bound of at least one product assigned. So, the multi-objective utility *z* value is optimal when all products have been assigned (f_1 is optimal and dominant objective and $f_1 \prec f_2$); otherwise, a zero-value indicates that f_2 is the dominant objective ($f_2 \prec f_1$). Constrain of available funds is presented in equation 4.

$$\sum_{j=1}^{m}\sum_{i=1}^{n_k} c_{ij}x_{ijk} \le a_k \qquad k = 1,2,...,s \tag{4}$$

As a result, the related formulation directs the construction of feasible solutions in the field of the multi-objective optimization. It is required to compute solutions using evolutionary algorithms in large-scale instances, being the genetic algorithm the object of study for this work.

5. THE GENETIC ALGORITHM

Genetic algorithm (GA) represents a good alternative when an iterative process is performed in an optimization problem. It was defined by Holland in (Holland 1975) according to the natural selection process defined by Charles Darwin, in which mathematical functions of gene recombination are able to produce new exemplars improved using a fitness indicator through the time.

Genetic algorithm has been used for solving problems in different scenarios, such as optimization (with money, time, efforts like objectives); machine learning based on the premise that the machine will be able to conduct decision-making using rules of specific domains; in economy in applications to simulate business strategies; in ecology to simulate several phenomena like evolutions of ecosystems; and in population studies for studying biological evolution through genetic information. All these applications are often solved with genetic algorithms, as solution space is defined as a large-scale problem with no exact approaches for obtaining optimal values.

5.1. The Genetic Algorithm

GA introduced by Holland is formed by three elemental stages: selection of individuals, crossover and mutation procedures. In a GA procedure, parents are initially chosen through elitism and then are used to create descendants following a reproduction process of GA called a crossover operator. When an individual is created, it inherits information from its parents and sometimes, its information is modified by environmental biological factors in a procedure called mutation. Both crossover and mutation are GA operators that can generate best or worst individuals, which are then evaluated in the natural selection process to determine the fittest descendants for next generation. The detailed GA scheme is shown in Figure 2.

```
1   Procedure  GA( )
2      t = 0
3      initialize(Pop(t))
4      evaluate(Pop(t))
5      While (stop condition is not reached)
6            selection (Pop(t + 1), Pop(t))
7            crossover (Pop(t + 1))
8            mutation (Pop(t + 1))
9            t = t + 1
10     End_of_while
11  End_Procedure
```

Figure 2: The General Genetic Algorithm

The GA algorithm starts with the construction of an initial population, in which, GA is performed to create a population *Pop* of size *n*. It occurs when $t = 0$ and this population is created in line 2 and 3. Initial population is completed when the fitness for all individuals is computed, giving place to the iterative process of lines 5-11, in which GA computes a determined number *t* of offspring generations or iterations (stop condition) for a combinatorial problem.

The GA procedure continues through the increment of the number of generation (or next *Pop* in line 6), performing the natural selection process in line 7 for next population *Pop*(t+1) to establish the selected descendent individuals in current population *Pop*(t).

Selection process finishes when the two best individuals (parents) are selected according to the fitness (objective) value. Once that the selected individuals are selected, line 7 invokes the crossover process in which, the parents are recombined to generate two different descendants (children) using the crossover (one or two point) operators. The next step in the GA is called in line 8, where mutations is applied in the two descendants, modifying the genetic information of them. When the children have been muted and the generation counter is increased in line 9. Genetic information is used in each iteration to define parents and descendants, giving with place to the representation scheme for PSP. According to (Coello 2007) a good design for GA increases the probability to compute optimal solutions. It is based on a representation scheme used by GA to build feasible solutions according to the characteristics of the problem.

5.2. Representation schemes of GA

The most common representation scheme of GA (Holland 1974) consists of a binary string, which is formed by chromosomes, and they represent genetic information as is done in the biological sciences. In this string each position is named “gene” and the value inside the position is named “allele”. These elements are represented in Figure 3.

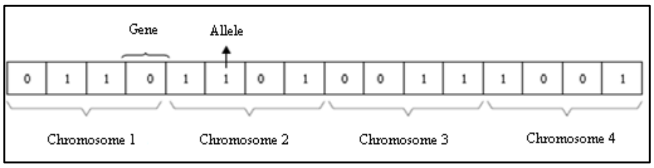

Figure 3: Binary representation of simple GA

This scheme is used to represent single values for a GA through chromosomes, for example, string represents the numbers 6539, in example and also numbers like 1234, 2564, 4687. In binary representations, chromosomes can represent integer values in the order of 2^k, where k is the amount of binary data stored.

Research about GA suggest grouping schemes to make it adaptive for solving aggrupation problems, for example, in (Falkenauer 1992) a group-based scheme defined to solve problems like bin packing, workshop layouting and graph coloring. These problems consist of partitioning a set U of items in a collection of disjoint subsets U_i of U, given $\cup U_i = U$ ∪ $U_i = U$ and $U_i \cap U_j = \varnothing$. The group-based encoding scheme designed by Falkenauer is applied to the bin packing problem in which a gene represents an item to be assigned in a container (group). Here is used a chromosomes string to represent groups, for example, ADBCEB in which the first item is in the group A, the second in the group D, third B, fourth in C, fifth in E and sixth in the group B.

Both schemes (binary and grouping) described are used to set the chromosome strings for PSP. In the binary scheme, a chromosomes string is extended, setting its size as a linear multiplication of n products (P) per m suppliers (S), where each chromosome represents a product, genes are used to represent a reference from the current product (chromosome) with a supplier, and each allele contains a binary value that defines a relation between the sets P and S.

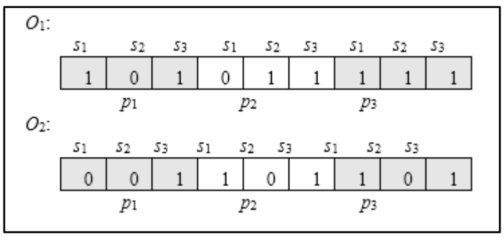

Figure 4: Binary scheme of representation for two orders for the P-SGA algorithm

Figure 4 for example, shows a string with three chromosomes (an order with three products: $p_1, p_2, p_3 \in P$ and three suppliers $s_1, s_2, s_3 \in S$). An allele with value 1 defines a valid relationship product-supplier, while a zero value represents a relationship no valid (there is not exist in the product catalogue).

With this representation scheme and the rules to compute feasible solutions the Pareto Simple Genetic Algorithm is proposed in this work as P-SGA to generate a structured purchasing planning. PSP has been initially solved in (Delgado 2014, Delgado 2015) with ant colony algorithms that are able to compute good solutions in problems where representation is based the scheme of Figure 4 and the solution strategy is based on path building algorithms as the ant colony optimization.

GA in the same way is able to compute good solutions for route-based problems using the binary and real schemes, but it is demonstrated that is not the most desirable in grouping problems; in contrast with the group based schemes where many authors in related works have supported their experiences as an efficient solver. For this reason, the proposed GA is developed to probe the most appropriate solver of PSP, exploring a clustering approach to solve the problem.

For this reason, the grouping scheme of Figure 5, is designed to compute alternative solutions for PSP, giving as a clustering unit a product (or chromosome with variable size as groups), using the genes as a reference to the suppliers and the allele as the referred suppliers (through an IdSupplier field).

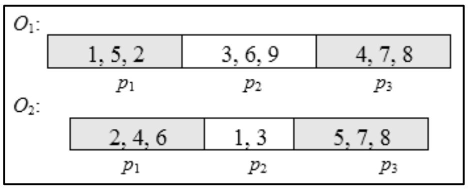

Figure 5: Binary scheme of representation for two orders for the P-GGA algorithm

For example, in order 1 (O_1) product 1 is purchased to the suppliers 1, 2 and 5; product 2 is bought to providers 3, 6 and 9, while product 3 is ordered to suppliers 4, 7 and 8. This scheme introduces the second variant of GA named Pareto Grouping Genetic Algorithm (P-GGA). According to (Coello 2004), a genetic algorithm requires appropriated representation schemes, which give to the GA the adaptive characteristic to solve efficiently a determined problem.

5.3. The GA selection operator

A fundamental point in GA is the selection operator. It indicates the form in which individuals are reproduced. For this reason, some parameters are used to choose those individuals that will make up the next generation; some approaches uses deterministic rules (often named tournament process) proposed in (Miller 1995), where individuals with better aptitude are those selected to generate the descendants in the next generation, this selection is performed in all individuals of the population; even though, in some approaches this selection is performed as a roulette (De Jong 1975) where the less fit individuals have also a certain probability of surviving. Deterministic and non-deterministic rules have been combined by other authors like (Mitchel 1992), obtaining hybrid selection operators that use a tournament selection, adding also a stochastic rule where population is shuffled *p* times, selecting *n* parents (where *n* is the size of population). This algorithm is similar to the deterministic approach, except at the stage where the winner is chosen, as it is selected through a boolean function *flip*(*p*). If *flip*(*p*) returns true, then individual with the highest fit is selected, otherwise the less fit individual is selected. Selection operators are widely boarded in literature according to the rules of natural selection proposed by Charles Darwin, which techniques represent the basis to select the parents that are reproduced to form the next generation.

5.4. The GA crossover operator

Reproduction in biological systems occurs when pairs of strings with genetic information are aligned. Information of chains is fractioned in shared parts, which are combined to form new individuals. Computational focus is quite similar; here linear segments of fixed-length strings are exchanged. GA usually uses three basic types of crossover strategies: one and two point crossover and uniform crossover. They were reported by (De Jong 1985). Both operators use a position value in the parents' strings, exchanging genes of the parent chains on the right and left side of this position to generate new individuals, an example of this process is shown in Figure 6.

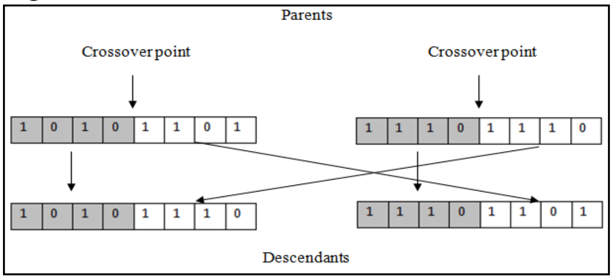

Figure 6: The one point crossover operator

Two point crossover implements the same strategy as the one point crossover, here the algorithm uses *n* cutting points for strings over a pattern (*n*=2), which are computed in terms of the GA parameter p_c, a percentage to define the application crossover operators. This value, according to (Ackley 1987), minimizes the destructive effects of crossover operator such as that used frequently (review of Figure 7).

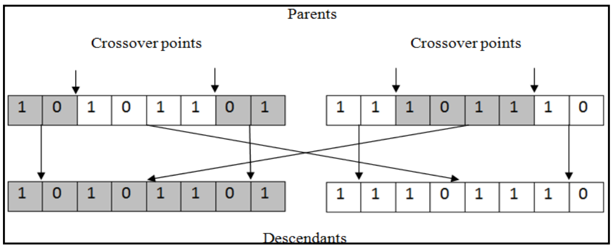

Figure 7: The two point crossover operator

The uniform crossover approached in (Syswerda 1989) is applied to the chromosomes of two parents according to a coin toss rule, made to decide whether a determined gene from a chromosome is added or not in the offspring. For example, Figure 8 shows a typical uniform operator.

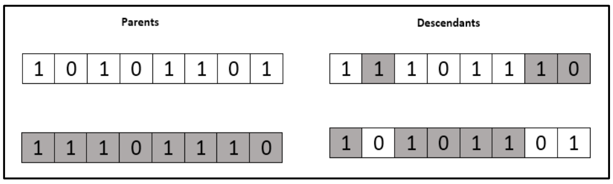

Figure 8: The uniform crossover operator

These crossover operators are commonly used in simple GA to define more genetic material in the offspring. However, this gene recombination often produces unfeasible solutions when GA is executed, where validation of these solutions is problematic and involves a repair strategy or penalty functions over the operators.
In the same way, a grouping scheme shows a similar behavior. For example, a two point crossover gives the next operations for five different groups (A, B, C, D and E), given the next two parents:
Parent 1: A|BC|DEF and Parent 2: C|FD|AEB
Here the two point crossover shows an example of redundancy, operator is able to obtain two children: the strings AFDDEF and CBCAEB, where groups are repeated.
This situation is also replicated in contained objects in each group. Falkenauer observes in this scheme a degree of redundancy with an exponential growth according to the number of groups or the size of the problem, giving the size of the space in GA covered in an impaired relation (item, container) of objects.
In spite of the redundant characteristics of this scheme, it is favorable to introduce additional heuristics in the crossover operator, such as the first fit (FFD) and the best fit decreasing (BFD), used in grouping problems in cases of unfeasibility, where products that are unable to assign are released to later seek an accommodation through the FFD and BFD techniques. Once neighbor solutions have been generated, step three consists of evaluating the neighbor solutions and selecting the best following their fitness value.
A direct reference towards about the use for this operator is presented in (Coello 2004) where is suggested that researchers define random search as the unique that does not present biases and it has been determined to be effective for heuristic searches. For this reason, authors recommend using distributional or positional biases.
Distributional bias refers to the number of transmitted symbols during a recombination of strings; it considers that a subset of information has a major tendency to occur rather than another. For example, a crossover with *n* points where *n*>2 has a moderated distributional bias, while uniform crossover has high bias (Eshelman 1991).
Positional bias is characterized by a value of probability, which indicates that a subset of chromosomes is recombined according to relative positions of cutting for

parents, and it becomes the reason why the two point crossover has a strong positional bias.

5.5. The mutation operator

Mutation consists of random selection of genes, modifying its allele values, which are randomly selected using a parameter p_m, which defines for example disturbances, insertions and reallocations in arbitrary positions of the chain genes according to the selected strategy. Mutation operator is often classified as a secondary operator of GA. Even though several studies suggest that it is a basic operator as the crossover. The use of this operator is recommended with low values according to a mutation percentage, a constructive parameter usually established between 0.001 and 0.01 in binary schemes. The most common mutation operators boarded in literature are: insertion (Offutt 1996), displacement (Yamamura 1999) and heuristic random exchange (Cheng 1997) of genes to explore a neighborhood in the search of candidate solutions, often used in simple GA.

6. ARCHITECTURE OF SOLUTION

The proposed approach follows the architecture of Figure 8, in which the constructive process of purchasing schedules of PSP is described. Architecture consists of two modules: Preprocessing and Optimization.

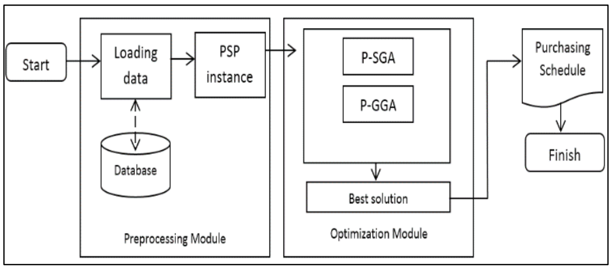

Figure 8: Architecture of solution

Preprocessing module of Figure 8 is used to extract information of the PSP input sets from a model database described in (Coronel 2014). This action generates a PSP input instance which consists of a plain-text file, used to establish the solver independent to the database. It permits the use of the architecture to solve the problem with the GA algorithms in the optimization module to generate the best solutions, presented as purchasing schedules. The orders are initially loaded from the product catalogue to transform it in a valid PSP input instance set, needed to compute a solution.

6.1. The input PSP instances set

An input model design was created to represent available information through the data structures needed to solve the problem. This design pattern is able to construct feasible solutions for PSP. The model scheme is shown in Figure 9. The first data group is formed by the Products entity, which is related with the Suppliers and Category entities. This relationship is given as follows: a product belongs to a category and can have several suppliers. The next part of the scheme is formed by the entities Purchaser, Funds and Orders, being this entity the most important to manage the data in the GA

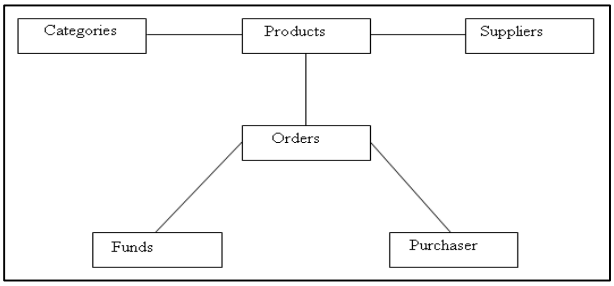

Figure 9: Input data structures of the preprocessing stage

Relation between entities is defined as follows: a purchaser can create several orders, and each order has a fund assigned. An order in the same way can have many products. Entities Products and Orders are used to provide the information of costs of products, and information of purchasers and funds. Once that information about orders is loaded from the inventory database in the architecture, related data are downloaded in two files, which are needed to store the information of classes defined in Figure 9. This information is loaded from a PSP instance that consists of two files: the ArchDescrip1 and ArchEntrada files where information about orders is detailed. The ArchDescrip1 file (described in Table 1) contains the metadata of the orders in a text-plain file structured by two sections as follows:

Table 1: Input data description of the ArchivDescrip file

Section header	Description
PROBLEM_ NAME	Section that establishes the name of the instance
INFO_ PRODUCTS	Section that contains a detailed rows of the product catalogue: [IdOrder * IdPurchaser * IdProduct *ProductName * IdSupplier * SupplierName] where * is a field delimiter.

An example of this file is shown in Figure 10, where the text-plain file described contains all historical orders (organized through the IdOrder field) where orders are organized in the inventory database for a current purchaser (identified by the IdPurchaser field).

```
PROBLEM_NAME: PURCHASING_SCHEDULING
INFO_PRODUCTS:
1 1     JACINTO PEREZ   1       DESK                    1       OFFICE DEPOT
1 1     JACINTO PEREZ   2       TABLET                  2       HUAWEI
1 1     JACINTO PEREZ   3       HDMI CABLE              3       MASTER COMPUTER
1 1     JACINTO PEREZ   4       AJAX IN J2SEE           4       PRENTICE HALL
1 1     JACINTO PEREZ   5       RAM MEMORY              5       KINGSTON
1 1     JACINTO PEREZ   6       USB MEMORY              5       KINGSTON
1 1     JACINTO PEREZ   7       PRINTER                 6       HEWLETT PACKARD
1 1     JACINTO PEREZ   8       KEYBOARD                7       MANHATTAN
1 1     JACINTO PEREZ   9       DVD WRITER              8       SAMSUNG
1 1     JACINTO PEREZ   10      DESKTOP COMPUTER        9       DELL
1 1     JACINTO PEREZ   11      LED LIGHTS              10      PHILLIPS
1 1     JACINTO PEREZ   12      OFFICE CHAIR            1       OFFICE DEPOT
2 1     JACINTO PEREZ   13      LADDER                  11      TRUPPER
2 1     JACINTO PEREZ   14      LAPTOP COMPUTER         12      APPLE
2 1     JACINTO PEREZ   15      NO BREAK                9       DELL
2 1     JACINTO PEREZ   16      LED PROJECTOR           13      LG
3 2     ELSA GALINDO    17      CHAIR                   1       OFFICE DEPOT
3 2     ELSA GALINDO    18      LAPTOP COMPUTER         9       DELL
3 2     ELSA GALINDO    19      SOLID STATE DISK        5       KINGSTON
```

Figure 10: The plain-text file ArchivDescrip

Information about the orders and the inventory cycles to perform the purchasing process is described in the file ArchEntrada (shown in Figure 11).

```
PROBLEM_NAME: PURCHASING_SCHEDULE
PRODUCTS_CATALOGUE:
1       4200.00         1       1       1       1
2       1000.00         2       1       4       1
3       25.00           3       1       2       1
4       8000.00         4       1       3       1
5       1500.00         5       1       10      1
6       899.00          6       1       7       2
7       6440.00         7       1       12      3
8       179.00          8       1       9       1
9       185.00          9       1       6       2
10      7100.00         10      1       8       1
11      500.00          11      1       5       3
12      1800.00         1       1       11      2

INFO_FUNDS:
1       1       25000

INFO_INV_CICLE:
1       1

ORDERS:
1
        1
                1       1
                2       1
                3       7
                4       1
                5       2
                6       2
                7       1
                8       4
                9       6
```

Figure 11: The input file ArchEntrada

Information of this file is detailed through the sections described in Table 2.

Table 2: Input data description of the ArchEntrada file

Section header	Description
PRODUCTS_ CATALOGUE	This section contains all data of products in the format: [IdProduct*UnitPrice*IdSupplier InventoryCycle*Priotity* IdCategory*]
INFO_FUNDS	Section that specifies the available funds, assigned to each purchaser with a format: [IdOrder * InventoryCycle * AvailableFunds]
INFO_INV _CYCLE	It is the section that specifies the current purchaser (person who performs a purchasing plan) with the format: [IdPurchaser * InventoryCycle]
ORDERS	A detailed view of the orders that shows the complete requirements in the current inventory cycle. The orders are described in the next format: [IdOrder * IdPurchaser* IdProduct * UnitsRequired*] where * is a field delimiter.

Once the described files have been generated according to the architecture, the next step consists of load the datasets in the needed data structures used by the PSP formulation to compute solutions for the problem, which are the input for the GA algorithms that solves the problem. It is performed in the optimization module that contains the two genetic algorithms described, whole the best solutions are a support in purchasing planning.

6.2. The purchasing plan (output shceme)

Once scheduling is finished, purchasing plans are presented to the purchaser who invokes the execution for the current algorithm, getting a report of solution in a printed form as a proposal with details about orders with the suggested amount of products to be purchased.

IdOrder	IdPuerchaser	IdProduct	IdSupplier	UnitPrice	RequiredUnits	SuggestedUnits	TotalCosts	AvailableFunds
1	1	1	1	4200	1	1	4200	
		2	2	1000	1	1	1000	
		3	3	25	7	4	100	
		4	4	8000	1	1	8000	
		5	5	1500	2	1	1500	
		6	6	899	2	1	899	
		7	7	6440	1	1	6440	
		8	8	179	4	2	358	
		9	9	185	6	1	185	
		10	10	7100	1	0	0	
		11	11	500	2	1	500	
		12	1	1800	1	1	1800	
----------	----------	----------	----------	----------	----------	----------	24982	25000

Figure 12: An example of purchasing plan

The report of Figure 12 is provided to the purchaser (or a purchasing manager) in a front-end application developed in Java to validate the desirable supply according to the goals defined in the inventory. As noted, planning in a purchasing department requires the processing of many operations to establish a purchasing plan that satisfies the proposed goals. This process usually involves many time resources, being also the reduction of these a goal of this work, being necessary the analysis of algorithms to establish the viability of the implantation of GA developed methods. For this reason, purchasing scheduling through the P-SGA and the P-GGA methods is observed in the test example of Table 3, it considers an order from a purchaser to be satisfied with an available fund of $50,000.

Table 3: An example of PSP solution

IdProduct	Amount	IdSupplier	UnitPrice
1	2	1	10000
		2	12000
		3	0*
2	2	1	18000
		2	15000
		3	20000
3	3	1	0*
		2	5000
		3	7000

* Product is not available for the current supplier.

In first place, the P-SGA algorithm supposes that two parents are selected according the context of Figure 13.

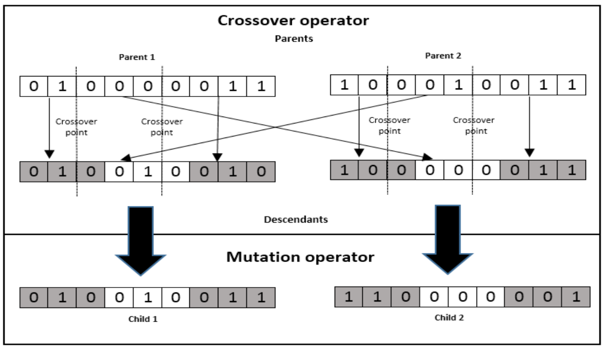

Figure 13: The P-SGA solver with a binary scheme

Then, a two point crossover is applied giving the descendant children. Once the descendants have been generated, a mutation is applied through the flip function applied over a random gene, in which its binary value of the allele is inverted. The proposed solution of the P-SGA obtains in child 1 a demand satisfaction f_1 =0.57 and a minimization cost coefficient of f_2 = 0.55, giving a z coefficient of 0.51 (51%). In the other hand, the P-GGA computes the solution of the Figure 14.

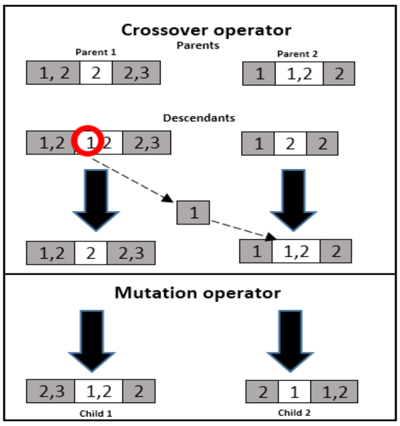

Figure 14: P-GGA solver with a group based scheme

P-GGA method uses also the two point crossover operator, obtaining an unfeasible solution in child 1 with a budget of $67,000. This assignation is released and reallocated in the second product of the child 2 using the BFD algorithm. Then, a displacement mutation operator is applied to generate the two children in which P-GGA obtains in child 1 the best solution using all available funds ($50,000), with a demand satisfaction f_1 = 0.71 and a minimization cost coefficient f_2 = 0.42, giving a z coefficient of 0.65 (65% with regard the optimal value). It supports the feasibility of the GA approaches.

7. EXPERIMENTS AND RESULTS

Due to real instances of unavailable PSP, a dataset of ten orders was built using a pseudo-random number generator. It uses the queries of web catalogs, stored in a database. The generator creates the orders with different prices and suppliers for products, maximum and minimum prices for products and available funds. Parameters of instances generator are shown in Table 4.

Table 4: Input parameters PSP instances

k	n_k	Min price	Max price	Available Funds
1	126	14.00	10999.00	25000.00
2	123	73.00	60000.00	50000.00
3	63	29.00	120000.00	40000.00
4	146	99.90	15980.00	65000.00
5	70	3.00	60000.00	30000.00
6	194	56.90	20000.00	80000.00
7	128	75.00	18799.00	75000.00
8	119	95.00	18000.00	55000.00
9	108	3.00	88996.00	48000.00
10	126	14.00	11499.00	40500.00

It supposes an inventory cycle with ten orders (purchasers), where products have costs more expensive than available funds. GA methods were developed in Java Standard Edition 9 with Eclipse IDE Foton; these algorithms use the constructive parameter defined by Holland of a population with 30 individuals. A tournament selection is performed for GA, in which the fittest individuals are chosen for next generation according to the fitness value based on the objective function of equation (1). Design of GA includes the one and two point crossover operators using a parameter p_c = 0.0005; and a mutation operator based on an insertion strategy, which uses a construction parameter p_m = 0.001. Tests in each execution register a cumulative sum ($\sum$ value) with the average number of times in which the values of best solutions are reached. It indicates a degree of exploration for each algorithm. Additionally, average time computation is measured (t) in which best solutions of ACS are reached, and the f_1 and f_2 average values for each instance. The performance for the developed AG algorithms (Table 5) is measured in the same way that the previous ant algorithms tested for PSP, therefore experiments consists of six tests with 30 executions with: 1000, 5000, 10000, 15000, 20000 and 30000 iterations for the P-SGA and P-GGA algorithms proposed.

Table 5: Performance tests of the PSP solvers

Itera-tions	Method	$\sum$	f_1	f_2	t	z
1000	ACS	22.31	0.843	0.102	895	0.87
	P-ACO[1]	16.45	0.864	0.081	667	0.89
	P-ACO[2]	28.72	0.880	0.084	1350	0.89
	P-SGA	22.26	0.843	0.027	585	0.90
	P-GGA	123	0.933	0.034	2989	0.94
5000	ACS	24.17	0.841	0.103	8753	0.86
	P-ACO[1]	12.29	0.851	0.096	5542	0.87
	P-ACO[2]	23.55	0.858	0.099	6922	0.88
	P-SGA	24.16	0.841	0.010	4753	0.91
	P-GGA	141	0.984	0.007	10699	0.98
10000	ACS	23.32	0.839	0.103	15831	0.86
	P-ACO[1]	18.73	0.821	0.123	8755	0.84
	P-ACO[2]	30.05	0.887	0.080	22533	0.90
	P-SGA	23.20	0.839	0.030	5830	0.90
	P-GGA	133	0.988	0.004	18160	0.99
15000	ACS	26.47	0.842	0.102	9840	0.86
	P-ACO[1]	17.55	0.880	0.079	5503	0.90
	P-ACO[2]	32.92	0.885	0.076	25073	0.87
	P-SGA	26.65	0.842	0.069	6840	0.88
	P-GGA	164	0.988	0.004	25435	0.99
20000	ACS	25.22	0.843	0.103	18963	0.87
	P-ACO[1]	17.34	0.889	0.075	13927	0.90
	P-ACO[2]	28.64	0.885	0.076	21569	0.90
	P-SGA	25.12	0.843	0.050	8963	0.89
	P-GGA	155	0.989	0.003	38007	0.99
30000	ACS	25.53	0.844	0.103	16732	0.87
	P-ACO[1]	22.73	0.877	0.089	29453	0.89
	P-ACO[2]	30.73	0.899	0.072	27955	0.91
	P-SGA	25.83	0.833	0.030	36059	0.90
	P-GGA	382	0.987	0.006	10732	0.98

8. DISCUSSION

Previous works report initial solutions of PSP through ant algorithms. The first approach developed in (Delgado 2014) computes feasible solutions with a *z* value of 0.86 (86%) in an average time of 10.9 seconds, under the design of a basic Ant Colony System (ACS). These results were improved in (Delgado 2015) until a *z* value of 0.9 (90%), where alternative versions of the Ant Colony Optimization (ACO) algorithm based on the Pareto approach are presented: the P-ACO[1] and P-ACO[2] methods. Having these values as a reference, the performance of the P-SGA and P-GGA can be compared against the path-build approaches of the ant algorithms.

Table 5 shows the performance of the P-SGA algorithm, using the same representation scheme that ant approaches, achieving the 90% of effectiveness in 10.5 seconds, which is similar to the results obtained by the ant algorithms. At the same time, it is shown a remarkable improvement of the P-GGA algorithm through the addition of the FFD and BFD strategies, which permits to the P-GGA method get the 0.98 (98%) in 17.7 seconds.

It concludes that FFD and BFD heuristics slightly increase computation time in P-GGA with regard to P-SGA in order to achieve the best solutions, in line with the PSP formulation, in which a general objective (*z* value) is looking for $f_1 \prec f_2$, giving a higher priority to satisfaction of demands, a typical rule in inventory systems.

Analysis of algorithms reveals that definition and solution of PSP is adjusted in best way to grouping problems, giving the future research towards this kind of solvers. However, the improvement is hard because of results of the P-GGA in the PSP test dataset can observe a small gap towards optimal values, which is caused by the nature of instances (values of remaining prices represents a barrier to get the 100%). Even though, improvement of P-GGA is statistically supported given the Pearson correlation coefficient of -0.99 in f_1 and f_2 values, which is better than the respective values of -0.21, -0.94, -0.96 and 0.26 of the ACS, P-ACO[1,] P-ACO[2] and P-SGA methods, obtaining evidence of a best solution in the front of Pareto and proving statistically that a clustering approach is the best option to solve the problem.

9. CONCLUSIONS AND FUTURE WORKS

This work presented a genetic algorithm to solve the Purchasing Scheduling Problem based on two different schemes of representation: a scheme with binary values, which is commonly used in literature to solve problems with solvers based on path building; and a real representation scheme, used in literature where the kind of problems to solve are related to clustering. Performance of the GA developed methods and the best results of the second approach (the P-GGA algorithm) probe that the best alternative to solve PSP is represented by grouping algorithms, in which experiments have demonstrated the supremacy of the grouping algorithms against the based-path solvers, giving the future research of PSP to reach an improvement through hybridization of the P-GGA and the addition of heuristics to achieve the set of Pareto optimal solutions for PSP.

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BUS FLEET SELECTION METHOD FOR PASSENGER PUBLIC TRANSPORTATION SERVICES

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ABSTRACT
The present paper addresses the problem of determining the bus fleet composition (size and mix) for a public passenger transportation service, where maximum revenue can be achieved, considering demand and passenger-km index as main operational restrictions. The proposed method relies on financial engineering to produce several cost inputs over time applying present value, used as main inputs for an integer programming model structured as an investment selection problem, to determine the optimal size and mix selection, applicable for two base scenarios, first assuming that any previous buses acquisition has been made, and second, assuming that some vehicles are in use and the decision is about supplementary acquisition of buses to fulfill a specific portion of the operational demand and expected service level.

Keywords: fleet size mix problem, public transportation, applied integer programming, decision support tools

1. INTRODUCTION

Public transportation in urban areas has gained greater attention in recent years due to ever-increasing of the world population (Saif, Zefreh and Torok 2019).
Public transportation systems may operate as a public service where the personnel, facilities, and equipment (trains, buses, etc.) belong to municipalities or federal government or as a public services operated by private companies, in some cases the private companies should provide the equipment and personnel required, then the period of concession to operate the systems is long enough to justify such investment, 10 years or more.
Concession contracts establish main operational requirements to guarantee an appropriate service level, and companies have to make decisions about the fleet that comply with these operational conditions but also may produce good economical results, examples of recent studies, which take into account the initial investment cost analysis can be consulted in (Wang, Li and Liu 2014) and (Lajunen 2014).
Companies require addressing two fleet-related decision problems: what types of vehicles to use and how many vehicles to use, this problem is commonly referred in the literature as fleet size and mix problem (FSM) or as fleet composition problem (FCP) (Baykasoğlu, et.al., 2019), both decisions have a direct impact on the service quality (level of service) and efficiency (capital and operational costs). (Fu and Ishkhanov 2004).
The present work seeks to illustrate the application of a method to decide which bus fleet (what type and how many buses are needed) is the best option for a company that needs to fulfill a specified passenger-km index with the aim to produce the highest revenue, considering initial investment and operational costs (maintenance, fuel, insurance, etc.), since decision periods for this decision is for medium or long term periods, the method proposes explicitly the updating of all the relevant costs using Net Present Value (NPV) and includes the Passenger Kilometer (PKM) as a measure of the expected utilization level of the fleet.
The paper is organized as follows, section 2 introduces and explains the main factors and relevant costs to be considered for the selection of bus fleet vehicles. Section 3, NPV analysis is introduced as a tool for producing valuable information for investment analysis. PKM index is introduced in section 4, as a main service level indicator for public transportation systems. Section 5 is included to provide a description of the capital budget problem, and how can be adapted to model the fleet size and mix problem. Finally, section 6, includes discussion of the proposed model characteristics and possible extensions.

2. MAIN FACTORS AND RELEVANT COSTS

Acquisition prices are very relevant in terms of the initial costs for a bus transportation system. The prices vary among vehicle sizes, types, and brands, and even each vehicle can be purchased through different financial plans.
However, since public transportation systems are usually operated at full capacity and under intensive schedules, fuel consumption and maintenance costs may become a major differentiating factor among brands and sizes.
Fuel is critical in terms of capital and operating costs in the transportation industry (Buxton, 1985). For instance, compressed natural gas has become a feasible alternative, because, despite that acquisition and maintenance costs, of vehicles using that technology, are higher, the reduction of fuel costs justifies its use due to

its financial and environmental benefits (Dyr, Misiurski, and Ziółkowska, 2019).
The abovementioned information is available directly from the vendors and also in some cases manuals and third-party companies (such as workshops) can provide good insights about fuel consumption or maintenance cost per kilometer in these cases.
Besides costs, projected sales or income is one relevant piece of information. For new public transportation systems or extensions of existent systems, is very normal to have data from technical studies that justify the decision based on figures of expected or potential population to be served, based on these figures and the expected service level, agreed in the contract for concession, it is possible to estimate the expected income per vehicle, this should be calculated like that to reflect the productivity of each vehicle, each type of vehicle may have different capacity (passengers and trip prices).
To illustrate how to produce relevant information from the listed data, some dummy tables are presented.

Table 1: Service characteristics

Factor	Value
Days of operation per month	X days
Days of operation per year	Y days
Daily cycles	n
Route distance	D km
Daily km traveled	(n x D) + extra km from depots to stations
Yearly km traveled	Y*(Daily km traveled)

3. NET PRESENT VALUE (NPV) ANALYSIS

The net present value method (also known as discounted cash flow method:

https://www.accountingformanagement.org/net-present-value-method/

This method is based on the concept of the equivalent value of all cash flows related to some base or starting point in time, called present. That is, all cash inflows and outflows are discounted at the present moment with an interest rate that is usually the minimum acceptable rate of return (r).

The NPV of an investment alternative is a measure of how much money an individual or company could devote to an investment, additional to its cost. Or, expressed in a different way, a positive NPV of an investment project is the number of utility dollars above the minimum amount that affects investors.
It is assumed that the cash generated by the alternative is available for other uses that have an interest at a rate equal to the rate of return.

Table 2: Financial results per vehicle (varies per type and brand)

Factor	All values in $
(A) Income from transportation services	Cost of trip per passenger * Annual passengers transported
(B) Income from advertising	Annual amount for ads displayed on/in the bus
(C) Initial payment for bus acquisition	Considered only at the beginning of the financing plan
(D) Annual payments due to financing	This amount may differ for a year, depending on the financing plan
(E) Fuel	Yearly km traveled x Fuel consumption ratio
(F) Tires	Number of tires installed on the bus x (Yearly km traveled / tire life span in km)
(G) Annual maintenance costs	This amount may increase over time due to mechanical detrition (direct effect of km traveled)
(H) Annual insurance costs	This amount may increase over time unless it is contracted for the entire fleet, then some scale economies can be achieved.
(I) Yearly financial result	I = (A+B) – (C+D+E+F+G+H)

The following formula is used to calculate NPV:

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+r)^t} \quad (1)$$

Where:

R_t = Net cash inflow-outflows during a single period t
r = Discount rate or return that could be earned in alternative investments

t = Number of periods (years)

Considering the financial results (Table 2) for three different brands of buses and three vehicle types (comparable among each vehicle category), it is possible to perform the NPV method for a time horizon T, to obtain the dummy Table 3, this table provides a summarized view of the financial and operational performance of each eligible option.

Table 3: VPN for a time period of T years

Type	Brand 1	Brand 2	Brand 3
Type 1	NPV_{11}	NPV_{12}	NPV_{13}
Type 2	NPV_{21}	NPV_{22}	NPV_{23}
Type 3	NPV_{31}	NPV_{32}	NPV_{33}

From a financial perspective, also is useful to know the initial capital availability and match this with the initial payment for the acquisition of the selected fleet, thus the following dummy table provides this information:

Table 4: Initial payment amount for bus acquisition

Type	Brand 1	Brand 2	Brand 3
Type 1	C_{11}	C_{12}	C_{13}
Type 2	C_{21}	C_{22}	C_{23}
Type 3	C_{31}	C_{32}	C_{33}

4. PASSENGER KILOMETER (PKM) INDEX

Passenger Kilometer (PKM) is a measure of passengers' mobility per kilometer in a public transportation system like bus rapid transit (BRT) or railways. It is calculated as follows:

$$PKM = TPC/TDC \quad (2)$$

Where:

TPC is Total Passengers Carried measured in terms of number of passengers and,

TDC is the Total Distance Covered measured in kilometers.

In our case, as previously mentioned, it is assumed that total route distance and the maximum cycles per day (see table 1) are provided.
Based on the above, the *PKM* for each type of vehicle can be calculated to produce the Table 5.

PKM_{11}= (bus capacity in the number of passengers for vehicle type 1 of brand 1 * cycles per day *% capacity in use) / (route distance*cycles per day)

Table 5: PKM for each vehicle type and brand

Type	Brand 1	Brand 2	Brand 3
Type 1	PKM_{11}	PKM_{12}	PKM_{13}
Type 2	PKM_{21}	PKM_{22}	PKM_{23}
Type 3	PKM_{31}	PKM_{32}	PKM_{33}

5. INVESTMENT SELECTION PROBLEM (OR CAPITAL BUDGET PROBLEM)

The capital budget problem (Hayes, 1984) often arises in a planning horizon of multiple time periods. The periods of time can be quarterly, semiannual or annual.

The multi-period problem can be described as follows:

A project manager has n projects that he would like to undertake, but not all of them can be selected due to the budget constraint in each period of time within a prescribed planning horizon.

Suppose the project y_j has a present value of c_j dollars and requires an investment of a_{tj} dollars in the period of time t (t = 1, ..., T). The capital available in the period of time t is b_t, dollars.
The objective of this problem is to maximize the total present value subject to the budget constraint in each period of time during a predetermined planning horizon T.

The problem can be modeled mathematically as follows:

Objective function

$$Maximize\ z = \sum_{j=1}^{n} c_j y_j \quad (3)$$

Subject to:

$$\sum_j^n a_{tj} y_j \leq b_t \quad \forall\ t = 1, 2, \ldots, T \quad (4)$$

$$y_j = boolean\ \{0, 1\} \quad (5)$$

$$j = integer\ \{1, 2, \ldots, n\} \quad (6)$$

5.1. Linear programming model to solve the company's fleet selection problem

Fleet expansion/reduction deals with the capacity growth and shrinkage of the available fleet size with respect to increase or decrease in transportation service demands, the company's growth rate and investment strategies.
For a comprehensive literature review of fleet planning problems, readers are referred to (Baykasoğlu, Subulan, Serdar Taşan and Dudaklı, 2019). However, it is worthy to mention, that models and approaches described by Baykasoğlu et. al., are focused on freight transportations exclusively, which reveals a gap in the literature about assisting these decisions for the passenger transportation domain.

In this paper, the model of investment selection is adapted to solve the FSM problem for a passenger transportation system, for illustrative purposes, in this section the proposed model considers that only 3 different brands are eligible, and each can provide 3 different types of vehicles.

5.2. Parameters and information

From Table 3:

NPV_{11} = net present value for a bus type 1 and brand 1

NPV_{12} = net present value for a bus type 1 and brand 2
.
.
.
NPV_{33} = net present value for a bus type 3 and brand 3

From Table 4:

C_{11} = Initial payment amount for acquisition of one bus type 1 and brand 1

C_{12} = Initial payment amount for acquisition of one bus type 1 and brand 2
.
.
.
C_{33} = Initial payment amount for acquisition of one bus type 3 and brand 3

IC = initial capital availability for fleet acquisition

From Table 5:

PKM_{11} = passenger-kilometer index for a bus type 1 and brand 1

PKM_{12} = passenger-kilometer index for a bus type 1 and brand 2
.
.
.
PKM_{33} = passenger-kilometer index for a bus type 3 and brand 3

PKMO = passenger-kilometer index agreed or objective
D = passenger demand per day

PC_{11} = daily passenger capacity for bus type 1 and brand 1

PC_{12} = daily passenger capacity for bus type 1 and brand 2
.
.
.
PC_{33} = daily passenger capacity for bus type 3 and brand 3

Q_{11}= minimum quantities for the acquisition of buses type 1 and brand 1
Q_{12}= minimum quantities for the acquisition of buses type 1 and brand 2
.
.
.
Q_{33}= minimum quantities for the acquisition of buses type 3 and brand 3

5.3. Decision variables

x_{11} = number of buses type 1 and brand 1

x_{12} = number of buses type 1 and brand 2
.
.
.
x_{33} = number of buses type 3 and brand 3

y_{11} = 1 if buses type 1 and brand 1 are acquired, 0 otherwise

y_{12} = 1 if buses type 1 and brand 2 are acquired, 0 otherwise
.
.
.
y_{33} = 1 if buses type 3 and brand 3 are acquired, 0 otherwise

Let’s use i = 1, 2 and 3, to specify each vehicle type, and j = 1, 2 and 3, for each brand.

5.4. Objective function and restrictions

$$Maximize\ z = \sum_{i=1}^{3}\sum_{j=1}^{3} VPN_{ij} * x_{ij} \qquad (7)$$

Subject to:
Budget availability

$$\sum_{i=1}^{3}\sum_{j=1}^{3} C_{ij} * x_{ij} \leq IC \qquad (8)$$

Service level (PKMO)

$$\sum_{i=1}^{3}\sum_{j=1}^{3} (PKM_{ij} - PKMO) * x_{ij} \geq 0 \qquad (9)$$

Service level (Demand)

$$\sum_{i=1}^{3}\sum_{j=1}^{3} (PC_{ij} * x_{ij}) \geq D \qquad (10)$$

Fleet composition requirements for type 1

$$\sum_{j=1}^{3} x_{1j} - \sum_{j=1}^{3} Q_{1j} y_{1j} \geq 0 \qquad (11)$$

Fleet composition requirements for brand 1

$$\sum_{i=1}^{3} x_{i1} - \sum_{i=1}^{3} Q_{i1} y_{i1} \geq 0 \qquad (12)$$

Fleet composition requirements for one specific vehicle type 1 and brand 1

$$\sum_{i=1}^{3} y_{11} \geq Q_{11} \tag{13}$$

6. RESULTS

The presented method was developed and applied for the assessment of a real passenger public transportation system, however, due to the confidentiality nature of the data provided by the stakeholders and the sensible meaning of the results, authors of this work are not able to share those empirical findings, not even with ratios or aggregate values that may affect the interest of the stakeholders, despite this fact, the proposed method is explained in detail and seeks to illustrate the proposed approach and its practical application.

The next section introduces possible extensions, aiming its application to asses and improve similar decisions with additional restrictions related to environmental impacts.

7. CONCLUSIONS

In this work, it is proposed a method to address the FSM problem. As stated in the body of the paper, several approaches have been developed to be applied exclusively on freight transportation, thus the present paper seeks to provide a model that considers specific and relevant factors for passenger transportation systems when a new fleet or extension of an existent is needed. The proposed method relies on the basic structure of the multiperiod capital budget selection problem, this problem is formalized as an integer LP model.

For purposes of modeling, the deployed method requires the definition of the main factors to be considered, incomes from transportation and no transportation services, as well as the relevant operational costs, to provide the inputs regarding the financial performance of each potential selection. The main service performance requirements included in the model are the PKM and demand coverability, key performance indicators (KPIs) appraised in the public transportation systems.

Besides the financial information, other operational restrictions to be considered are formulated and implemented in the model, such as the fleet composition requirements.

It is worthy to mention that, extensions of the present model may arise from the formulation and introduction of other operational or service factors, these can be introduced in the model as additional constraints, included some sustainability metrics to assess undesirable outputs coming from the selected fleet, for example, CO_2 emissions, or from the financial perspective, these factors can be easily formulated in the form of additional costs, cost that will penalize the selection of less efficient or less clean vehicles, to do so then the same procedure illustrated in section 3 is required, that information will produce an additional row in table 2, and implies the reformulation of I (sum of all these financial results) before applying the NPV to generate the main inputs (Table 3).

On the other hand, if the consideration of a maximum level of emissions is needed, then it is required to follow the same formulation applied for budget availability (setting the admissible level of aggregate emissions produced).

In summary, this paper seeks to illustrate the main structure and procedure to formalize and implement a model capable to provide a comprehensive decision support tool, with the flexibility to be adapted accordingly to each manager's information extent.

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Freight transport

TOTAL LOGISTIC COSTS EFFICIENCY WITH AN ALTERNATIVE FOR CONSOLIDATE GOODS

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ABSTRACT
This paper considers an application of the capacitated transshipment problem on a real case of supply chain network design, considering a problem of large-scale dimension as the main principle in the modeling of important natural and social phenomena. The problem first is formulated as a mixed-integer linear programming model. Then, a Benders decomposition algorithm is appropriately developed as the solution methodology. In the presented algorithm, the problem is decomposed into two models, called master and subproblem. The master problem is improved by means of a preprocessing and solving the primal of the subproblem, exploiting its network structure. Moreover, the Benders Cuts, optimality and feasibility, are developed for the algorithm. The general relative performance of the algorithm is proposed for its experimentation and evaluation.

Keywords: Benders Decomposition, transshipment problem, supply chain, logistic costs

1. INTRODUCTION

The impact in emergent economies globalization, and product life cycles shorter and more complex, in part due to new supply chain era consumers, are not just tendencies anymore. Day by day we see how these factors push us to achieve an operative logistics environment that can be in due time and form according to the necessities of every economy participant.
The world around us is full of important questions without answer, nevertheless, exist the security of every intent of find their solution, requires of the use of mathematics, in most of the cases, through the creation, application and refinement of math models. Math modeling is a great support to large organizations in the decision making to solve complex problems.
Is common for the organizations to have a generalized policy of filling containers under the rationale that this practice will result in lower unit total costs however the excess product brought will end up into inventory thus increasing the inventory cost, depending on the cost relationship between transportation and carrying cost, this situation does not always hold. It's complex to accomplish a balance between freight and inventory costs without using sophisticated techniques and solid strategic planning.

According to a study made by (Gutierrez and Jaramillo 2009), the automatization of warehouses, to optimize the operation and management, and the tools for the processes and analysis that optimize time and space available, are growingly utilized by organizations of different sectors in the country. According to this study, 57% of enterprises use quantitative tools to generate and improvement in the supply chain management, of this 57%, 30% focus on the use of the type of tools to reduce costs.
The total logistic cost goes from the aggregation of the following four type of costs: transport, inventory, storage, administrative and supply. Being transport and inventory costs, the first associate ones to logistic costs (Montanez *et al*. 2015).
In figure 1, it can be observed the correlation that exists between the total logistic costs, if one of them decreases or increases, the total logistic cost is affected, in other words, if the approach is to reduce inventory costs, it would implicate an increase in transport costs given the reason that it will be required more lower volume shipments.

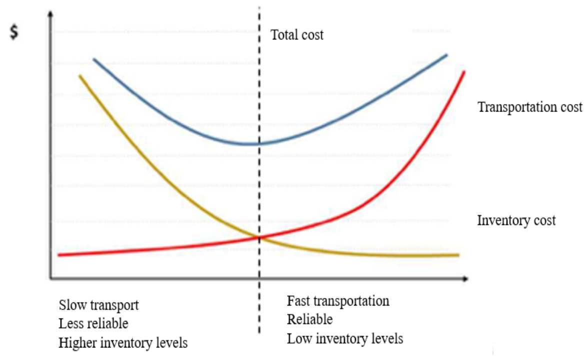

Figure 1: Correlation between logistic costs.

2. THE TRANSSHIPMENT PROBLEM

In real life, transshipment problems are composed of a considerable number of products and suppliers, when trying to be translated into mathematical modeling they take a very high solution time, there are many techniques that have been studied to combat this problem.
They occur when there are intermediate establishments in the flow of merchandise from one point to another where the merchandise has the possibility of passing

through and being handled before being distributed to the destination point, with the characteristic of involving additional costs to traditional transport problem, from the point of origin to the point of transshipment, and from this to the point of destination (Rajendran and Pandian, 2012), According to the strategies of the company, the option of having these points must be considered. Open intermediates including the option of their absence can be considerate.

2.1 Logistic costs

Logistic costs are the costs incurred in companies to meet the needs of the customer, that is, those costs involved in the process of generating value that ensures the level of service desired by the customer. These logistic costs can be classified in distribution costs, procurement costs, customer service costs.

Distribution cost: Among the most representative costs are the transportation costs of the finished product, inventory costs of finished products, administrative expenses, among others, especially costs involved in the distribution of the product.

Procurement costs: Costs involved in the supply of the product, including transportation of raw materials, inventory of these materials, among others.

Customer service costs: This cost is associated to customer service; it is not easy to calculate due to the comparison that must be made with the expected level and offered to the client.

We can observe that distribution and supply costs are involved in the same activities in different processes, for our case study we will focus on supply costs, including:

Cost of holding inventory of a pallet: generated by all the expenses incurred in the movement of the material and that correspond to the investment, storage and use of inventory.

Cost of transporting a pallet from the point of origin to the transhipment point: the costs are associated with the value of transporting pallets through land transport.

Costs of transporting containers from the transfer point to the final destination: costs are related depending on the capacity of containers to be transported, which may be in volumes smaller than 10, 20 and 40 feet.

Cost of use of the consolidation centers: it is generated when in a specific period the consolidation center is used, otherwise the cost is not considered.

2.2 Transportation costs

According to (Mexican Institute of Transportation, 2007), transportation can be conceived as the need generated by the production shortage presented in a location of both consumer goods and other products as well as the possibility of manufacturing in larger quantities than local requirements, transportation is an activity that adds value in the supply chain, a product cannot be perceived for its value until it is in the hands of the customer.

The importance of transportation in distribution problems lies in being a basic activity from the economic and social point of view, allows to communicate both consumers and suppliers, reinforcing the productive approach and helping to consumers to obtain quality products in the conditions and time desired.

Transportation problems are studied with a series of variants that offer a greater visualization of scenarios when facing business problems from day to day, in this paper we focused in the variant called transshipment problem. When companies manage a large distribution network, they need an intermediate point for the merchandise to arrive, then being managed and distributed. When there is an intermediate point between a destination and an origin, where the merchandise is distributed, the structure is known as a transshipment problem. An example of the structure is shown below:

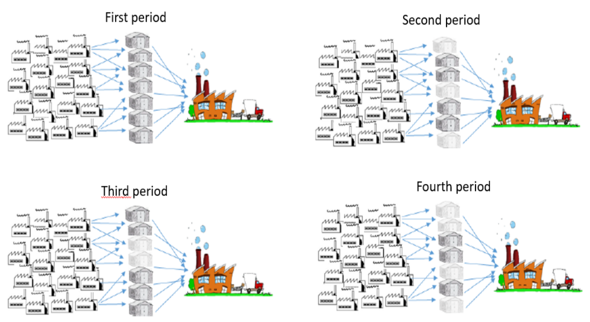

Figure 2.1: Example of the selection of the intermediate points to use, for fourth periods in the transshipment problem.

The transshipment problem is a problem that companies have to face every day, regularly when talking about transport is associated with the reduction on costs, however, if parameters at stake are not the costs, and the main situation for the company is the distribution, the objective of the problem would be the maximization of shipments, so that profits are higher; in this case the problem becomes from minimizing costs to maximizing benefits, this means that the objective of the problem depends on the importance of the parameters at stake. For this research, our problem has more similar characteristics to the problems of transshipment because there are intermediate points known as centers of distribution. We will focus on two specific objectives to minimize: the costs associated with the distribution of products in a reasonable solution time for business decision making and the inventory cost, ensuring we're seeing these as a global cost called logistic cost.

Transportation problems are often analyzed as specific cases of linear programming, however when complexity increases, it is necessary to develop special algorithms that are more efficient in computational structure means. A characteristic for this model, is that is has a variety of products that are treated through a distribution network. It makes it a multiple products problem, increasing its complexity, it also works as a transshipment problem du to having intermediate points in the network where the product can arrive for its storage, handling, and distribution. As we mentioned earlier, transportation problems are analyzed as specific cases on linear programming, however when large quantity of data is added, computational complexity increases and it is convenient to develop algorithms that exploit a special structure to be more efficient in its solution.

2.3 Inventory costs

The process of generating value in the supply chain is a complex issue, due this, companies focus on the operation and management of internal logistics, including inventory management as one of the most complex logistics aspects (Gutierrez and Jaramillo, 2009) because they perform as buffers between supply and demand. To achieve a good inventory management, it is necessary to make use of quantitative tools that offer effective results for the company, the cost of maintaining inventory tends to be high if they are uncontrolled, damaging customer service.

2.4 Nature of transshipment problems

Transshipment problems are operational in nature that they require updated information due to the uncertainty that the demand may present, they aim to minimize total costs, always selecting the best distribution alternative to meet the demand across the entire distribution network, facilitating the shipment or receipt of merchandise, adapting to the needs and capabilities of the company. Each point that intervenes in the supply network is a transshipment point, however, if initially, the node has a supply or tries to satisfy a requirement, they retain the identity as a point of origin or destination. When the arcs that connect the nodes have a limited capacity in each shipment, the problem is known as a problem with bounded variables, that is, a trained problem, as mentioned previously, in our problem there is the restriction of capacity at the points of origin and transshipment, for our investigation it is necessary that the shipments from the origin point to the transshipment points are shipped in pallets with unlimited capacity, while the distribution of the transshipment points to the origin point is made by 20 and 40 foot containers, and if necessary, the idea that the product is sent through a consolidated shipment is contemplated (see figure 2.2).

For the mathematical formulation of the case study, the practical way of solving transshipment problems will be taken, that is, by formulating it as a transport problem with the characteristic that at each intermediate point the quantities received are equal to the quantity of shipping, implying that in intermediate points products cannot be kept in inventory.

Because the delivery time plays an important role in the supply of products, especially in products from foreign suppliers, it is necessary to make a model that analyzes the optimal amount of shipping during different periods, satisfying the demand of each of them, offering the possibility of having the minimum inventory quantity if necessary, but ensuring the merchandise that meets the demand. Sometimes companies consider the consolidation of products that come from more than one supplier, incurring in transportation costs, the addition to the mathematical problem of the characteristic of having an intermediate point where the merchandise lands before arriving at the destination point, transforming it into a transshipment problem.

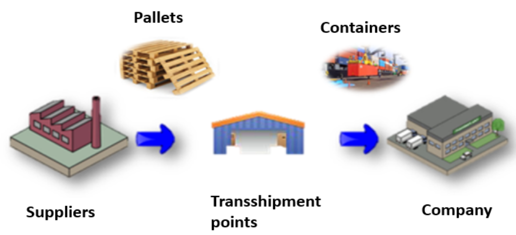

Figure 2.2. Decision making variables in present distribution case study.

The problem that will be raised in this paper, is expressed as a problem of mixed integer linear programming, as it has both discrete and continuous variables, therefore, there are decision variables that must be seen as a whole, such as the quantity of pallets of products that must be sent from the supplier facilities to a consolidation center, or directly to the customer, as well as shipments through containers; Other variables can be relaxed, such as the amount of product to keep in inventory, which causes the response time to solve the problem is long.

A total of 4 different scenarios are tested for the purpose of this research, all based on a real supply chain problem in an automotive components' manufacturer company, that imports components ready to assemble from China, we consider 3 components to test for every scenario, 4 periods, 2 types of containers, 20ft and 40ft capacity, for every scenario. Details of said scenarios are shown below:

Table 1: conditions in the 4 scenarios tested

Scenarios evaluated				
Scenario	1	2	3	4
Periods	4	4	4	4
Distribution Center Qty	1	2	3	4
Containers size	20ft and 40ft	20ft and 40ft	20ft and 40ft	20ft and 40ft
Components	3	3	3	3
Suppliers	3	4	6	9

3. METHODOLOGY

3.1. Literature review

To solve complicated problems with a considerable number of variables that are unknown, it is necessary to use special techniques, as are the decomposition methods. These decomposition techniques allow certain types of problems to be solved in a decentralized way and, alternatively, lead to a drastic simplification of the problem-solving procedure being studied in a considered less time than other linear programming techniques (Conejo *et al*. 2006).

In literature is observed that deal with problems of greater complexity require support in more than one solution technique in order to arrive at a better solution that would be initially available. (Chen and Garcia-Diaz 2011), use the combination of lagrangian relaxation with heuristics for the creation of lagrangian heuristics. (Marjani *et al*. 2012) use a heuristic to generate the initial solution that will be the beginning of the algorithm of three different heuristics. While (Naderi 2019) used a two-stage stochastic programming model, achieving an optimality gap of 0.1%.

There are other solution tools that consider the structure of the problem presented in this paper, as is the case of the branching and dimensioning method, which is used to solve mixed medium-sized integer programming problems, using decomposition methods for large scale problems, where the branch and bound method can no longer provide an effective solution (Moradi-Nasab 2018).

In this investigation, a solution is proposed through the decomposition of Benders, since it is a technique that allows us to offer a solution to the problem presented, however, its application can be extended to problems of greater dimensions.

3.2. Definition of the problem

Its importance lies in establishing the objectives to be achieved, the limitations to reach these objectives and the information that is available, which may be valuable for the solution of the problem, this information is called assumptions. The assumptions of the present problem are:

• The demand for each product is known.

• Products can be sent directly from the supplier, or sent from the supplier to a consolidation center, and then to their final destination.

• The number of suppliers, consolidation centers, ports, transportation costs, inventory costs, and container capacity that make up the supply network is known.

• We have the option of keeping the inventory for future periods at the final destination.

• In the consolidation centers no inventory is maintained for future periods.

• Transportation costs are seen as total costs, that is, they include costs for containerization, paperwork, transportation from the point of origin to the destination, human capital, collection costs from the supplier to the consolidation center, etc.

• Inventory costs are total, that is, they cover costs for damage, obsolescence, inventory management, human capital, etc.

Sets

e: Set of container capacity.

p: set of suppliers.

s: Set of products.

b: Set of distribution centers.

t: Set of time periods.

k: Set of a future time period $t + 1$.

Parameters

CD_{ep}: Cost of direct shipment from the supplier $p \in P$ of a container of capacity $e \in E$ (en tarimas) to Mexico.
CC_{spb}: Cost for shipment a pallet of component $s \in S$ from the supplier $p \in P$ to the consolidation center $b \in B$.
CM_{eb}: Cost of shipment of one container of capacity $e \in E$ from the distribution center $b \in B$ to Mexico.
CI_s: Cost of inventory a component $s \in S$.
d_{st}: Demand in pallets of the product $s \in S$ in the period $t \in T$.
Q_e: Capacity of the containers, expressed in pallets.

Variables

XM_{ept}: Quantity of containers from capacity $e \in E$ sent from the supplier $p \in P$ in the period $t \in T$ directly to Mexico.
XC_{spbt}: Quantity of pallets of component $s \in S$ sent from the supplier $p \in P$, to the distribution center $b \in B$ in the period $t \in T$.
XT_{spt}: Quantity of pallets of product $s \in S$ sent from the supplier $p \in P$ in the period$t \in T$ directly to Mexico.

XL_{ebt}: Quantity of containers of capacity $e \in E$ that are sent from the distribution center $b \in B$ to Mexico in the period $t \in T$.
$I_{stk:}$ Quantity of pallets of product $s \in S$ to store in the period $t \in T$ and the inventory in the period $k \in K$.

Once the parameters are well defined and the variables are clearly understood, the problem is obtained as it shows:

3.3. Benders decomposition applied to a transshipment problem

It is proponed a solution for the problem presented, utilizing the Benders decomposition, for testing, GAMS math modeling tool will be used due to maintaining an interface with great quantity of other math modeling software, specifically CPLEX. The Benders decomposition algorithm has been successfully applied to a wide range of difficult optimization problems, proposed by (Benders, 1962), with the main objective of tackling problems with complicating variables, which, when temporary fixed, yield a problem significantly easier to handle. This method has become one of the most widely used exact algorithms, because it exploits the structure of the problem and decentralizes the overall computational burden (Rahmaniani, 2016). The problem is decomposed in two parts, called master problems and one or more subproblems. The method is based on a

sequence of projection, outer linearization and relaxation. The model is first projected onto the subspace defined by the set of complicating variables. The resulting formulation is then dualized, and the associated points and extreme rays define the feasibility requeriments, called feasibility cuts, and the projected costs, called optimality cuts, of the complicated variables.
The generic modeling of the problem is shown below:

$$Min\ Z = \sum_e^E \sum_p^P \sum_t^T CD_{ep} XM_{ept} + \sum_s^S \sum_p^P \sum_b^B \sum_t^T CC_{spb} XC_{spbt} + \sum_e^E \sum_b^B \sum_t^T CM_{eb} XL_{ebt} + \sum_s^S \sum_t^T \sum_{k=t+1}^T (k - t)_e (CI_s) I_{stk} \quad (1)$$

$$\sum_s^S XT_{spt} - \sum_e^E Q_e XM_{ept} \leq 0 \begin{cases} p = 1, 2, \dots, P \\ t = 1, 2, \dots, T \end{cases} \quad (2)$$

$$\sum_s^S \sum_p^P XC_{spbt} - \sum_e^E Q_e XL_{ebt} \leq 0 \begin{cases} b = 1, 2, \dots, B \\ t = 1, 2, \dots, T \end{cases} \quad (3)$$

$$\sum_s^S XT_{spt} + \sum_p^P \sum_b^B XC_{spbt} + \sum_{k=1}^T I_{skt\,[k \neq t]} - \sum_{k=1}^T I_{stk\,[k \neq t]} = d_{st} \begin{cases} s = 1, 2, \dots, S \\ t = 1, 2, \dots, T \end{cases} \quad (4)$$

$$XM_{ept}, XT_{spt}, XC_{spbt}, I_{stk}, XL_{ebt}, \in \mathbb{Z}_0^+ \quad (5)$$

Where (1) represents the minimization of the total costs integrated by total direct shipment cost, consolidated cost, and inventory cost.
We have two sets of constraints that can be resolved separately, being the first set (2) that refers to the capacity condition of the direct shipment from the foreign supplier to Mexico, meanwhile the second constraint (3) achieves the capacity of the consolidate goods. Furthermore, a set of constraints of demand achievement it is presented (4), where it takes account of keeping the product in inventory.

Due to the special structure of the problem, it is proposed to get a solution by the Benders decomposition method, parting the problem in two, in this case, a master problem (6), and a subproblem(7), considering the constraints mentioned above, the master problem and subproblem objective function are expressed in the following:

$$Min \sum_e^E \sum_p^P \sum_t^T CD_{ep} XM_{ept} + \sum_e^E \sum_b^B \sum_t^T CM_{eb} XL_{ebt} + \alpha \quad (6)$$

$$Min \sum_t^{T-1} \sum_{k=t+1}^T (K - 1)\,(CI_s) I_{stk} + \sum_s^S \sum_p^P \sum_b^B \sum_t^T CC_{spb} XC_{spbt} \quad (7)$$

$$XM_{ept}, XT_{spt}, XC_{spbt}, I_{stk}, XL_{ebt} \in \mathbb{Z}_0^+ \quad (8)$$

4. RESULTS AND DISCUSSION

Results obtained for every scenario are shown below:

Table 2: logistic costs evaluation

Scenario	Total logistic cost	Absolute gap	Computing time
1	36798	0.00%	1.703 s
2	16732.156	0.0%	1.109 s
3	16887.156	0.0%	1.87 s
4	13205.43	0.21%	3.7 s

According to the performance of the algorithm, in every scenario is considered to reach an optimum result, where the best solution possible is the scenario 2, in distribution center exploitation means, where 2 distribution centers are used at a minimum transportation and inventory cost. This option is viable when a company has no choice but use distribution centers. Whereas scenario 4 shows a lower logistic cost result, for the nature of the test, evaluating 9 suppliers with only 3 components, most of the components are picked by the same supplier and sent directly from their location to the destination, implying that no usage of distribution centers result in a lower logistic cost, for this case.

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COMPETITIVENESS OF SCHIPHOL AIRPORT AS EUROPEAN HUB IN THE CUT FLOWER SUPPLY-CHAIN

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ABSTRACT
The Netherlands is the largest export country of cut flowers in the world. Air cargo transport of flowers amounts to 25 percent of the total annual tonnage of goods that go through Schiphol Airport. However, due to uncertainty of the future development in international trade, as well as the increasing competition from other hub airports in Europe and new developments in the maritime transport sector, forecasts point to a less rosy picture for the Schiphol airport and Netherlands.
To maintain and improve the international competitive position of Schiphol airport as a 'preferred hub' for flowers, it is important to keep up with developments in the international markets, changes in the international value chain of flowers and to strengthen the competitive position of Schiphol in relation to competing airports (Brussels, Liège, Frankfurt and Paris).
In this paper, we develop a conceptual framework that assesses the competitiveness of Schiphol airport compared to its European competitors, based on a model that takes into consideration transport and logistics costs, as well as other variables like quality of services and local and business environment. The results show that Schiphol can maintain it competitive advantage due to competitive indicators as trade costs, hub position in international air-networks, quality of handling goods, and the existence of high-quality airport infrastructure and a unique business environment, which attract international business.
However, the results of the flower trade analysis show that Liège airport has become a direct competitor of Schiphol, as this airport scores better than Schiphol for trade in flowers above 1,000 kg. Liège airport scores equally to Schiphol in terms of monetary, transport costs and quality of services.
Keywords: Preferred flower hub, Trade, Air-cargo, Airport competition, Schiphol airport

1. INTRODUCTION

The cut flower sector is of great importance for the Dutch economy. Worldwide trade in cut flowers is estimated to about $7.4 billion, of which 3.3 billion dollars are exported by the Netherlands (Rabobank, 2017). This makes the Netherlands the largest cut flower export country in the world. Cut flower exports began in the late 1960s when wide-bodied jets were introduced and used in air freight transport.

Due to the central geographical location of the Netherlands in Europe and the international position of Schiphol airport, Schiphol has become one of the most important European hubs, with strong European and intercontinental connections. Because of the hub function of Schiphol airport and its location near the largest flower auction in the world (Flora Holland auction) the airport developed into the biggest flower airport in the world. However, the international position of the Netherlands and Schiphol as the main European flower hub is challenged by multiple (market) trends within the sector (direct trade to end consumers without using the auction, E-commerce, etc.), as well as the increasing competition from other European airports (Liège, Brussels, Charles-de-Gaulle), and the rising competition from other transport modes, mainly the container transport of flowers.

The aim of this paper is to analyze the impact of these trends on international competitiveness of Schiphol airport in relation to the competing European airports like Brussels, Liège, Frankfurt am Main and Paris Charles de Gaulle, in order to find solutions whereby Schiphol can improve it position as the best preferred European hub for cut flowers. The paper is organized as follow; in section 2 the cut-flower supply chain is analyzed and a detailed description of recent developments in international trade and trade flows of cut flowers is given. Section 3 presents and discusses the methodology and presents the analytical framework of analysis. In section 4, preliminary results of benchmarking Schiphol airport to its competitors are presented and discussed. Section 5 concludes.

2. THE CUT FLOWER SECTOR

2.1. Cut flower supply-chain

The cut- flower supply chain consists of many actors: growers, traders (exporters/wholesalers), retail and finally customers (Figure 1).

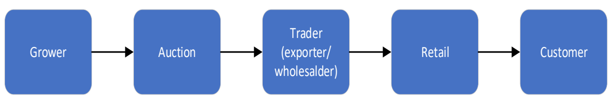

Figure 1. Composition of cut-flower supply chain.

A special actor in the supply chain is the flower auction, which traditionally provides a physical trading platform for transactions between growers and traders.

The main actors in the fresh flower supply chain are the following:

1. *Growers*: producers are specialized in the production of small number of cut-flower species. A large number of the Dutch growers is member of the Flora Holland cooperation, which represents the growers and supports in marketing their products, including transport and logistics, packaging and the physical and on-line trading their products.
2. *The Flora Holland auction:* Flora Holland auction is the physical location where the growers traditionally sold their flowers. Flora Holland, as the auction owner, performs physical quality checks and distributes the flowers to traders/buyers at the auction site. Three auction-locations are relevant for international trade of cut-flower in the Netherlands: Naaldwijk, Rijnsburg, and Aalsmeer. The latter is closely related to air cargo activities at Schiphol airport.
3. *Direct trade*: producers/growers can seal directly to traders upon agreement on prices, transport and logistics requirements. Flora Holland supports these transactions administratively, but transport and logistics are organized by the traders or the growers themselves.
4. *Retail*: the retailers are responsible for the distribution of cut-flowers to the end-customers. The cut-flower market can be divided into the specialized market, in which flowers are the primary product, and the unspecialized retail market, that sells flowers in addition to their regular assortments, like supermarkets and gas stations. Both market channels show differences with respect to quality requirements, packaging, logistics and business practices (CBI, 2017).

The supply-chain configuration of cut-flowers does not necessarily include all parties in the supply-chain network described above, as illustrated by Figure 2 illustrates.

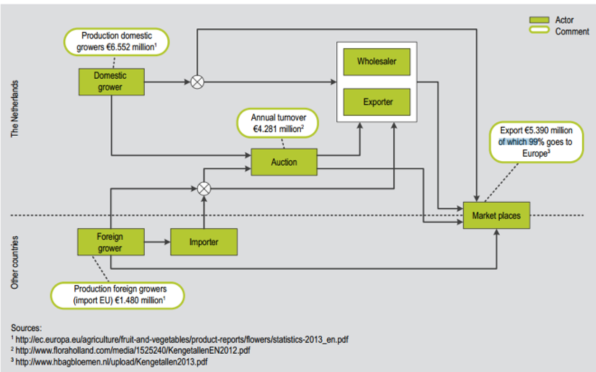

Figure 2. The Netherlands in international flower trade (de Keizer et al., 2015).

During the past six decades, cut flowers have been traded through the flowers auction in Aalsmeer. Flora Holland dominated the worldwide auctions in this sector thanks to the historically developed hub position in the flower sector by The Netherlands. Flowers are traded through the auction clock, which is a unique system based on the price that is determined by the first buyer that pushes the button at a given price level. In case the buyer waits too long, it is possible that the flowers in which he/she is interested could be bought by another buyer.

The packaging of the flowers is one of the major issues, regardless of the transport modality. Flowers are often placed horizontally in boxes and loaded into pallets. Once loaded, trucks transport the flowers to the nearest (air)ports for the export. At the airport, the flowers are then put into containers or pallets and loaded into the airplanes, mostly intercontinental air transportation to or from the Netherlands (Hortibiz, 2017). Because of the lack of international standards regarding the packaging and the loading practices and shipments of flowers, most imported and/or exported flowers are over- and/or under-packed. This results into inconsistent volumes, and unnecessary expenses and damage to flowers (Hortiwise, 2012).

2.2. Recent developments in the cut flowers sector

The most important development in the cut flower sector is the increased competition from the container sector for the export of flowers, as new technological advances in the container sector make it possible to shift towards other transport modality than air transport alone. Another development is the change in trade flows of cut-flowers and the diversification of production strategies. For example, there is an increase in the number of Dutch growers who produce flowers in west Africa and export their products to the Netherlands or directly to traders around the world.

The main consideration for the selection of the optimal transport mode for cut flowers is based on costs and quality of flowers. Due to their perishable character, flowers are transported by air to maintain the advantages of short supply chain and the living time of the flowers. However, due to an increased sustainability awareness, lower transport costs and new technological developments in container transport, cut flower transport by sea containers is becoming more and more important, despite the difference in the transport time between air and sea transport (Frazier, 2016). However, due to sophisticated cooling installations (0.5ºC in the container) and the use of sensors in sea containers, flowers can maintain an average vase life of almost 3 weeks. When transported by air, flowers endure strong temperature differences and cooling moments during the flight, depending on the distance and variation in temperature along the air network.

Also, the main trading strategy of cut flowers has changed in the last two decades, because of – among other things – the rapid growth of e-commerce and increase digitization of the supply chain. Nowadays, a large proportion of flowers are sold directly to the customer instead of using the auction mechanism or tradition market channels (Van der Ploeg, 2015). In 2008, 65% of the flowers traded worldwide were sold through the auction, and six years later (2014), this percentage has dropped to 49%. Direct trade of flowers

between growers and traders eliminates significant overhaul costs like warehouses, importers, distributors, auctioneers (PR Newswire, 2017), reduce the supply-chain and optimize logistics processes. In addition, consumers choices and needs concerning cutting size, packaging unit and type of transport can be discussed directly. The increasing virtualization of trade in flowers has transformed existing flowers supply-chains where growers and the customers position become important.
Furthermore, the marketing channels have direct impact on the way cut flowers are distributed (Rabobank, 2017). The market share of the traditional marketing channels (e.g. the local florist) is declining at the cost of the increasing market share of the online sales channels and the non-specialized one, such as supermarkets and gas stations. The non-specialized market channel is more based on quality, delivery, reliability, and traceability than on price (as in the Auction market channel). This increase in the non-specialized marketing channel could increase the volumes and share of total flowers that go directly to these retailers, resulting in a gradual shift in purchasing power towards mass-market retailers.
Finally, as transport and vase life conditions of flowers are improved by the application of technological innovations, growers of cut flowers are moving towards the development of new varieties that are specific for producing countries (e.g. East Africa and South America). This development has led to an increase in the number of varieties of cut-flowers that are exported to Europe.

2.3. International trade flows of cut flowers

The main flower producing countries are summarized in table 1. China is considered as one of the most important producers of cut flowers, but still nonvisible at international market in terms of import and export. One of the reasons for this is the probably because China production of flowers is for a large part consumed locally (Hanks, 2015; Rabobank, 2017). The largest area used by floriculture sector is found in India (FAO 1998; Hanks, 2015; Harisha, 2017). However, the most important producers of flowers in the world are the USA, the Netherlands, and Japan.

Table 1: Top 10 flower production countries in 2014 (Hanks, 2015)[1]

Country	**Production value** (millions of €)
China	5,095
USA	4,434
Netherlands	4,130
Japan	2,512
Brazil	1,747
Italy	1,330
Germany	1,319
Columbia	1,012
France	954
Spain	880

[1] Figures include the production of pot plants as well

First, concerning the international flows of cut flowers, the most important exporter countries are Kenya, Ecuador, Colombia, and the Netherlands. Together, these four countries account for 80% of the total export value of international trade of flower worldwide (Chatham House, 2018). Note, however, that Ecuador and Colombia mainly serve the North American markets, while the African countries i.e. Kenya and Ethiopia, serve the EU market.
Figure 3 shows the national shares of cut flower export. Particularly, Ethiopia has increased its share to 9% in 2015, while in 2008 it was not included in the top 10 export countries.

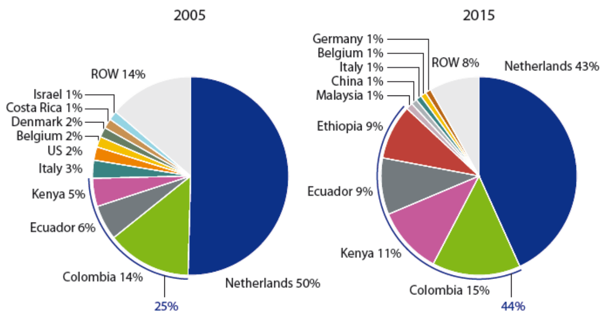

Figure 3. National shares of cut-flower export (van Rijswijk, 2016).

As mentioned before, The Netherlands is still the most important trader of flowers in the world. The share of the Netherlands in global trade has declined from 50% in 2008 to 43% in 2015, at the cost of Colombia, Ecuador, Ethiopia, and Kenya. In 2015, these four countries accounted for 44% of the total exports of flowers in the world.
An important rising trade lane of flowers is between Africa and the United States. In terms of value of export, Kenya and Ethiopia have raised their share by 37% and 108% respectively (2015). In term of weight e.g. volume in kg/ton, the export of flowers from Ethiopian increased by 118% in the same year. However, the value of exported flowers from South American countries (Ecuador and Columbia) to the USA is much higher than the value of exported flowers from African countries to the EU. The rapidly increasing market in the USA opens new possibilities for export of flowers from Schiphol, as direct intercontinental flights from these African countries towards the US are limited or not existing. However, direct connections between Kenya and the USA will soon be available for air freight (Kangethe, 2017).

Figure 4 shows the global trade flows of flower bulbs, cut flowers, cut foliage and other living plants (excluding intra-EU), worldwide.

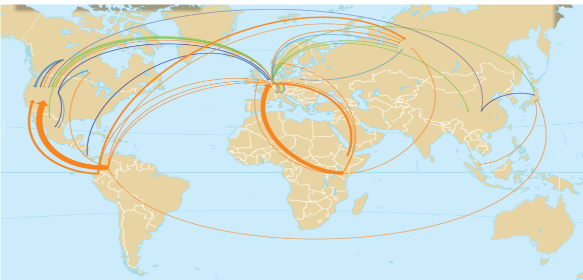

Figure 4 Global flower trade flows (van Rijswijk, 2016). The thickness of the lines shows the ratio in transported volume between two countries.

Table 2 shows the top 10 importing and exporting countries of cut flowers.

Table 2: Top 10 importing (a) and exporting (b) countries (2016)

(a) Country	Import Value ($)	Weight (tons)	(b) Country	Export Value ($)	Weight (tons)
USA	1,391,227,495	-	Netherlands	4,169,944,171	551857
Germany	1,152,549,403	185299	Colombia	1,312,261,768	234937
Netherlands	1,024,297,306	365259	Ecuador	802,437,685	143182
UK	1,010,643,199	150356	Kenya	327,268,428	-
France	385,897,855	59910	Ethiopia	162,173,804	-
Russia	357,375,461	56329	China	105,500,303	33464
Japan	346,688,518	42581	Malaysia	104,547,246	43416
Italy	181,991,838	27159	Italy	93,313,017	11169
Switzerland	174,678,165	15963	Belgium	90,617,808	-
Belgium	153,036,164	-	Israel	81,825,000	-

In 2016, the value of export of cut flowers from Ecuador and Colombia to the United States reached 1.2 billion dollars. In 2015, 39% of Ecuadorian and 72% of Colombian flower value was exported to the US, while Europe accounted for 20% and 11%, respectively (Chatham house, 2018). It is worthy to note that export of flowers by sea is increasing on the route Colombia-USA (van Rijswijk, 2016). Other countries like Kenya and Ethiopia are more focused on the European market, the Netherlands being the dominant importer of cut flowers from these two countries.

In order to reduce the production costs of flowers, many growers of cut flowers have moved from the Netherlands to these two African countries during the 1980's (Kavilu, 2016). In 2015, an estimated 500,000 people were employed in the flower sector in Kenya, with a total export value of around 620 million dollars (Kavilu, 2016).

Second, concerning the intra-European flows of cut flowers, The Netherlands is considered as the most important hub for flowers in Europe. In 2016, the total value of exported cut flowers to European countries reached 3.1 billion dollars, from which 2.2 billion dollars of export value goes to top 5 importing countries. These countries are Germany (1 billion dollars), England (649 million dollars), France (300 million dollars), Italy (151 million dollars) and Switzerland (114 million dollars).

Note, however, that a large part of intra-European freight traffic of cut flowers is carried out by trucks (e.g. road traffic) within a distance of 700 km. Due to its central geographical location, most of European countries can be easily reached from Flora Holland auction in Aalsmeer, where thousands of trucks drive daily from the Netherlands to the Benelux, France, Spain, Germany and (some) Eastern European countries.

A close look on KLM data (KLM, 2017) provide better insights concerning air freight activities and international flows of cut flowers between Schiphol and the world. The data gives a nice picture of the trucking activities of cut flowers between Schiphol and other European airports. Almost 19% of the total exported and imported cut flowers by KLM at Schiphol airport is tracked between Schiphol and other airports or their final destinations. The rest (10.780.689 kg in 2017) is transported as bulk goods on regular passenger flights. Figure 5 shows the most important airports that are used by KLM to transport fresh flowers to Schiphol airport, based on total weight. The figure shows that 36.5% of cut flowers is imported from NBO airport/Nairobi in Kenia, 31.7% from Quito Airport in Ecuador (UIO,) and 17.9% from Bogota in Colombia. Other origins of cut flowers are Harare in Zimbabwe (HRE, 4.8%) and Cape Town in South Africa (CPT, 3.2%).

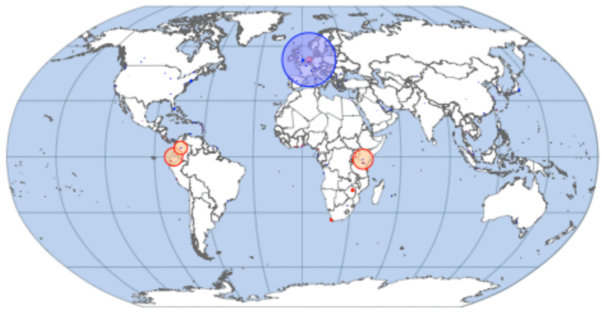

Figure 5 Flower departures (in red) and arrivals (in blue) transported by KLM in 2017 The size of the circles is proportional to the transported volume (KLM, 2017).

Furthermore, only 10% of the total imported cut flowers by KLM from the largest production countries (the blue circle in figure 5) is transported to the auction in Aalsmeer before export to the rest of the world. The remaining 90% are transported by tracks within the Netherlands and to other European countries.

Figure 6 gives an illustration of worldwide air freight flows of flowers that are transported by KLM.

Figure 6 Overview of the export of flowers from the Netherlands (transported by KLM) in 2017. The thickness of the lines shows the ratio in transported volume between two countries (KLM, 2017).

As shown in Figure 6, the most important importer of cut flowers from the Netherlands is the USA, which accounts for 51.6% of the total transported weight. The main destination of flowers from Holland is New York (JFK), accounting 31.4% of the total export of flowers (corresponding to 60% of the total volume/weight arriving from Amsterdam).
Data form Resourcetrade for the year 2016 (Table 3) are consistent with the analyzed KLM data. Kenia and Ethiopia remain the most important exporters of flowers to the Netherlands. Note that, because KLM is not allowed to fly from Ethiopia, due to the government restrictions, air freight of cut flowers is done by the Ethiopian home carrier who has direct connection to the airport of Liège in Belgium. From there, flowers are tracked to Schiphol airport and/or the auction in Aalsmeer.

Table 3: Top 10 flower import (a) and export (b) flows from and to the Netherlands.

(a)			(b)		
Country	Value ($)	Weight (tons)	Country	Value ($)	Weight (tons)
Kenya	327,268,428	133496	Germany	1,251,804,705	16,457
Ethiopia	162,173,804	82901	UK	621,064,303	91,170
Belgium	154,620,021	73091	France	524,082,994	69,477
Uganda	28,526,744	13339	Poland	132,698,812	22,781
Ecuador	78,503,714	11993	Russia	133,978,791	22,058
Germany	63,574,632	6847	Belgium	179,650,162	20,122
Colombia	42,638,934	6220	Italy	166,139,486	189,276
Zambia	8,004,926	6065	Sweden	107,958,803	14,854
Zimbabwe	5,359,918	5285	Switzerland	120,691,030	12,552
Italy	39,906,839	5187	Denmark	96,466,943	12,397

Source: (Chatham House, 2018)

2.4. Schiphol and its competitors: a brief review

Schiphol is the largest airport in the Netherlands and the third largest in Europe. Schiphol's direct European competitors in trade of cut flowers are Brussels Airport (BRU) and Liége Airport (LGG), both located in Belgium, Frankfurt Airport (FRA) in Germany and Paris Charles de Gaulle Airport (CDG) in France.
Schiphol is recognized as the most important hub for flowers in the world, due its position in international air networks, the large intercontinental connections of the home carrier KLM (312 destinations in 114 countries) and the relative higher flight frequencies. The cooperation between Schiphol and KLM ensures that handling times and delivery to end destinations in Europe are lower than at other airports. Also, the quality of flowers delivered at or from Schiphol remains high, despite the fact that the cool chain facilities at Schiphol Airport are relatively limited, compared to, for example, Dubai or Frankfurt. Note, that 15 to 29% of Schiphol's cargo volume is composed by perishables, and flowers account for the largest part of this freight volume. Currently, 60% of the world cut flowers that are transported by air passes through Schiphol airport.
In this respect, Schiphol's most important competitive advantages are: (1) a strong commitment to digitization, implementation of the most advanced technologies and information systems in the airfreight sector; (2) the presence of large warehouse capacity (400,000 m^2, from which 60% is directly accessible from the airside); (3) The existence of high-quality equipment's and installations of cooling facilities for perishables; (4) high standards customs facilities and reliable cargo control and handling (SSGC, 2016). In addition, Schiphol is subject to several restriction affecting the air cargo activities. The most important restrictions at Schiphol are the strong regulation limiting noise nuisance at and around the airport and airport region (Franssen et al., 2004), and the ban of night flights at Schiphol airport (Wubben and Busink, 2004; ACNL, 2018).
Brussels Airport is the national airport of Belgium and an important pharma hub in Europe. Its proximity to the flower auctions in the Netherlands makes this airport attractive for the import of flowers from Africa. However, storage costs at this airport are relatively higher than other airports. Also, Brussels Airport only allows aircrafts with specific noise certificates (Brussels Airport, 2019) and has a limited number of slots per year for night flights (maximum 5,000 departing aircraft per year between 11 PM and 6 AM) (Sienaert, 2018).
Liège Airport, also known as The Flexport, is the largest Belgian airport in terms of the total volume of goods transported by air, particularly the biotechnological and pharmaceutical products. The storage costs and transport costs are higher at Liège Airport than Schiphol. Nevertheless, the airport is located outside the urban area, which allow the airport to receive night flights. Noise nuisance for surrounding areas is less severe than in other airports, such as Schiphol or Frankfurt. Hence, the airport can operate 24 hours a day without any restrictions on takeoff and landing of aircraft (CAPA, 2018; WDP, 2017).
Frankfurt Airport is the largest airport in Germany and the fourth largest airport in Europe. In terms of air freight, Frankfurt is the first air cargo airport in Europe. During the last decennia, Frankfurt airport (hereafter FRA) has focused on increasing its share of air cargo of perishables in Europe, by investing in setting up new cooling storage facilities and equipment's for control of temperature. As the case for the Brussel's airport, transport costs for air cargo are also high, due to the increasing landing fees. Also, the existence of strong regulations restricting noise nuisance and environment damage (e.g. pollution), and night flights restrictions, limit the capacity and growth of the air cargo activities at this airport. Note that Frankfurt airport does not suffers from the regulation limiting the maximum number of flight movements per year, the airport is closed between 23:00 and 05:00.
Finally, the airport Charles de Gaulle (CDG) is the largest airport in France and the second largest airport in Europe after Heathrow. CDG has an automated G1XL terminal for perishables goods, which is one of the modern and sophisticated terminals in Europe. The terminal is owned by Air France and KLM and includes, among other things, a special customs clearance, where

the storage time of goods at the airport and the shipment of goods from the airport to road transport are very short. As FRA, CDG airport charges relatively high landing fees. Despite the location of the airport Charles de Gaulle on the outskirts of Paris, the airport has to deal with very strictive rules with regard to noise nuisance and the limited number of slots for shippers, especially in the air cargo. Airlines should pay a 'Noise Tax', which is calculated for take-off flights (DGAC, 2008). Also, the airport is closed for incoming flights between 00:30 and 05:29, and from departing flights 00:00 to 04:59 (COHOR, 2019).

3. METODOLOGY

3.1. Costs distribution along the value chain

The costs distribution along the supply chain of flowers depend on various factors such as the costs of production, transportation, insurance, storage, oil price, freight rate, tariffs, etc. All transaction costs are subject to contractual obligations and rules regulating transactions between trading parties e.g. buyers and sellers. Most of the trade rules involving costs are standardized in the so-called incoterms. Incoterms are a set of rules, commonly used in international contracts and are protected by International Chamber of Commerce copyright, which define the responsibilities of sellers and buyers for the delivery of goods under sales contracts. Shippers worldwide use standard trade definitions (called Incoterms) to spell out who's responsible for the shipping, insurance, and tariffs on traded good.

In the case of the traditional supply-chain with the auction (see 2.1), the grower is the shipper and therefore the one responsible for arranging air freight transport. This is the case when flowers are imported from East African countries.

According to Hortiwise (2012), cost of air freight is the most important element for growers when choosing between direct or indirect flights or making the decision on how to transport their flowers. The quality and reliability of cold chain infrastructure are also important for the choice of shipper. In the case of (mass-market) direct trade, the shipper can be a seller and buyer at the same time. 95% of imported flowers from Ecuador fall under the so-called FOB (Fret On Board) regime, which means that air freight transport costs are incurred by the importing party (APEFE, 2015).

Besides transport costs, air freight costs also include landing/airport fee, as well as handling (loading and unloading), storage and customs costs. While airport fees might be lower at Schiphol airport, handling costs are substantially higher than, for example, at Frankfurt airport. According to a world bank study, the costs of air freight transport are estimated to approximately 25% of the wholesale price. In a more recent study (Hortiwise, 2012), airfreight costs of Kenyan roses account for 25% of wholesaler price, and 9% of the retailer price. Table 4 illustrates a typical cost distribution along the cut flower supply chain.

Table 4. Costs distribution along the value chain of flower supply chain.

Costs (EUR)	Actor in Value chain (EUR)	% of retail price
	Grower (grower price): 0.12	15%
0.005	Handling agent (incl. export costs; product value): 0.125	0.75%
0.075	Airline (product value): 0.20	9%
0.005	Handling agent (incl. import costs; product value): 0.205	9%
0.01	Importer (product value): 0.215	125%
0.035 (grower & buyer)	Auction (clock price): 0.24	4%
0.04 (+15%)	Wholesaler (wholesale price): 0.29	5%
0.51 (+175%)	Retailer (retail price): 0.80	64%

3.2. Analytical framework

In this paper transport costs are calculated as total costs (C_i) that includes all costs of shipping flowers by air from origin to destination, regardless of their indirect activities such as marketing, packaging, information support and general administration. In other word, the total transport cost is composed of freight rate (F_i) + inventory costs (IC_i) + air cargo handling cost (H_i) + insurance cost (I_i).

Freight rate is closely linked to market conditions, international trade and macro-economic development, affecting the air freight cargo sector. Inventory costs, whether at the consignor, in-transit, or at the consignee, depend on inventory-holding cost rate (%) and the total value of freight moving on route. These costs are related to the total freight value on air routes and air transport time between origin and destination. The total time of air cargo between OD route is given by the ratio of distance to speed.

The air cargo handling cost occurs in the process of loading and unloading and is related to the air freight value and cargo volume. Finally, the insurance costs of air cargo transport (similar to inventory cost) are related to the freight value, transport time, and the insurance cost rate.

Besides the analysis of the total transport cost of air cargo of cut flowers between origin and destination airports, we developed a conceptual framework for assessing the main determinant factors for the choice of a certain airport as hub for flowers, based on an extensive review of existing literature. From the literature review, six main factors were identified for the selection of the air transport hub for cut flowers' transport. These factors are monetary and transport costs, time costs or transition times, supply chain characteristics, quality, logistics infrastructure, and specific restrictions.

Monetary costs include air and road transport costs, customs and storage costs, airport charges and finally handling and fuel costs. The monetary costs depend on distance and weight. Lower costs make an airport more attractive to goods transport via the airport in question.

Time costs are the costs related to the transit time of goods including the pre- and post-transport waiting times at departure and arrival airports. Within the chosen assessment framework, analyzed time costs are transport time, control time, customs time, handling time and storage time. Loss of time during delays at and around airports due to congestion, long cargo handling and long customs clearance times can increase lead-time and transport costs. Because flowers are time-sensitive products, a longer turnaround time has negative effects on the quality and efficiency of the entire logistics chain and the competitive position of the airport. Airports with reliable, timely customs clearance often have a competitive advantage.

Another important factor is the length of the supply chain, determined in this study by estimating the distance (in kilometers) and time (in a number of hours) of the route traveled for the transport of flowers per airport. The cut flower sector is highly dependent on the quality, speed, and reliability of the logistics chain.

To take into account the quality, both flower and service quality are considered, as they determine the lifespan of the flower and therefore how long the end-user can enjoy the product. A good service quality demands less loss and damage to cargo. The entire transport chain is about maintaining quality; that is why this item is included in the assessment framework.

The logistics infrastructure concerns the presence of logistics companies, freight forwarders, forwarders, transporters, handling agents, accessibility and the presence or absence of a high-quality airport infrastructure and airport services (refrigeration facilities, warehouses, etc.), as well as the availability of an extensive network of destinations and connections to other modes of transport. A good road connection is crucial for the accessibility of the airport.

Finally, restrictions affecting freight transport include landing rights, number of available slots, noise, and environmental restrictions, and government restrictions on night flights. Such restrictions impede airports in their development. This study includes the following factors: slot restrictions, opening hours and government restrictions.

The choice of these factors has been validated in various consultation rounds with the main stakeholders from air freight logistics (forwarders, shippers, transporters, etc.) and traders from the horticulture sector (cut flowers). In this study, 24 interviews were conducted with the following actors in the flower supply chain: 86 agents, 2 florists, as well as 5 forwarder representatives, 2 airline representatives, 6 of flower processing company representatives and 3 growers of cut flowers.

In order to compare Schiphol to competing European airports, each factor taken into consideration in this study, was given a weight (e.g. weighted average) based on its importance. The choice of the weighting factor was determined on the basis of expert judgment from the interviews. The weights range lies between 1 (less important) and 5 (highly importance). Table 5 shows the weight of each factor. The first two factors are of great importance for the choice of the airport as hub for flowers. Also, the length of the supply chain is important. Service quality, although important, only comes in the fourth place.

Table 5. Weights of factors.

Factor	Weight (1-5)
Monetary costs	4.7
Time costs	4.5
Supply chain	4.4
Quality	3.7
Logistical infrastructure	3.4
Restrictions	1.9

In addition, a score for each airport has been calculated per each factor. Finally, the ranking of the airports is determined by the sum of the scores per factor.

4. PRELIMINARY RESULTS

As distance, capacity and airport and logistics infrastructure conditions vary for different import routes, total transport costs will depend on the location of the selected hub. Table 6 shows the distance, transport time and total costs for air freight transport of flowers from Nairobi and/or Addis Ababa to the 5 analyzed European airports.

Costs of air cargo transport of flowers from Addis-Ababa (Ethiopia) is cheaper than air transport from Nairobi, because of the short distance of the route and shorter lead time of air cargo transport of flowers to the European airports (Brussels and Liège). The transport time includes transport from the grower to the airport (2 h, on average), the latest cargo acceptance time imposed by the airline (5 h, on average), flight time (around 7.5 h for flights from Addis-Ababa and around 8.5 h for flights from Nairobi), customs clearance (1h, on average) and the transport time to the Aalsmeer auction, which depends on the distance between the airport and the auction site. As this part of the transport is done by truck, the long distances from FRA and CDG airports increase the lead time of the supply chain by 2-3 hours with respect to BRU and LGG, and with 5-6 hours with respect to AMS.

More generally, total transport costs are lower for transport to Schiphol and the Belgian airports, mainly due to the lower landing fees and the shorter distance from the airport to the auction site.

Table 6. Air freight transport costs of cut flowers from Africa to various European airports.

	Distance & total transport	Price 1 kg	Total Costs (1.000 kg)
Nairobi-Schiphol	6817 km (16 uur transport)	1,70 Euro	1780 Euro
Nairobi-Brussels **Addis-Abeba-Brussels**	6566 km (19 uur transport)	1,70 Euro 1,43 Euro	- 1776 Euro
Nairobi-Frankfurt	6830 km (21 uur transport)	1,70 Euro	2118 Euro
Nairobi-Luik **Addis-Abeba- Luik**	8648 Km (14 uur transport) -	1,70 Euro -	2010 Euro 1777 Euro
Nairobi-CDG	7053 km (22 uur transport)	1,70 Euro	2165 Euro

4.1. Benchmarking Schiphol to other European Airports

The total costs are strongly influenced by monetary costs, including airport charges and the price that carriers ask for transporting the flowers e.g. freight rate per volume. The analysis of total monetary costs per airport shows that the total monetary costs of flowers from Ethiopia (the Addis Ababa airport) are lower than from Kenya (Nairobi airport). This is because fixed costs are lower on this route. Ranking the airports, based on their competitive advantage with regard to total monetary costs shows Schiphol and Liège airport as the best competitive airports for flowers in Europe. Both airports share the first place, with Brussels in third place and Frankfurt and Paris in fourth place.

Table 7 summarizes the ranking of Schiphol airport and its competitors Liège, Brussels, Frankfurt and CDG., according to their competitiveness based on total monetary costs. It shows Schiphol and Liège as the airports with the best scores on monetary costs compared to other European airports.

Table 7: Monetary costs for the airports

Airport	Monetary cost score
Amsterdam Schiphol	17.7
Liège	17.7
Brussel Zaventem	14.9
Frankfurt am Main	13
Paris Charles de Gaulle	13

As mentioned before, the price of air freight transport is highly dependent on the freight rate and the total transported volumes (weight). Generally, the cost unit, e.g. EUR/per kg, is lower for bookings of larger shipments of flowers. However, the storage and handling costs may vary per handler, which, at the end, affect the total cost of air freight transport. In this respect, Schiphol airport is still the cheapest airport in terms of total air freight costs of flowers for shipments that are less than 1000 kg. For shipments of flowers that are greater than1000 kg, Schiphol loses its position to the airports of Liège and Brussels (see figure 7). Several reasons may explain this shift in position of Schiphol airport, such as the level of airport fees, freight rate, storage costs, shipment and handling costs, etc.

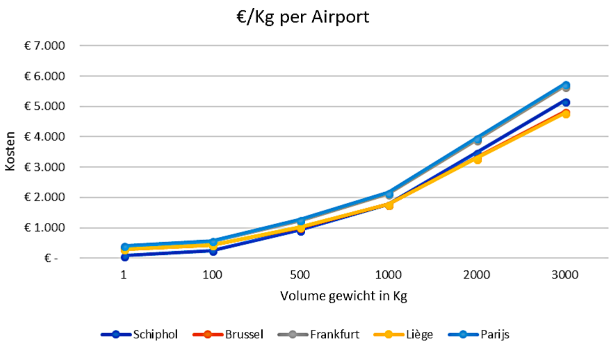

Figure 7: Cost per airport, for different weights of flowers per shipment.

Figure 8 shows the total score per factor for the five analyzed airports and table 8 shows the average score and the final ranking of the airports, based on the six analyzed factors.

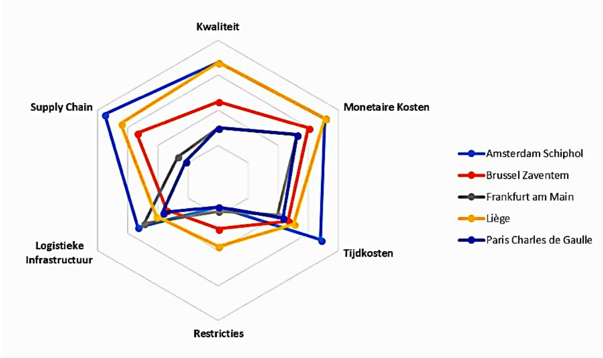

Figure 8: Airport score obtained for each of the factors.

The airport of Liège shows high scores on monetary costs and quality of air freight transport of flowers, but scores less on logistics infrastructure, time cost and supply chain. Also, the position of Schiphol as hub for flowers is affected by existing restrictions such as restrictions on noise nuisance and night flights.

Table 8: Ranking of the airports, based on the total costs. Source: Online survey flower sector (2018).

Airport	Total cost score
Amsterdam Schiphol	14.6
Liège	13.8
Brussel Zaventem	11.1
Frankfurt am Main	9.0
Paris Charles de Gaulle	8.3

Summarizing, Schiphol airport scores are higher than its competitors. The only factors that are subject to significant improvement are the airport logistic infrastructure and external restrictions. The study shows that Liège airport is Schiphol's most important competitor in the air freight transport of flowers. The overall scores of Liège airport are close to Schiphol’s scores. Both score equally on important factors, such as monetary costs and quality. In terms of restrictions, Liège scores better than Schiphol (because of no restrictions on night flights) but has to improve significantly to decrease its time costs. Brussels airport scores lower than Liege airport on all factors. Frankfurt and Paris score lower on almost all factors, although (particularly Frankfurt) both airports have a high-quality logistical infrastructure. The low score of these two airports is probably due to their distance from the auction. Paris is not really a competitor for Schiphol because the airport is far away and has not many connections with Kenya and Nairobi.

5. CONCLUDING REMARKS

Worldwide, large quantities of flowers are produced on three continents; South America, East Africa, and Europe. The major production sites of flowers that are transported to Europe are located in Africa. In East Africa, Kenya, Ethiopia, Rwanda, and Zimbabwe are the major suppliers of flowers. These locations have grown

rapidly because Dutch growers are very active in these countries. However, new production locations such as Colombia and Ecuador are strongly emerging as important production locations of cut flowers.
In Europe, the Netherlands is the traditional producer of flowers. From production locations outside Europe, the flowers are flown into Europe and America. Amsterdam is the main hub for flowers in Europe, but this position is under pressure. The analysis of KLM data (2017) shows that only 10% of what is being transported to Schiphol is again spread over the world by air. The remaining 90% is transported by trucks.
This study analyses the current international position of Schiphol as a hub for flowers in Europe. The analysis of various factors and the benchmarking of Schiphol with its competitors show that Liège Airport Schiphol is on the heels. Liège scores equally well on both monetary and transport costs, as well as the quality of services, and Liege scores over Schiphol in the area of restrictions. However, Schiphol is still at the forefront of logistics costs, particularly time costs, the quality of the logistics infrastructure and the location next to Aalsmeer. Of course, Schiphol can only benefit from its location when flowers are sold through the Flora Holland auction in Aalsmeer. As more and more flowers are increasingly sold outside the auction, the competitive advantages of Schiphol as flower hub in Europe, which was built around the international auction for flowers in Aalsmeer, comes under pressure, and raise serious questions about the future of the airport as European hub for flowers. Increasing competition from other airports, changes in networks of flowers, technological innovations and the possibilities of using other transport modalities for transporting flowers (e.g. containers) pose important challenges to the international Dutch airport in keeping ahead of its direct competitors in Europe and worldwide.

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DEFINITION OF DATA AND ENERGY EFFICIENCY INDICATORS OF FREIGHT TRANSPORT SECTOR IN MEXICO

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ABSTRACT
Throughout 2017, Mexico showed an energy independence index of 0.76. If the last ten-year trend continues, in fifteen years the country will become a full dependent nation on primary energy. It is necessary to pay attention to those economic sectors of significant influence for energy dependence. This paper contributes to the calculation of energy efficiency indicators for freight transportation, which can be used to design an integrated transport policy and subsequently monitor their effectiveness. Previous research indicates that national energy intensity for road freight transport was 0.5 MJ/tkm in 2011. This study estimates a new energy intensity value of 1.845 MJ/tkm by 2017 corroborating that the class T-3 is the predominant vehicle to move goods in the country with almost constant fuel economy in more than a decade. Consequently, transport efficiency has been poorly implemented. In a second phase, the survey methodology will be used to strengthen the estimated indicators.

Keywords: Indicators, energy efficiency, freight transport, integral policy.

1. INTRODUCTION

Globally, it is projected that the demand for energy will grow around 27 %, or 156 711.9 PJ from 2017 to 2040. Shared petroleum, natural gas, and coal use is estimated to grow 16 % between 2017 and 2040. Each of these fuels is projected to grow, but at different rates, led by natural gas at 43 %, petroleum at 10 %, and coal at 2 %. Electricity demand will exceed that of total energy demand growth with a 62 % increase in global power generation in the same period, the majority of which will come from developing countries. Total demand for renewable energy sources is expected to increase approximately 81 % by 2040, which would mean a share of 20 % of overall energy demand (Eule 2018).

Energy efficiency is the least expensive way to meet new energy demand. Improvements in energy efficiency reduce the amount of energy use required to provide a service. In this way, governments that encourage investment in energy efficiency and design policies to support their implementation generate multiple economic, social and environmental benefits. However, globally, energy efficiency has not been appropriated massively despite its multiple proven benefits and its potential to become the most abundant resource to meet the growing demand for energy worldwide (ACEEE 2019).

Worldwide, statistics show that the impact of energy efficiency on demand has been reduced by half in the last 20 years compared to the previous 20 years. One of the most important reasons is the lack of adequate data to construct the appropriate indicators. Without data there are no indicators, and without indicators it is tough to make a reliable situation assessment. Therefore, this information deficit entails difficulties to optimize the way of evaluating and designing policies, as well as to monitor progress and failures (IEA 2018).

As a result of globalization, transport sector is one of the major activities which consume more energy and produce gas pollutants (Mraihi 2012). According with Mihyeon and Amekudzi (2005), in order to assess progress towards a transportation system sustainability (defined through impacts of the system on the economy, environment, and general social well-being), energy efficiency indicators that can measure and monitor important deviations will be needed.

Before any strategy to make transport sector more sustainable and reduce its energy consumption and gas emissions, it is necessary to evaluate the sustainability degree of transport sector. Sustainable transport literature poses several indicators through them it is possible to measure energy demand and gas pollutants production associated to transport activity (Mraihi 2012).

The overall objective, according with Vera and Langlois (2007), is to develop a set of indicators that can lead obligatory modifications to appropriate databases and energy planning/evaluation models (and then be combined into those databases and models) to make them more reactive to sustainable energy development issues.

Existing studies give some evidence of how to perform road freight energy efficiency analysis from different perceptions and methods (Faberi, Paolucci, Lapillone and Pollier 2012; Leonardi, *et al*., 2008). Some of the possible approaches involves using national statistics, surveying, measuring and modelling, and analyzing them with a vehicle-approach perspective.

This paper is based on the approach of using administrative data for the information collecting according to the methodological proposal of the International Energy Agency (IEA 2018). In a second phase, it is intended to use, in combination, the survey methodology to validate and support data collection to build complete sets of energy efficiency indicators (EEI).

1.1. Freight transport in Mexico and energy efficiency performance

In Mexico according to the National Development Program (PND, for its acronym in Spanish) 2013-2018, given the importance of energy for the development of any economy, it was essential to supply energy to the country with competitive prices, quality and efficiency along the productive chain. The foregoing implied increasing the capacity of the State to ensure the supply of energy that the country would demand; strengthen the rational supply of electricity; promote the efficient use of energy, as well as the use of renewable sources, through the adoption of new technologies and the implementation of best practices (SEGOB 2014).

Specifically, the National Program for the Sustainable Use of Energy (PRONASE, for its acronym in Spanish) 2014-2018, is a guiding document that articulated energy efficiency policies by national and sectoral goals. It featured to the promotion of better use of energy resources through the increase of energy efficiency throughout all production processes and final consumption, contributing to achieve the energy security of the country, reduce the energy intensity of the economy and decrease the impacts of climate change on the environment.

Six objectives were established with their respective compliance indicators, to achieve the above. Being the primary the design and develop programs and actions that favor the optimal use of energy in processes and activities of the national energy chain, and a binding goal of: maintain at 2018 an energy intensity at least equal to that of 2012 (667.47 KJ / USD of GDP produced in 2008 currency) (SEGOB 2014).

Generally, according to data from the International Energy Agency (IEA 2019), the country performance in terms of energy intensity considering primary energy, has shown a decreasing trend in recent years, going from 0.102 toe / 1000 USD (2010) in 2012 to 0.0809 toe / 1000 USD (2010) in 2016, which represents a compound annual growth rate (CAGR) of -3.8 %.

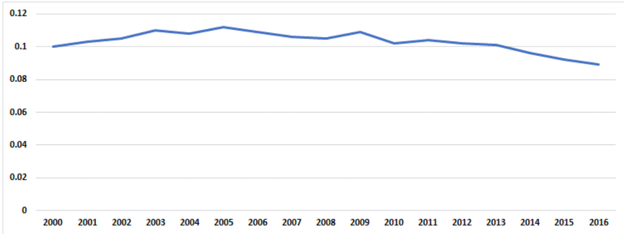

Figure 1: Mexico´s energy intensity considering primary energy (2000-2016). Own elaboration based on IEA (2019).

Regarding the country's energy security, at the end of 2017, Mexico showed an energy independence index equivalent to 0.76. That is, the country generated 24 % less energy than necessary to satisfy the various productive and consumption activities within the national territory. The energy independence is an index used internationally to measure the degree to which a country can cover its energy consumption derived from its production; if this is greater than one, it is considered that the country is energetically independent (SENER 2017).

During the last ten years, this indicator has varied on average by -5 %, so if the trend behavior is followed, in 15 years Mexico will become a country dependent on primary energy.

Therefore, it is necessary to pay special attention to those economic sectors that influence energy dependence and the definition of new ways of decarbonizing the economy in the short and medium-term, such as the transport sector, which currently consumes 44 % of the total energy of the country (SENER 2017), and is the primary source of equivalent carbon generating 148 megatons of CO_2e (SEMARNAT 2015).

Specifically, for the road transport subsector, key stakeholder of this study, among the different strategies proposed in the PRONASE 2014-2018 that would allow optimizing the use of energy at the country level, the principal one was: increase efficiency in the energy consumption of the transport sector.

In this sense, in the recent International Energy Efficiency Assessment published by ACEEE (2019), where Mexico occupies the position 12 of the 25 most energy-consuming countries in the world, it is recognized the need to incorporate more rigorous components on standards of fuel-saving for heavy-duty vehicles (HDV). Besides, the country could benefit if it increases its investment in rail transit. Regarding the efficiency of the road transport system, it is also shown as a potential area for improvement since Mexico has a high energy consumption per ton-km transported.

Indeed, based on data reported by Base of Energy Efficiency Indicators (BIEE, for its acronym in Spanish) (2019), the country consumes an average of 2 times more fuel per ton-km (tkm) than countries with higher share of road transportation in the total freight traffic, such as Germany, South Korea and Spain. Moreover 2.5 times more than its leading trading partner, the United States of America (Figure 2).

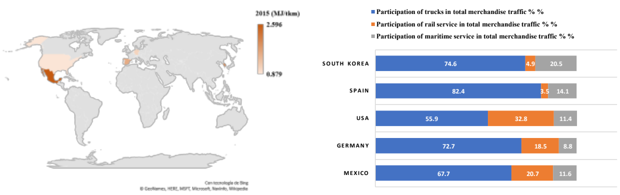

Figure 2: Unit consumption of freight transport assuming the same modal distribution as Mexico (2015). Own elaboration based on BIEE database, 2019.

Therefore, this research proposal intends to contribute to the definition of energy efficiency indicators (EEI) for the freight transport sub-sector, which can be used for the design of integrated public policies that consider and promote the interaction between infrastructure, transport and logistics (ECLAC 2010), and subsequently, monitor its effectiveness. Initially, this proposal is based on the approach of using administrative data (available until 2017), for the information compilation according to the methodological proposal of the International Energy Agency (IEA 2018). In a second phase, it is intended to use, in combination, the survey methodology to validate and support data collection and thus create more robust sets of indicators.

As the foremost previous research about energy efficiency indicators and its importance as an instrument for the energy transition at the country level, in 2011, the Ministry of Energy (SENER, for its acronym in Spanish) (SENER 2011), with financial and technological support from the IEA and the British Embassy, published the document "Indicators of Energy Efficiency in Mexico: 5 sectors, 5 challenges". Based on the statistical review, the assigned authors concluded that available information on freight transport was insufficient for the indicator's calculation; therefore, several meetings were held with different institutions and organizations related to the road transport. The result obtained for the road freight transportation using 648.5 PJ in 2010 - of which use of diesel predominated with 49.6 %, followed by 46.3 % of gasoline and 4.1 % of LP gas – was an energy intensity of 0.5 MJ per ton-kilometer.

2. METHODOLOGY

Under the principles of: a) the collection of data and the development of indicators should not be seen as an end in itself, but rather as a beginning for their subsequent use and b) collect only the necessary information to design and implement adequate policies, this proposal is based on the EEI suggested by the International Energy Agency (IEA 2018), which suggests an analysis of information by type of energy carrier. Thus, the following sections show the required information obtained from various databases and administrative documents that allow calculating the EEI for freight transportation.

2.1. Road Transport

During the last decade, the national GDP has shown a decreasing trend, going from 1.2 to 0.92 trillion dollars (Figure 3). Through the same period, the contribution of road transportation increased from 2.87 % in 2010 to 3.25 % in 2017 (CANACAR 2018).

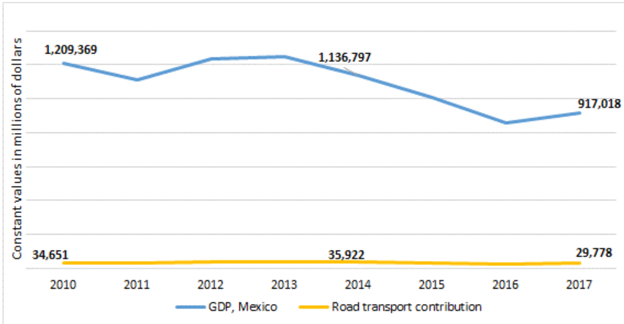

Figure 3: National GDP and road transport contribution (2010-2017) (constant values in millions of dollars). Source: Own elaboration based on data of CANACAR (2018).

Between 2000-2016, the total energy consumption of HDV compared to the total energy consumption of road transport (public and private) increased from 23.9 % to 24.9 %, with a total energy consumption of 524.3 PJ in 2016 (Figure 4) (BIEE 2019).

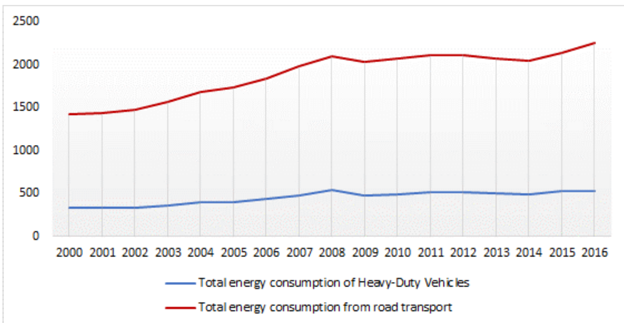

Figure 4: Total energy consumption of Heavy-Duty vehicles compared to total road transport (PJ). Own elaboration based on data from BIEE (2019).

It is obtained a value of 519.6 PJ as HDV total energy consumption by 2017, performing a polynomial approximation (r^2 = 0.9) for the data represented on the graph of Figure 4.
According to SENER (2018), in 2017 the national demand for oil derivatives was 1 543 thousand barrels per day (tbd), of which 79.4 % was destined to satisfy the needs of the transport sector. By type of engine, 97.6 % of the vehicle fleet used systems based on gasoline, that is, 33 489 thousand vehicles. The same year, approximately 1 148 thousand vehicles used diesel-based systems (SCT 2017).
The consumption of gasoline in 2017 was 798.8 thousand barrels per day, value which when divided by the number of vehicles with gasoline engine, an average consumption of 0.024 barrels per day/vehicle and a daily generation of 294.9 thousand tons of CO_2 are obtained (considering an average emission factor of 2.322 kg CO_2/liter (INECC 2014)).
From total diesel supplied in 2017 (344 tbd), 12.9 tbd were consumed by maritime transport and 13.4 tbd by rail transport. By difference, it is estimated that the road transport consumed 317.7 tbd (Figure 5), obtaining an average consumption value of 0.277 barrels per day/vehicle, 11.5 times more than vehicles with gasoline engine, and a daily generation of 131.13 thousand tons of CO_2 (considering an average emission factor of 2.596 kg CO_2/liter (INECC 2014)).

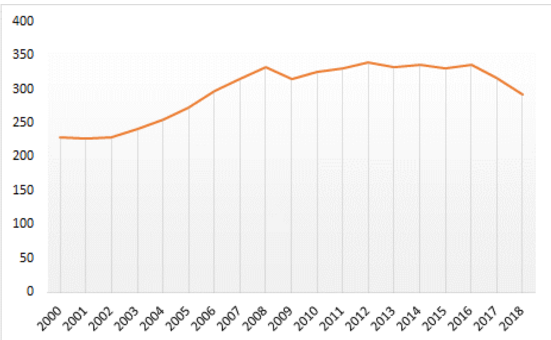

Figure 5: Demand from PEMEX Diesel during the period 2000-2018 (tbd/year). Own elaboration based on the Energy Information System (SIE)

In the medium term, SENER (2018) foresees that gasoline will continue to be the fuel with the highest demand for motor transport, increasing its demand by 30 %, reaching 1 040 tbd in the year 2032. Similarly, during the period 2018-2032, the consumption of diesel will increase by 55 %, reaching 492.7 tbd, because of the increase in the vehicle fleet that uses this fuel intensively.
Currently, in Mexico, the demand for diesel in the transport sector is mainly used to the transport of cargo and passengers (SENER 2014). During 2017, the classification of vehicle units of the cargo motor carrier by vehicle class consists of four types of vehicles, as shown in the following Table 1.

Table 1: Classification of units of road freight transportation by vehicle class and the number of units in 2017. Source: Own elaboration based on SCT (2017).

Vehicle	Class	Total, at a national level
Two axle truck	C-2	84 226
Three axle truck	C-3	73 909
Two axle tractor	T-2	2 968
Three axle tractor	T-3	301 088
Others		825

From previous Table 1, a total of 463 016 vehicles are obtained, of which 420 527 (91 %) operated with diesel (Table 2). Another type of cargo vehicle, such as cranes, hoppers, mixers, represent 497 124 units. Likewise, in the same year, 231 000 diesel passenger buses circulated in Mexico (SCT 2017).

Table 2: Vehicles for freight transportation by type of energy carrier, 2017. Own elaboration based on SCT (2017).

Diesel	Gasoline	Natural gas	NG-Gasoline	Electricity
420 527	35 853	1 862	4 773	1

According to data of Ministry of Transportation and Communications (SCT, for its acronym in Spanish) (2017), the traffic of tons-kilometer (tkm) transported by road during the period 2010-2017, has grown at a compound annual rate of 2.18 % in the different modalities of transportation. In the following Figure 6, can be seen that the vehicle class T-3 is the predominant vehicle with a share of 82 % from total material displaced in 2017 (281 617 million of tkm).

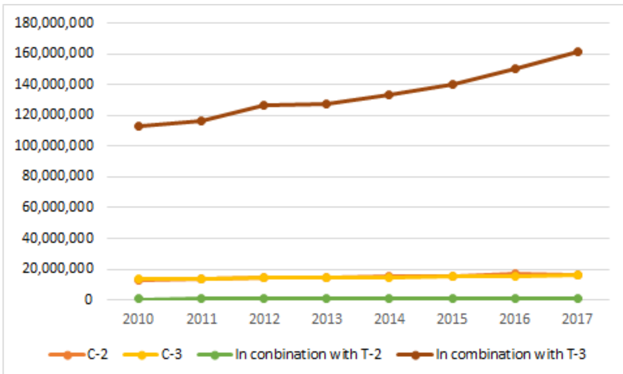

Figure 6: Thousands of tons-kilometer (tkm) of cargo transportation by type of vehicle. Own elaboration based on data from SCT (2017).

Concerning total tons transported by vehicle class in 2017, 71.8 % or 431.5 million tons were transported in vehicles class T-3 with an average distance traveled per ton transported of 535 km (Table 3).

Table 3: Demand served, ton-km and average distance traveled per ton transported, by vehicle class, own elaboration based on data from SCT (2017).

Vehicle class	Demand served, tons (thousands)	Traffic, tkm (thousands)	Average distance traveled per ton transported (km)
C-2	37 732	7 238 163	192
C-3	73 206	16 371 699	224
In combination with T-2	4 149	1 574 249	379
In combination with T-3	431 501	230 951 889	535
Others	54 396	25 480 800	468.4
Total	600 984	281 616 800	

Another variable suggested by the IEA about EEI of freight transport is the total vehicles-km (vkm), which is obtained from the sum of the product of the number of vehicles of the different classes multiplied by its average distance traveled per ton transported (km), obtaining a total of 427.8 million vkm in 2017 (Table 4).

Table 4: Estimation of vkm for different types of cargo vehicles, 2017.

Vehicule class	Number of vehicles	km	vkm
C-2	84 226	192	16 136 298
C-3	73 909	224	16 528 693
T-2	2 968	379	1 126 207
T-3	301 088	535	161 150 771
Others	497 124	468.4	232 852 882
		Total	427 794 851

Concerning the average performance of fuel consumption from HDV, during the period 2000-2016, it has practically remained constant, going from 40.7 liters/100 km to 40.1 liters/100 km (2.46 km/l to 2.49 km/l) (Figure 7). In the same period, traveled kilometers per year (km/year), fluctuated from 29 201.5 to 33 555.7 (BIEE 2019).

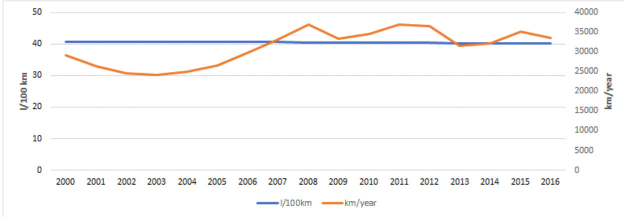

Figure 7: Kilometers traveled by HDV versus specific fuel consumption (2000-2016). Source: Own elaboration based on data from BIEE (2019).

It is obtained that by 2017 the different types of vehicles with diesel combustion systems traveled 31 036.4 km on average, performing a polynomial approximation (r2 = 0.91) for the data represented on the graph of Figure 7. With this new information and considering as a constant the fuel consumption performance of 2016 (2.49 km/l), is estimated that the 917 381 vehicles consumed 197 tbd. It represents 57.3 % of diesel consumption from total transport sector, with an average daily consumption of 0.215 barrels/vehicle, what represents 407.83 PJ on an annual basis (considering an average density= 0.826 kg/l and average calorific value= 43.18 MJ/kg (INECC 2014)).

2.2. Rail service

During the period 2000-2017, the railroad freight system increased its participation in ton-kilometers transported at a compound annual growth rate of 2.7 %. In 2017, the system mobilized 86 332 million tons-km, with an average distance traveled per ton transported of 680.45 km (SCT 2018). According to SENER (2018), diesel consumption in the same year was 13.4 tbd, which represents an energy demand of 27.73 PJ (considering an average density= 0.826 kg/l, one barrel= 158.987 liters and average calorific value= 43.18 MJ/kg (INECC 2014)).

In 2017, the total number of locomotives was 1 295. Total number of locomotives multiplied by the average distance traveled per ton transported (680.45 km), it was obtained a total of 881 182.75 vkm in 2017.

2.3. Maritime service

In 2017, considering only the coastal shipping, 37 658.8 million of tkm were transported, approximately 20 % less tkm than in 2011 (maximum value in the period 2000-2017) (SCT 2018, BIEE 2019). In 2017, the total energy consumption of the maritime service was 27.528 PJ (SENER 2018), although the referred document does not specify whether this consumption is entirely for national cargo or also consider recharging fuel for foreign vessels. In the absence of information, 50 % of energy consumption will be considered for coastal shipping or 13.764 PJ during 2017. The total number of cargo ships in 2017 was 2 496. Given that the average distance traveled per ton transported is 631 km (SCT 2018), the vkm for coastal shipping is 1 574 976.

2.4. Air Service

The participation of air cargo transport in this study is not considered, due to lack of data and because it only transported 1 % of the 733 884 thousand tons of national cargo in 2017.

3. RESULTS AND DISCUSSION

Based on data reported by BIEE (2019), in the following Figure 8 shows the performance of energy intensity of different types of freight transportation between 2000-2016, in units of megajoules per ton-kilometer (MJ/tkm). The energy data include the different energy carriers used by type of transport. In the case of road transportation, its energy intensity (IE) has grown with a CAGR of 0.9 % showing a short-term decrease trend, in the case of rail transport, this has decreased its IE by -1.26 % per year as well as maritime transport with a CAGR of -2.23 %, with a negative trend behavior in the short term for both.

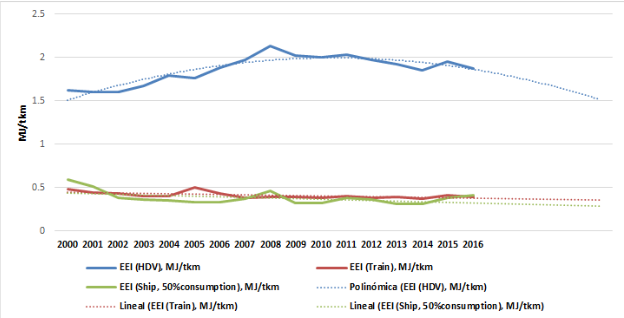

Figure 8: Energy intensity of freight transport between 2000-2016 (MJ/tkm). Source: Own elaboration based on data from BIEE (2019).

Following the methodology from IEA, the calculation of EEI of freight transportation, specifically for the year 2017, is shown below. For the calculation of F1a indicator, the total freight transport energy consumption value was obtained from BIEE (2019) and the total transport sector energy consumption value of 2 360.16 PJ was obtained from SENER (2017). Following the same procedure, with data from BIEE (2019), SENER (2013) and SCT (2012), the resulting indicators for 2012 are shown as a comparison.

F1a = Total freight transport energy consumption

- F1a = Total freight transport energy consumption / Total transport sector energy consumption
- F1a = 586.91 PJ / 2 360.16 PJ = 0.2487

	2012	2017
F1a	0.2544	0.2487

F1b = Share of each energy source in total freight transport energy consumption

- $F1b_{diesel}$ = Total diesel energy consumption / Total freight transport energy consumption
- $F1b_{diesel}$ = (407.83 + 27.73 + 13.76) PJ / 586.91 PJ
- $F1b_{diesel}$ = 449.32 PJ / 586.91 PJ = 0.7656

	2012	2017
F1bdiesel	0.964	0.766

F1c = Freight transport oil consumption (tbd)

	2012	2017
$F1c_{truck-diesel}$	247.2	197
$F1c_{train-diesel}$	12.7	13.4
$F1c_{ship-diesel}$	15.6	12.9

F2a = For each cargo mode / vehicle type: energy consumption per vkm (GJ/vkm)

- $F2a_{truck-diesel}$ = 407 830 000 GJ / 427 794 851 vkm
- $F2a_{truck-diesel}$ = 0.9533 GJ/vkm
- $F2a_{train-diesel}$ = 27 734 656.61 GJ / 881 182.75 vkm
- $F2a_{train-diesel}$ = 31.474 GJ/vkm
- $F2a_{ship-diesel}$ = 13 763 840.78 GJ / 1 574 976 vkm
- $F2a_{ship-diesel}$ = 8.739 GJ/vkm

	2012	2017
F2atruck-diesel	1.632	0.9533

F2c = Freight transport energy consumption per total tons-kilometers (MJ/tkm)

- F2c= 586.91 PJ / (281 617 + 86 332 + 37 658.8) million tkm
- F2c= 586.91 PJ / 405 607.8 million tkm
- F2c= 1.44699 MJ / tkm

	2012	2017
$F2c_{diesel}$	1.4965	1.447

F3a = Freight transport energy consumption / GDP (MJ/dollar)

- F3a= 586.91 PJ / 917 018 million dollars
- F3a= 0.64 MJ / dollar

	2012	2017
$F3a_{diesel}$	0.45	0.64

F3b = For each freight mode/vehicle type: energy consumption per total tons-kilometer (MJ/tkm)

- $F3b_{HDV}$ = 519.6 X 10^9 MJ / 405 607.8 million tkm
- $F3b_{HDV}$ = 1.281 MJ / tkm

- $F3b_{Train}$ = 27 734 656 606 MJ / 405 607.8 million tkm
- $F3b_{Train}$ = 0.0684 MJ / tkm
- $F3b_{Ship}$ = 13 763 840 778 MJ / 405 607.8 million tkm
- $F3b_{ship}$ = 0.034 MJ / tkm

	2012	2017	CAGR
$F3b_{HDV}$	1.333	1.281	-0.8%
$F3b_{Train}$	0.0786	0.0684	-2.7%
$F3b_{ship}$	0.042	0.034	-4.1%

Freight transport in Mexico reduced its energy intensity by 3.3 percentage points between 2012 and 2017. In 2017, national freight transport consumed 24.87 % of total energy consumption from transport sector, 2.2 % less than in 2012. Data also indicate that T-3 vehicle class is the transport unit that most displaces goods (tkm) in the country, using diesel as the primary fuel for long travel distance.

Considering diesel as the single fuel of the freight transport sector, due to lack of information for others energy carriers, the energy intensity of freight transport (MJ/tkm) shows a slightly negative trend for the different types of transport in the country between 2012-2017, in the range of -0.8 % to -4.1 % this is possibly due to technological progresses or infrastructure improvements.

Comparing the HDV energy intensity value estimated in 2011 to the one estimated in this paper by 2017, there is a growth of 3.7 times, going from 0.5 MJ/tkm to 1.845 MJ/tkm (519.6 PJ / 281 616.8 million tkm). Given that fuel economy (liters/km) has remained constant for the last ten years, the only variable that could affect the energy intensity growth are the tons transported per trip, which should have been reduced in 3.7 times also, but the tons transported have also increased in the last ten years. Which could mean that today to move the merchandise in the country it needs more vehicles than before or that the load capacity is underutilized, causing an excess in fuel consumption.

Since productivity is defined as the relationship between the quantity of what is produced and the quantity of inputs used (ECLAC 2016), making an analogy to the transport of goods, the inverse of the energy intensity would be the productivity of the transport of goods, that is, how many tons-kilometer move through a unit of energy.

So, at higher energy intensity, lower productivity and vice versa.

Therefore, in order to move towards greater productivity values in freight transport, it is necessary to consider the following factors in the design of integrated transport policies: technological change (e.g. reduction of vehicles life cycle, technologies for reducing fuel consumption, multimodality), increasing efficiency (doing more with less), greater use of load capacity and improving fleet management and distribution processes (ECLAC 2016).

Also, in 2017, the freight transport sector requires 42 % more energy to produce an additional dollar of GDP compared to 2012.

4. CONCLUSIONS

Considering the imminent forecast of growth in demand for diesel and gasoline in the country, it is necessary to be clear about how these fuels are consumed in order to define and implement the necessary measures to improve its consumption. This study describes freight transport in Mexico: utilization, productivity and efficiency. Vehicle class T-3 is the principal means of transport to move goods in the country with 82 % of tkm in 2017, using diesel as its primary fuel and with almost constant fuel economy in more than a decade.

The study makes a comparison of freight transport performance between 2012 and 2017 and shows that freight transport efficiency has been poorly implemented, especially for the most used type of transport, the HDV, which has only reduced its energy intensity by 0.8 percentage points.

Although the energy intensity of road freight transport has been decreasing in the last five years, the sector consumes twice as much energy per tkm than countries with higher share of road transportation in the total freight traffic. This situation represents several improvement opportunities through the identification of the most appropriate technologies and the optimization of materials handling and distribution processes that would reduce fuel consumption, thus impacting on the reduction of polluting emissions.

It is necessary to complement the results found in this study with other data collection methodologies such as the application of surveys or measurement, to obtain highly reliable indicators for the design of an integrated transport policy.

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ECONOMIC IMPACT OF FREIGHT TRANSPORT´S VULNERABILITY IN MEXICO

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ABSTRACT
In recent years, the risk involved in merchandise transportation in Mexico generates a particular interest among citizens, government and private companies, due to the impact that the latent risk causes in the socio-economic activities of the affected areas. Researchers in these fields of study have analyzed the vulnerability of transport from different approaches, considering information as the fundamental resource to develop some strategies that may offer security to the companies involved, meanwhile their merchandise is moved through the local territory. This document shows an overview of the situation of vulnerability of freight transportation in Mexico, giving statistics on the modes of transport that allow us to describe the economic impact that this activity represents in the economy of the country and the changes that it has had over the last, due to the risk to which transport is exposed.

Keywords: Freight transport, Cargo theft of transport, Multimodal transport, Economic impact

1. INTRODUCTION

Freight transportation in Mexico is considered an important productive sectors in the country's economy, because this sector contributes 3% to the country's gross domestic product (GDP), which moves 56% of goods by road (Enfasis Logistica 2018). The means of transport used for the transfer of goods through the local territory are land transport (truck and rail), ship, plane, pipelines and the combination of these, by intermodal transport and multimodal transport. The risk level of these modes of transport depends on the area which it operates. Under this context it is important to define risk and level of risk as basic concepts for the development of the document. *Risk* is the combination of the probability of an event and its negative consequences.
The word "risk" has two distinctive connotations: in popular use it is generally placed in the concept of chance or possibility as in "the risk of an accident"; while in technical settings the emphasis on consequences is generally placed, in terms of "potential losses" for some particular cause, the place and period. On the other hand, "*Risk Assessment"* is a methodology to determine the nature and scope of the risk, through the analysis of the potential danger and the evaluation of the existing conditions of vulnerability, which together could cause damage to the exposed people, to the material goods, services, livelihoods and the environment.
Flores (2018) mentions that "the evaluation of risk that involve operations of handling, storage, transport and distribution of products requires primarily the identification of causes of losses, detection of risk probability situations and establish preventive measures aimed at reduce and minimize the risks in the transport area". Therefore, to define the methodology for risk assessment it is important to review the characteristics of the agents that generate the hazard, such as hazardous materials, human factors and natural phenomena, as well as the analysis of the exposure and vulnerability of the population and the environment.
In short, cargo transportation is exposed to natural and human factors, as well as to the handling and transportation of products from an origin to a destination through the different modes. The cargo risk depends on the characteristics of the merchandise. The classification is showed in Figure 1, 2 and 3.

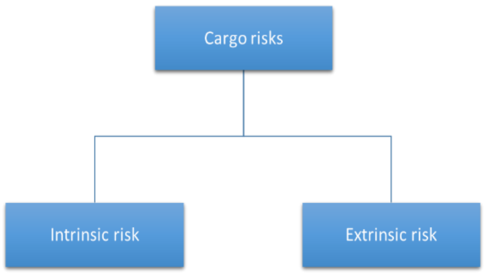

Figure 1: Cargo risk according to the merchandise.

- Intrinsic risk is evaluated according to the intern characteristics of the product and the special operation to transport and handling the product. Figure 2 shows some factors.
- The extrinsic risk is determined according to the external environment, natural events or external agents through the movement of the load. Figure 3 shows some factors in this case.

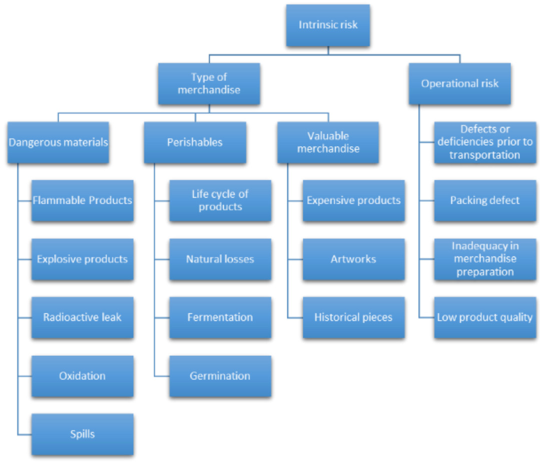

Figure 2: Cargo risk according to intrinsic risk of merchandises.

Figure 3: Cargo risk according to extrinsic risk of merchandises.

The risk factors analyzed in this document are those in which the human are involved as an active part of the event (human interface), such as:

- Intentional: The person has a clear objective and knows the consequences to do the action, for example: robberies, piracy, captain's bargain, employee infidelity, etc.
- Unintended: Accidents during loading, unloading and handling of merchandise, considering improper handling due to lack of expertise or training (Parada 2017).

The main objective of this research is to show a global panorama of the current situation of freight transport in Mexico in its different modes of transport, and the economic impact that the latent risk, specifically in cargo theft, on the operation and transfer of merchandise has in the economy of the country, as well as mentioning the security measures that are currently being implemented by the government and the companies to prevent these events. The study is developed through the statistical analysis of data obtained from databases of institutions such as: the National Institute of Geography (INEGI 2018), the Ministry of Communications and Transportation (SCT 2018), the Mexican Institute of Transportation (IMT 2017), National Chamber of Freight Transport (CANACAR 2018), Petróleos Mexicanos (PEMEX 2019) and the Senate of the Republic (2016) among other institutions.

2. BACKGROUND

The issue of risk in the supply chain is being a relevant issue for researchers because of the impact it has on the economy of a country, state, municipality and the companies involved in this activity, however the issue of security in the transportation area is still scarce and promptly in theft in cargo transportation, due to the variety of factors that influence this link in the chain.

The theft of merchandise during its transfer from its origin to its destination is caused due to social, political and economic events, such as terrorism, vandalism, organized crime, corruption, impunity, changes in political power, ungovernability, unemployment, etc., in addition of the lack of mechanisms to prevent and combat these situations. This phenomenon is known in the literature as one of disruption factor of the supply chain.

Some studies carried out by researchers interested in this topic can be found in works developed by Sheffi (2001) who shows a study to understand the risk of the supply chain considering disruption events due to terrorist events; Tsamboulas, Moraiti (2008) designed a model from a multicriteria approach to assess the risk of international supply chains to prevent terrorist acts. The IMT (2003) shows in its diagnosis about logistics platforms and some of the problems that freight transport in Mexico has during the transfer of goods from Canada and the United States. On the other hand, the interruption of transport is identified as a result of the destruction and loss of cargo according to Cavinato (2004). The interruption of the supply chain and specifically in the interruption of freight transport is studied by authors as (Young, Esqueda, 2005; Martner, Morales, De la Torre, 2005) who consider transport as the link more fragile and with greater risk in the chain.

Rodríguez et al. (2008) show in their research the impact of uncertainty on transport operations in supply chains. De la Torre et al. (2013) analyze the phenomenon of theft to freight transport and show a methodology to evaluate this risk caused by the theft of goods, in addition to proposing the relevant variables of irrigation for this type of events.

Currently, one of the factors that has increased the insecurity of freight transport in Mexico is violence, which causes transport operators to lose their lives, be physically and psychologically affected, or abandon their job due to the high risk. Urciuoli (2010) believes that transport insecurity impacts directly to the companies, causing large losses and the country's economy too. This factor has made that researchers focus their works on it, looking for the causes and its effects. Some related works to the cargo theft with violence have been developed by Van Marle (2015), Karlsson (2014), Ekwall, Lantz (2013, 2015a, 2015b, 2016, 2018).

Data are fundamental in this kind of works and statistics is one of the basic and easy tools to study and to determine the disruption of transport in the chain, however the necessity to identify with more detail other qualitative factors together with quantitative ones, have allowed to propose methodologies such as the SCOR (Supply Chain Operation Reference Model) that allows to evaluate and to explore each one of the members involved in the chain and the way to develop their activities, Böhle et al. (2014) explore and evaluate the disruption of transport from this approach; Cedillo et al. (2014); Gu, Tagaras, Gao (2014) propose a system dynamics model, Burgholzer et al. (2013) used micro traffic simulation in the analysis of intermodal transport networks. De la Torre et al. (2013) using the Delphi method and establishing weights through the Analytic Hierarchy Process (AHP) defined the disruption´s variables in the transport. Lorenc, Kuźnar (2018) developed Algorithms based on the artificial neural networks, just to mention some works.

3. TRANSPORTATION INFRASTRUCTURE IN MEXICO

In Mexico has five transport modes: road, rail, air, sea, and pipeline. The infrastructure in this field is growing every year to support the move merchandise all over the country. Tables 1, 2, 3, and 4 show the infrastructure data for each transport mode.

Table 1 shows the length in kilometers of the national road network by type of road in Mexico and the growth of the infrastructure.

Table 1. Length of the national road network by type of road and surface state

National Road Network	2000	2006	2011	2012	2013	2014	2015	2016	2017
Federal route	48,464.00	48,319.00	49,102.00	49,652.00	49,986.00	50,241.00	50,403.00	50,499.00	51,020.00
Toll route	6,598.00	7,558.00	8,459.00	8,900.00	9,174.00	9,457.00	9,664.00	9,818.00	10,430.00
Free route	41,866.00	40,761.00	40,643.00	40,752.00	40,812.00	40,784.00	40,739.00	40,681.00	40,590.00
State route	64,706.00	72,179.00	80,774.00	83,982.00	85,076.00	93,521.00	94,983.00	95,855.00	120,414.00
Rural route	149,338.00	167,877.00	169,072.00	169,429.00	169,311.00	175,775.00	175,521.00	177,657.00	157,348.00
Small route	60,557.00	68,570.00	75,314.00	74,597.00	74,550.00	69,808.00	69,394.00	69,462.00	69,367.00
Total	323,065.00	356,945.00	374,262.00	377,660.00	378,922.00	389,345.00	390,301.00	393,473.00	398,149.00

*Numbers in Kilometers. Source: SCT (2018).

Table 2. Length of railway and rail transport equipment

Concept	2000	2006	2012	2013	2014	2015	2016	2017	2018
Rack length (Kilometers)	26,656	26,662	26,727	26,727	26,727	26,727	26,727	26,914	26,914
Main	20,688	20,687	20,722	20,722	20,722	20,722	20,722	20,826	20,826
Secundary	4,413	4,420	4,450	4,450	4,450	4,450	4,450	4,533	4,533
Private	1,555	1,555	1,555	1,555	1,555	1,555	1,555	1,555	1,555
Railway equipment									
Freight cars	30,635	32,013	29,318	30,168	30,855	32,054	31,627	32,454	32,286
Passenger cars	220	60	129	135	128	130	123	135	148
Locomotives	1,446	1,245	1,231	1,243	1,207	1,280	1,298	1,295	1,274

*Numbers in Kilometers. Annual series 2000, 2006 and 2012 to 2018. Source: SCT (2018).

Table 3. Airport infrastructure and air fleet

Concept	2000	2006	2012	2013	2014	2015	2016	2017	2018
National Airport System	85	85	76	76	76	76	76	77	77
Airports national service	28	26	12	12	13	13	12	13	13
Airports international service	57	59	64	64	63	63	64	64	64
Airfields	1,130	1,259	1,388	1,393	1,431	1,413	1,424	1,433	1,451
Aircraft	6,476	7,216	9,367	8,799	8,961	9,751	10,081	10,247	9,689
Commercial	1,173	1,489	2,166	1,933	2,011	2,295	2,414	2,561	1,767
Officers	517	324	569	439	441	563	575	473	392
Private	4,786	5,403	6,632	6,427	6,509	6,893	7,092	7,213	7,510

Annual series 2000, 2006 and 2012 to 2018, Source: SCT (2018).

Table 4. Port infrastructure, number of ports per litoral, abanderated boats and fleet Mexican merchant

Concept	2000	2006	2012	2013	2014	2015	2016	2017	2018
Port maritime infrastructure									
Protection works (Meters)	136,001	155,076	166,944	167,296	172,161	179,404	179,649	181,438	181,438
Docking works (Meters)	184,946	202,144	212,579	210,854	211,651	214,155	215,040	216,946	217,211
Storage areas (M2)	5,539,091	4,840,512	7,791,591	7,872,112	7,872,252	7,937,483	7,951,983	8,248,310	8,589,690
Porlitoral ports	108	113	117	117	117	122	122	122	122
Pacific	54	55	58	58	58	59	59	59	59
Gulf and caribbean	54	58	59	59	59	63	63	63	63
Standard- bearer ships like Mexicans	34	57	42	47	48	49	47	82	61
Mexican Merchant Fleet flagged	2,200	2,367	2,504	2,538	2,572	2,570	2,371	2,735	2,565

Annual series 2000, 2006 and 2012 to 2018, Source: SCT (2018).

The previous infrastructure for transport modes offer services for private and official activities in Mexico. The current statistics regarding the modes of transport reported by the SCT (2018) are shown in Table 5.

Table 5: Freight and passenger transported in México

Transport mode	Tons transported	%	Passengers transported	%
Freight and passenger motor transport	556.4	55.5	3773.0	95.6
Rail Transport	128.0	12.8	58.0	1.5
Maritime transport	317.0	31.6	19.0	0.5
Air transport	0.8	0.1	96.0	2.4
Total	1002.0	100.0	3946.0	100.0
* Numbers in Millions				

Source: SCT (2018).

Figure 4 and Figure 5 show the comparison among different modes of transport in terms of freight and passenger transport services.

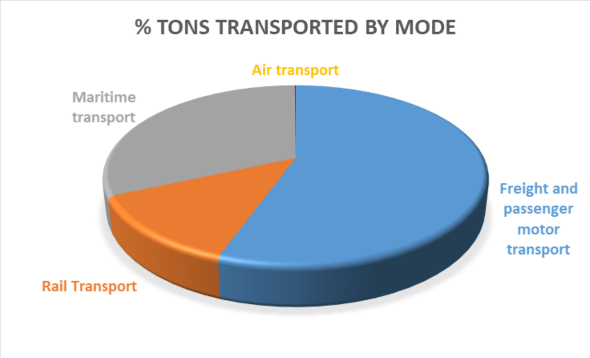

Figure 4: Comparison modes to freight in tons transported. Source: SCT (2018).

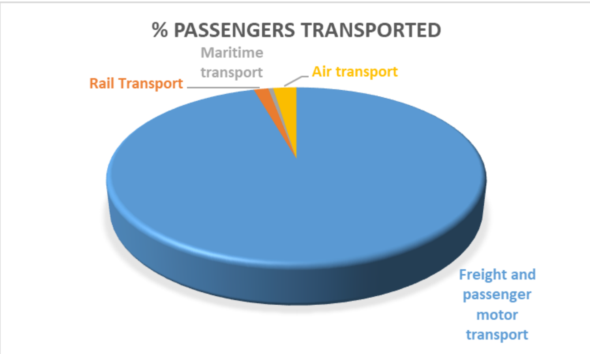

Figure 5: Comparison modes to passengers transported. Source: SCT (2018).

CANACAR (National Chamber of Freight Transport) in its 2018 economic agenda, reports 982 million tons per year during 2017. Tons transported by truck 55.7%, ship 31.3%, train 12.9%, and plane 0.1% (CANACAR 2018, Loza 2019).

4. STATISTICS ON THE VULNERABILITY OF TRANSPORT

4.1. International vulnerability of transport

A global overview of the situation of freight transport in the world and promptly about the cargo theft is described by Van Marle (2015), who mentions the top 10 hotspots for violent freight crime in Europe, they are Paris, Italy (Lombardy, Apulia, Campania), Germany, Russia (Moscow, St Petersburg), UK, South-east Netherlands and Rotterdam, Belgium, Sweden, Spain (Madrid, Catalonia, Andalusia), Poland, and Ukraine. According to Sensitech's second-quarter 2018 U.S. and Canada cargo theft analysis "157 cargo thefts were reported in the period, slightly down from 2017. The average cargo value per theft event was $186,779 dls for a total of $29.3 million of dls in losses. The thefts involved 342 stolen vehicles, including 120 semi-tractors and 155 semi-trailers. The most targeted goods: food, building supplies, household goods such as appliances, and electronics, including computers and televisions", (Transport Topics 2018). Willett (2019) reported that when assessing risk of cargo theft moving goods by sea appears to be a relatively less risky mode of transport compared with other modes, but it exists by piracy and armed robbery. In terms of the top two modalities of theft, 84% occurred from vehicles, 13 % occurring from fixed facilities, and 1% occurred from rail transport, other modes was 2%. The risk on Transport Sea is at the point of loading or off-loading. Risk to maritime cargo in port remains, with theft from facilities featuring as the fourth risk (13%). In terms of theft from facilities, Asia was the region of largest risk, with 43% of cargo thefts across the region occurring at fixed facilities. In the Middle East/Africa region, facility theft accounted for 23% of thefts. Values for North America 9%, South America 8%, and Europe was 4%.
CargoNet (2018) Command Center recorded in United Stated that thefts at warehouses were the most common in third-quarter 2018 with 19 % of cargo thefts. Warehouse thefts also accounted for more than $3.7 million in loss value in the same quarter. Thefts at truck stops were the next common loss location and finally thefts at parking lots.

4.2. Mexican vulnerability of transport

Johnson (2018) reported that in Mexico highway robbers and railway bandits are riding high, causing serious damage on the national economy. Criminal gangs along the highways and rail lines increasingly rob in league with powerful narcotics cartels that are diversifying into other types of crime. Train robberies occur an average of 4.5 times a day, and parts of Mexico are so rife with truck hijackings that one newspaper labeled them "Bermuda Triangles," referring to the Atlantic Ocean region where ships and planes supposedly have vanished.
González (2010) said "the highway section of the Federal District to Veracruz (passing through the State of Mexico and Puebla) is the most dangerous in the country and with the highest criminal incidence, which has led truckers to classify the area as the Bermuda Triangle, due to how dangerous it is to travel through it".
CANACAR (2018) reported approximately more than 10,000 highway cargo thefts last year, a 40 % spike over the previous year. Mexican Association of Security and Industrial Satellite Companies estimated that losses from cargo theft last year amounted about $9 billion MX, or nearly 1 % of the country's economic output. Cargo theft is a problem worldwide, but it has a violent edge in Mexico. The drug cartels get more efficient, they get information from warehouses and customs personnel about truck routes and valuable cargo loads, also CANACAR says that other factor in cargo theft was collusion between corrupt police and gangs.
Harmon (2019) mentiones that cargo theft in Mexico has exploded since 2015, and totaled more than 4,000 thefts in 2017, according to SensiGuard Supply Chain Intelligence Center's annual report on cargo theft in the country. The 1,105 thefts in 2015 grew by 61% to 1,773 in 2016. The state of Puebla had 1,235 thefts last year, a rise of more than 300% from 2016. Nuevo Leon saw a rise of more than 1,000% from 23 in 2016 to 262 thefts last year.
Comparative statistics presented for the year 2018 and 2019 by SensiGuard (2018, 2019) and Hernández (2019), shows that the states with the highest incidence of theft are Puebla, State of Mexico and Michoacán.

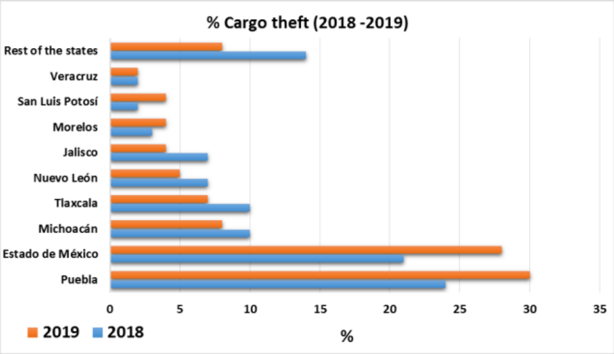

Figure 6: Comparative statistics Cargo theft (2018 -2019). Source: SensiGuard (2018).

During the second quarter of 2018, 94% of incidents of cargo theft by region in the country were concentrated in the Central (63%), West (20%), and Northwest (11%) regions. Figure 7 shows the data.

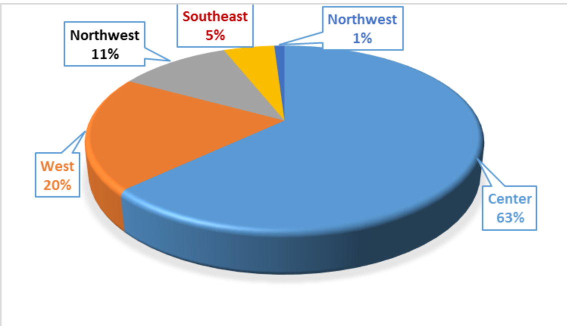

Figure 7. Percentage of Theft per region in México (Q-2, 2018). Source: SensiGuard (2018).

The theft of cargo by location of transport were in transit 77%, train 16%, unsafe parking 4%, and inside the facilities 3%. "The high risk roads are now Mexico-Veracruz with 18% of thefts, followed by Mexico-Saltillo (11%), Maxipista (10%), Mexiquense External Circuit (9%), Mexico-Zacatepec and Uruapan-Lázaro Cárdenas (6% both)" (Almonte 2019). Figure 8 shows the data.

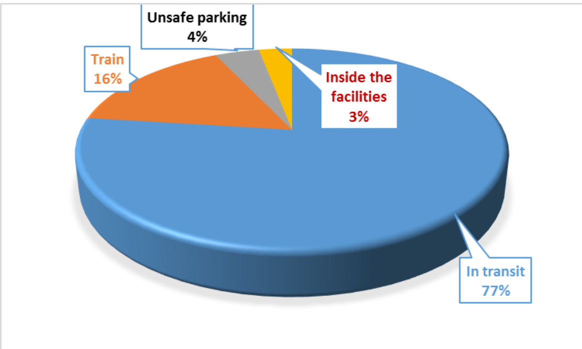

Figure 8. Percentage of theft per location during the event in México (Q-2, 2018). Source: SensiGuard (2018).

Other important data are the cargo theft by type of event which the robbery with deprivation of the freedom of the operators was 82%, rappiration 16%, last mile 1%, and theft of insulations 1%. The products with the highest incidence of cargo theft are fuel 39%, food and beverages 24%, construction and industry 6%, chemicals 4%, and electronics 4% (SensiGuard 2018).

5. IMPACT OF THE CARGO THEFT

In general, the impact of insecurity in cargo transportation in Mexico is directly reflected in the economic losses that the companies involved have. The physical and psychological damage that operators suffer when they are threatened or deprived of their freedom at the time of performing their daily work. The marginalization of the development of the regions in which cargo theft events take place, because companies do not want to invest in local businesses, to cross these dangerous regions, to make use of the services of the companies installed in risky areas, and the distrust of the employment of the people of those places. Finally, the unnecessary expenses for the government for the deployment of security forces to keep the protected areas.

Some factors that are directly affected in the Supply Chain are the costs involved in the handling of goods: Supply costs (supply and transport), which are affected at the time of making a supply of merchandise again due to the theft of this in its transit. The replacement of the merchandise, which implies production costs, reprocessing or replacement of the order placed by the customer. The cost of time and labor invested in the order requested by the customer, also the costs for late delivery time with the customer. Delivery guarantee costs to ensure the customer service offered by suppliers. Insurance costs of merchandise in transit, based on contracts made by customer-supplier. Costs of lost sales due to lack of fulfillment in order delivery. Loss of delivery reliability the suppliers and the transport companies who offers the service, (LPM 2018).
Milenio (2019) points out that "Mexico daily loses at least 17 million pesos a day, due to the theft of merchandise", these data are reported by information obtained from the National Institute of Statistics and Geography (INEGI), the Executive Secretariat of the National System Public Security (SESNSP), the Mexican Insurance Association. Also, they ensure that the total cost of motor transport insecurity during 2018 was estimated in 43,665 million of MX, affecting 38% of the country's economic activities.

6. PREVENTION MEASURES FOR THEFT OF CARGO

Currently the federal government in conjunction with state and municipal governments are implementing security measures against cargo theft in transportation, however due to the magnitude of the problem, the work done by the government is not reflected.
Some private companies and government agencies are designing prevention plans and practices of prevention within their facilities, such is the case of IMT, SCT, National Association of Private Transportation (ANTP), and CANACAR, among others. CIMA (2017) shows an article for best practices for the prevention and control of

cargo theft. The IMT together with the federal government and private transport companies in Mexico seek, through the use of new technologies and implementation of intelligent systems, the monitoring of transport throughout the national territory. The federal government is taking special attention in the security all over the country, just to mentions some preventions strategies.

CONCLUSIONS

The main objective of this research was to show a global panorama of the current situation of freight transport in Mexico in its different modes of transport, and the economic impact that the latent risk, specifically in cargo theft, on the operation and transfer of merchandise has in the economy of the country, as well as mentioning the security measures that are currently being implemented by the government and the companies to prevent these events. At the end of this research, the main objective was achieved.

As a result of analysis of the showed statistics in the research, it is important mention that the cargo theft is a complex problem, which involves many factors (qualitative and quantitative) difficult to measure them. Researcher are looking for new methodologies and tools to measures the risk in this kind of problems from different approach, with the objective to help and to prevent the people, government, and private companies about cargo theft. Also, on base of the statistics, cargo theft is a problem worldwide, but it has a violent edge in Mexico.

The cargo theft has a deep impact of the countries' economy, in the economic losses of the private companies, human damages, marginalization of the development of the regions in which cargo theft events take place, local businesses, and the distrust of the employment of the people of those places, unnecessary expenses for the government, and the increment of the costs in the supply chain, among others.

In México and the other countries government in conjunction with private companies are implementing security measures against cargo theft in transportation, however due to the magnitude of the problem, it is not easy to solve the problem immediately.

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Air transport

ARE MEXICAN LOW-COST AIRLINE ROUTES FEASIBLE TO BE DIVERTED FROM MEXICO CITY TO TOLUCA AIRPORT?

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ABSTRACT
Mexico City airport is presenting important saturation levels, and strategies for demand balancing in the centre of the country are urgently needed. Considering the Mexican low-cost sector and growing demand to Mexico City, we analysed the diversion of flights to secondary airports, to reduce the congestion for the principal airport in the Mexican Multi-Airport System.
The characteristics of the most important low-cost carriers in Mexico are pointed out, as an air sector that can potentially be diverted to less crowded airports. The growth of this sector is forecast for the next 15 years, to compare the estimated number of operations and passengers with the current capacity of Toluca airport as a proposed destination. We conclude that Toluca airport can receive the operational demand for the planned LCC flights until 2035, but the capacity of the terminal building was determined to be insufficient to receive all passengers on these flights.

Keywords: low-cost airlines routes, Mexican airport system, aviation, airspace management

1. INTRODUCTION

For some years, Mexico City airport (IATA code MEX) has faced a significant saturation in various slots. Currently, the military airport *Santa Lucia* (NLU) is planned to be rebuild in a commercial international airport. The new airport will be designed to handle 18 million passengers when it starts operating in 2022 (Aristegui, 2019), but this could increase to around 80 million passengers in 2050 (Riobóo and Samaniego, 2017).
The new airport will form part of a multi-airport system (MAS), together with Toluca International Airport (IATA code TLC), Puebla International Airport (IATA code PBC) and Queretaro Intercontinental Airport (IATA code QRO) (FORBES, 2019); see Figure 1. The multi-airport system approach has proven worldwide to offer different advantages, such as in London, New York or Tokyo.
The planification of a multi-airport system implies that some of the main hub traffic will be diverted to nearby airports. To make a proposal of which routes to divert, it is necessary to characterize the demand, analyse traffic routes and consider the technical characteristics of the secondary airports in the MAS. Part of this analysis is addressed in this paper.

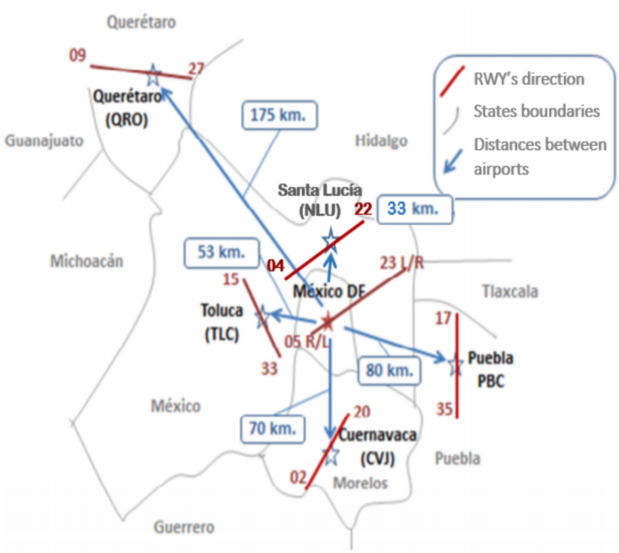


Figure 1. Multi-Airport System in Mexico (ICAO, 2013)

Special attention is given to Toluca Airport as a potential secondary airport (A21, 2019a; Milenio, 2019a) to divert low cost carrier (LCC) routes from Mexico City airport This research assesses the feasibility of a partial operations transfer for three of the four most important Mexican LCCs, *Interjet, Volaris* and *VivaAerobus*.
The work is organized as follows: after the literature and the presentation of the applied methodology, sections 4.1 ad 4.2 present the demand of the main Mexican LCCs and an analysis of their main routes. Section 4.3 describes the most relevant information regarding the available capacity in Toluca airport. Sections 4.4 and 4.5 contain the analysis of demand growth in the early future and the comparison with TLC airport capacity.

2. LITERATURE REVIEW

2.1. Low cost carriers and multi-airport systems

LCCs are distinguished by factors as fleet simplicity, high seating density, fast turnaround times, internet booking and absence of connecting services (Pels et al., 2009; Canseco et al., 2015; Bowen and Rodrigue, 2017), which return this sector of the market more competitive compared to full service carriers (FSC). In Latin

America, the importance of LCCs has been centred mainly in two actors that account for more than half of the seat capacity: Mexico and Brazil. LCCs have captured traffic from regular intercity buses, and a couple of significant budget airlines were formed by bus line entrepreneurs.

LCCs, unlike flag airlines, operate mainly in so called secondary or regional airports (O'Conell and Williams, 2005; Pels et al., 2009; Jimenez et al., 2017; Costa and Almeida, 2018). Congestion costs at busy airports are high, so concentrating airline operations at a secondary airport is a good strategy to reduce costs and offer low-fare trips (Cohas, 1993). Bonnefoy et al. (2010) show the importance of multi-airport systems, defined as a set of two or more significant airports that serve commercial traffic within a metropolitan region. De Neufville (2008) mentions that the diversion of LCC operations to secondary airports is key to the strengthening of the operations of a MAS.

According to Mujica et al. (2017), the capacity of an airport system is given by three factors: technical, environmental and the business model. In this work, only the technical capacity is considered. This refers mainly to the airport infrastructure for passengers in the terminal building and for operations on the runway; IATA provides comfort KPIs for the development of operations.

2.2. The Mexican air transport system

The commercial air transport system in Mexico underwent a great change in 2005, when new airlines entered the market with a new LCC business model. Prior to this date, the market leaders were *Aeromexico* and *Mexicana*, which transported about 5 million passengers a year between 2000 and 2005. As has happened in other regions of the world, the traditional service model in Mexican airlines was affected by the arrival of LLCs.

Mexico has a network of 76 airports, from which 61 are categorized as international. Since 2006, MEX airport has been conceptualized to be integrated into a MAS to meet the demand towards Mexico City (ASA, 2006); however, this multi-airport system has not been implemented in practice. Currently, the concept has been redesigned towards an airport network that includes an ex-military airport (NLU), TLC and MEX airports (Milenio 2019b). According to Boonekamp and Riddiough (2016) and Beria et al. (2017), to develop Mexico City's multi-airport system, different analyses have to be performed, beginning with a 'concept of operations" where the premises and strategic objectives are clearly presented and, therefore, the guidelines for airspace redesign, or the balance of the demand through traffic deviation, to mention a couple.

This work analyses the potential traffic deviation of the Mexican LCC sector to Toluca airport with the objective to balance the current and future demand of the metropolitan area using the potential that TLC airport offers. With its current design, Mexico City airport can serve up to 38 million passengers per year, but in 2018 it operated at 32% above the passenger capacity and 14% above the limit of operations (Expansión, 2019), managing to handle up to 61 op/h (arrivals and landings) with an average occupancy factor for this destination of 92% (El Economista, 2019).

3. METHODOLOGY

Figure 2 represents the methodology used in this work. In the first phase, the demand of the main three Mexican LCCs (*Volaris, Interjet* and *VivaAerobus*) is analysed, paying special attention to the routes with origin or destination at Mexico City airport, to recognize the demand by route offered by these airlines.

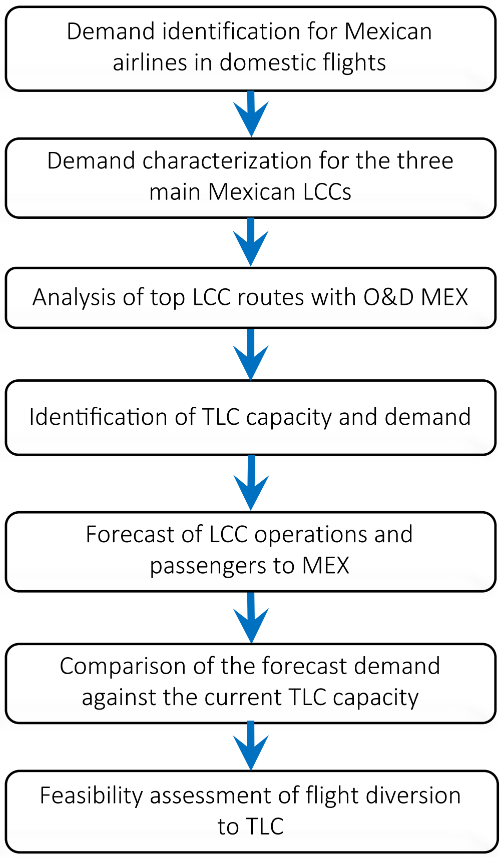


Figure 2. Methodology

The definition of the problem includes a literature review with respect to the congestion problem in Mexico City airport, as well as on LCC management and preferred strategies for demand management. Historical data on the demand and growth of Mexican airline operations and the specifications of Toluca airport were obtained from the DGAC (General Directorate of Commercial Aviation). Based on *fligthradar* (2019) data obtained for October 25-31, 2019, an origin-destination analysis (O&D) was performed on all routes offered by Mexican LCC airlines, and specifically on those that arrive to MEX airport. Airport and airspace characteristics are obtained from the Publication of Aeronautical Information (AIP, 2019).

LCC demand characterization focused on two variables: passengers and operations handled per year. DGAC demand data was analysed from 2005, which is the year in which the first Mexican LCC airline (*Interjet*) emerged. Number of passengers and operations served by LCC in flights to MEX were estimated with a linear regression model until 2035. Finally, the projected demand is analysed with two capacity constraints to assess the feasibility of the diversion to TLC of (part of) the demand towards MEX.

4. RESULTS

This section presents the analysis of both LCC demand in MEX airport and capacity of TLC airport. We analyse the demand of the main three Mexican LCCs that could be feasible to divert to Toluca airport. Both the current and forecasted LCC demand at MEX airport are analysed in detail.

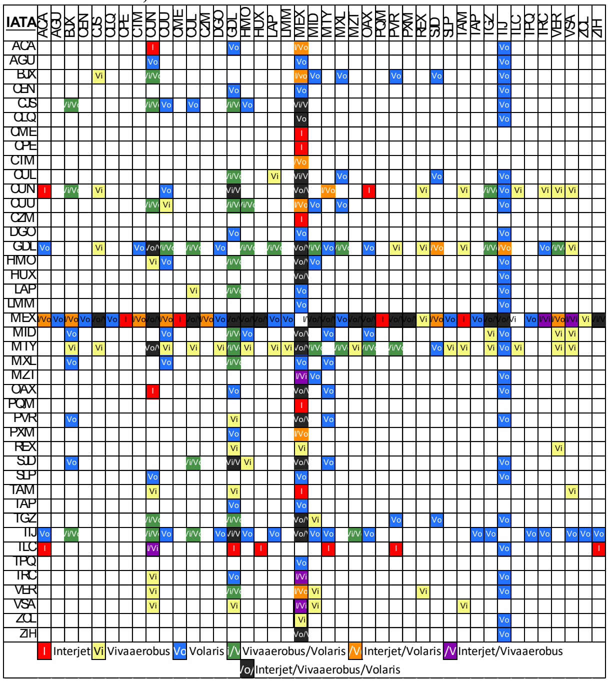
4.1. Identification of the demand for the main three Mexican LCCs

The low-cost sector is gaining force in Mexico since 2005. Particularly, *Volaris*, *Interjet* and *VivaAerobus* and *Aeromexico Connect* represent the Mexican LCC (SCT, 2019). In 2018, they moved over 95% of the low-cost sector in Mexico. *Volaris*, *Interjet* and *VivaAerobus* have been consolidating operations over the last years: in 2018, these three LCCs moved 40.3 of the 64.5 million passengers across Mexico (over 60%). *Volaris* is leading the national market (A21, 2019b), transporting about 14 million passengers, followed by *Interjet*, accounting for 10 million passengers and *VivaAerobus* with 9.1 million passengers. However, *VivaAerobu*s is growing faster than the other LCCs and is forecasted to be one of the leaders in the sector (AnnaAero, 2019), earning revenues from auxiliary services or disaggregated sources, such as selling drinks on board and giving workers a commission (Bachwich and Whitman, 2017); that is, the business model is also evolving in Mexico.
In the international market, there are mainly two actors, *Volaris* and *Interjet*, with respectively 3.7 and 2.9 million passengers.

4.2. Top LCC routes with O&D MEX

Initially, Mexican LCCs operated mainly in secondary airports. However, when one of the flag airlines, *Mexicana,* declared bankruptcy in 2010, Mexican LCCs took advantage of the situation and increased operations at the country's main airport, MEX. Table 1 summarizes the participation of the national airports (represented by their IATA codes) in the current *Volaris*, *Interjet* and *VivaAerobus* origin-destination routes, according to the analysis of *flightradar* data. The red, yellow and blue squares represent exclusive LCC routes for respectively *Volaris*, *Interjet* and *Vivaaerobus*. The green, orange and purple squares correspond to routes shared respectively by *Volaris/Interjet,* by *Volaris/Vivaaerobus* and by *Interjet/Vivaaerobus*. The black squares represent nodes where the operations of the three LCCs converge. They correspond to operation peaks and a consequential airport saturation; most of them are concentrated in MEX airport, the most important node of this study.

Table 1. Mexican LCC routes according to flightradar data for October 25-31, 2019



Of the 850 routes handled by any of the three airlines, 40 national routes were identified with origin in or destination to MEX; 37.5% of the routes are shared by the three LCCs.
Figure 3 shows the importance of Mexican air transport routes, according to the total number of transported passengers.

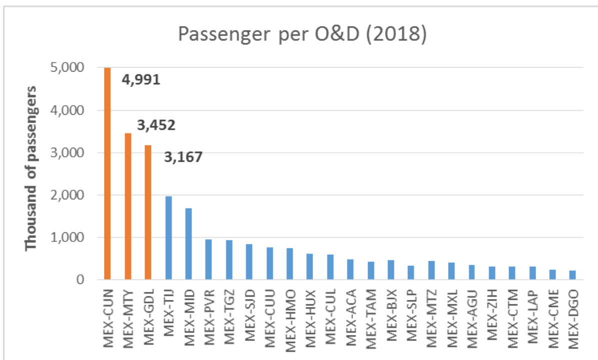


Figure 3. Passenger density for top routes in Mexico.

As shown in Figure 3, four airports concentrate the national commercial aviation activity from MEX (DGAC, 2019). The three main routes are: MEX-CUN, MEX-MTY and MEX-GDL, which in 2018 transported almost 25% of the passengers in the country. These three routes are shared by the three LCC airlines under study (Table 1).

4.3. Identification of TLC airport current capacity and demand

Toluca airport is located 53 km (around 55 min) from Mexico's city centre and 25 min from the main business centre in Mexico. At present, it handles domestic flights within Mexico and some international flights to the

United States, Cuba, Colombia, and Costa Rica. It serves 16 destinations, 6 of which are to USA.
TLC airport was inaugurated in 1984, with a runway of 3,000 meters in length. In 1991, the project of a MAS including TLC is presented. Three years later TLC began receiving commercial aviation operations that were diverted from MEX airport; i.e., the original TLC project arose due to the demand to and from MEX. Investments for the airport continued to grow and, in March 2007, the extensions of the terminal 1 building and the construction of terminal 2 were completed, allowing it to receive up to 8 million passengers per year (AIT, 2019). In 2008, TLC airport reached its maximum occupancy, transporting 4 million passengers and handling 96, 801 operations (see Figure 4).

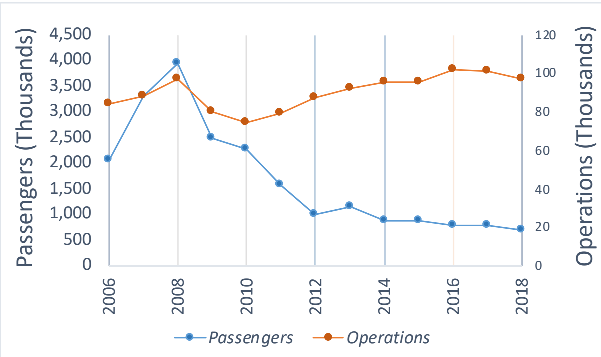


Figure 4. Transportation statistics, TLC airport

After 2008, the number of transported passengers decreased, reaching in 2012 its lowest point, when only one million passengers were moved. In 2016, the airport's annual passenger levels dropped to 771,152; therefore, two of the four terminals were closed. On the other hand, after an annual decrease of 17% in 2009 and 2010, the number of operations has been increasing since 2010; this may be due to an increase in general aviation and cargo operations.
TLC has had strong variations in its annual demand. The number of operations continues to grow at an average rate of 2.98%, but passenger demand has an annual average decrease of 9.47%. Undoubtedly, the motivation to transfer part of the Mexican LCC demand to TLC is an opportunity to take advantage of the existing infrastructure and reactivate the airport.
Due to the altitude (2580 MSL), the airport has the longest runway in Mexico: 4.2 km with a 15/33 direction (AIP, 2019). The runway is instrumented with ILS CAT-II / IIIA for landings with low visibility. As shown in figure 5, it has parallel taxiways of 190 m long between the axles.
TLC infrastructure has the following characteristics:

- Passenger terminal with 28,000 m^2 that can handle 8 million pax per year
- 1,850 pax/h capacity
- 36 op/h on runway
- 17 aircraft stations
- Critical plane: Boeing 747 (pax) or DM11 (cargo)

- Number of movements in 2018
  - Passengers: 691,712
  - Cargo: 36,491 ton
  - Operations: 96,725

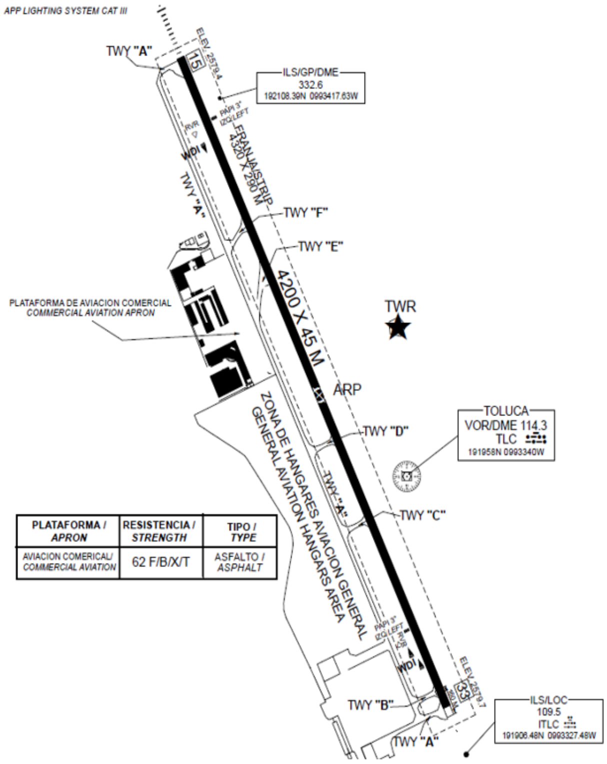


Figure 5. TLC Runway

Regarding ground connectivity, Toluca will have soon an interurban train that connects it through 6 stations to: Mexico, Ixtapan de la Sal, Morelia, Naucalpan, La Marquesa (MVT, 2017). According to estimates, the trip will take 39 minutes and the system can transport 230 thousand passengers daily. This initiative also promotes the growth of regions near the airport, as well as corresponding ground connections (SCT, 2019).
As demonstrated in 2008, TLC airport has appropriate internal logistics for a much higher demand than the current one. The capacity and infrastructure of the runway and the terminal building are not a limitation to increase the current number of LCC operations. As TLC airport has no saturation problems, passengers will have a higher comfort level than that offered by MEX airport.

4.4. Forecasted LCC operations and passengers

One of the main reasons for the diversion of air traffic is an excessive expected demand, in this case for MEX airport. In this research, we will use quantitative methods to forecast future demand. This section addresses the main factors that make the diversion of flights necessary, both for airlines in terms of aircraft capacity and for airports in terms of terminal building capacity. Analysed factors are:

a. Annual number of passengers transported
b. Number of operations at the airport

The annual data presented by DGAC (2019) for Mexico were considered to assess the aforementioned factors. We analysed the data from 2011, where stable behaviour could be observed. Earlier data considered unusual events, such as the LCCs' market entry, etc., and was discarded. Our analysis indicated that both the growth in number of operations and passengers show a linear behaviour for the 3 studied LCCs, so a Pearson's R correlation model was chosen to characterize the demand. The corresponding slope and intercept were determined, as well as the correlation coefficient, for both passengers and number of flights.
As the three analysed LLCs in 2018 served nationwide 50.8% of the flights with 67.3% of the passengers, this same proportion was used to determine the number of LCC operations and passengers for flights to Mexico City airport. From the local flights offered by national airlines, the proportion of flights to MEX was determined to be 30.5%. These proportions were used in order to adjust the obtained regression models for demand forecasting to MEX. Estimates were determined for 2020, 2025, 2030 and 2035. If all flights to MEX for the three most important Mexican LCCs are considered to be diverted to Toluca airport, the previous estimates correspond to the number of flights and passengers subject to diversion to TLC. The results of the forecast are presented in Table 2.

Table 2. Forecast of LCC operations and passengers subject to diversion to MEX

Year	Airline	Flighs to MEX (3 LCC)	Passengers to MEX (3 LCC)	Operations to/from TLC	Passengers to/from TLC
2020	Volaris	32,300	5,039,621	84,257	11,665,711
	Interjet	33,600	3,672,567		
	Vivaaerobus	18,357	2,953,522		
2025	Volaris	43,246	7,609,736	110,986	15,967,793
	Interjet	43,294	4,722,966		
	Vivaaerobus	24,446	4,175,091		
2030	Volaris	54,192	9,099,851	137,715	20,269,875
	Interjet	52,988	5,773,364		
	Vivaaerobus	30,535	5,396,660		
2035	Volaris	65,138	11,119,965	164,444	24,571,957
	Interjet	62,683	6,823,763		
	Vivaaerobus	36,623	6,618,229		

The final columns correspond respectively to the sum of operations and passengers for the three airlines, for the four future periods. Results indicate that, in 2035, 164,444 operations per year (or 18 op/h) and 24,571,957 passengers per year (or 2,843 pax/h) can be expected to be served by the three LCCs in flights subject to diversion to TLC.

4.5. Demand vs capacity

To determine if it is feasible to divert part of the LCC demand for Mexico City towards TLC, the technical capacity of the terminal building and runway in the latter must be compared with the expected future operations and passenger demand. In order for the diversion of flights to be feasible, the following capacity constraints should be met:

$$D_{ops,\,2035} \leq TLC_{Runway\ cap}\ (36\ ops/h) \quad (1)$$

$$D_{pax,\,2035} \leq TLC_{Terminal\ building\ cap}\ (1{,}850\ pax/h) \quad (2)$$

The previous constraints correspond to a maximum of 315,360 operations and 8 million passengers per year, making the diversion of all flights from the three LCC airlines to TLC a viable option under the criterion of the runway capacity, as the total number of expected operations for 2035 is 164,444, which is below TLC's saturation capacity. However, if all LCC flights to MEX would be diverted to Toluca Airport, the current infrastructure of the terminal building would not support the expected passenger demand. Even in 2020, the expected passenger demand (over 11.6 million pax/year) would exceed TLC's capacity of 8 million passengers.
The decision could thus be to divert only the flights of one of the airlines. However, even if only *Volaris* diverts all its flights to MEX, the maximum passenger capacity will be reached in 2027. According to the information presented in table 2, or *Interjet* or *VivaAerobus* flights might be diverted, but not both. Either of these LCCs would relieve the saturation in Mexico City airport, without compromising TLC's terminal building capacity. If diversion of more flights is needed, an infrastructure extension might be needed in Toluca airport.

5. CONCLUSIONS AND FUTURE WORK

This work analyses the current low-cost sector in Mexico to assess a possible deviation of flights from this type of airline to regional airports (in this case TLC), to increase the efficiency of the Mexican airport system centred on Mexico City. We have identified the most important routes for the three most important LCCs in Mexico, as well as the potential demand towards MEX for the next 15 years, considering the number of operations and passengers.
Until 2035, TLC can manage all operations towards MEX estimated for the three analysed LCCs; however, it will not have sufficient terminal building capacity to receive the 24.5 million passengers these flights imply. Even from 2020, 11.6 million passengers would be expected in TLC if all MEX flights of the three LCCs are diverted to TLC, which is above the airport's capacity. If *VivaAerobus* or *Interjet* were required to divert their flights to Toluca Airport, the current building capacity would be enough until 2035, but for *Volaris* there would be problems in some 8 years from now.

ACKNOWLEDGMENTS

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EXPLORATORY ANALYSIS OF THE TURNAROUND TIMES IN MEXICAN AIRPORTS

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Abstract
The time that an aircraft remains on the ground between two flights (turnaround time) is expensive, so it is a crucial element in defining the costs of an airline. Although there are studies that propose solutions to reduce these times in different sub-operations, there are not many studies that characterize global turnaround times.
Databases such as *flightradar* have large amounts of information regarding the flight and ground times of airplanes. This type of information is essential, for example, in simulation applications, were the corresponding probability distributions are needed to generate input data. This work aims at providing a preliminary characterization of the probability distributions that represent the behavior of turnaround times in Mexican airports, to determine by which variables they are influenced.
The behaviour of turnaround times in Mexico was analysed by airport, aircraft type and airline, finding larger turnaround times and a higher variation for the Mexican flag carrier than for low cost carriers, and larger turnaround times and a higher variation than for Mexican carriers than for US carriers serving Mexican airports.

Keywords: Probability distribution, statistical analysis, turnaround time.

1. INTRODUCTION

During the last twenty-five years, the airport industry in most countries has transformed from being a government concession to a dynamic business that must operate efficiently (Canseco et al., 2015). In the current era of competition, exorbitant airport fees and rising fuel rates worldwide, it is important for airlines to find ways to reduce costs (More and Sharma 2014). One way to reduce airline costs is by reducing ground time, also called *turnaround time*, that consists of different sub-operations, such as maintenance, security review, luggage loading, catering services and fueling (Ashford et al., 2012), several of which occur simultaneously and/or are interdependent. This makes the turnaround of an aircraft complicated, difficult to manage and subject to delays (Wu and Caves, 2004). Several aspects influence a flight's turnaround time, among which the type and size of the aircraft, the degree of saturation and the type (hub or non-hub) of the arrival airport and airline strategies (full-cost or low cost carriers) (Kolukisa, 2011).

1.1. Influence of turnaround times on flight delays

A decrease in turnaround time can increase the airline's profits. A study conducted in 2005 by the Bureau of Transportation Statistics (BTS, 2017) found that more than 80% of domestic flights on US airlines are not completed within 15 minutes after their scheduled arrival time, indicating a flight delay. These statistics are not necessarily indicative of bad programming or poor management of operations. On the contrary, for many reasons, forecasting the on time arrival of a specific flight can be very difficult. Two main sources of variation, bad weather and air traffic congestion at origin and destination airports, cannot be predicted reliably during the development of a schedule, which can take place up to 6 months before the scheduled departure.
What further complicates the problem is the interdependence of air networks (Coy, 2006): the delay of a flight of a certain airline can generate delays in flights of another airline. In addition, 25% of the delayed flights were found to be caused, at least in part, by a flight arriving late in the ascending segment (Coy, 2006).
A 2010 study conducted for the US Federal Aviation Administration estimates that flight delays cost the airline industry 8 billion euros a year, mainly for concepts such as rental of ground support equipment, fuel and maintenance costs (Bubalo, 2011). Delays cost passengers even more, almost 17 trillion euros. In addition, it is estimated that when the plane is delayed it costs approximately 25 euros per minute (Cook et al., 2004).
In MEX airport, flight delays range from 16 to 60 minutes, depending on the time of day (de la Rosa, 2014); this delays implies opportunity costs for not operating the aircraft, gate costs for the delayed plane, increased fees, etc. As delays usually spread to later segments, knowledge and characterization of turnaround time can help understand and reduce observed delays.

1.2. Cycle times in air transport

Air transport corresponds to a series of operations that all together complete a single trip. Different authors define these operations and the time required to perform them, such as:

- **Taxi-In**: time elapsed since the plane lands until it is parked at the arrival gate (Coy, 2006).
- **Taxi-Out**: time elapsed between the push back of the aircraft at the departure gate and take-off (Coy, 2006; Poornima, 2010).
- **Air time**: starts when the plane takes off and ends when the plane lands (Coy, 2006).

- **Turnaround time (TAT):** Time needed to unload a plane after arrival at the boarding gate and prepare it for your its flight (More and Sharma, 2014).
- **Block time** (or gate-to-gate time): time it takes for a plane to travel from the departure gate at the origin airport to the arrival gate at the destination airport (Coy, 2006).
- **Cycle time:** time between two consecutive take-offs (Gittell, 2001) or time required to complete a flight cycle (van Landeghem and Beuselinck, 2002).
- **Runway queue**: time in which the aircraft is taxiing to the waiting queue for take-off (Coy, 2006).
- **Airspace queue**: time the aircraft spends in the air waiting for permission to land (Coy, 2006).

When the aircraft is landing, the corresponding gate is considered ***arrival gate*** and when the plane is ready to depart it is known as the ***departure gate*** (Coy, 2006).

Figure 1 shows the mentioned times schematically.

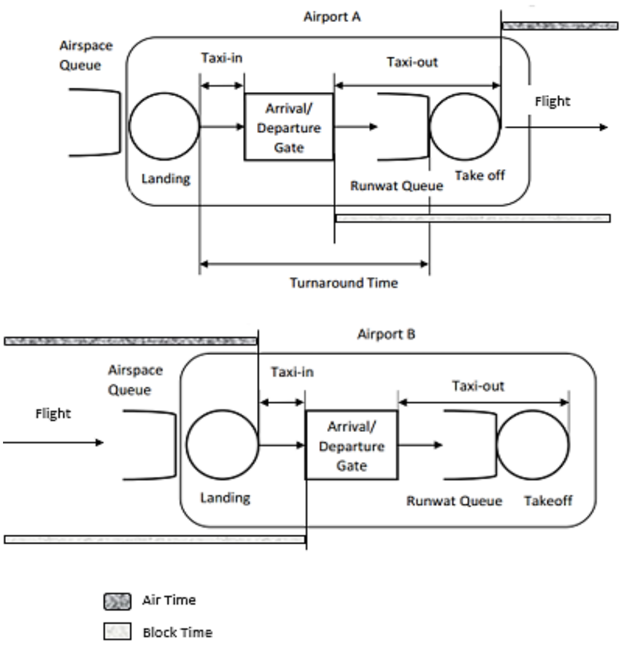


Figure 1. Times in aviation (prepared with information from Coy 2006; Poornima, 2014; Dileep, 2014; Gittell, 2001; Landehan et al., 2002)

This work focuses on analysing the turnaround time observed in Mexican airports and characterizing the corresponding probability distribution(s). This type of information is essential, for example, in simulation applications that evaluate proposals for the reduction of flight delays.

2. LITRATURE REVIEW

Different authors have studied turnaround times with a focus on their critical operations as, for example, passenger boarding (Schultz et al. 2013; Bachmat et al., 2005). Schultz et al. (2013) evaluate statistical criteria (expected value, variance, quantiles) for different boarding strategies in three aircraft models (Airbus A320, Boeing B777 and Airbus A380), achieving a 20-25% time saving with the use of an additional door, 10-15% with a change in boarding strategy and 3% for a different seating design. On the other hand, Bachmat (2005) relates the space-time geometry with boarding efficiency, showing that the efficiency of a boarding policy depends fundamentally on a parameter k which in turn depends on the interior design of the aircraft. Policies that are good for small values of k are bad for large values of k and vice versa.

Other authors focus on the taxi-out time to reduce delays. Wu and Caves (2004) use a Markovian simulation model to analyse the turnaround time of two flights, as well as the impact of delays on them. Rizal (2016) demonstrates that taking off at the scheduled departure time (STD) has a great impact on passenger satisfaction, showing turnaround time control as a main component for timely take-off. They study the optimally programming of the turnaround time in the case of an existing low cost company. It explores the disturbances that cause delays in the aircraft, the activities that take place during the aircraft turnaround, the observed impact due to the delay of a critical activity, the effectiveness of the response and the viable solutions for delay reduction. Coy (2006) uses a two-stage statistical model to estimate the block time of commercial passenger aircraft. The model considers many of the factors that contribute to airport congestion and provides a basis for the future development of multivariate statistical models of the flight operation process. The model is tested using 2 million US domestic flights by six airlines in 2004. The analysis of the model provided information on the relative impact of weather conditions and the use of the airport at the time of blockade. In particular, the passenger population, the arrival time, the airport use, the interaction of bad weather conditions and traffic were found as significant predictors of blocking time. Schultz et al. (2009) indicate that, in 2007, 19% of all European flights were more than 15 minutes late. One of the causes of this delay was found to be the insufficient performance of critical turnaround operations, such as landing, fuel, cleaning, catering and shipping, provoking excessive durations in the turnaround process. Delays in these operations immediately propagate an accumulated delay through the ATM network. The document by Fricke and Schultz (2009) revealed a correlation between the duration of the TAT process and the robustness of the system, regarding system stability for delays.

The frequency distribution of the turnaround or other air cycle times is useful for estimating how frequently a critical time is exceeded. Knowledge of the frequency distribution can be used to develop strategies to diminish turnaround times, or to estimate the cycle time more precisely. Few authors describe probability distribution for air transport times. van Landeghem and Beuselinck (2002) examines the factors of flight delays at airports and develops performance indicators such as waiting time and punctuality, for which he uses the real arrival and departure distributions.

Wellens and Mujica (2017) use a small set of data to estimate turnaround time distributions to be used in a simulation study for Mexico City airport, suggesting lognormal, loglogistic, Weibull and beta distributions, depending on the type of aircraft. However, their study was not specifically focused in TAT and can therefore not be generalized.

3. METHODOLOGICAL APPROACH

The analysis of this research focuses on getting to know the behaviour of TATs for specific airports, airlines and aircraft types in Mexico. Likewise, these results were compared with 3 US airlines operating in Mexico City airport. Our preliminary results bring up possible factors that could intervene in the observed turnaround times. Figure 2 shows the steps applied in the investigation.

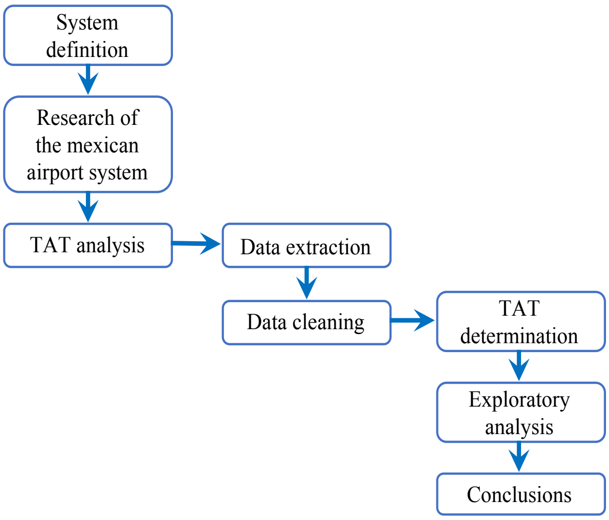


Figure 2. Research methodology.

Rstudio® was used for statistical analysis, which is a free and open source professional software for data analysis, package management and data exchange. Flight data from January 14 to April 14, 2018 were obtained from flightradar24.com (2019). The resulting database was debugged, removing records without information on the actual time of departure (ATD) and actual time of arrival (ATA). Once the data purification was completed, the TATs were determined from the aircraft's history as the difference between the aircraft's arrival time and the time of departure for the next flight.

The statistical analysis was performed dividing the data into groups according to airport, airline and aircraft type. A goodness of fit test was performed to determine the most appropriate distribution to model the phenomenon. As the data is continuous, the Kolmogórov-Smirnov (Lilliefors, 1967) and Anderson-Darling (Anderson and Darling, 1954) tests were used; an $\alpha = 0.05$ significance level was used. The hypotheses tested are:

H_0: The observed distribution is consistent with the theoretical distribution – Good fit

H_1: The observed distribution is not consistent with the theoretical distribution – Bad fit

Once the H_0 hypothesis is accepted, the parameters of the corresponding distribution were determined, in addition to the time range for which the model is valid.

4. RESULTS

4.1. Analysis of the Mexican airport system

The Mexican airport system consists of 77 airports, 64 of them international. There are 34 airports concessioned to private groups (ASUR, GAP and OMA) and one to a parastatal entity (Mexico City airport: AICM). In 2018, 97.3 million passengers were transported by air (DGAC, 2018). From 2013 to 2018, passenger transport grew in total with 58.2%, with an average annual growth rate of 9.6% (Table 1).

Table 1. Growth of air transport in Mexico (in millions of passengers).

Year	Millions of pax		Total	Annual increase (5 years)
	National	International		
1998	17.5	17.7	35.2	4.3%
2003	18.7	20.6	39.3	2.2%
2008	28.2	27.9	56.2	7.4%
2013	30.6	30.9	61.5	1.8%
2018	49.7	47.6	97.3	9.6%

Table 2 shows the ten airports with the highest demand in Mexico, as well as their growth from April 2018 to April 2019.

Table 2. Airports with the highest demand in Mexico (in thousands of passengers).

Airport	April 18	April 19	%var
Mexico City	2,537.0	2,710.1	6.8%
Guadalajara	855.7	861.4	0.7%
Monterrey	767.7	789.8	2.9%
Cancún	705.7	745.0	5.6%
Tijuana	626.8	741.6	18.3%
Mérida	184.2	220.1	19.5%
Culiacán	191.3	218.0	14.0%
Bajío	131.6	169.8	29.0%
San José del Cabo	136.8	161.2	17.8%
Hermosillo	141.6	153.1	8.1%
Others	1,901.2	2,107.0	10.8%
Total	**8,180**	**8,877**	**8.5%**

Source: SCT, SST, DGAC, DDE. Figures provided by airport groups.

Figure 3 shows the participation in the Mexican airport market in 2018, with MEX airport being the busiest with a share of 30.5%, followed by the GDL airport with 9.7%.

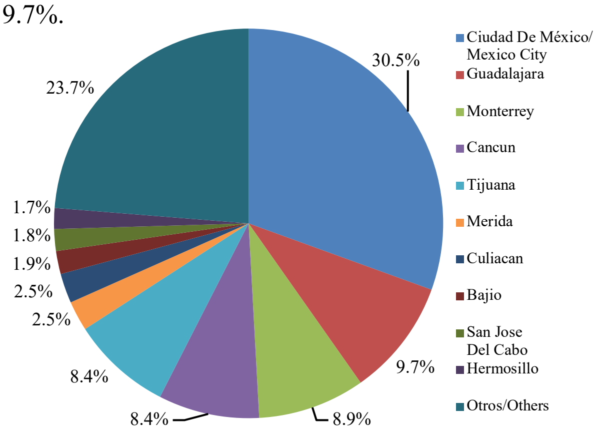


Figure 3. Airport market share (2018).

Table 3 shows the composition of Mexican aviation in domestic service and the change it had in the last 10 years. Some airlines that in 2008 had 40.5% of the market at present do not longer exist (Mexicana, Aviacsa, Mesoamerican Airlines, Avolar and Aerocalifornia); This participation was distributed among the remaining national airlines and other newly created ones.

Table 3. Composition of the Mexican air traffic market in the last ten years.

Carrier	2008	%Part	2018	%Part	Var %
Volaris	3.4	12.2%	14.1	28.4%	16.2%
Grupo Aeromexico	7.7	28.0%	13.7	27.7%	-0.3%
Intejet	3.0	10.8%	10.2	20.5%	9.7%
Vivaaerobus	1.3	4.8%	9.1	18.4%	13.6%
Grupo Mexicana	6.6	24.0%	NA	NA	-24.0%
Aviacsa	2.6	9.5%	NA	NA	-9.5%
Otros	2.9	10.6%	2.5	5.0%	-5.6%
Total	27.5		49.6		

4.2. Data records

The analysed *flightradar* database covered 4 months in the beginning of 2018. The records of the airlines with the highest representation in Mexico were included, which in addition to the Mexican airlines also include American Airlines, Delta Airlines, United Airlines, Avianca and Iberia. As a whole, these airlines handle 90% of air flights to MEX airport, the most important hub in Mexico.

As they lack some of the required information, flights with an incomplete record, cancelled flights or flights with status "Unknown" or "Scheduled" were not considered, reaching a total of 901,268 analysed records. Of these, 8,371 flights (<1%) were diverted, 13,548 flights (1.5%) were missing the actual time of arrival and 135491 flights (15%) did not have the record of the previous or subsequent flight, required for the determination of turnaround time, so only 743,858 records were left for analysis (Figure 4).

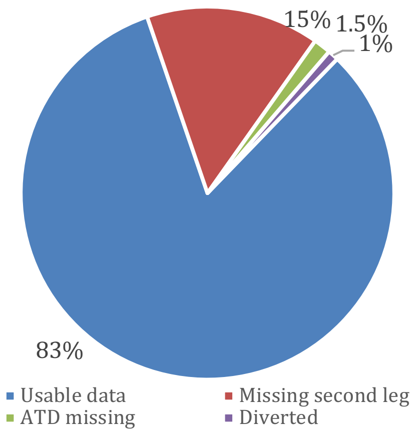


Figure 4. Data records collected.

Table 4 shows the number of records per airline. The airline with the highest number of records is American Airlines with 261,669 registrations, while the one with the lowest number was Aeromar with 2,123. In order to have a basis for comparison, not only Mexican domestic flights were analysed, but all the registered flights for the airlines included in the study.

Table 4. Records by airline

Carrier	Number of registers	%
American Airlines	261669	35.2
Delta Airlines	199357	26.8
United Airlines	182129	24.5
Avianca	35777	4.8
Iberia	18180	2.4
Volaris	13361	1.8
Interjet	11180	1.5
Aeromexico	8881	1.2
VIVA Aerobús	6270	0.8
Aeromexico Connect	4931	0.7
Aeromar	2123	0.3

Within the analysed database, 24 aircraft families were registered. Table 5 shows the 10 aircraft families with the highest number of records. In Mexico, the most commonly used aircraft are A320 (47.2%), B737 (20.3%), ERJ (12.2%) and A321 (9.8%), all being aircraft with a wake category corresponding to M (*medium*). These aircraft types account for 89.5% of the flights in and to Mexico.

Table 5. Records by aircraft type

Aircraft	Number of registers	%
Bombardier CRJ	175337	23.6
Embraer ERJ	144461	19.4
Boeing 737	131322	17.7
Airbus A320	78976	10.6
Airbus A321	52978	7.1
Airbus A319	50027	6.7
McDonnell Douglas MD	26241	3.5
Boeing 757	23854	3.2
Boeing 717	18155	2.4
Boeing 777	9404	1.3

Of the available records, 48,595 correspond to flights to a Mexican airport. For these, table 6 shows the 10 Mexican airports with the highest number of records. Of these, Mexico City airport is the one with the highest concurrence.

Table 6. Records by airport

Airport	IATA	Number of registers	%
México City	MEX	16742	2.25
Cancún	CUN	6258	0.84
Guadalajara	GDL	5521	0.74
Monterrey	MTY	4009	0.54
Tijuana	TIJ	2881	0.39
San José del Cabo	SJD	1177	0.16
Puerto Vallarta	PVR	1100	0.15
Silao	BJX	1012	0.14
Mérida	MID	910	0.12
Culiacán	CUL	797	0.11

4.3. Turnaround times

The turnaround time behavior was visualized by histograms. Only ground times under 24 hours were taken into account, considering that longer turnaround

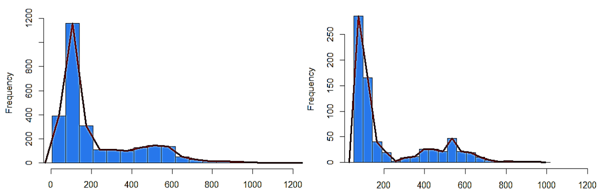
times correspond to airplanes that are not in active service, probably for maintenance reasons.
To compare the behavior of turnaround times, the data was grouped ny the following variables:

- Airport
- Airline
- Aircraft type
- Overnight stay of the aircraft

Aircraft are considered to stay overnight when arriving after 5 pm, being at least 6 hours at the airport and leaving at the next day at the latest at 11 am.

4.3.1. Mexico City airport

Upon arrival in Mexico City, aircraft from low-cost Mexican airlines (mostly medium size, such as A320 or B737) show a TAT mode around 71 min (1.2 h). Their data do not adjust to a normal distribution, because they have a high variability and their distribution shows an important right tail. In general, about 40% of the values are above 200 min (3.3 hours). Figure 5 shows as an example the TAT behaviour for Interjet A320 and A321 aircraft, but a similar behaviour is observed for most of the Mexican low-cost airlines' airplanes.



(a) (b)

Figura 5. Turnaround times for Interjet aircraft arriving to MEX airport. (a) A320, (b) A321.

For the examples in Figure 5, a second peak is observed around 470 min (7.8 hours), which probably corresponds to aircraft that overnight in MEX airport. However, the presented variation is very high, observing TAT values of up to 1200 min (20 hours) for some airlines. The pronounced peaks that are observed around the distribution mode suggest that low-cost airlines try to maintain their TATs low, while the high variability suggests that, for different reasons, they do not always manage to keep them that way.
As observed in figure 6, the TATs for Aeromexico, the Mexican flag airline, has a much more defined and regular distribution for airplanes of comparable size, suggesting better planned TATs.
The observed average TAT for Aeromexico B737 aircraft is 144.4 min (2.4 hours) and the standard deviation of 65 min (1.1 hour). Although there is also a second peak around 600 min, it is much less pronounced and more regular than for low-cost lines, probably due to planned overnight stays. When comparing the first observed peak of Aeromexico B737 aircraft with the first peak of low-cost airlines (average: 101.74 min; standard deviation: 35.93 min), we see that, for comparable aircraft types, Aeromexico has TATs which are in average 42% larger and with a standard deviation 80% larger than for low-cost airlines, concluding that Aeromexico probably plans slightly larger TATs than the ones proposed by low cost airlines, but manages to comply with the proposed times.

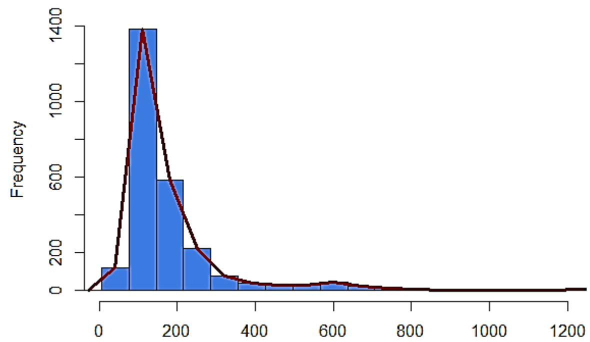


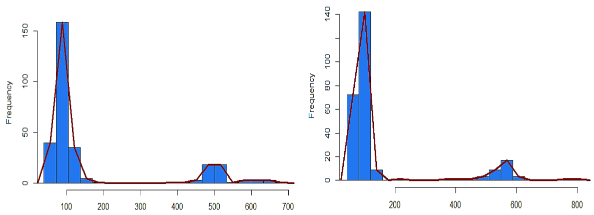
Figure 6. Turnaround times for Aeromexico B737 aircraft arriving to MEX airport.

The observed average TAT for Aeromexico B737 aircraft is 144.4 min (2.4 hours) and the standard deviation of 65 min (1.1 hour). Although there is also a second peak around 600 min, it is much less pronounced and more regular than for low-cost lines, probably due to planned overnight stays. When comparing the first observed peak of Aeromexico B737 aircraft with the first peak of low-cost airlines (average: 101.74 min; standard deviation: 35.93 min), we see that, for comparable aircraft types, Aeromexico has TATs which are in average 42% larger and with a standard deviation 80% larger than for low-cost airlines, concluding that Aeromexico probably plans slightly larger TATs than the ones proposed by low cost airlines, but manages to comply with the proposed times. The low-cost airlines seem to plan stricter TATs, but fail to comply with them in a large proportion of the time. It should be noted that the low cost section of Aeromexico (Aeromexico Connect) has a similar behaviour to the rest of the low cost airlines.
The aircraft of the analysed US airlines that arrive at MEX airport (American Airlines, Delta Airlines and United airlines) generally show a similar behaviour among them, again with two superimposed distributions. According to the applied goodness-of-fit tests, the distributions for the first peak could be adjusted to the normal distribution, for all airlines and airplanes. Table 7 shows the mean and standard deviation for the first observed peak of the TAT distribution for the previous airlines.

Table 7. Mean and standard deviation for normal TAT distributions of US airlines arriving at MEX airport.

Airline	Aircraft	Mean (min)	Standard deviation (min)
Delta	A319	83.1	15.6
Delta	B737	83.1	14.3
Delta	B757	110.3	20.6
American	B737	88.4	18.4
American	A319	97.4	33.1
United	B737	86.7	14.9
United	A320	79.8	11.9
United	A319	86.6	17.2

As an example, Figure 7 shows the histograms corresponding to B737 of American airlines and United airlines for flights arriving to MEX airport.



(a) (b)

Figure 7. TAT for B737 aircraft arriving to MEX airport. (a) American Airlines, (b) United Airlines

The TATs of US airlines at MEX airport are considerably shorter (21% on average) and have standard deviations half of the amount of the ones observed for Mexican low-cost airlines. On the other hand, American airlines presents TATs on average 17% larger than Delta Airlines for A321 aircraft and 6% larger for the B737 aircraft. United airlines has TATs similar to Delta, but with less standard deviation.
AVIANCA, which is the only Latin American airline included in our study, presents a Gauchy distribution for A320 turnaround times, with an average 268.9 min (4.5 hours) with standard deviations of 49.7 min (figure 8). The large observed TATs may be due to a lower flight frequency for AVIANCA than for Mexican or US airlines.

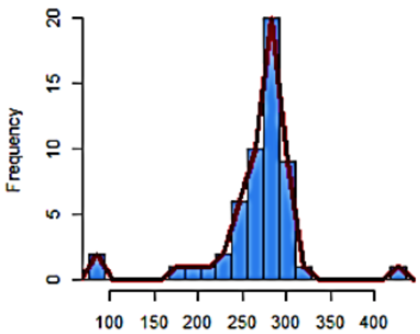


Figure 8. TAT for AVIACSA A320 aircraft arriving to MEX airport.

Larger aircraft, such as B787, have larger TATs; however, there was not enough data to determine which distribution was best fitted.

4.3.2. Other airports

For flights to the Cancun airport (IATA code CUN), the TAT behaviour of Mexican airlines resembles that of the analysed US airlines. The second peak is no longer observed for some of the aircraft families, suggesting that few aircraft spend the night in Cancun. Also, the distributions are more symmetrical and with less variation between different airplanes and/or airlines. Figure 9 shows an example for Delta Airlines B737. A normal distribution with an average of 92.8 min (1.5 hours) and standard deviation of 14.3 min is observed, being equivalent to the TAT found for Delta and United Airlines in Mexico City. Figure 8 shows as an example the distribution of TATs for Delta B737, for flights arriving in Cancun.

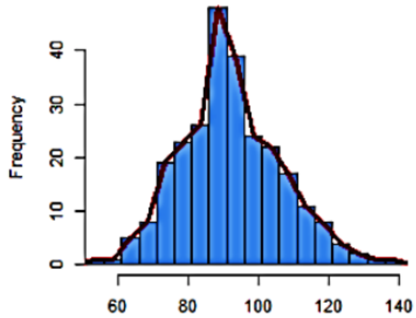


Figure 9. TAT for Delta B737 aircraft arriving to CUN airport.

Smaller aircraft such as ATR42 have TATs between 32 and 55 min; however, there was little data to reach a final conclusion.
For flights arriving in Guadalajara (IATA code GDL), we observed again an increase in the variation and number of flights with TATs between 200 and 600 min for Mexican airlines, similar to what was observed for the MEX airport. The same is observed in the Monterrey airport (IATA code MTY), but less pronounced. In Tijuana airport (IATA code TIJ), there are minor TATs and standard deviations.

5. CONCLUSIONS

With the analysis presented in this paper, we found that turnaround times depend on both the type of plane, the type of airport and the type of airline. We find the following general relationships (for the moment preliminary):

- TATs have two superimposed distributions. For the US airlines and the Mexican flag airline (Aeromexico), both distributions are well defined and separated, suggesting that they correspond to two different phenomena. The first peak or distribution may, possibly, correspond to the TATs planned and desired by the airline, while the second peak may correspond to aircraft that plan to overnight at the airport.
- For Mexican low-cost airlines, the two distributions overlap and are not very distinguishable, indicating a lot of variation and an increase in TATs for a large percentage of flights.
  - Mexican airlines have significantly larger TATs than US airlines (21% larger for low-cost airlines, but about 70% higher for Aeromexico).
  - Mexican low-cost airlines plan TATs that are 42% lower than those of the flagship airline, Aeromexico. However, its large number of incidentals makes both the average (220.6 min) and the standard deviation (201.91 min) increase to levels above those of Aeromexico (respectively, an average of 182.88 min and standard deviation of 165.19 min).
  - US airlines have standard deviations of 11 to 20%, with corresponds to approximately half of

the observed standard deviation for Mexican low cost carriers, and only a quarter of those of Aeromexico.

- In less crowded airports, contingencies seem to decrease and the behavior of TATs is more similar between different types of airlines than in more crowded airports. In other words, the behavior of the TATs starts looking more like those of the US airlines, without reaching their degree of efficiency.
- In general, the observed distributions for Mexican airlines do not follow a normal distribution, as they have an important right tail. The TATs of the US lines present Cauchy and logistic distributions; for the Mexican lines it was difficult to adjust a theoretical distribution due to its great variability and overlap of different phenomena.

In a future stage, more extensive goodness-of-fit tests will be carried out to corroborate the preliminary findings. Likewise, other statistical tools, as well as specific tools of data mining and machine learning, will be applied to reach results at a deeper level.

ACKNOWLEDGMENTS
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EFFICIENCY IN INTERNALIZING EXTERNAL ENVIRONMENTAL COSTS IN MARITIME AND AIR TRANSPORT

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ABSTRACT

The transport sector is the third largest source of emissions in Germany and accounts for 17.7% of the total greenhouse gas emissions. Between 1990 and 2005, the total emissions from the transport sector declined by two to four percent per year. Although the contribution of aviation and shipping to global warming is low (3.2% from shipping and 2.1% from aviation), compared to the environmental impact of road traffic, a possible mitigation potential should be elaborated and the transfer of cargo traffic from road to air or water should be made more attractive. In this study, the most efficient policy instruments to regulate the emissions considering the technological and operational savings potential of each sector have been elaborated. While maritime transport mostly benefits from technology-based and performance-based instruments, air traffic needs marked-based standards to establish operational improvements.

Keywords: maritime transport, air transport, environmental impact, emission trading system

1. CLIMATE GOALS

On 12 December 2015, 197 Parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed in the UN Climate Change Conference in Paris on a limitation of anthropogenic global warming to well below 2°C compared to pre-industrial levels (Nations 2015). To reach this ambitious goal, each member state undertakes to lay down legally and to tighten up every five years the measures to achieve its objectives (Nations 2015).

For the aviation sector an improvement of 2% per year in fuel efficiency between 2015 and 2020 is aspired by the International Civil Aviation Organization (ICAO), an agency to manage the administration and governance of the Convention on International Civil Aviation since 1944. Because a growth of the air traffic demand of 3% to 4% per year is widely excepted, this aim would still result in an increasing amount of aviation induced greenhouse gases (GHG). That's why, ICAO additionally demands no net increase in international aviation emissions from 2020 (Lee, Lim and Owen 2013). In 2010, Canada, Mexico and the US proposed a carbon-neutral growth by 2020 (compared to the emission level in 2005) to the ICAO 37th General Assembly, whereas the European Union proposed a 10% reduction of the 2005 level by 2020. In 2008, the Air Transport Action Group (ATAG) delivered a strategic vision for aviation's sustainable development. Therein, the most important aviation industry partners agreed on three goals. First: improving fuel efficiency by an average of 1.5% per year from 2009 to 2020. Second: stabilizing emissions from 2020 with carbon-neutral growth; and third: reduce net emissions from aviation by 50% by 2050 compared to 2005 levels (Air Transport Action Group 2008). ATAG coordinates the industry position ahead of the ICAO Assemblies and formulates objectives agreed with industry as white papers.

On the other hand, the International Maritime Organization (IMO), aims in reducing the greenhouse gas emissions of ships to 50% of the 2008 level by 2050. This target corresponds with a target, defined by ATAG. Therefore, vessels with zero carbon emissions would be required by 2030. Furthermore, IMO established a series of internationally baselines to increase the energy efficiency resulting in a gain in energy efficiency by 30% of newly built ships in 2025, compared to those built in 2014.

Three different political instruments have been invented to reduce the radiative impact of on an international level. First, technology-based standards specify the mandatory method and technological execution to comply with a particular command and control regulation.
Second, performance-based standards are also a command and control regulation, but only define a target or threshold value, and leave the technological execution to the operators. For example, the MARPOL Annex VI SECA requirements can be classified as a performance-based standard, because ships are able to either switch to

low-sulphur fuel or use proven technologies to reduce an equivalent amount of SO_2 emissions.

Third, market-based instruments use policy tools, such as emission taxes and charges whose value depends on the market price and intent to change the incentive structure for polluters (Efthymiou and Papatheodorou 2019).

The efficacy of these instruments strongly depends on the required time frame to achieve improvement, on the potential of the stakeholder to be able to reduce the emissions and on the scientific knowledge of this potential. For example, the potential for improving ship fuel efficiency is rated as high due to dated engine technologies and a state-of-the-art efficiency is known. Thus, it can either be reduced (1) by command and control regulations defining a threshold value for fuel efficiency, (2) by command and control regulations regarding an improvement of the engine technology or (3) by fuel charges forcing the shipbuilder to invest in up-to-date engines.

The targets for a sustainable transport by ship or plane defined by ICAO and IMO are international performance-based instruments without recommended actions. The transposition of these targets into national law is the responsibility of the respective countries and is not uniformly regulated internationally.

2. CLIMATE METRICS

Usually, the impact of radiative active contributors to the greenhouse effect is quantified by the radiative forcing *RF* which is the imbalance in the Earth-Atmosphere radiation budget as a result of a disturbance, e.g. the emission of a greenhouse gas (Myhre, et al. 2013). To consolidate the scientific knowledge of single radiative effects (i.e. to estimate the RF of a single emission in a specific region of the atmosphere), highly complex global climate-chemistry models are required (Lee, Lim and Owen 2009) (Lee , Fahey, et al. 2009) (Fuglestvedt, Berntsen, et al. 2009). Large differences in life time, dispersion and emission quantity of these disturbances in the atmosphere cause different periods of time in which the emissions contribute to global warming (Archer, et al. 2009). The different life times are caused by different abilities of the emissions to mix with the atmosphere or to be transported elsewhere mainly as function of emission location and altitude. Thus, it is difficult to compare the effects of different emissions. For example, small amounts of black carbon (BC) emitted by aviation contribute significantly to global warming, compared to large quantities of BC emitted by vessels and washed out quickly by rain. For comparison, the Global Warming Potential (GWP) has been investigated, transferring the impact of non-CO_2 emissions into CO_2-equivalent emissions by integrating the radiative forcing over the exact same time horizon H (Rosenow, Lindner and Fricke 2017)

$$GWP = \frac{\int_0^H RF_x(t)dt}{\int_0^H RF_{CO2}(t)dt} \qquad (1)$$

where $\int_0^H RF_x(t)dt$ denotes the radiative forcing of the specific contributor over the time H and $\int_0^H RF_{CO2}(t)dt$ the radiative forcing of CO_2 over the same time horizon. Due to strong differences in the life time of the emissions in the atmosphere, GWP refers to a time horizon H (Archer, et al. 2009). Therewith, the comparison of emissions with different lifetimes H, e.g. aviation emitted carbon dioxide (with lifetimes in the order of thousand years) and shipping emitted carbon dioxide (with lifetimes in the order of 100 years) is possible with the GWP.

To quantify the radiative impact of combustion products of fossil fuels both transport sectors must be considered separately from each other, due to different emission altitudes and background concentrations.

The total radiative forcing of a fossil fuel burning engine exceeds the radiative impact induced by its CO_2 emissions alone (Lee , Fahey, et al. 2009) (Lee, Pitari, et al. 2010). For example, on a short-term time-scale, the total radiative forcing of shipping is smaller, than the contribution due to shipping CO_2 emissions (Eyring, Isaksen, et al. 2010). The potentially negative radiative impact from shipping is caused by large amounts of sulfur emissions with a cooling effect. However, sulfur emissions are expected to be reduced according to IMO regulations for reasons of air quality and public health. For health reasons, a global sulfur limit for marine fuels has been tightened up from 4.5% to 3.5% in 2012 and to 0.5% until 2025 (Lee, Lim and Owen 2009). This will attenuate the negative short-term radiative effect of shipping.

The maximum fuel Sulfur content in aviation, on the contrary, is limited to 600 ppm which is 0.06% by weight (Protection 2014) (Kapadia, et al. 2016), which is why, aviation Sulfur emissions are too small for inducing a cooling effect. Overall, the accumulated global and long-term positive response to aviation and maritime emitted CO_2 will overpower the regional and short-term negative response to sulfur emissions, so that the overall response will change sign (Fuglestvedt, Berntsen, et al. 2009) (Fuglestvedt, Shine, et al. 2010).

3. SHIPPING EMISSIONS IN THE MARINE BOUNDARY LAYER

In 2015, maritime traffic burned 298 million tons of fuel and emitted 932 million tons of CO_2 on a global scale. Compared to 2013 the consumption increased by 2.4% (Olmer, et al. 2017). Therewith, shipping has been the sixth largest emitter of energy-related CO_2 in 2015 (Olmer, et al. 2017). The carbon dioxide emissions from shipping accounted for 3.1% of the total global CO_2 emissions (Lee, Lim and Owen 2009). The emissions mainly come from the combustion of heavy oil, which remains as residual oil in the refineries during oil processing. As an unavoidable product of complete combustion, CO_2 is a well-known green-house gas which absorbs and re-emits terrestrial radiation and induces a

warming of the Earth's surface. Other products of complete combustion emitted by vessels, such as water vapor H2O do not have a significant impact on global warming, because of a high background concentration of water vapor above the water surface. Because heavy oil further contains sulfur, aromatic hydrocarbons (PAH) and heavy metals; the combustion of heavy oil further produces particulate matter (PM), especially soot particles (BC), sulfur (SOx) and nitrogen oxides (NOx) (Eyring, Isaksen, et al. 2010).
Today, around 90% of the entire cargo ship fleet is powered by heavy fuel oil. The average fuel consumption of a freighter or tanker is between 30 and 80 tons of heavy fuel oil per day at sea depending on capacity (in terms of twenty-foot equivalent units TEU), year of construction and cruising speed.

3.1. Shipping Contribution to Global Warming

The impact of each specific exhaust gas emissions on the environment strongly depends on the location (climate zone and altitude) of the emissions and shall not be generalized (Rosenow, Lindner and Fricke 2017).
Considering a hundred-year timescale, shipping CO_2 equivalent emissions in 2005 amount to 1,000 million tons to 1,025 million tons (Olmer, et al. 2017).
Beside CO_2 as typical green-house gas with a warming effect, black carbon (BC) contributes the most to the climate impact of shipping (see Figure 1 RF and GWP), representing 7% of total shipping CO_2-eq emissions on a 100-year timescale and 21% of CO_2-eq emissions on a 20-year time scale (Olmer, et al. 2017). Soot emissions by shipping induce a warming effect and significantly change the microphysics and optical properties of clouds. Depending on the Sulfur content in the exhaust plume and on the life time of soot particles in the marine boundary layer, the warming effect of soot can be negligible or significant (Zhou and Penner 2014). Due to the emission in altitudes, where most precipitation takes place, the washing out by rain or snow is more effective for shipping soot emissions than for aviation soot emissions. Since the life time of BC is a short-lived climate pollutant, reducing BC emissions from ships would immediately reduce the climate impact of shipping (Jacobson 2002). However, the conditions of soot formation are not trivial to quantify and nearly impossible to avoid during combustion processes (Mansurov 2005).
Furthermore, Sulfur dioxide SO2 represents an important share of maritime emissions. Sulfur containing substances are short-living substances in the atmosphere in the order of days and cause a cooling effect (Lee, Pitari, et al. 2010). The dominant aerosol components are sulfate (SO4) and sulfuric acid H2SO4, which results from oxidation of SO2 emissions. By reflecting the sunlight, SO4 has a negative radiative Forcing (Myhre, et al. 2013).
Mainly emissions of NOx act as ozone precursor, lead to the formation of tropospheric ozone (O3) by catalysis (with a warming effect) and shorten the life time of methane (CH4) with a cooling effect. Furthermore, indirect effects of aerosols cool the atmosphere by changing the properties of clouds. Although aerosols might cool the atmosphere, local and regional air quality problems are induced by aerosol emissions in coastal areas and ports with high traffic volumes. The effect is gaining in importance, since 70 % of maritime emissions take place within 400 km of the coast (Eyring, Isaksen, et al. 2010).

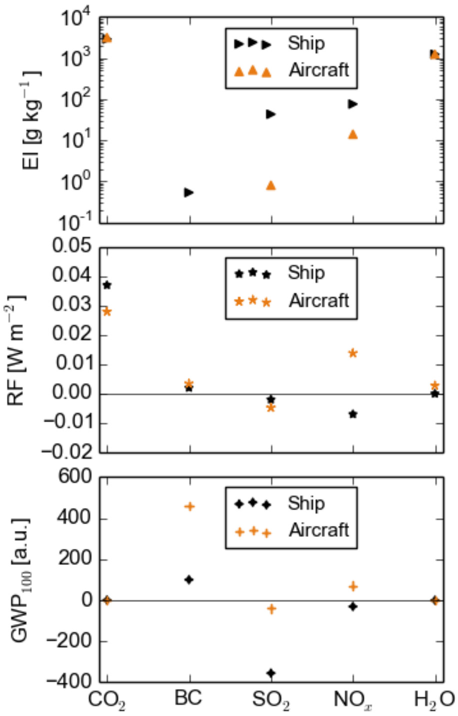

Figure 1: Emission index EI, radiative forcing RF and 100-year-Global warming potential GWP of aircraft and ship emissions in 2005. Ship values are taken from (Eyring, Isaksen, et al. 2010), aircraft values are taken from (Lee, Pitari, et al. 2010).

3.2. Technical improvements to reduce the maritime impact

Most of the technical improvements in ship traffic can be classified in two strategies. First, the improvement of the fuel quality mainly reduces products of incomplete combustion, such as Sulfate, soot and other particle emissions. For example, the reduction of sulfur dioxide emissions can instantaneously be achieved by limiting the sulfur content of the fuel. Soot emissions can be reduced along the entire engine load range up to the invisibility of the exhaust gas. Other particulate emissions are also largely dependent on fuel quality. In order to comply with the sulfur limits, in addition to the possible use of fuels of a higher quality than heavy fuel oil (i.e. the switch to marine diesel or natural gas), exhaust aftertreatment systems and thus technically retrofitted engines are primarily used.
In order to comply with the so-called Trier III limits for both nitrogen oxide emissions, catalytic converters and gas engines are currently used if necessary for new buildings. With regard to the reduction of CO_2 emissions,

no greater pressure for action has yet developed. In principle, technical and operational measures can be taken to reduce CO_2 emissions, some of which are already in use today. In addition, alternative fuels and drives will be further investigated. The potential of liquefied natural gas (LNG) in particular is currently being addressed and to a lesser extent already realized; synthetic and biogenic gases from renewable energy sources are more likely to be used in the medium to long term, but will then be seen as the future of carbon-neutral shipping. The emission-reducing potential of alternative electricity, wind or solar propulsion systems in shipping is currently regarded more as supplementary propulsion systems. Shipping companies are not yet switching to alternative technologies on a large scale. Maybe, hybrid engines will be the means of choice in the near to medium term.

3.3. Shipping forecast

Several future scenarios based on four predicted growth scenarios of the world's real Gross domestic product (GDP) according to the four storylines of the Special Report on Emission Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic and Swart 2000) have been transferred to four predicted traffic scenarios by applying a linear correlation between a growth in GDP and growth in marine traffic demand yields in a growth in maritime traffic demand of 2.3%; 2.8%; 3.1% and 3.6% (Eyring, Köhler, et al. 2005) and in an annual increase of 2.6%; 3.1%; 3.4% and 4.0% in total maritime transport between 2001 and 2050. Assuming more or less optimistic technological improvements, the emissions from shipping can be predicted and thereafter the contribution from shipping to global warming. Eyring et al. (Eyring, Köhler, et al. 2005) predict a total fuel burn from shipping of 536 to 725 mega tons for the year 2050, assuming a complete adjustment towards diesel driven engines and 402 to 543, if 25 % of the diesel-only fleet is replaced by alternative propulsion plants. These fuel burns have been transferred into CO_2 emissions per year by several researchers. Figure 2 gives an impression in expected emission scenarios, even under very optimistic conditions as considered by Eyring et al. (Eyring, Köhler, et al. 2005), green line. Other reports such as the second IMO GHG Study projected emission scenarios, which nearly double the optimistic studies (see Figure 2).

3.4. Shipping regulation

Regulations in shipping emissions exist since the International Convention for the Prevention of Pollution from Ships (MARPOL) has been established in 1973. MARPOL is a legal instrument which is intended to protect the environment from pollution caused by ships. The International Convention is also known as MARPOL 73/78, has been amended in 1978 (Lee, Lim and Owen 2009) and is valid worldwide. The tasks of the Secretariat are performed by the International Maritime Organization (IMO) which is responsible for international regulations on pollution by ships.

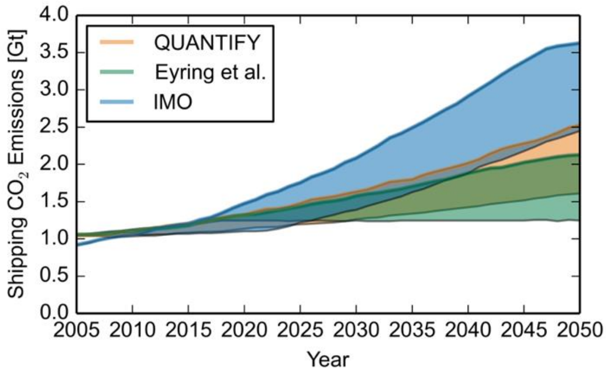

Figure 2: Predictions of CO_2 emissions from the shipping industry following different forecast studies, QUANTIFY (Eide, et al. 2007), IMO (Buhaug, et al. 2009) and Eyring et al. 2005 (Eyring, Köhler, et al. 2005)

Together with the Safety of Life at Sea (SOLAS) Convention of 1974, the MARPOL Convention forms the legal basis for environmental protection in maritime shipping and thus the basis for worldwide efforts to minimize the pollution of the marine environment. The Convention or the Protocol itself only regulates the general framework conditions. The practically relevant provisions are laid down in the annexes.

For example, in 1996 the Maritime Environmental Protection Committee (MEPC) of the International Maritime Organization (IMO), set international limits for NOx emissions from marine engines in Annex VI to the MARPOL Convention (Wissenschaftliche Dienste und Deutscher Bundestag 2018).

Emission Control Areas (ETA) have been established as MARPOL Annexes in 2012. Within these areas, a limitation of the SO2 and particulate matter emissions is regulated which is primarily realized by a limited sulphur content in the fuel. From this follows, that approximatively 90 % of the vessels use Marine Gas Oil within ETA. Only 10 % are equipped with a flue gas scrubber to eliminate Sulphur and particles from the exhaust of burned heavy fuel oil. The areas are located in the following regions (see also Figure 3):

1. Baltic Sea area as defined in Annex I of MARPOL (concerning SO_x only)
2. North Sea area as defined in Annex V of MARPOL (concerning SO_x only)
3. North American area (entered into effect 1 August 2012) as defined in Appendix VII of Annex VI of MARPOL (concerning SO_x, NO_x and PM)
4. United States Caribbean Sea area (entered into effect 1 January 2014) as defined in Appendix VII of Annex VI of MARPOL (concerning SO_x, NO_x and PM)
5. Pearl River Delta (concerning SO_x, NO_x and PM) established as regulation of the Ministry of Transport of P.R. China in 2016

6. Yangtze River Delta established as regulation of the Ministry of Transport of P.R. China in 2016
7. Bohai Rim (concerning SO_x, NO_x and PM) established as regulation of the Ministry of Transport of P.R.China in 2016

From Figure 3 it is clear, that ECAs are only concerning small, but heavily frequented areas and Heavy Fuel Oil is still the mostly used fuel.

The MARPOL Convention is very important, because only domestic CO_2 emissions of ships and aviation are considered in the Kyoto protocol from 1997.

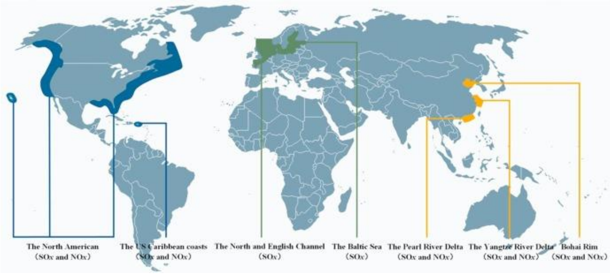

Figure 3 Emission control Areas (ECA) (Zhen, et al. 2018) with limited emissions established as MARPOL Annexes in 2012

The international contribution of shipping and aviation emissions is only considered under Article 2.2 of the Kyoto Protocol for Annex I Parties to "...pursue limitation or reductions of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO), respectively."

Emissions from ships are not at all regulated by any European legislation and should be done on an international level. As responsible agency, IMO is specialized by the United Nations and responsible for the safety and security of shipping and for the prevention of marine and atmospheric pollution by ships. The overall aim of IMO is to create a fair, effective and international regulatory framework for the shipping industry. In 2011, the IMO adopted the Energy Efficiency Design Index (EEDI) aiming to gradually improve the efficiency of newly built ships by 2025. Since 2013, each newly built ship, existing ships of 400 gross tonnage and above during renewal survey receive an International Energy Efficiency Certificate with a defined EEDI in grams CO_2 per ton mile. For the entire fleet, an effect can therefore be expected in the medium to long term, because old ships will be replaced by new ones. However, the increase in fleet efficiency is likely to be offset by growth in the sector. The EEDI enables a comparison of the energy efficiency of individual ships with a similar capacity (in terms of TEU). The EEDI further allows to compare the effect of different engine systems and fuels of ships with similar capacity.

As international maritime agency, IMO is responsible for taking further steps in the near future to reduce greenhouse gas emissions by ships. In October 2016, the IMO already adopted a roadmap for the period 2017 to 2023. The roadmap stipulates that a preliminary strategy with possible measures and time horizons will first be drawn up by 2018. The strategy is to be further developed if additional information is available, in particular from the CO_2 data collection. A final strategy is to be adopted by spring 2023. The long-time horizon with an open outcome to negotiations carries the risk that an effective measure for maritime transport will not be adopted or will be adopted too late. If the negotiations in the IMO do not achieve the necessary successes, the EU should include maritime emissions in European emissions trading from 2023.

In October 2016, the IMO adopted a Data Collection System to record CO_2 emissions from shipping. This system stipulates that CO_2 emissions from ships larger than 5000 gross tonnage (GT) must be recorded from 2019 and reported to the respective flag state.

This is the IMO's reaction to the EU's Monitoring, reporting and verification (MRV) maritime traffic regulation (European Comission 2015), which requires recording, reporting and verification of CO_2 emissions from ships larger than 5000 GT on voyages to and from EU ports from 2018. The MRV regulation, which is directly applicable in all EU member states, regulates obligations to record and report annual greenhouse gas emissions, but does not yet contain an obligation to reduce greenhouse gases in maritime transport and can therefore only be a first step. International shipping remains the only mode of transport to be exempted from the European Union's greenhouse gas reduction obligation (European Comission 2015). The MRV Regulation is more comprehensive than the IMO system - but it is planned that the EU system will be adapted to the IMO system in order to have a globally uniform solution.

In principle, the clear analogy of this reporting obligatory to the European Emission Trading System (ETS) enables legislatives to treat the emissions of both transport sectors in a similar way.

In February 2017, within the framework of the negotiations on the fourth trading period of the EU ETS, the European Parliament explicitly declared itself in favor of the inclusion of shipping traffic in the EU ETS from 1 January 2023, if the International Maritime Organization does not have an efficient system comparable to the ETS in place by 2021 (European Parliament 2017).

Considering all these instruments and regulations, the ambitious goal to restrict the increase in the global mean surface temperature to 2°C by 2100, compared to pre-industrial temperatures (Lee, Lim and Owen 2009) is an international challenge and requires a continuous decline in emissions starting in 2020. From this follows, that regulating instruments have to efficient from today on (Lee, Lim and Owen 2009).

4. AVIATION EMISSIONS IN THE UPPER TROPOSPHERE

The aviation emissions and their impact on global warming are shown in Figure 1 for 2005 following (Lee, Pitari, et al. 2010). In 2005, the aviation carbon dioxide emissions accounted for 2.1% of the global total CO_2 emissions (Lee , Fahey, et al. 2009). Aircraft are powered by jet fuel which is a high-quality mix of pure kerosene. Due to a high variability of environmental conditions in terms of temperature and pressure and a lack of evasion possibilities, aviation fuel must meet high safety requirements. For this reason, additives for the reduction of the risk of icing and explosion due to high temperature are mixed in. The quality and purity of jet fuel differs significantly from that of heavy fuel oil and explains the significant differences in the emission index of both transport sectors (see Figure 1). Especially products of incomplete combustion (BC, SO_2 and NO_x) are reduced in aviation. A significantly smaller Sulphur content in jet fuels induces lower Sulphur emissions from aviation. Currently the sulphur limit in jet fuels is 0.06% (Kapadia, et al. 2016). Per kilogram of jet fuel burned, an aircraft engine emits on average 3160 g carbon dioxide CO_2, 1240 g water vapor H_2O, 14 g nitric oxides NO_x, 0.025 g soot (Lee, Pitari, et al. 2010). However, the emissions take place in high altitudes with low background concentrations and low atmospheric mixing. Hence, the impact of these emissions is partly higher, especially for soot emissions, and the life time is longer. In high altitudes, water vapor emissions H_2O act as a greenhouse gas (see Figure 1).

4.1. Aviation Forecast

The demand for air traffic until 2038 is expected to grow by 4.3 % per year (Airbus 2019).

In 2009, a forecast for aviation emissions has been provided by ICAO from the Committee on Aviation Environmental Protection (CAEP) activities (MODTF/FESG2009 2009) with 3 Gt emitted carbon dioxide in 2050 (see Figure 4). Furthermore, the German Aerospace Center (DLR) published a future scenario in the research project Constrained Scenarios on Aviation and Emissions (CONSAVE) with 0.5 Gt less carbon dioxide emissions in 2050. Both studies by IPPC (J. E. Penner, et al. 1999) and QUANTIFY by Owen et al (Owen, Lee and Lim 2010) also agreed on emissions around 2.5 Gt in 2050. The range in emissions of each study is the result of different mitigation strategies (Figure 4).

All studies predict a weaker increase in CO_2 emissions in comparison to ship traffic forecasts (Figure 2). Unfortunately, the increased aviation demand has always been outstripped CO_2 emissions reductions through technological and operational improvements (J. Penner, et al. 1999).

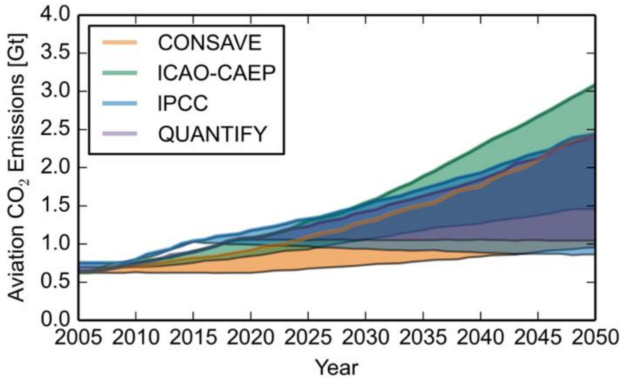

Figure 4: Predicted CO_2 emissions from aviation gained in different studies QUANTIFY (Eide, et al. 2007), CONSAVE (Berghof, et al. 2005), IPCC (J. Penner, et al. 1999), ICAO CAEP (MODTF/FESG2009 2009).

4.2. Aviation Contribution to Global Warming

Although a lower amount of aviation induced greenhouse gas emissions compared to shipping, the impact on global warming is larger, due to lower background concentrations and longer life times. Beside the greenhouse gas effect of three-atomic gas emissions, lots of indirect effects influence the total impact on global warming.

Soot emissions by aircraft sometimes have a cooling effect by providing additional condensation nuclei for cloud droplets (Lee, Pitari, et al. 2010). However, if old soot particles are coated with sulfuric acid, a warming effect dominates. Furthermore, a warming effect dominates by absorbing terrestrial radiation and by covering snow surfaces in the case of young soot particles depleting natural condensation nuclei for cloud droplets (Zhou and Penner 2014). From this follows, the total soot effect mainly depends on the sulfur content in fuel (Zhou and Penner 2014) and on the life time of soot particles in the upper troposphere until washed out by rain or snow. Due to an improvement of aircraft engine technology between 1960 and today a decrease of soot mass emissions by a factor of 40 has been estimated (Petzold, et al. 2003).

Sulphur emissions of SO_2 are converted to sulfuric acid H_2SO_4, which is the principle component of volatile particles. Furthermore, H_2SO_4 is an important aerosol precursor in the upper troposphere resulting in a cooling effect.

Emissions of NO_x cause a destruction of ambient methane (CH_4), with a negative Radiative forcing. NO_x emissions cause the formation of tropospheric O_3 with a warming effect (Lee, Pitari, et al. 2010). Furthermore, NO_x emissions destroy ambient methane CH_4, resulting in an atmospheric cooling. The amount of NO_x emissions used for methane destruction, cannot induce ozone which is why the aviation induces production of tropospheric O_3 decreased in the last decades (Wild, Prather and Akimoto 2001). Additionally, parts of the NO_x emissions are converted to nitric acid HNO_3 which is why and the O_3 production is decreased (Lee, Pitari, et al. 2010). The net effect of NO_x emissions on O_3 depends on altitude and atmospheric transport and on the indirect sulphate effect.

The aviation soot and water vapor emissions cause another effect on global warming: The formation of condensation trails, short contrails, induces an additional barrier in the Earth-atmosphere radiation budget (Rosenow and Fricke 2019) in the same order of magnitude, as the total aviation induces carbon dioxide emissions (Lee, Pitari, et al. 2010), although contrails are only formed during approximatively 10% of all flights (Rosenow, Lindner and Fricke 2017).

4.3. Aviation Regulations

Since 2008, the EU decided to include aviation activities in the EU ETS (European Comission 2008). Therefore, the European Emissions Trading System (ETS) and the Effort Sharing Decision (ESD) are used for the implementation of the objectives of the European Union under the UN Convention on Biological Diversity. The Emission Trading System is a powerful tool to transfer the environmental influence of emissions into cost functions and therewith into objective functions. This procedure of an internalization of social costs, which are caused by external effects, is a market-based instrument to reduce emissions of polluting substances, for example CO_2 (European Comission 2017). It works on the principle of cap and trade using a quantitative limit (cap) of which the price is controlled by supply and demand in trade. Allocation schemes throughout Europe share this cap to the individual companies in terms of emission allowances, also called EU Allowance (EUA). One emission allowance corresponds to one ton of emitted CO_2. The limited quantity of emission allowances thus gives the company prior to minimization objectives. The emission allowances are tradable. The price per EUA since its market launch in 2010 declined from about 15 €/EUA to about 5 €/EUA in 2013 (finanzen.net). In February 2014, the so-called back loading had been introduced by the amended EU Auctioning Regulation. Hence, the available quantity is reduced to 2016 in steps of 900 million EUA (dehst.de). Since then, the price of EUA is more stable at approximately € 6.5/EUA until 2017. Due to a continuous reduction of the number of emission allowances in 2018, the price finally increased up to 30 €/EUA. The reduced sale volumes have been returned to market in 2019 and will be continued in 2020 (dehst.de). However, it is expected to start from a desired price stability which will be implemented. The strong depreciation of the emission allowances suggests a high potential for savings in CO_2 emissions in each company. It is assumed that this potential will be saturated in 2050. A continuous reduction in the emission allowance per company (due to an assumed increasing environmental awareness) would result in an increased value of the certificates. This is enhanced by an assumed growing demand for air transport. To use this instrument in the air traffic optimisation, a sensibility study of the price of an EU Allowance had been performed to estimate the required value in the cost-based optimisation (Bertram, et al. 2015).

The cap-and-trade system implies, that emission allowances are distributed amongst Carbon dioxide producers with completely different potential to increase their efficiency. In aviation, the efficiency enhancing potential is very small, compared to ships and power stations, for example. Since 2010, the total fuel efficiency by commercial aircraft increased by only 2.6% annularly due to technological improvements (Kharina and Rutherford 2015). Compared to a growth in air traffic demand by 4.2% (Airbus 2019), the current gain in fuel efficiency will not compensate the increase in aviation greenhouse gas emissions (see Figure 4). Hence, for the reduction of aviation emissions, the ETS is not effective. Furthermore, the ETS is not accounting for the impact of a ton of CO_2 on global warming, depending on the life time, location and altitude of the emission.

In October 2016 the ICAO developed a marked-based instrument, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), wherein airlines will have to pay for carbon offsets to compensate a growth in CO_2 emissions. The price per offset (i.e. per ton CO_2) will be marked-based. The money will be used to finance CO_2-reducing climate protection projects worldwide, in which emissions from air traffic will be offset to a corresponding extent. In the first place, the production of biofuels is one of the climate protection programs eligible for support. The measure concern emissions from international aviation (flight between two different member states) that exceed the 2020 baseline. As a first step of implementation, all airlines operating international flights are mandated to monitor their fuel consumption emissions and report them to their national authorities since 1 January 2019. On July, 16, 2019, 81 States corresponding to 76.63% of international aviation, voluntarily intend to participate in CORSIA from 2021. All countries with a share of more than 0.5 percent in international air traffic in 2018 have to participate in CORSIA by 2027. The focus of CORSIA on biofuels will increase the demand on biofuels, much of which is produced from palm oil, leading to an increase in emissions (Abdul-Manan 2017) is subject to worldwide criticism, as is the market-based approach, which distracts from the actual goal of reducing aviation emissions (Scheelhase, et al. 2017). However, the biggest weakness of this system is the neglect of national short-haul flights (less than 463 km), which emit almost twice as much CO_2-equivalent emissions per passenger kilometer as long-haul flights (Lipasto calculation system, VTT 2008).

5. COMPARISON

Aviation and ships are emitting greenhouse gases and harmful substances in different altitudes. While aircraft operate during cruise in the upper troposphere and lower stratosphere which are characterized by weak exchange with neighboring atmospheric layers, ships are operating in the boundary layer with an intense mixing. From this follows, on average the life time and the effective duration of the emissions is increased for aviation emission. Since aviation is the only emitter in the upper troposphere, low background concentrations in high altitudes imply an increased climate efficacy of aviation emission. This result is reflected in the figures for the global total radiative forcing of both modes of transport. In 2005, the total radiative forcing of ship traffic was 0.001 W/m^2 (Eyring, Isaksen, et al. 2010), aviation contributed to global warming with a radiative forcing of 0.055 W/m^2 (Lee, Pitari, et al. 2010).

Whereas the total carbon dioxide ship emissions accounted for 960 Tg (Eyring, Isaksen, et al. 2010) and 700 Tg from aviation (Lee, Pitari, et al. 2010) in 2005.

Combustion engines do not only emit greenhouse gases with impact on climate, but also harmful substances for life on Earth which impact on air quality and visibility. These effects are not covered by the radiative forcing and are even more difficult to assess. This makes it all the more difficult if special emissions have an influence on both effects on different time scales. On the one hand, ship sulphur dioxide emissions irritate the mucous membranes and can cause eye irritation and respiratory problems. On a long-term scale, sulphur dioxide can damage plants and, once deposited in ecosystems, cause acidification of soil and water, especially in the boundary layer. On the other hand, sulphur dioxide emissions have a short-term cooling effect on global warming. If higher sulphur limits apply in heavy fuel oil, compared to jet fuel, higher sulphur emissions are to be expected from ship traffic. Contrariwise, higher sulphur limits will further reduce the cooling effect.

Current and expected future technology improvements to mitigate the impact of transport on global warming and life on Earth will not be able to compensate the expected growth in traffic demand and will not fulfill international climate goals. Although there is a huge mitigation in newly build ships, the operating time of ships is too long and the duration between maintenance intervals of ship engines is too long. Jet engines are already operating on very high efficiency level. To further increase the aviation efficiency with respect to a carbon neutral growth of aviation, alternative power units are required which have to comply with high very safety standards, elaborate certification standards and strong differences in ambient conditions of operation. It follows that emissions can be reduced more effectively by internalizing external costs in shipping than in aviation.

For aviation, instruments to decrease the number on inefficient and avoidable short-term flights would be the most promising strategy. This will be achieved by market-based instruments, such as taxes on jet fuel or depending on the expected flight time. Furthermore, take-off and landing charges have a stronger impact on a short-haul flight. In return, acceptable low-emission alternatives must be offered for these routes.

The integration of maritime transport into emissions trading is hampered by an additional difference between shipping and aviation. While airlines often own the operating aircraft, they are responsible for their induced emission. Airlines should therefore be able to pay for their induced emission. They are also able to operate with 4D fuel optimized trajectories (Rosenow, Strunck and Fricke 2019) and gain a high seat load factor by forming alliances. Ships are seldomly operated by the owner, but by a charterer. The owner (i.e. the shipping company) primarily deals with the equipment, manning, maintenance and deployment of its ship or ships. In addition to ship management, the shipping company can also deal with chartering. Today's monitoring, reporting and verification (MRV) maritime traffic regulation (European Comission 2015) affects the shipping company, which has only a limited influence on the fuel efficiency (i.e. the cruising speeds) of individual voyages. A fuel-efficient ship with a low Energy Efficiency Design Index EEDI (in the order of 5 gram CO_2 per ton and per mile) is sometimes operated with EEDI = 50 gram CO_2 per ton and per mile. These differences are the result of load factor, weather conditions and time constraints. Hence, even the charterer is not always able to control the efficiency. The question of who should be penalized for ship emissions remains open. In the event of integration into the emissions trading system, it is also unclear who should acquire the CO_2 certificates.

Finally, it should be noted that the emissions trading system currently only includes connections within, from or to Europe. In the worst case, this restriction could lead to detours with regard to internationally operating modes of transport. As long as the mitigation potential of ship emissions is as high as it is today, technology-based standards and performance-based standards are more effective. Both are applied by IMO regulations on an international level are going to be further tightened in the future.

6. SUMMARY

In this study, a comparison between ship induced and aviation induced emissions and their impact on global warming has been elaborated. Subsequently, technological mitigation strategies of both sectors are confronted with the expected traffic growth as function of a growth in GDP. From a review of political instruments to control the environmental impact of each traffic sector, most efficient strategies are identified and confronted with political goals to mitigate traffic impact on global warming.

It has been found that emissions are strongly dependent on the type of fuel used. The cleaner the fuel, the lower the proportion of incomplete combustion products and the higher the fuel efficiency, which in turn reduces the emission of complete combustion products. Because jet fuel has a higher purity than heavy fuel oil, aircraft emit less substances than ships per mass fuel burned.

In addition, the location of the emission plays an important role in the effectiveness of the species and differs significantly between shipping and air traffic, as it determines the background concentration and the residence time of the emission in the atmosphere. Due to low background concentrations and long life times in the upper troposphere, aviation emissions have a higher radiative forcing.

The technological optimisation potential determines the effectiveness of the policy instruments that can be applied to achieve the policy climate objectives. Ship engines are much more flexible with respect of fuel quality. It follows from this that the use of purer fuels alone has increased efficiency by more than 50%. Furthermore, alternative power units, such as gas or fuel cells have become into operation on a short-term scale which is not possible in aviation due to special certification procedures, high safety standards and challenging boundary conditions.

From this follows, that technology-based and performance-based instruments have been and will further be very effective in maritime traffic, whereas marked-based instruments are disputable, due to unclarified affiliations and responsibilities. In air traffic, marked-based instruments such as taxes or charges might be most effective to reduce the number of less efficient short-term flights.

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DESIGN OF SELECTIVE LINES FOR SECURITY FILTERS IN AIRPORTS AND MULTIMODAL FACILITIES

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ABSTRACT
With the increase of incidents of terrorist attacks, or just control of the passengers that use different modes of transport like airport, ports, rails, or future ones like hydrofoils or hyper loops, security facilities are a key element to be optimized. In the current study we present a design of segregated lines based on categories of passengers. The results indicate that by designing a proper category in combination with novel technology is possible to sweat the assets up to values of 2 digits. As a proof of concept, we present a real-case study of an area within an airport in Mexico.

Keywords: AICM, congestion, airports, multimodal, logistics, simulation, decision support systems

1. INTRODUCTION
Security filters are fundamental areas especially in all the transport modes facilities, ranging from bus stations to high-speed trains, and probably in the future hyper loops or other transport facilities. The objective of those filters is to detect hazardous objects/liquids that can potentially cause an accident that put in risk the safety of the transport operation; in the most extreme cases they aim at detecting terrorists incidents like those that have happened in the past.

Most of the security systems are formed of queue lines that scan the passengers and their belongings, in most of the cases there is a mixture of passengers of diverse types; like those that are business passengers that travel with the very minimum belongings, which in some cases are reduced to only a lap-top, and those that travel with the whole family with baby strollers and a lot of equipment for their leisure activities.

The main problem of the mix of passengers in a line is that it is *unfair* in the sense that those passengers that make an effort to travel *light* are hindered in the queue by those that do not make that effort, and the variability that is created as a consequence reduces the efficiency of the process. This situation causes, in some situations and in some infrastructure, in some hours of the day that the capacity of the system is reached, and long waiting times happen, big queues build up and a throughput drop of the system occurs.

To overcome these situations, most decision makers take the easiest solution and just try to expand the resources adding more lines or changing the systems with the correspondent associated cost.

For similar queue systems it has been proven that different policies produce different results, and scientific community is constantly investigating the effect of novel policies for improving the performance which under variability has a different impact.

In this study we investigated a potential situation of creating categories of passengers based on their amount of belongings. The results suggest that by making specific categories for people with less belongings and modifying slightly the layout of the system it is possible to have an increase of 2 digits in the throughput of the system under study. The latter has been verified by developing a model of a real case study in an airport in Mexico using real data.

2. STATE OF THE ART
There are several studies related to security in different areas. For instance, in Janssen et al. (2019), the authors focus on the analysis using ABM using a RISK approach for improving performance in the security of airport terminals. In Al-Safwani et al. (2018) the authors look for reducing vulnerability using an information security control prioritization that can determine the critical vulnerable controls based on diverse assessment criteria. Other authors focus on the use of optimization techniques for selecting the best strategy based on current performance of technology, which is the case of Candalino et al. (2004). The work of Sahin and Feng (2009) focuses on the selection of different technology for reducing the probability of errors like false positives or false negatives. Other authors like Pettersen and Bjornskau (2015) approach to the problem from a more strategic angle. Lee and Jacobson (2011) present a similar analysis that we present in the current work, they focus on assigning passengers based on the type of technology available which might be more complicated to apply. Stewart and Mueller (2015) present a risk analysis for the pre/check programs in order to increase safety. As it is reviewed, the proposal presented in this work aims at investigating the impact in capacity of segregated lines based on the profile of the passengers which is a novel approach with simulation as the right tool for evaluating the performance.

3. METHODOLOGY
The methodology followed for this study follows the methodology presented by Mujica et al (2018). Figure 1

illustrates the steps of the methodology; in this case it was used one layer with the layout and a 2nd layer with the simulation model was built over it.

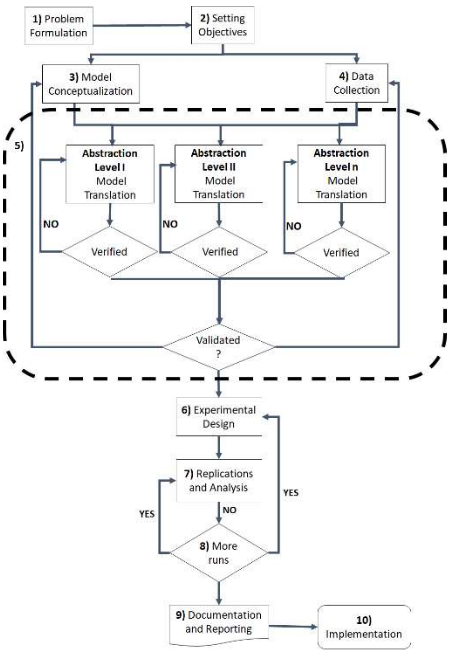

Figure 1. Methodology of the n-model virtual cycle approach for airport capacity

The general system description is presented in the following table.

Table 1. System Description for the security control

Element	Description
Corridor	The corridor runs perpendicular to the area of boarding pass control
Boarding pass control area	Pax are moved through a snake queue all aggregated where two people request the boarding pass and check the reconciliation of boarding pass and passport
Boarding pass control	This process is carried out manually and takes some specific amount of time which is variable
Security lines	There are 4 lines where there is limited space. The pax are directed towards the different lines without making any segregation.
Drop off luggage/belongings	The pax manually drop their belongings using the trays available for them, this process is manual and variable. In the drop area there is limited space
Bands	The bands are moving at a constant speed
X Ray Machines	The systems count with X ray machines for the luggage that is reviewed in a screen by the officer, this process is variable
Metal detector	Once the pax has dropped its luggage, then, they cross a metal detector that sends a signal if some metal is detected. If that is the case, then the pax is directed to an officer for a 2nd check
2nd Metal check	The process is done manually by an officer using another machine, this procedure is variable
2nd Check for luggage	If the luggage scanned by the X ray machine has something strange to the eye of the officer that is reviewing it, it will be directed to a 2nd manual check. This procedure is manual and variable
Reconciliation pax-luggage	Once the pax and the luggage have been screened by the X Ray and metal detector machines, they should be reconciled at the end of the band. This process is variable
Exit of the system	The pax and luggage exit the system through a door at the end without further processes to be performed
Physical limitations	The described system is in an area that has physical limitations and it is not allowed to expand its area.

3.1. Conceptual model

The different elements used in the model together with the assumptions are presented in the following table. In this case the bound of the model is the area under study and physically and a section of the corridor of the airport. W considered this an important limitation since from real observations, the dynamics of the passengers change from the corridor to the security area. During some time of the day, there is string congestion which is part of the problems to be addressed by this study.

Table 2. Example of passenger data

Element	Description
Arrival queue	This object will direct the pax to two servers that simulate the boarding pass control
Passengers	The passengers are entities that flow within the model where they have variation of speed and number of luggage, they carry
boarding pass agents	These processes are modelled by servers of one resource and one capacity where the processing time is variable and according to the sample from the real process
Dropping areas	It is a server where the entities enter and suffer a delay according to real situation. In this area the luggage of the passenger is created based on the characteristic of the passenger
Transport bands	These are paths connected to the dropping areas, and X-ray machines and reconciliation
X-Ray machines	These are servers with capacity of 1 where the processing time is variable and according to the sample of reality
Metal detectors	These are servers like X-ray machines, and they follow a processing time according to the sample of the real situation
Manual revisions	These are servers that represent an officer that manually checks either the pax or the luggage
Reconciliation areas	These are objects that recombine the luggage that belongs to the passengers altogether.

4. CASE STUDY

The area under study is a security control area in a Mexican airport which has suffered from a lot of congestion during the peak hours of the days. As it can be expected, some days are worse than others depending on the season of the year. The airport operator wants to improve the system so that the level of service and the capacity is increased, for that reason, a progressive improvement is taking place. First, they will add more security lines; and later they have the plans to update the different systems e.g. automatic boarding pass controls, implantation of body scanners and new X-Ray technology among others.

The current layout is illustrated by Figure *2*. Previously, there were only three lines, and as the figure illustrates, now there are four lines. With the new line in place, it is expected the increase of capacity. However, as it is noted, there are limitations of space and that might influence negatively the LOS indicator which is an important one for airports.

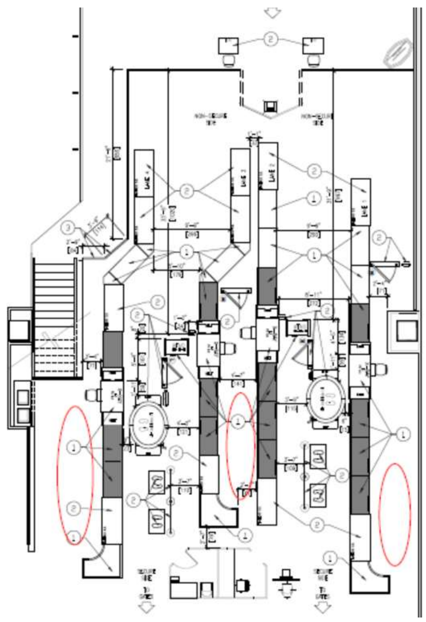

Figure 2. Current layout of security

We have proposed to create the following categories of passengers: No-luggage, with-luggage, special-needs and use them to evaluate new policies.

In addition, we proposed a policy that only some of the passengers take a dedicated line, those that are travelling without luggage and with disabilities, assuming that a significant part of the variability will be reduced and also the unfairness present for the passengers that travel light. Furthermore, we consider this would incentivize potential passengers to travel light with the benefit to the airport, airlines and passengers.

4.1. Experimental Design and results

To investigate the effect of the modification of layout or a novel policy, we run first a base case which models the current situation and then we evaluated different variations of the policy for identifying the effect. Table *3* shows the experimental design for the study.

Table 3. Experimental Design

Factor	Levels	
Demand	Low	High
Configuration Of Lines	Mix Mode	Segregated Mode

For this factorial design, we considered as low demand approximately 5000 pax/day while for high demand 12 300 pax/day based on the real information obtained for the airport under study.
We run a full factorial design, where the segregated mode referred to using one of the security lines after boarding pass control only for the passenger with no-luggage and those with disabilities. The results are presented in Table *4*.

Table 4. Full Factorial Design Result

	Luggage Pax NC	Luggage Pax ND	No Luggage NC	No Luggage ND	Special needs NC	Special Needs ND
Low Demand Mix Mode	μ=4195 σ=63	μ =4180 σ= 62	μ =784 σ= 24	μ =782 σ= 24	μ =258 σ= 18	μ =257 σ= 17
Low Demand Segregated	μ=4173 σ=56	μ =4157 σ= 57	μ =786 σ= 29	μ =783 σ= 29	μ =266 σ= 17	μ =265 σ= 17
High Demand mix Mode	μ=9866 σ=88	μ =7151 σ= 37	μ =1841 σ= 43	μ =697 σ= 27	μ =612 σ= 19	μ =230 σ= 11
High Demand Segregated	μ =9872 σ=99	μ =7121 σ= 30	μ =1854 σ= 42	μ =702 σ= 20	μ =616 σ= 23	μ =230 σ= 10

The results from this initial experimental design provided no significant effect in the security lines; for that reason, a major modification has been proposed. In this case we analysed the effect of extending a dedicated line for the previous categories but starting from the boarding pass control. The following figure illustrates the proposed layout.

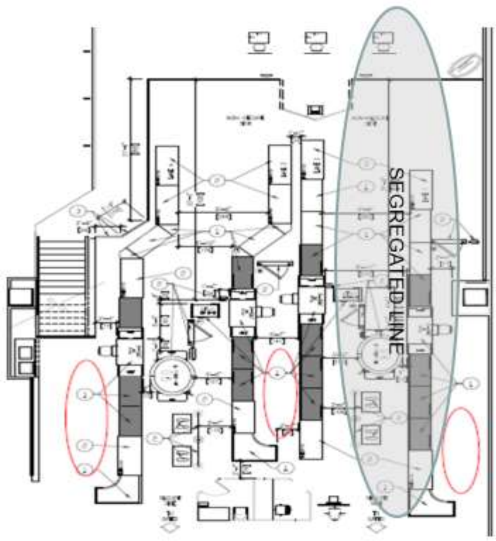

Figure 3. New layout for the security control

As this policy extends the categorization to the boarding pass control, no-luggage passengers and passengers with special needs will have special lines for boarding pass control and for the revision of the luggage. For identifying the effect of this new layout, we assumed a range of percentages of people that are travelling light. Table *5* presents the new experimental design.

Table 5. Experimental design for layout X

Factor	Levels: % of No/Luggage Pax					
Percentage of Non-Luggage Pax	3	10	20	50	60	70

We run the design of experiments with 100 replications of every scenario and the results are those presented in the next figures

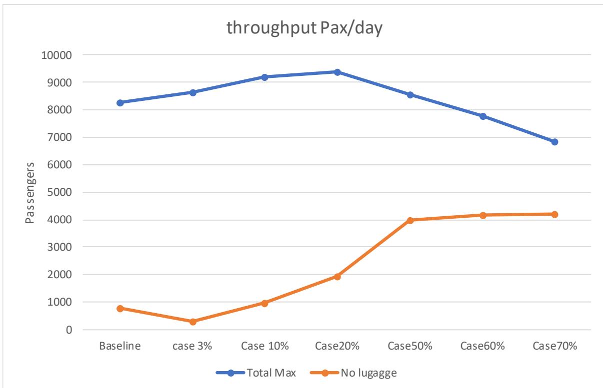

Figure 4. Variation of Throughput vs reduction of luggage

As the results show, the improvement of the throughput is clear just by segregating the passengers (case 3%). However, it can be perceived that the total amount of passengers behave in a non-linear way. For that reason and just by looking at the graph it can be inferred that for this system, the capacity drops after 20% or 30% of increase in amount of non-luggage passengers. It is evident that the total capacity increases until a maximum reached around 20% or 30%. For this situation, the capacity increased by 13% at least which means at least 1500 more passengers/day or 0.5 Million more passengers/yr. which applied to the remaining areas of the airport mean an important increase.

Since the behaviour of the system is not linear at all, in the future, it will be necessary evaluate all the parameters that play a role to maximize the throughput without modifying greatly the layout of the current facilities. Furthermore, it will be necessary to investigate further why is the reason that the throughput drops with the increase of non- luggage passengers and improve the system even more.

5. CONCLUSIONS AND FUTURE WORK

As the study has illustrated, the use of dedicated lines for managing some categories of passengers can have a big impact in a dynamic system, when variability is present. In our study, we proposed a new way to manage passengers, those that carry almost no luggage or those that require special attention. In our experiment with the simulation model we could improve the throughput of the system by approximately 13% in a day of demand that corresponds to approximately 1500 pax more a day or 500 k more passengers a year in that area. The results show that by implementing the proposed policy, it will be possible to sweat the assets at their maximum without expanding the facilities or by reducing the quality of the revision.

In the future work, the authors will investigate the causes of the reduction in capacity as the no-luggage passengers increase. It is important to mention that by following the results of the study, we could identify that, in order to make the segregation work, it was necessary to extend it to the boarding pass control and the security lines. In future work, attention will be paid to more realistic values of the current operation, and we will evaluate the potential of changing the technology in some of the processes that compose the security control process. In addition, we will investigate incentives so that the passengers are discouraged to carry more luggage than necessary, thus making the increase in the capacity of the system more relevant,) especially in systems whose capacity is at the very limit and it is complicated to expand the facilities.

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ALGORITHMS FOR OPTIMIZING SCHEDULING OF AIRCRAFT TAKE-OFFS

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ABSTRACT
We study aircraft departure scheduling optimization with a focus on optimal sequencing on the runway and applied it to data from the Mexico City Airport. Our model considers runway layout operational, and safety restrictions. We evaluate solution methods including dynamic programming, and a beam search approach, providing computational results and comparisons. Our proposed methods run at reasonable times for implementation in an on-line decision system. The results also provide insight into the impact of runway layout and scheduling to reduce aircraft total time throughput and waiting times.

Keywords: scheduling, aircraft take-off, beam search, dynamic programming.

1. INTRODUCTION

Air traffic has increased steadily this last decade and is expected to continue to do so with global air traffic volumes anticipated to handle over nine billion passengers by 2025 (see Ghoniem (2014)). Capacity expansion at airports require considerable investment and long construction lead times. The efficient operation of airports, and runways in particular, is critical to the throughput of the air transportation system as a whole. Scheduling arrivals and departures at runways is a complex problem that needs to address diverse and often competing consideration of efficiency, safety and equity among airlines. The runway system has been identified as a primary bottle neck in airport capacity Bennell (2011). Improving, even by a small percentage, such operations can have an important impact on cost reduction, without the big financial requirements of expansion investments, as well as improving CO2 emission by lowering aircraft waiting times.

The literature on aircraft scheduling studies two types of aircraft scheduling problems: the aircraft landing problem and the aircraft take-off problem. As explained in Bennell (2011), the ALP has been studied more extensive than the Aircraft take-off problem. The interesting paper by Balakrishnan and Chandra (2010) provide a dynamic programming framework to explore the *Constrainted Position Shifting* (CPS) of airport take-offs and landings which they then try out at the Denver Airport. Recently Ma (2019) proposes two integer linear programming models and propose a simulated annealing algorithm to schedule aircraft departures, with data from the Pairs Charles De Gaulle Airport. We study the Aircraft take-off problem with CPS using a model similar to Mesgarpour (2012), and implement a beam search approach to find a schedule for aircraft take-offs using data from the Mexico City International Airport (AICM, it's Spanish acronym).

Runway scheduling and safety is the responsibility of the controllers at the airport traffic control tower. When an aircraft takes off any aircraft that follows needs to wait for the turbulence from the wake vortices of the preceding aircraft to dissipate. Larger aircrafts create stronger vortices than lighter aircrafts, and are more affected by them, so that safety separation between aircrafts is dependent on the type of aircraft in the departing sequence. Also, as aircraft depart along fixed departure routes, called *standard instrument departure* (SID) routes, airport traffic controllers need to ensure that correct in-flight separation is taken to keep airspace from over congesting. Hence, the frequency of departures along each SID route and group of SID routes is controlled by applying minimum separation times between aircrafts. These and other constraints are explained in more detail in Section 2.

There are a variety of layouts for runways in airports, and a runway may be dedicated exclusively for landing or for take-off only, or alternatively be managed in a mix-mode where both landing and departing planes are allowed intermittent use of the runway. Even though the AICM has two runways due to safety regulation only one can be used at a time as explained in Section 3. As mentioned by Atkin et. al (2007) given the uncertainty in taxi and pushback times as well as the availability of stands it is more practical to reorder aircrafts at holding points than it is at stands, and the geometry of the runway holding points adds physical constraints to the reordering of aircraft that are usually ignored in the academic literature. We are interested in designing and evaluating algorithms to schedule the aircrafts to include restrictions given by the layout of the departure holding area. Dynamic programming, descent local search and beam search methods for optimizing take-off schedules, subject to timing, layout and separation constraints are proposed in Section 4. The performance of the proposed algorithms is evaluated using data from AICM. The experiments and results are presented in Section 5. Our conclusions are discussed in Section 6.

2. AIRCRAFT DEPARTURE MODEL

The take-off scheduling problem is to find a sequence and corresponding scheduled take-off times that optimizes an objective function subject to safety, and operational constraints. As stated in Mesgarpour (2011), generally, ground movement controllers are responsible for giving clearance and guidance to the pilots for leaving the gate and the route for taxiing to the runway. Then, the responsibility is passed onwards to the take-off runway controller. Therefore, the initial take-off sequence, which we will name the *First-Come First-Served* (FCFS) order, is generated by the ground movement controllers and it will be modified and finalized by the take-off runway controller. Planning the taxiing of departing aircraft to the runway so that these aircraft reach the runway threshold in the right sequence just in time is unrealistic based on the infrastructure and current level of technology see Bennell (2011). Therefore, aircrafts have to wait frequently in the holding area before departure. Depending on the layout of the holding area and the number of entry points to the runway, runway controllers usually re-sequence the aircrafts for take-off instead using the FCFS sequence to improve runway utilization and to meet planned departure times.

Our study involves scheduling *n* aircraft for take-off on a single runway. The arrival times of these aircraft into the runway holding area are given by at_1, at_2,…, at_n, where the indices are chosen in a way that they are ordered in non-increasing order of times: $at_1 \leq at_2 \leq \ldots \leq at_n$. Our aim is to determine take-off times T_1, … , T_n for these aircrafts.

2.1. Objective Functions

We consider a hierarchical objective function. The main objective function is minimizing the maximum take-off time (makespan or runway throughput), $T_{\max}$, where

$$T_{\max} = \max_{j=1,\ldots,n} T_j \qquad (1)$$

is regarded as being of primary importance by air traffic controllers. Minimizing the total waiting time

$$TWT = \sum_{j=1}^{n} (T_j - at_j) \qquad (2)$$

is chosen as the second objective, where the waiting time of an aircraft is defined as the difference between its scheduled take-off time and its arrival time into the holding area. The first objective (1) aims to maximize the runway's utilization, which has been identified as the main bottle neck in airport capacity. Fairness among the departure flights, fuel burn, CO2 emission and delay are dealt by the second objective function (2).

2.2. Constraints

There two main type of constraints that need to be taken into account when generating the schedule and in modifying the FCFS sequence, which we will described with more detail below.

2.2.1. Safety Separation Constraints

Safety separation constraints need to be imposed due to wake vortex turbulence. Wake vortex generated by departing flights pose a potential risk to the following aircraft. Therefore, aircraft should maintain minimum standard separation to avoid wake turbulence hazard. Another component of the separation time is the SID route and aircraft speed considerations. Unfortunately, these two components make it impossible to ensure that the minimum standard separation is maintain by only looking at adjacent take-offs. A SID route defines an air route out of airport to facilitate transition between take-off and on route operations. Generally, if the following aircraft is in a higher airspeed class category than the leading aircraft, two minutes separation is required; otherwise, a one-minute minimum separation is imposed. Moreover, the minimum separation increases by one minute if two consecutive take-off flights use the same departure route.

In addition, if two consecutive take-off flights are of different weight turbulence category, then the route-based separation needs to be modified. The International Civil Aviation Organization divides aircraft into different wake turbulence weight categories based on the maximum certificated takeoff mass as state in Ma (2019). Therefore, separations are different for the various combinations of departure flights. They are asymmetric and do not necessarily satisfy the triangle inequality. We have observed that it is sufficient to ensure that separation constraints are satisfied between each group of four consecutive departing aircraft.

Let

$$\lambda_{ij} = \begin{cases} 1 & if\ i\ and\ j\ have\ the\ same\ SID\ route \\ 0 & otherwise \end{cases}$$

an indicator that aircraft *i* and *j* took the same SID route, and let $l(i,j)$ the adjustment on the separation time due to the speed and weight group of aircraft *i* followed by aircraft *j*, then then the separation constraint can be expressed by the following inequality

$$T_i + l(i,j) + \lambda_{ij} \leq T_j \qquad (3)$$

2.2.2. Layout constraints

The layout and configuration of the holding area represents the main limiting factor for the take-off runway controllers in changing the position of the aircraft in the sequence. The departure holding area can be divided into two sections; one section is used for holding and the other one is used for queueing (taxiway). It is assumed that aircrafts form a queue before entering to the holding section which we refer as the *queueing section* represented by the letters *Q* in Figure 1 (which is a simplified model of the runway layout of AICM). The *holding section* comprises the waiting positions before the entrance to the runway represented by *R* letters, and the positions in-between denoted by the *M* letter. It is assumed that aircrafts cannot overtake each other in the queueing section, and should follow the physical restrictions imposed by the layout in the holding section. It is also assumed that heavy class aircrafts must enter the runway using the last entrance R_1, so that the aircraft may use the whole length of the runway. As is shown in Figure 1, there are three holding points, namely R_1, R_2 and M_1. An aircraft in position R_1 cannot be overtaken by an aircraft in position M_1. Likewise, an aircraft in position Q_1 can only access position R_1 if there is no aircraft occupying positions M_1 and R_1. However, if there is an aircraft in position R_1 and one in position R_2 either aircraft can be allowed to take off before the other, and thus the departure position of an aircraft can be altered from its initial position in the queue (FCFS). More complicated configurations (with greater number of entrances and waiting positions) allow greater deviation from the FCFS order in the queue (taxiway).

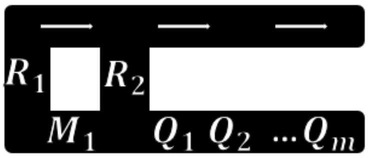

Figure 1: Layout of AICM

Unlike the Mesgarpour (2012), we do not need to consider the Calculate Time of Take-off (time windows) constraints since these are only assigned for flights within Europe by EUROCONTROL and there is no equivalent international control agency in our case.

3. MEXICO CITY INTERNATIONAL AIRPORT

Mexico City International Airport has two terminals (T1, and T2 as shown in Figure 2) that use the same runways, with a total of 56 departure fixed gates and 18 positions for mobile departure lounges for a total of 74 departure lounges. It is Mexico's and Latin America's busiest airport by passenger traffic and aircraft movements. There were one average 1,160 operations per day (including landing and take-off operations) in 2018, see AICM statistics, ACIM (2019). The AICM declared maximum amount of operations (official capacity) has been set to 61 operations per hour.

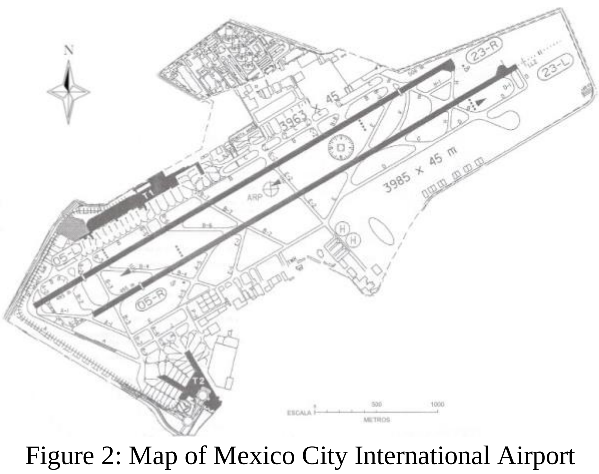

Figure 2: Map of Mexico City International Airport

As can be seen in Figure 2 the Airport has two parallel runways (23-L and 23-R) with a separation of 310 meters which inhibits the use of both runways simultaneously. For this study, we have taken data of take-offs over the 24 hours of a day from the 26 of July of 2016 until de 10 of August of 2016, covering total of 16 days of a busy holiday season. As can be seen in Figure 3, there are more than 20 departing flights on average from 6:00am until 11:00pm. With the maximum average amount of departures in the 10:00-11:00 hour slot, with an average of 37 departures. In fact, during our observation period there was a day (outlier observation) when there were more than the 61 aircrafts departing in an hour (See Figure 4), which the media has reported as been the upper limit of allowable operations.

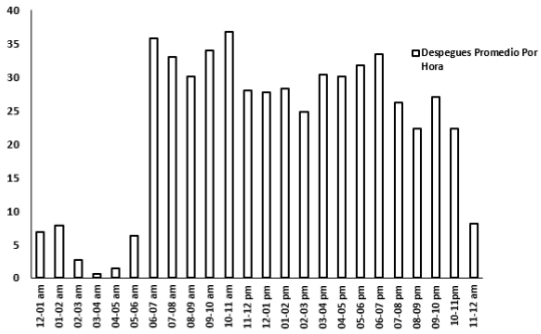

Figure 3: Average number of departure per hour period on a day

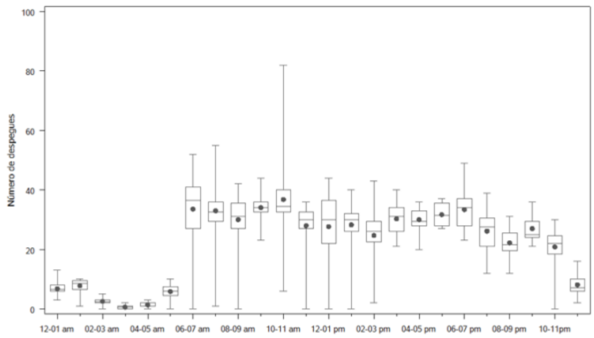

Figure 4: Box Plot of take-off per hour of day

This Figure shows the spread of the number of take offs (Y axis) for each hour period (X axis). Where the lowermost delimiter of the box is the first quantile and uppermost the third quantile the middle line represents the median and the data for that period, and the whiskers (lines show the minimum and maximum observations). This plot is helpful to understand the variability and range of the data, as can be seen there is more variability in number of takeoff from 6am until 11pm.

In this observation period, there were 588 flights on average per day. For this study, we considered a flight as being delayed if it took off more than one minute after its designated time of take-off. Using this definition then 423 flights on average were delayed per day (72% of departures). However, aviation companies define as on-time operation one within a deviation of up to 14 minutes and 40 seconds form the planned take-off time, which will bring the number down to 42% on the busy time slots. We have identified 3 main SID routes and 3 types of aircrafts (by weight) with the following behaviour with respect them been delayed (see Tables 1 and 2).

Table 1: Distribution of Aircrafts by weight

Type of Aircraft				
	Light	Medium	Heavy	Total
Delayed	401	6,002	367	6,770
On time	218	2,282	138	2,638
Total	619	8,284	505	9,408

Table 2: Distribution of Aircrafts by SID route

SID route taken by Aircraft				
	Route 1	Route 2	Route 3	Total
Delayed	1,279	3,407	2,083	6,770
On time	613	1,291	735	2,638
Total	1,892	4,698	2,818	9,408

Lightweight aircrafts and SID route 1 have slightly less delays than other type of aircraft and routes. It seems that there might be an opportunity to improvement the operation of the airport with regards with on-time departure of aircrafts.

4. SOLUTION APPROACH

In this section, we describe three different solution methods that were applied to solve our Aircraft take-off problem.

4.1. Dynamic Programming Algorithm

Similar to Mesgarpour (2012), we define a dynamic program where the state:

$$S_j = (r_1, r_2, m_1, t_1, t_2, t_3)$$

represents a configuration of the holding area of the runway, and the order of the last three departing aircrafts of a partial sequencing of j-1 aircrafts, where r_1 is the aircraft waiting in position R_1 of the runway, r_2 is the aircraft waiting in position R_2, and m_1 the one in position M_1, while t_1, t_2 and t_3 are the last three aircraft to have taken off. A zero value on any of the three first entries of a state represent that the holding position is empty, and in the last three entries that less than three aircrafts have departed. At each state S_j we want to minimize

$$F_j(S_j) = F_j(r_1, r_2, m_1, t_1, t_2, t_3)$$

the minimum take-off time of the j-th aircraft to depart among all partial schedules reaching the state (r_1, r_2, m_1, t_1, t_2, t_3). Let $N(S_j)$ be the set of possible states reachable from $S_j = (r_1, r_2, m_1, t_1, t_2, t_3)$.

Then we can state the dynamic programming recursion to solve the problem of minimizing the throughput time of aircrafts for j=1, … , n as:

$$F_j(S_j) = \min_{S_{j+1} \in N(S_j)} \{F_{j+1}(S_{j+1})\}$$

Let q_1 be the first plane in the queueing section of the runway in state $S_j = (r_1, r_2, m_1, t_1, t_2, t_3)$. If r_1, r_2 and m_1 are nonzero, then $N(S_j)$ is a set with the following 4 possible states:

- (m_1, r_2, q_1, r_1, t_1, t_2) representing the case where aircraft r_1 takes off, aircraft m_1 moves from position M_1 to position R_1 and aircraft q_1 moves from the queue to position M_1.
- (m_1, r_2, 0, r_1, t_1, t_2) representing the case where aircraft r_1 takes off, aircraft m_1 moves from position M_1 to position R_1 but aircraft q_1 stays in the queue.
- (r_1, q_1, m_1, r_2, t_1, t_2) representing the case where aircraft r_2 takes off, and aircraft q_1 moves from the queue to position R_2.
- (r_1, 0, m_1, r_2, t_1, t_2) representing the case where aircraft r_2 takes off, and aircraft q_1 stays in the queue.

The dynamic programming algorithm we propose can be implemented on a directed acyclic graph that represents the feasible take-off schedules of planes. It bears some resemblance to the approach used by Balakrishnan and Chandra (2010) for scheduling landings with a constraint on the number of positions an aircraft can shift relative to the FCFS landing sequence. There are n main stages to consider in the construction of the graph, where n is the number of available aircrafts to be sequenced. Additionally, we consider an initial node s directed to all the nodes in the first stage and a final node t with incoming arcs form all nodes at stage n, thus finding a shorter path in the graph is equivalent to finding the optimal take-off schedule. Each transition from one stage to the next one corresponds to the take-off of one aircraft and the movement of aircraft to different holding points. Given $N(S_j) = N(r_1, r_2, m_1, t_1, t_2, t_3)$, it is straightforward to use equations (1) and (2) to compute the take-off time of the next aircraft r_1 or r_2 (length of the arc), or to discover that the state transition is impossible (there exists no arc), because the aircraft weight class is heavy and cannot enter to the runway via position R_2. Take-off times are subject to separation and layout constraints as defined by the network.

The holding section is the only area where runway controllers can re-sequence departing aircraft. To model the problem of sequencing departing aircraft in the holding area, we construct a network that defines allowable movements of aircraft in the departure runway holding section, representing the state transitions of our dynamic programming algorithm. The idea behind the dynamic programming is to find a minimum length s-t path in the network to maximize the runway throughput which is measured by the maximum take-off time. Total waiting time is used to break the ties among any identical solutions and it can be also considered as the second objective.

4.2. Beam Search

Beam search (BS) method is an adaptation of branch-and-bound algorithm, see Morrison (2016), in which only the best β promising nodes at each level of search tree are selected to branch based on global evaluation, where β is the *beam width*. Then, the other nodes are pruned permanently. During filtering process, some nodes are discarded permanently based on a local evaluation function value and is performed for each set of child nodes branching from the same parent node. The best α children of each beam node are retained for global evaluation step, where α is the *filter width*. Figure 5 illustrates an expanded beam search tree with α =2 and β =3.

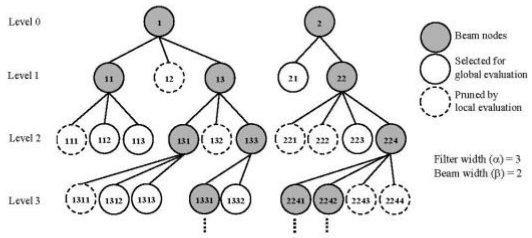

Figure 5: Illustration of a beam search

The idea is to reduce the running time of the algorithm to be polynomial for large-sized problems by restricting the search space, unlike a complete branch and bound search. The local evaluation function is usually designed to be computationally fast; however, it may lead to eliminate good nodes. On the other hand, global evaluation functions tend to be more accurate but require higher computational time. There usually is a trade-off between computation time and solution quality.

For the local evaluation we have used:

- T_{max}: take-off time of the last aircraft scheduled in the partial sequence;
- ATT: average take-off time of the aircraft scheduled in the partial sequence;
- TWT: total waiting time of aircraft scheduled in the partial sequence;

Minimizing the T_{max} is chosen as the main objective for the global evaluation and the total waiting time of the aircraft according to is selected as the second objective. In order to perform the global evaluation, a local search method, as explained in Section 4.3, has been adapted to construct the rest of the partial sequence. The general idea is to first sequence in FCFS order the unscheduled aircraft to obtain an initial solution for the local search. Then, a local search performed to complete the rest of the schedule and estimate the minimum T_{max} of the sequence that can be reached from the current node.

4.3. Local Search

The idea of a local search algorithm is to define a neighborhood of a solution, exploring and moving to a better solution within the neighborhood. In our case we have chosen a *single insert* neighborhood, which considers all feasible sequences that can be obtained from the current solution by removing an aircraft from its current position and inserting it into a new position in the sequence. There are different searching strategies to explore the neighborhood, we have applied a *best improvement* strategy, choosing the best value of all neighbors to be the new solution (sequence of aircrafts). If the best neighborhood does not improve the current solution, then the algorithm terminates with a local optimal solution, otherwise the local search is repeated until no better solution is found.

One disadvantage of focusing on sequences rather than schedule is the fact that a complete schedule also indicates the assigned entrance to the runway of the aircraft and departing time. For this purpose, a Feasibility Check (FC) algorithm has been developed. First, we can observe that the possible insert moves are restricted by the layout, in particular for the layout introduced in Figure 1, an insert move three spaces forward or backward is not possible, second for the FC algorithm we check the compliance with restriction (3) and the weight restriction (R_1 for heavy), third an entrance is assigned is assigned to the aircraft starting in the first un-positioned aircraft in the sequence, and a final check, to comply with the layout of the holding area is done to determine the feasibility of a given sequence.

We compare the above proposed local search with simple best-improve insert neighborhood against the beam search and the dynamic programming approach, summarizing the results in Section 5.1.

5. COMPUTATIONAL EXPERIMENTS AND RESULTS

In this section, we first evaluate the methods proposed on random generated data based on the general behavior the collected data from ACIM, later we evaluate the advantage of these methods of scheduling with respect to the operations observed in the period under study, and conclude in the last section pointing out interesting further research to be done.

5.1. General Evaluation of the Methods

We have generated 3 sets of random data each with 20 instances of n=10 departing aircrafts based on three different scenarios for the inter-arrival times to the queue. We assume that the inter-arrival times of aircrafts, variables at_j, are exponentially distributed with arrival rate λ=1/85, λ=1/80, λ=1/75, each one representing, in that order, a less traffic-dense volume of arrival. The distribution of light, medium and heavy aircrafts follow the observed numbers (as shown in Table 1: 6.5%, 88%, and 5.2% respectively) as well as the SID route (as shown in Table 2: 20%, 50%, and 30%). The algorithms were implemented in Excel-VBA for ease of use by Air Traffic Control, and ran in a MacBook Air 1.3GHz Intel Core i5 with 4 GB of memory.

5.1.1. Parameter Setting for the Beam Search

We have first done some initial runs taking a subset of 5 instances of each scenario to find good values for the filter α and beam width β parameters for the beam search. We have observed the improvement on the FCFS sequence using different local evaluation functions as is summarized in Table 3.

Table 3: Average Percentage of Improvement on FCFS

α	Local Evaluation Criteria	β 50	80	110	140	170
2	Tmax	15.7	15.9	16.4	16.5	17.1
	ATT	15.8	15.9	16.4	16.7	17.1
	TWT	14.9	14.2	14.4	14.7	14.2
3	Tmax	16.7	16.8	17.5	17.6	18.0
	ATT	16.8	16.8	17.4	17.6	18.1
	TWT	15.2	15.6	15.7	16.1	16.3
4	Tmax	17.4	18.2	18.8	18.8	18.8
	ATT	17.6	18.1	18.8	18.8	18.8
	TWT	16.9	16.2	17.5	17.8	18.8

As can be observed the bigger values of α and beam width β result in a greater improvement on the FCFS, however it also implies a longer time for the beam search to finish its search for a better solution. However, it seems that improvement on the FCFS sequence stabilizes for α=4, and values above $\beta \geq 110$ nodes. It is also interesting to note that using T_{max} for the local evaluation is not always the best, using ATT is sometimes better, but TWT is not useful for the final T_{max} of the 10-aircraft schedule. Perhaps focusing on the total waiting time is a function that does not go exactly towards minimizing the utilization of the runway. However, TWT is interesting in terms of fairness between airlines and CO2 emissions. For the comparisons on the next subsection (where we use the complete data set) se have chosen α=4, and values above β = 110.

5.1.2. Comparison of the different Algorithms

We now present, in Table 4 and 5, the results of applying the different algorithms to the random data set we generated, we present averages over all instances in each set of 20 instances.

Table 4: Results of Comparing Different Algorithms Tmax in seconds

Data Set	FCFS	Local Search	Beam Search	Dynamic Programming
λ=1/85	526	511	475	446
λ=1/80	520	505	455	431
λ=1/75	519	500	425	412

Table 5: Results of Comparing Different Algorithms (running time) in seconds

Data Set	FCFS	Local Search	Beam Search	Dynamic Programming
λ=1/85	0.02	0.32	4.7	175
λ=1/80	0.01	0.35	4.5	164
λ=1/75	0.01	0.41	3.9	158

We see that one may improve the schedule up to 21% from the FCFS in the best case (λ=1/75) where there are less aircrafts arriving at the taxiway. That would free almost 1.8 minutes in an eight minute period to allow more aircrafts to depart, without any investment in infrastructure, just by reordering aircrafts in the holding area. This is an important result for practitioners.

We also note that the dynamic programming algorithm may take up to 3 minutes on average to find the optimal schedule (λ=1/85). However, the Beam Search does no take more than 5 seconds do find a solution of good quality. Hence, an on-line decision system for Air Traffic Control may thus prefer an implementation of the Beam Search. It is important to note that we tried a case with 15 aircrafts and the dynamic programming approach started having problems with some instances in terms of memory. However as there tends to be no more than 37 departures in a given hour, considering 10 aircrafts waiting on the taxiway seems a reasonable. It is also interesting to see that a simple local search improves on the FCFS sequence, and that is it is very fast to construct/evaluate the feasibility of such a sequence (less than 0.02 seconds).

5.2. Comparisons with the ACIM operation

To apply our algorithms, we divided each hour period into six 10-minute time slots so we had less than 10 aircrafts in each slot and ensure that our algorithms could cope with the computation. When applying our Beam Search to the observed data of the period we obtained on average a 19% of improvement. We should note that there are variabilities on weight and SID routes depending on the hour of the day, which we did not consider when generating our random data set. As shown in Table 5 where we present the data on three selected one-hour time slots.

Table 5: Percentage of Planes in Each SID Route and type of Aircraft.

SID Route Distribution			
Hour Slot	Route 1	Route 2	Route 3
10-11am	29%	48%	23%
8-9pm	16%	48%	36%
12pm-1am	29%	32%	39%
Type of Plane			
Hour Slot	Light	Medium	Heavy
10-11am	9%	89%	2%
8-9pm	4%	83%	13%
12pm-1am	1%	63%	36%

However, this did not impact considerably on the improvements obtained with our algorithms. The best improvements were obtained on time slots with between 20 to 37 aircrafts departing.

6. CONCLUSIONS AND FUTHER WORK

We have proposed three different algorithms for aircraft take-off scheduling with important improvements on the current schedules. This exercise points to the fact that an on-line decisions system based on a Beam Search approach may prove useful to air-traffic controllers. Air-traffic controllers, have to deal with more than just the take-off schedule of aircrafts, hence providing them with automated and fast suggestions is ideal to increase the efficiency and capacity of airports with minimum investment.

It would be interesting to evaluate the algorithms in more complex layouts to evaluate the advantage of having more waiting point in the holding area. We expect greater improvements as more holding points allow bigger changes in the sequence.

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Author's index