Multimodal Transport and Deglobalization Trends

Conference proceedings

June 6 – 7

Universidad del Mar

Huatulco, Oaxaca, México

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Multilog Conference 2024
Multimodal Transport and Deglobalization Trends
UNIVERSIDAD DEL MAR
CAMPUS HUATULCO

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Preface Multilog 2024

Multimodal Transport amidst Deglobalization Trends

The 2024 edition of the Multilog Conference focuses on the new trends in deglobalization. This is a trend that our current generation is witnessing: a shift from global networks to more localized or regional networks. To address these new challenges, various approaches are emerging as ways of dealing with different problems.

We have divided the presentations into four different clusters: Green Transport Solutions, Urban Transportation and Infrastructure, Logistics and Supply Chain Management, and Technology and Transportation Efficiency. These clusters, along with keynotes from various parts of the globe, including South and Eastern Europe, Northern Europe, and highlights of the local situation, made the conference a comprehensive wrap-up that encompasses key facts, new technologies, and intelligent solutions. The audience enjoyed and gained insights that could enlighten their vision for future challenges.

In summary, there are diverse challenges ahead, and the networks are dynamic. Solutions such as simulation optimization, machine learning, computer vision, and various architectures for combining these technologies, as presented at the conference, exemplify the type of knowledge that will be required in the medium and long term by industry and government to address these challenges. Future professionals should anticipate that more technical skills will be necessary and that simply having a bachelor's degree will not suffice to develop solutions like those presented at Multilog. It will be essential to further climb the knowledge pyramid to acquire the skills demanded by industry and government.

In this respect, efforts like Multilog, where we aim to bring together government, industry, and academia, are crucial for identifying challenges and requirements across all areas affected by the changing tides of the future. The Multilog series will continue to make this effort, following trends like a surfer riding a wave, aiming to break into new waters.

We extend our heartfelt thanks to Universidad del Mar for providing the venue for the 2024 edition. We also express our gratitude to the Scientific Committee and the authors for their efforts in sharing this knowledge with the local community of Universidad del Mar. Additionally, we appreciate the Local Committee, whose dedication made it possible to achieve this edition after the challenging years of the COVID-19 pandemic.

Dr. Miguel Mujica Mota

Amsterdam The Netherlands 8 June 2024

Table of contents

Green Transportation Solutions

Articles

- **Importancia del Transporte Multimodal.** Transporte Multimodal y el Interoceánico

  Jessica Margarita García Hernández. Universidad del Mar, Oaxaca, México

- **Reducing Energy Consumption by Improving Routes for Green Freight Transport Vehicles Using Heuristic Algorithms.**

  Enrique de Jesús Mohedano Torres. División de negocios, UVM.

  Carmen Angelina Garcia-Cerrud. Facultad de Ingeniería, UNAM.

  Idalia Flores de la Mota Idalia. Facultad de Ingeniería, UNAM.

- **A bi-objective vehicle routing and inventory control model for coin distribution.**

  Carlos A. Alfaro. Banco de México

  Mariana Gómez Vargas. Banco de México

  Edgar Possani. Department of Mathematics - ITAM

- **Transforming the BRT system for a greener future**

  Paulina Santiago-Martínez. Facultad de Ingeniería, UNAM.

  Emma Laura Hernández Albarrán. Facultad de Ingeniería, UNAM.

  Carmen Angelina García-Cerrud. Facultad de Ingeniería, UNAM.

  Francisca Soler Anguiano. Facultad de Ingeniería, UNAM.

  Idalia Flores De La Mota. Facultad de Ingeniería, UNAM.

Importancia del Transporte Multimodal

Transporte Multimodal y el Interoceánico

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Se abordará las características, ventajas, desventajas y las combinaciones que se pueden obtener de los modos de transporte, para concluir con la importancia del transporte multimodal y del interoceánico, mostrando los objetivos que en su momento presentó el Gobierno de México, así mismo porque puede ser una alternativa ante los problemas que enfrenta el canal de Panamá ante el desabasto de agua y verlo como una opción.

Palabras claves: Transporte, multimodal, intermodal, combinado, logística, interoceánico.

I. INTRODUCCION

La globalización económica, el desarrollo del transporte y los servicios logísticos constituyen un elemento fundamental en las cadenas productivas, ya que el proceso productivo está precedido por el transporte en el movimiento de materias o primas y le sigue la distribución de los productos manufacturados o semimanufacturados. Ante esta gran necesidad se genera el gran desarrollo del transporte multimodal que se ha dado por la revolución del contenedor que tuvo origen en los años cincuenta.

El movimiento de carga en contenedores significa el desarrollo de los sistemas intermodales de transporte de mercancías entre regiones, países o continentes. El contenedor no solo contituye una forma de embalaje de fácil transbordo, sino una reducción de costos y de disminución del riesgo en la carga y descarga. El uso del contenedor ha traído al sector del transporte el servicio "puerta a puerta".

El transporte multimodal, la combinación de diferentes modos de transporte (como carreteras, ferrocarriles, marítimo, fluvial y aéreo) ha emergido como un elemento crucial en la logística y la cadena de suministro moderna. Su importancia radica en su capacidad para optimizar la eficiencia, reducir costos, mitigar riesgos y mejorar la sostenibilidad en el movimiento de bienes y personas a nivel global.

En un mundo cada vez más interconectado, el transporte multimodal ofrece una solución integral para superar los desafíos inherentes a cada modo de transporte individual. Por ejemplo, mientras que el transporte marítimo es ideal para el envío de cargas a largas distancias, el transporte por carretera es esencial para la entrega final rápida y directa. Al combinar múltiples modos, se pueden aprovechar las fortalezas de cada uno, minimizando las debilidades y optimizando la cadena de suministro en su conjunto.

El transporte multimodal es una estrategia logística clave que permite a las empresas maximizar la eficiencia y la flexibilidad en el movimiento de mercancías a nivel local, nacional e internacional. Al integrar diferentes modos de transporte de manera inteligente, las empresas pueden optimizar sus operaciones y mantenerse competitivas en un mercado global en constante cambio.

Desde el punto de vista politico, el transporte facilita la aplicación y el control en las disposiciones administrativas, y dinamiza las comunicaciones, así como los diversos documentos para el traslado de la mercancía y permitiendo el desplazamiento hacia lugares especificos en lo que se require su presencia.

La globalización ha motivado a los países que se integren sus operaciones de forma eficiente en la cadena suministro. Principalmente México necesita desarrollar sistemas de transporte más modernos y articulados, para que apunte a redes multifuncionales y de sistemas logísticos, seguros y competitivos en los intercambios de mercancías nacionales e internacionales.

Se mostrará concepto del transporte multimodal, características, las diferencias de transporte intermodal, multimodal y combinado. En este artículo,se pretende conocer la importancia del Transporte Multimodal y del corredor interoceanico del Istmo de Tehuantepec y las diferentes modalidades, tales como: terrestre, marítimo y aéreo.

II. TRANSPORTE MULTIMODAL

¿Cuál es la importancia del transporte multimodal en el Interoceánico?

El transporte Multimodal representa un pilar fundamental en la logística moderna en el movimiento de mercancías, sobre todo a nivel internacional. La importancia es reducir costos y mejorar los tiempos de entrega, al usar diferentes modos de transporte. Se necesita conocer la definición de transporte multimodal para que sea entendible la importancia en el interoceánico.

¿Qué es el transporte multimodal?

Se define como la coordinación y utilización de dos o más modos de transportes diferentes en un solo contrato, haciendo una gestión integral completa desde el punto de origen hasta el destino final, implicando diferentes vías como mar o fluvial, carretera, ferrocarril y aire.

Es importante tener claro la diferencia entre transporte combinado, intermodal y multimodal.

III. DIFERENCIAS ENTRE TRANSPORTE COMBINADO, INTERMODAL Y MULTIMODAL.

Se abordarán las diferencias entre transporte combinado, intermodal y multimodal.

En el transporte combinado implica el uso de diferentes vehículos sin coordinación central, es decir, cada sector opera bajo contratos independientes, sin una gestión unificada.

En el transporte intermodal se caracteriza por el uso de una unidad de carga intercambiable entre rutas con coordinación y manipulación de mercancías, a través de un único contrato y un único operador.

En el transporte multimodal se define por la integración de múltiples modos de transporte bajo un único contrato y gestión coordinada, se requiere una persona responsable de gestionar y coordinar toda la operación.

IV. CARACTERISTICAS DEL TRANSPORTE MULTIMODAL

Las características determinan la eficacia en la gestión general de la cadena de suministro y represента los pilares que dan flexibilidad, y eficiencia de este enfoque logístico, con el fin de adaptar y optimizar el movimiento de mercancía a través de diferentes modos de transporte, considerando entonces las siguientes características:

- Comunicación: Transporte fluido de mercancías entre diferentes medios de transporte
- Simplicidad: Un contrato por ruta, solución de envío completo y sencillo.
- Eficiencia: Reducir el tiempo de tránsito al mejorar las rutas y reducir los costos operativos.

Dentro de los tipos de transporte multimodal se pueden combinar de la siguiente forma:

1. Transporte Marítimo + terrestre.

Consiste en transportar el contenedor desde el puerto hasta el destino final, es decir, La mayor parte de las navieras te incluyen dentro de la cotización el flete terrestre en origen, el marítimo de un puerto de origen al puerto de destino y el flete terrestre en destino. Pero no siempre aplica así, solo se aplica el flete terrestre y el marítimo o depende en algunos casos el tipo de contrato y servicios que se requiera en el momento.

2. Transporte Ferroviario + Otros Modos

La capacidad de carga y la eficiencia del transporte ferroviario para grandes volúmenes a largas distancias, las mercancías se transfieren a otros medios, como camiones o barcos para un lugar específico o lugares donde no se puede llegar en tren.

3. Transporte Aéreo + Terrestre/Marítimo

Se aplica para envíos urgentes o de alto valor, con el fin de una entrega rápida y segura. Se suele usar desde aeropuertos nacionales, utilizando camiones o barcos.

4. Transporte Fluvial + Terrestre

Se utiliza vías fluviales para transporte mercancías a través de ríos, las mercancías de transportan en camiones o trenes en puertos fluviales para llegar a destinos finales que no están conectado directamente por mar.

5. Transporte Intercontinental

Se combina los modos de transporte por mar, ferrocarril y las carreteras para facilitar el movimiento de mercancías entre continentes.

Todas estas combinaciones mencionadas es necesario mencionar que se hace uso del contenedor para permitir el traslado directamente de la mercancía, sin manipulación de la misma en los diferentes modos de transportes, efectuando con ello solo las maniobras del contenedor en los diferentes modos de transporte.

Es importante menciona que cada medio de transporte tiene sus propias ventajas, depende de la naturaleza de la mercancía, la distancia y la urgencia; es importante una buena gestión para coordinar de forma eficaz y eficiente la logística para garantizar una transacción fluida entre los distintos medios de transporte.

Para entender la efectividad y viabilidad de integración de la logística en el transporte multimodal, es importante conocer las ventajas y desventajas que se pueden encontrar:

Ventajas:

- Reducir los costos operativos, esto se ve reflejado cuando se hace de forma correcta la planeación y buscar las mejores rutas.
- Reducción de los plazos de carga.
- Mayor flexibilidad y capacidad de adaptación a diferente condición y requisitos de carga.
- Mejorar los recursos y métodos para aumentar la eficiencia logística
- Primas de seguro son menores, brinda competitividad a los exportadores.

Sin embargo, de los beneficios citados el transporte multimodal no está exento de desafíos y limitaciones. Se pueden encontrar cuellos de botellas que pueden afectar la eficiencia y flexibilidad de la cadena de suministro, a continuación, se consideran algunas desventajas:

Desventajas:

- Retrasos o problemas al traslado.
- Gestión de envíos y documentación debido a la participación de múltiples partes.
- Mayor requerimiento de seguridad, al emplear varios tipos de transporte, es más probable que las autoridades de los puertos o rutas puedan realizar inspecciones de la mercancía.
- Limitaciones legales en cuanto a normas internacionales o nacionales del transporte.

El transporte multimodal desempeña un papel vital en la optimización de la cadena de suministros, en el que se requiere una integración entre modos de transporte para satisfacer las necesidades actuales y futuras. Hay que recordar que el transporte es una respuesta a las necesidades del Mercado, para responder a las exigencias impuestas por los usuarios, como el "just in time".

V. LA IMPORTANCIA DEL CORREDOR INTEROCEÁNICO DEL ISTMO DE TEHUANTEPEC (CIIT):

Los corredores multimodales de transporte internacional se vinculan con el Desarrollo de puertos concentradores y distribución de carga en contenedores llamados Puerto Hubs que denomina Jan Hoffmann[1]. El corredor multimodal es de contenedores, no de mercancía a granel. Los puertos concentradores para este caso son: Salina Cruz y Coatzacoalcos. Son la parte principal del corredor y estos deben contar con la infraestructura correspondiente, para que pueda darse el flujo de mercancía.

Como señala Martner, el Istmo adquiría un mayor valor estratégico en el comercio internacional si se desarrolla como un nodo regional de concentración, procesamiento y distribución…[2]

Antes de conocer la importancia, es necesario mostrar a que se refiere con el CIIT como un organismo público descentralizado, con personalidad jurídica y patrimonio propio, consiste en un proyecto de conectividad en México, este conecta las costas del Pacífico y el Golfo de México, la importancia es impulsar el comercio y agilizar el movimiento de mercancías a través de esta ruta. Así mismo, promete superar las limitaciones del tráfico en las carreteras y reducir los costos logísticos.

A esta ruta se le llama Corredor Interoceánico del Istmo de Tehuantepec (CIIT), que consta de 3 líneas de transporte con casi, 1,000 km de Vía férrea: línea "Z", Línea "FA" y Línea "K".

Figura 1. Linea Z
Fuente: Gobierno de México

Línea "Z" Recorre de Veracruz hacia Salina Cruz y Cuenta con 212 km.

[1] HOFFMANN, Jan. "El potencial de los puertos pivotes en la costa del Pacífico sudamericano", Revista CEPAL, agosto de 2000.

[2] MARTNER-PEYRELONGUE, Carlos. "Restructuración del espacio continental en el contexto global: corredores multimodales en Norte y Centroamérica", Economía, Sociedad y Territorio, vol. VII, No. 25, 2007.

Figura 2. Línea FA
Fuente: Gobierno de México

Línea "FA" Recorre los estados de Veracruz, Tabasco y Chiapas con un total de 310 km de vía férrea.

Figura 3. Línea K.
Fuente: Gobierno de México

LINEA "K"

La línea K recorre los estados de Oaxaca y Chiapas tiene 472 km de vía férrea y se plantea que tenga conexión con el país hermano de Guatemala.

Considerando al Corredor Interoceánico del Istmo de Tehuantepec (CIIT) como una ruta estratégica que atraviesa el país conectando el pacífico y Golfo de México, dando consigo la reconfiguración de los patrones del comercio mundial.

Se pretende establecer un centro logístico que integre los diferentes modos de transporte, para optimizar los procesos, almacenamiento y distribución de la carga.

Figura 4. Corredor ferroviario
Fuente: Gobierno de México

Permitirá una movilidad eficiente de mercancías entre varias regiones de nuestro país y permite la conectividad entre el Pacífico y el Golfo de México a través de una red ferroviaria, para impulsar el comercio y agilizar los tiempos a lo largo de su ruta estratégica.

Cabe mencionar que el servicio de pasajeros en la Línea Z del tren que conecta Coatzacoalcos, Veracruz, con la ciudad de Salina Cruz se inauguró el 22 de diciembre del 2023.

VI. ACCIONES DEL GOBIERNO DE MEXICO EN EL CORREDOR INTEROCEÁNICO-ISTMO DE TEHUANTEPEC

El objetivo de este proyecto es: Instrumentar una plataforma logística que integre la prestación de servicios de administración portuaria que realizan las entidades competentes en los Puertos de Coatzacoalcos, Veracruz de Ignacio de la Llave y de Salina Cruz y su interconexión mediante el transporte ferroviario, así como cualquier otra acción que permita contribuir al desarrollo de la región del Istmo de Tehuantepec (Gobierno de México CIIT, 2024).

Dentro de las acciones más importantes del Gobierno de México a realizar se citan las siguientes:

1. Procurar, mediante inversión pública y privada, la construcción de la infraestructura física, social y productiva necesaria para fortalecer la base económica de la región del Istmo de Tehuantepec;

2. Promover, a través de la realización de los actos jurídicos necesarios, la modernización de la infraestructura física y la capacidad productiva de la región del Istmo de Tehuantepec

Figura 5. Principales Sectores de importación y exportación.
Fuente: Agencia Nacional de Aduanas de México. Aduana Salina Cruz

En el Puerto de Salina Cruz los principales sectores de importación y exportación son: Refinación de petróleo, refinación de petróleo, extracción de petróleo y gas, elaboración de azúcar de caña y otros servicios relacionados con el transporte.

Figura. 6. Conectividad del CIIT
Fuente: Gobierno de México.

El CIIT conecta el Océano Pacífico con el Océano Atlántico. Siendo el Puerto de Coatzacoalcos, Salina Cruz, Dos Bocas y Puerto Chiapas quienes integran la plataforma logística, y sabe mencionar que se tiene acceso al sur de Estados Unidos, Europa, América del Sur y Asia.

Se pretende que a largo plazo la circulación de mercancía internacional por el istmo de Tehuantepec capte parte del flujo que hoy transitan por el canal de Panamá o por los puentes terrestres, aquí es importante la presencia de actores locales, regionales y globales vinculados al desarrollo de las cadenas logísticas.

Si el Transístmico pretende ser un nodo estratégico de circulación de mercancías, no es suficiente ofrecer menores tiempos de viajes para cierta ruta, se debe posicionar como una plataforma logística de producción y distribución con múltiples servicios para la circulación de las mercancías. Se requiere que los operadores de transporte multimodal, las grandes navieras, empresas ferroviarias, agentes de carga y distribuidores deben hacer posible el desarrollo de hubs regionales de contenedores en el corredor interoceánico usando a Salina Cruz y Coatzacoalcos como puertos concentrados y redistribuidores de la carga.

Es importante mencionar que Coatzacoalcos y Salina Cruz operan con infraestructura y maniobras convencionales, por lo que se tiene que invertir en la construcción de dos terminales especializadas de contenedores en cada Puerto, infraestructura y equipamiento ferroviario.

A finales de 2019 en el Puerto de Coatzacoalcos se dio inicio a los trabajos de modernización de infraestructura para el CIIT, la que consiste en dos muelles que concluyeron en el 2021, se construye el acceso ferroviario y la remodelación de la aduana. Se contemplan las obras de acceso carretero, con vialidades internas y vehicular, sistema ferroviario, bodegas de almacenamiento, drenaje, obras eléctricas, adquisición de terrenos.

Se construyó un rompeolas para permitir el arribo de barcos de gran calado, con una inversión superior a los 5 mil 927 millones de peso, generando 639 empleos directos e indirectos y la colocación de 5.64 millones de toneladas de rocas de diferentes tamaños, el rompeolas tiene una longitud de 1 mil 600 metros, una profundidad de 25 metros y posee la capacidad de albergar portacontenedores de hasta 250 mil toneladas.

Sabemos que el sexenio está por concluir y las preguntas son las siguientes ¿Qué pasará con el CIIT con el cambio de gobierno? ¿Tendrá continuidad o será olvidado por dar prioridad a otros proyectos presidenciales?

VII. CONCLUSIÓN

En el mundo del comercio internacional, la eficiencia en la cadena de suministro es la clave del éxito y el transporte multimodal desempeña un papel importante para lograr dicha eficiencia al optimizar la logística y la movilidad de mercancías. Al integrar los diferentes modos de transporte como: carretero, ferroviario, marítimo y aéreo, se busca reducir tiempos de tránsito y reducción de costos operativos.

Al transporte multimodal se le considera como una herramienta para impulsar el comercio internacional y promover el desarrollo económico a nivel regional y global, para esto se requiere contar con la infraestructura adecuada.

Es importante la coordinación entre los modos de transporte y operadores logísticos se vuelve fundamental, así como el uso de software de logística para permitir una gestión eficaz

Es importante mencionar que no solo se requiere una excelente gestión, sino también una correcta infraestructura de los distintos medios de transporte, para permitir un transporte de mercancías más fluido, como es el caso del traslado terrestre de contenedores a Coatzacoalcos y las maniobras de carga y descarga debe realizarse de forma eficiente.

El sector público juega un papel importante, ya que los proyectos y compromisos deben cumplirse, sin desatender los requerimientos de la demanda de transporte y logística, sin dejar de lado el bien común de la sociedad.

Además, permitirá optimizar el transporte entre los océanos, superar las limitaciones del tráfico en las carreteras y reducir los costos logísticos, al mismo tiempo que constituye a la disminución de la huella ambiental

El Puerto de Salina Cruz es una alternativa, pero se requiere plataformas para descarga de contenedores, terminales con la infraestructura correspondiente, infraestructura y equipamiento ferroviario de carga, para lograr generar el transporte multimodal y traer con esto el desarrollo económico de la región.

Recordemos también que este Proyecto es a largo plazo y aquí la incertidumbre con el nuevo cambio de gobierno, si es cierto se espera que se dé continuidad y que se llegue a concretar el Desarrollo del CIIT, se necesitará apoyo del sector público y privado para la inversión en infraestructura y los procesos que se requieran.

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Reducing Energy Consumption by Improving Routes for Green Freight Transport Vehicles Using Heuristic Algorithms

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***Abstract*— In the realm of freight transportation, oil is the primary source of energy consumption. Therefore, assessing energy efficiency in this field involves examining various aspects, such as modal distribution, industrial structure, regulatory framework, management capabilities, and technology adoption. Improving energy efficiency in freight transportation has the potential to directly enhance economic viability, making it a worthwhile pursuit. Energy conservation in freight transportation should not be seen as a burden or sacrifice, but rather as an opportunity to increase the productivity and competitiveness of companies. Effective distribution systems can lead to significant cost savings for companies by managing customer locations and utilizing the necessary means and resources for physical goods distribution. The Vehicle Routing Problem (VRP) is a significant challenge in this domain. It involves constructing routes from a warehouse to a specific number of clients within a defined geographical area. The Green Vehicle Routing Problem (G-VRP) is a potential alternative solution to mitigate energy consumption. To address this, a thorough examination of its current applications and constraints is necessary.**

Keywords-component Energy consumption, Freight transportation, merchandise flows, physical distribution

Introduction

The use of fossil fuels in freight transport, combined with poor route planning, results in increased energy consumption for companies. Therefore, transitioning to alternative fuels and operating a fleet of alternative fuel vehicles (AFVs) is a potential solution to the energy consumption problem in freight transportation. The Green Vehicle Routing Problem (G-VRP) is a variant of the Vehicle Routing Problem (VRP) that considers the operation of AFVs. However, the adoption of AFVs requires careful consideration of associated challenges, such as limited refueling infrastructure. Therefore, refueling planning techniques must integrate stops at alternative fuel stations (AFS) to mitigate the risk of fuel depletion while optimizing cost-effective routes. [3]; [10].

The G-VRP aims to identify the shortest possible vehicle routes. Each route starts from the depot, serves a predetermined set of customers within a specified time limit, and returns to the depot without exceeding the vehicle's driving range, which is determined by its fuel tank capacity. These routes may include stops at one or more alternative fuel stations (AFS) to facilitate refueling along the way [26].

Considering the significant impact of fuel consumption on costs and energy efficiency, the focus within a G-VRP framework should be on developing solutions that integrate consumption calculation models with route optimization models (VRP). However, this approach increases the complexity of the problem, as fuel consumption depends on various factors, such as vehicle type, driver behavior, environmental factors, and traffic conditions, among others [4].

This paper examines the use of G-VRP as a solution to address energy consumption concerns. The structure is organized as follows: Section 2 examines the challenges of route assignment while considering energy consumption. It presents a literature review that focuses on the limitations of techniques for solving G-VRP and the classification of environmentally friendly vehicles. Section 3 discusses the vehicles used in G-VRP scenarios. The paper concludes by summarizing the usefulness of G-VRP and proposing strategies for consideration.

Literature Review

Currently, organizations are actively seeking alternatives to overcome challenges in competitive landscapes. Each entity must customize its processes to meet the demands of chosen markets [21], while also devising strategies to reduce energy consumption. Consequently, due to the intricate nature of distribution systems, which cater to a wide array of products requiring flexibility, they are inherently complex. The contemporary logistics paradigm integrates activities within a system, which results in complexity. The main goal is to ensure a seamless flow of products that meet client requirements in terms of quality and affordability [12], while minimizing energy usage and environmental impact to foster sustainability.

The Green Vehicle Routing Problem (G-VRP) is an extension of the conventional Vehicle Routing Problem (VRP) that plays a crucial role in facilitating efficient product flow. It ensures high customer service standards while optimizing resource utilization in distribution operations by enabling delivery, simultaneous collection, and energy consumption reduction [28].

Companies consider various factors when selecting specific vehicle types to address this variant. Considerations for selecting a vehicle include the availability and distribution of fuel stations within the service area, the vehicle's driving range, cost, fuel efficiency, and maintenance expenses.

G-VRP

To achieve the objectives of the G-VRP, one approach involves using environmentally friendly vehicles (EFVs). These EFVs can be powered by alternative and green fuel sources, such as biodiesel, electricity, ethanol, hydrogen, methanol, and natural gas, which can replace internal combustion engine vehicles (ICEVs). This has led to the adoption of alternative fuels in VRP, with alternative fuel-powered vehicles (AFVs) being classified as a general category of EFVs.

Figure 1 shows how some studies in the literature have framed the Alternative Fuel Vehicle Routing Problem (AF-VRP) without specifying the vehicle's fuel type. It is worth noting that electric vehicles (EVs) and hybrid vehicles (HVs) have been considered as specialized types of AFVs and have been examined separately due to their distinct characteristics. EVs have been considered an ideal alternative to ICEVs for load distribution in many studies due to their zero emissions during use and minimal noise pollution [5].

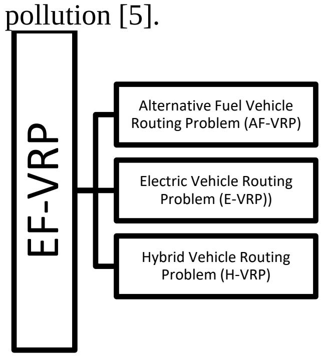

Figure 1. Variants of the route generation problem for green vehicles

Source: Own elaboration based on Ghorbani [5].

In 2020, the Secretary of Communications and Transportation reported 650,000 registered heavy vehicles in Mexico, which represents approximately 1% of the national vehicle fleet. Among these, 99% relied on diesel as their primary fuel source, while less than 1% were powered by natural gas (NGV). NGV is predominantly used for both cargo and passenger transportation in urban areas. Only a small fraction, 0.004%, of the registered vehicles were electric (EVs), primarily used for urban passenger transport in cities such as Mexico City and Guadalajara. Concerningly, 69% of the heavy vehicles registered in 2020 were over a decade old [24].

Of these heavy vehicles, 87% were used for freight transport, with the remaining 13% allocated to passenger transportation. Within the cargo transport segment, 63.2% were categorized as 'T3,' followed by 20.3% classified as 'C2,' and 15.7% as 'C3.' The report states that Freightliner accounted for 31% of the prominent brands, followed by Kenworth at 30% and International at 14%.

Identify applicable sponsor/s here. *(sponsors)*

In the bus segment, vans made up only 5% of the market, while the majority (95%) were buses primarily falling under the B2 category, with minimal representation from B3 and B4 categories. The leading brands in this segment were Mercedes Benz at 31%, followed by International at 18%, and Scania at 15% (National Institute of Statistics and Geography [INEGI], [9]; [23]).
Currently, diesel is the primary fuel used for heavy vehicles in Mexico. On average, B2 buses, which are commonly used for urban passenger transport, consume 22.72 L/100 km and emit 777 gCO2/km. Similarly, T3 tractor-trailer vehicles, which are widely employed for long-distance cargo transport, consume an average of 40.2 L/100 km and emit 1063 gCO2/km. These figures are consistent with findings from comparable studies conducted globally, considering vehicle weight.
Despite the prevalence of diesel, less than 1% of heavy vehicles operate using compressed natural gas (CNG) or electricity. However, CNG-powered vehicles have exhibited higher consumption rates than anticipated, while electric vehicles have shown promising results.

Limitations in G-VRP solution techniques

The use of heuristic and simulation algorithms to solve vehicle routing problems (VRPs), including variants such as G-VRP, has numerous real-world applications. These methods allow for strategic resolution of VRP challenges, accommodating diverse requirements such as route time, distance, fuel logistics, station locations, service types, and transported product specifications, among others. Table 1 in the annexes outlines the limitations of solution techniques for G-VRP and its variants. Authors primarily focus on heuristic techniques and metaheuristics to address key constraints, such as alternative fuel loading time, consideration of load factors in route planning to optimize energy consumption, and enhanced processing times on computational devices. These approaches aim to provide solutions that approximate the optimal with improved efficiency and quality.

Table 2. Limitations in solution techniques for ecological vehicle routing problems

Solution algorithms for the VRP		Limitations	Author
Exact methods for G-VRP	Direct tree search, dynamic programming, integer linear programming	The ability to effectively solve problems using mathematical programming or combinatorial optimization is limited by the size of the problem and its variations in practical applications, particularly for larger nodes like clients and fuel loading depots. Exact methods require significant computing time, making them impractical for such scenarios. The literature on G-VRP mainly focuses on developing heuristic and metaheuristic methods to efficiently produce high-quality solutions.	[2]
Heuristics for G-VRP	Savings Algorithms, Exchange Algorithms, Two-Phase Algorithms, Sequential Algorithm and Petal Algorithm	In most cases the solution is suboptimal or close enough to a reliable solution. In the G-VRP literature, heuristic methods can be divided into constructive and improvement heuristics. The consideration of charging stations is necessary in the initial solution. In the improved solutions, the local search stops when no further enhancements can be made. During the solution process, the neighborhood of the current solution, also known as the local environment, can be observed.	[11].
Metaheuristics for G-VRP	Popular local Popular local metaheuristics. Methods Simulated Annealing (SA), Tabu Search (TS) Neighborhood search	When using population-based or natural selection methods, they require more computational resources and result in longer resolution times compared to classical heuristics.	[15]

Vehicles used in G-VRP

G-VRP with conventional vehicles

[29] categorizes the literature on G-VRP into three primary domains: (1) G-VRP with conventional vehicles, (2) G-VRP with alternative fuel vehicles, and (3) G-VRP with a mixed fleet of vehicles. The first category includes studies that focus on conventional multi-objective G-VRP investigations, where CVRP (vehicle capacity restriction) considers multiple objectives.[4] initially introduced this approach. The researchers addressed the bi-objective pollution routing problem (PRP), aiming to minimize fuel consumption and driver time. Demir's methodology has been expanded upon by several scholars to address PRP, including [1]. [7]

addressed a multi-objective problem with velocity constraints.
Several studies have explored multiple objectives in the realm of conventional vehicles, aiming to minimize factors such as marginal cost, fuel consumption, and travel time, often combined with other variants. For example, [13] and [25] integrated connectivity and automation into their multi-objective exploration of ecological pathways. Various articles have addressed constraints such as road conditions, congestion, topography, vehicle loading, and their impacts on route cost and fuel consumption. [21] examined the green vehicle routing problem with time windows, considering a heterogeneous fleet of vehicles and service stations.

G-VRP with alternative fuel vehicles

The second category is the alternative fuel vehicle routing problem (AFVRP), which is divided into six categories based on fuel type, as shown in Figure 2. In a recent study,[14] addressed stochastic waiting times at charging stations within specified time windows. Another significant contribution was made by [17], who proposed a hybrid heuristic that combines a search algorithm with a tabu search heuristic. This approach takes into account limited vehicle loading capabilities and customer

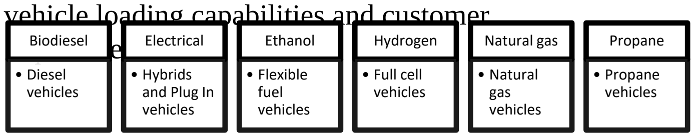

Figure 2. Classification of vehicles with alternative fuel
Source: Own elaboration from (2022).

In a parallel case study, [19] developed a heuristic approach that incorporated simple loading time to yield a more efficient solution. [8], on the other hand, used an enhanced ant colony optimization (ACO) algorithm hybridized with improved local search and insertion heuristics to address the problem, with a particular focus on partial recharging and battery swapping. [14] conducted practical research on the EVRPTW-PR, implementing full recharge as a constraint while allowing for partial recharge.

This concept involves fully recharging a vehicle each time it visits a service station, enabling it to continue its service as long as its battery allows. [16] explored EV routes with time windows and proposed two refueling strategies. In addition, [27] investigated the design of mobile charging stations. [18] addressed the issue of locating electronic refueling stations for electric vehicles within a traffic network to optimize network performance. [6] introduced a novel approach to the EV routing problem, incorporating charging stages along the road at available charging stations to mitigate range limitations.

G-VRP with a heterogeneous fleet

In the context of the third category, [31] modeled and solved a variant of G-VRP with a heterogeneous fleet for the first time. They found that employing a heterogeneous fleet has advantages over a mixed one in urban areas.

Conclusions

The literature review discusses the characteristics and limitations of the G-VRP, highlighting its potential to reduce energy consumption. However, it also reveals a significant gap in route design, particularly in areas such as refueling depot placement, operational decisions, utilization of alternative fuel vehicles, and refueling intervals for alternative fuels.
To address this, developing heuristic algorithms to solve the G-VRP problem is proposed by conducting a comparative analysis of each algorithm's solution efficiency, considering various types of electric cargo vehicles. This study aims to provide future researchers with insights into the operational dynamics and efficacy of these techniques. For logistics companies, this will provide a foundation for selecting the most appropriate algorithm, especially if they are involved in distribution activities that aim to reduce energy consumption.

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A bi-objective vehicle routing and inventory control model for coin distribution

Minimizing traveling costs and CO_2 emissions in Mexico

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Abstract— Cash distribution of metallic coins is a legal requirement and mandatory process of the Central Bank of Mexico. In this paper we propose a mathematical programming model to optimize the routing and inventory levels satisfying the demand of customers to minimize both traveling costs as well as CO_2 emissions. We solve the bi-objective model via an ϵ-constraint approach and a heuristic dependent on the definition of the serviceable neighborhood for the regional distribution centers. We show the advantages of implementing this model, discuss the trade-off of minimizing cost versus emissions, as well as various sensitivity analysis for a planning period of one year.

Keywords—inventory control; vehicle routing optimization; coins distribution; bi-objective optimization

I. Introduction

One of the mandates of Mexican Central Bank (Banco de México) is to supply domestic currency to the economy [1]. To fulfill such mandate, in addition to printing banknotes and ordering the minting of coins by the Mexican Mint (Casa de Moneda de México), an entity that is subordinate to the Ministry of Finance and Public Credit (SHCP, for its acronym in Spanish), a money supply system must be in place to guarantee the availability of cash (money) wherever and whenever, in the denominations and with the quality required by the general public. The Mexican Central Bank, jointly with commercial banks and cash carrier companies, is responsible for the proper functioning of this distribution system.

As in any supply chain, the speed or frequency of cash handling, the cost of circulating cash, and the quality (fitness) of cash indicate the efficiency, resilience, and robustness of the cash supply chain. The structure of a cash supply chain is largely dictated by the policy of the Central Bank, which is responsible for all aspects of cash circulation: production, issuing, movements, storage, receiving, sorting, authenticating, and destroying. In response to the increase in Automated Teller Machines (ATM's), the rising demand for fit cash by businesses, and the overall increased use of cash within economies, the central banks of many countries have increased their capacities, and the cost of providing currency services has risen as well. In the U.S. alone there has been a 200% increase in coin demand in the last decade as stated in [2]. This has led governments to promote various cash supply chain business models. These models are differentiated by the currency services offered by the central bank. Cash circulation is mainly driven by the demand for cash by customers for transaction purposes. In Zhu et al. [3] a methodology concerned with the safety of banknote transportation is presented where the capacity of the vehicle is limited (not by its physical capacity, but) by the face value of the banknotes, and the decision of deploying decoy empty vehicles together with the filled vehicles is solved under different scenarios to fulfill weekly demands. A paper that studies the Colombian cash supply chain is the one by Osorio and Toro [4], they solve a mixed integer linear problem to minimize transportation and inventory related costs.

The distribution of coins is less studied than distribution of banknotes, because coins have lesser value the policies and challenges in dealing with them are very different, this distribution cannot be treated as the banknotes distribution. A recent paper by Huang et al. [2] presents a framework to analyzing the U.S. Coin

The research of C.A. Alfaro is partially supported by the Sistema Nacional de Investigadores grant number CVU 220797. The research of E. Possani is supported by Asociación Mexicana de Cultura A.C. and Sistema Nacional de Investigadores grant number CVU 121231

Supply Chain. Their focus is in optimizing the flow of coins in the supply chain. In their case they have two Mints (Denver and Philadelphia) where their priority is to cost-effectively produce and supply the required quantities of coins, they present a network flow model with linear restrictions and propose an algorithm to solve this model for a 6-month period. In the work by Gómez-Vargas and Huerta-Barrientos [6], [7] the Indigo software [8] which is a heuristic with constraint programming was evaluated for the Central Bank of Mexico to decide the vehicle routing with homogeneous vehicles to distribute coins to minimize the travelling cost, but without inventory restrictions. We expand this work by proposing an optimization model that considers the inventory restrictions and non-homogeneous vehicles.

In the past decade there has been an increased interest in the consideration of CO_2 emissions when optimizing routing of vehicles in different settings. A comprehensive review of the literature, as well as the solution approaches can be found in [5]. In this paper we present flow based mixed-integer model with a bi-objective function that not only considers minimizing transportation costs but also the minimization of CO_2 emissions. The questions we want to answer in this study are:

1) What are the optimal transportation routes to satisfy the demand?
2) What is the trade-off between minimizing traveling costs and CO_2 emissions?

In the following section we describe the general methodology of solving bi-objective problems.

II. Bi-objective Optimization

Considering $\overline{x} = (x_1, \ldots, x_n) \in \mathbb{R}^n$ as a vector of *n* decision variables, a bi-objective optimization problem is one where there are two objective functions $f(\overline{x})$, and $h(\overline{x})$ subject to a set of inequalities $g_i(\overline{x}) \leq b_i$. When the objective is to minimize both functions we can write the problem as:

$$\begin{array}{ll} \min & (f(\overline{x}), h(\overline{x})) \\ \text{subject to} & \\ & g_i(\overline{x}) \leq b_i \qquad i = 1, \ldots, m \end{array} \tag{1}$$

Note that any point $\overline{x} \in \mathbb{R}^n$ that satisfies all *m* inequalities is a feasible solution, and the set of all feasible solutions is usually referred to as the *solution space* (see [10]).

A. Pareto optimal set

A bi-objective optimization problem, like the one presented in problem (1), gives no single optimal solution with respect to both objectives, but rather a set of optimal solutions known as the *Pareto frontier* or *Pareto optimal set*. To specify the Pareto frontier, we need to define when a solution dominates another. If $\overline{x}$ and $\overline{x}'$ are points in the solution space, under cost functions $f(\overline{x})$ and $h(\overline{x})$ we say solution $\overline{x}$ *dominates* solution $\overline{x}'$ if the following conditions are satisfied:

$$f(\overline{x}) < f(\overline{x}') \quad \text{and} \quad h(\overline{x}) \leq h(\overline{x}'),$$

or

$$f(\overline{x}) \leq f(\overline{x}') \quad \text{and} \quad h(\overline{x}) < h(\overline{x}').$$

A solution belongs to the Pareto frontier if it's not dominated by any other solution in the solution space. In other words, to improve one objective in a given solution in the Pareto frontier requires a certain sacrifice on the other objective.

Solving a bi-objective optimization problem requires finding the Pareto frontier. There are different methods to find it, we now explain one we have applied in our research in the following subsection.

B. The epsilon constraint solution method

To construct the Pareto optimal set, we may solve for a given objective function, say $f(\overline{x})$, the problem when bounding $h(\overline{x})$ by an ϵ value, $\epsilon \in \mathbb{R}$. That is solving:

$$\begin{array}{ll} \min & z_\epsilon = f(\overline{x}) \\ \text{subject to} & \\ & g_i(\overline{x}) \leq b_i \quad j = 1, \ldots m \\ & h(\overline{x}) \leq \epsilon \end{array} \tag{2}$$

For example, in Figure 1 we may set ϵ a given level in the x axis (values of the $h(\overline{x})$ function) there are different feasible solutions for that level of ϵ (red dots in that line), however when solving problem (2) we arrive at the non-dominated solution (blue dot). We may then solve this problem repeatedly for different values of ϵ to obtain all the solutions that are not dominated to obtain the Pareto frontier (set of blue dots). This method is practical since solving the single objective function problem tends to be an easier than dealing with both objective functions in conjunction. In particular, if $g_i(\overline{x})$,

$f(\overline{x})$ and $h(\overline{x})$ are linear functions the problem (2) is a linear programming (LP) problem for which LP solvers software is available. Note that an alternative way to construct the same Pareto frontier is to minimize $h(\overline{x})$ and bound $f(\overline{x})$ for different values of ϵ.

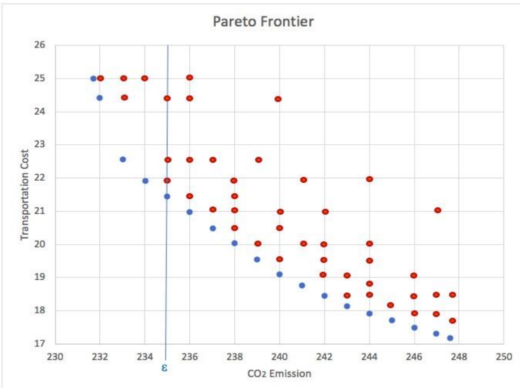

Figure 1. Pareto Frontier

In the next section we describe with more detail the supply chain and data for the Coin Distribution problem we are interested in solving.

III. Mexican Coin Distribution Problem

Coinage distribution [1] begins at the Mexican Mint of San Luis Potosí, see (Figure 2). It is the lawful duty of Banco de México to order coinage to the Mexican Mint and pay for these services. From this location coins are delivered to the Regional Cashiers that store and distribute coins. There are six Regional Cashiers in the country: Hermosillo, Monterrey, Guadalajara, San Luis Potosí, Ciudad de México, Veracruz, and Mérida, see (Figure 2).

Figure 2. Mexican Coin Supply Chain. Mariana Gómez 2023.

Cash carrier companies then transport by land the coins to their destinations. There are 86 peer to peer and banking places (PP&B) in Mexico, where coins may be demanded and delivered. Coin requirements at the sites that do not have Regional Cashiers are met directly by Banco de Mexico’s head offices´ through cash carrier companies that transport the coins from the Mint and Regional Cashiers to the requesting local PP&B. Local banks requests are handled directly by the Regional Cashiers and is not the direct responsibility of Banco de México, and thus is not considered in our model. To evaluate our model, and solution approach, we have used a pre-pandemic database for the PP&B demands for 2018 which considers 54 different PP&B [12]. That year thirty-two PP&B did not request coins directly from Banco de México, they probably obtained their required coins through local transactions.

In Figure 3 we show a histogram of the total demand of all PP&B for each month of the year. We can see how the demand is not constant throughout the year, April and December had higher levels, almost doubling what was requested in July.

On the other hand, Figure 4 shows the demand variation in each region. Here we can observe the differences between

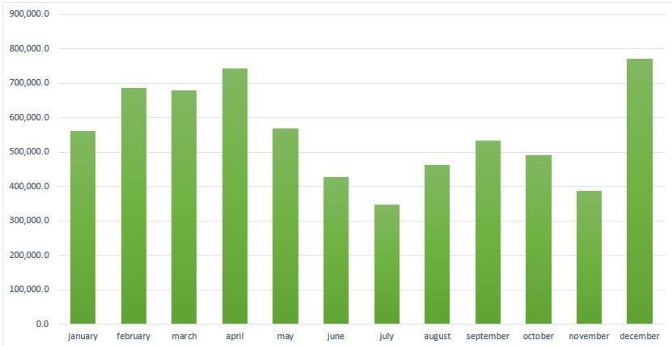

Figure 3. Behavior of the demand over different months (kg.)

various PP&B. The average demand per month of all the PP&B is of approximately 10,000 Kg. However, the average yearly demand for each individual PP&B varies widely (from an average 60.4 Kg in Lazaro Cardenas to almost 29,500 Kg in Queretaro). Some PP&B may only demand twice a year (Lazaro Cardenas) while more than 65 % of all PP&B do request coins every single month throughout the year.

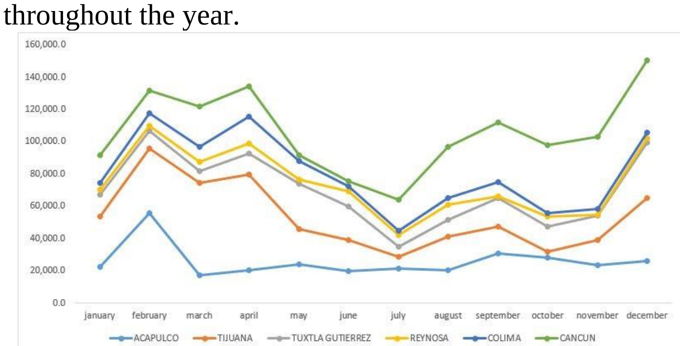

Figure 4. Demand for various PP&B in different regions

In next section we present the bi-objective model we are interested in solving.

IV. Coin Distribution Optimization Model

Our model considers the following data, parameters and sets:

- N the set of PP&B, where *n* is the number of them,
- M the set of Regional Cashiers where *m* the number of them,
- P the set of vehicles, and *p* is the number of vehicles,
- Q_k the capacity of vehicle *k* (weight capacity in Kg),
- q_i the demand (Kg of coins) at PP&B *i*,
- c_{ij} cost of traveling from location *i* to *j* (kilometers),
- e_e is the CO_2 emission of an empty vehicle, it is measure in *Kg* per *Km* traveled (*Kg/Km*),
- e_c is the difference in CO_2 emission (*Kg/Km*) from a fully loaded vehicle and one that is empty,
- I_d is the upper limit on the number of coins available at regional cashier *d*.

We define the following variables:

- x^k_{ijd} binary variable indicates that vehicle k is dispatched from Regional Cashier *d* and moves on arc (*i,j*). We denote the vector of all such variables by $\overline{x}$,
- y^k_{ijd} is a non-negative continuous variable denoting the total load remaining in the vehicle k before reaching node j while traveling along arc (*i,j*),– departing from Regional Cashier *d*. We denote the vector of all such variables as $\overline{y}$.

We are interested in two functions to minimize:

- The total traveling cost:
$$f(\overline{x}) = \sum_{d=1}^{m}\sum_{k=1}^{p}\sum_{i=1}^{n+m}\sum_{j=1}^{n+m} c_{ij}x^k_{ijd}$$
- The CO_2 emission of the routes:
$$h(\overline{x},\overline{y}) = \sum_{d=1}^{m}\sum_{k=1}^{p}\sum_{i=1}^{n+m}\sum_{j=1}^{n+m} c_{ij}\left(e_c\frac{y^k_{ijd}}{Q_k} + e_e x^k_{ijd}\right),$$
this function is based on information provided in [9] where $e_e = 0.722$ and $e_c = 0.324$. Note that the emission is not only dependent on the distance traveled but also on the load carried by the vehicle on each arc of the route.

The bi-objective mixed integer linear programming we are interested in is:

$$\min(f(\overline{x}), h(\overline{x},\overline{y})) \quad (3)$$

Subject to:

$$\sum_{i=1}^{n} x_{ijd}^{k} + \sum_{i=1}^{m} x_{ijd}^{k} = \sum_{i=1}^{n} x_{jid}^{k} + \sum_{i=1}^{m} x_{jid}^{k}; \quad (4)$$
$$\forall j \in N \cup M, \forall d \in M, \forall k \in P$$

$$\sum_{d=1}^{m}\sum_{k=1}^{p}(\sum_{i=1}^{n} y_{ijd}^{k} + y_{djd}^{k} - \sum_{i=1}^{n} y_{jid}^{k} - y_{jdd}^{k}) = q_j;\ \forall j \in N \quad (5)$$

$$\sum_{k=1}^{p}\sum_{j=1}^{n}\sum_{d=1}^{m} y_{djd}^{k} = \sum_{j=1}^{n} q_j;\ \forall j \in N \quad (6)$$

$$y_{ijd}^{k} \le Q_k x_{ijd}^{k};\ \forall i,j \in M \cup N, \forall d \in M, \forall k \in P \quad (7)$$

$$\sum_{i=1, i\neq j}^{n+m} x_{ijd}^{k} \le 1\ \forall j \in N, \forall k \in P, \forall d \in M \quad (8)$$

$$y_{djd}^{k} + \sum_{i=1}^{n} y_{ijd}^{k} \ge y_{jdd}^{k} + \sum_{i=1}^{n} y_{jid}^{k};\ \forall j \in N, \forall k \in P, \forall d \in M \quad (9)$$

$$\sum_{j,k} y_{djd}^{k} \le I_d;\ \forall d \in M \quad (10)$$

Equations (4) to (10) are very similar to the ones proposed for the inventory routing problem presented in [11]. However, unlike their single objective model, in our case equation (3) is the bi-objective function of minimizing the total travel cost of the routing of all vehicles to satisfy the demand as well as minimizing the CO_2 emission of delivering the coin demand at each PP&B. To generate routes, constraints (4) requires that the number of arcs entering each location *j* is equal to the number of arcs leaving that particular point *j*. Equations (5) ensure that the difference between the load of all vehicles arriving at PP&B *j* and the load departing is equal to the demand at point *j*, in other words that the demand of the PP&B at point *j* is satisfied. Constraints (6) verifies that the total load carried by the different vehicles form all Regional Cashier is equal to the total demand of all PP&B, these implicit constraints help in finding the optimal solution faster. To ensure that the vehicle capacity is not exceeded traveling between node *i* and *j* we include constraints (7). Equations (8) ensure that for a given vehicle *k* and Regional Cashier *d* not more than a single arc is incoming to PP&B *j*, to ensure a route between the Regional Cashier and the PP&B. To verify that the amount of coins incoming is greater than those that depart from the Regional Cashier we use constraints (9). Finally, equations (10) guarantee that the total load departing Regional Cashier *d* does not exceed the total amount of coins available at that Regional Cashier *d*.

We implement this model in SCIP [13] on a Windows 11 (64-bit), 11th Gen Intel(R) Core (TM) i7-11370H @ 3.30GHz and 16 GB RAM machine. We have observed that solving this formulation minimizing only $f(\overline{x})$ (for a fixed value of $h(\overline{x},\overline{y})$) with data of the demand of one month for the 54 PP&B did not arrive at the optimal solution within a 24-hour limit. Consider that this is only for a given ϵ level of CO_2 emission, and we must solve this problem over a range of relevant values. Hence, we have proposed implementing a heuristic that only considers neighboring banking places. As explained in the following subsection.

A. Regional Heuristic Solution

Solving our model considering all Regional Cashiers has proven to be time consuming as explained before, and we have observed that in practice it is very unlikely that a Regional Cashier at a considerable distance (say Mérida) would be asked to provide coins to faraway PP&B (say Tijuana). However, there are regions in the country where it is not uncommon for several PP&B to be served indistinctly between four Regional Cashiers (Monterrey, Guadalajara, San Luis Potosí, and Ciudad de México). Hence, we propose solving the model restricting those PP&B that are within a neighborhood, say no more than $\delta_{\max}$ distance (in Km), of a given Regional Cashier.

Let $N_d^{\delta_{\max}} = \{i \in N \cup \{d\} \mid c_{id} \le \delta_{\max}\}$, and let $2N_d^{\delta_{\max}} = \{(i,j) \in N_d^{\delta_{\max}} \times N_d^{\delta_{\max}} \mid i \neq j\}$ be the set of pairs of PP&B
that are no more than $\delta_{\max}$ distance from Regional Cashier *d*.

We then change restrictions 4 to

$$\sum_{i,j \in 2N_d^{\delta_{\max}}} x_{jid}^{k} = \sum_{i,j \in 2N_d^{\delta_{\max}}} x_{ijd}^{k}; \quad \forall d \in M, \forall k \in P, \forall j \in N_d^{\delta_{\max}} \quad (11)$$

also change equation 5 for

$$\sum_{d=1}^{m}\sum_{k=1}^{p}\left(\sum_{i,j \in 2N_d^{\delta_{\max}}} y_{ijd}^{k} - \sum_{i,j \in 2N_d^{\delta_{\max}}} y_{jid}^{k}\right) = q_j;\ \forall j \in N \quad (12)$$

Substituting 6 and 7 for:

$$\sum_{k=1}^{p}\sum_{d=1}^{m}\sum_{j\in N_d^{\delta_{\max}}} y_{djd}^k = \sum_{j=1}^{n} q_j \tag{13}$$

$$y_{ijd}^k \le Q_k x_{ijd}^k; \qquad \forall d\in M, \forall k\in P, \forall i,j\in 2N_d^{\delta_{\max}} \tag{14}$$

finally, the route constructing restriction 8 become:

$$\sum_{i=1, i\neq j}^{n+m} x_{ijd}^k \le 1;\ \forall k\in P, \forall d\in M, \forall j\in N_d^{\delta_{\max}} \tag{15}$$

$$y_{djd}^k+\sum_{i=1}^{n} y_{ijd}^k \ge y_{jdd}^k+\sum_{i=1}^{n} y_{jid}^k; \qquad \forall j\in N_d^{\delta_{\max}}, \forall k\in P, \forall d\in M \tag{16}$$

We have solve the problem using an ϵ-constraint method, with the previously mentioned heuristic to approximate the optimal solution for a given ϵ of CO_2 emissions (that is starting form a feasible solution x^*,y^* that only minimizes the travel cost, setting $\epsilon = h(x^*,y^*)$ and reducing ϵ down to where there is no longer a feasible solution). In the next section we present and discuss our results.

V. Results

Now the Banco de México is interested in minimizing traveling cost, while satisfying the demand, and does not consider the minimization of CO_2 emissions. An example of a route that minimizes the travelling cost form the Regional Cashier Monterrey is shown in Table I. The cost of travelling is proportional to the Km travelled by the vehicle and so we state the total cost in km rather than in pesos. The Table specifies the order in which the PP&B are visited, the quantity of demand that was delivered, and the total cost of the route (distance travelled) as well as the CO_2 emission. In Figure 5, we show a representation of the route in a map of that region.

When running our model, we observe that we may obtain in some cases solutions with smaller travelling costs ($f(\overline{x})$) than the ones that were implementing by the Central Bank. The solution shown in Table I, is one such example. This gives evidence that using the mathematical programming model presented in this paper can be advantageous and may improve the current practices of the Banco de México.

TABLE I
TRAVELING COST MINIMIZING ROUTE

Route	CO_2 Emission	Travelling Cost
MONTERREY CHIHUAHUA TORREON MONTERREY	1450.9	1603
MONTERREY CIUDAD-VALLES MONTERREY	836.6	1024
MONTERREY DURANGO TORREON MONTERREY	1028.4	1159
MONTERREY MONCLOVA TORREON SALTILLO MONTERREY	809.4	896.6
MONTERREY REYNOSA MATAMOROS CD-VICTORIA MONTERREY	795.8	910.9
Traveling cost	5593.5 Km	
CO_2 Emission	4921.1 Kg CO_2	

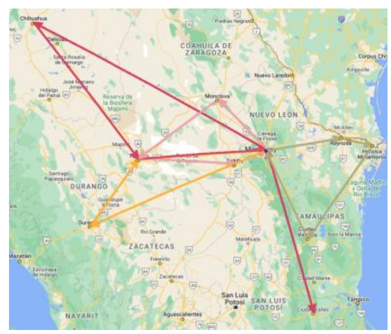

Figure 5. Map showing optimal routes

A. Trade-offs between travelling costs and CO_2 emissions

When considering emissions the order of visiting the PP&B have an impact on the CO_2 emissions. For example, using the same PP&B of Table I but in reverse order when the first visited node is not the one with greatest demand decreases the emission by 85 Kg CO_2. Hence in this case the routing may change depending on the load of the transporting vehicle. It is better to deliver the heavier loads earlier in the route. In fact, an alternative route that gives even smaller emissions is the one given o Table II. In Figure 7, we show a representation of the route in a map of that region.

TABLE II

ROUTE THAT MINIMIZES CO_2

Route	CO_2 Emission	Travelling Cost
MONTERREY MONCLOVA TORREON MONTERREY	778.4	891
MONTERREY REYNOSA MATAMOROS CD-VICTORIA MONTERREY	711.9	910.9
MONTERREY SALTILLO TORREON CHIHUAHUA MONTERREY	1385.1	1608.6
MONTERREY SALTILLO DURANGO MONTERREY	999	1163.6
MONTERREY CD-VICTORIA CIUDAD-VALLES MONTERREY	875.6	1025
Traveling cost	5599.1 Km	
CO_2 Emission	4750.0 Kg CO_2	

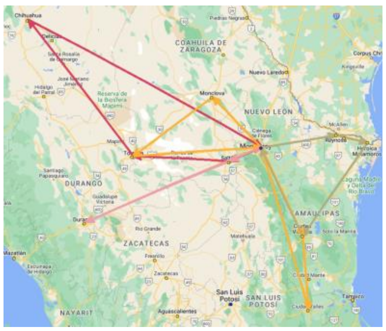

Figure 6. Map showing the routes that minimize CO_2 emissions.

The result of running our model shows that there are tradeoffs when focusing in these two objective functions. The Banco de México could in the future decide to use these insights to evaluate the cost of lowering emissions. In fact, in the next section, we show that there are many options (pairs of cost and emissions) to choose form.

B. Pareto Frontier

After running the ϵ-constraint method we were able to obtain the Pareto Frontier. We show such frontier for region X in Table III

TABLE III
PARETO OPTIMAL SET

$f(\overline{x})$	$g(\overline{x}, \overline{y})$
5599.1	4750
5595.4	4835
5593.5	4857

In Figure 7, we graph the Pareto Frontier

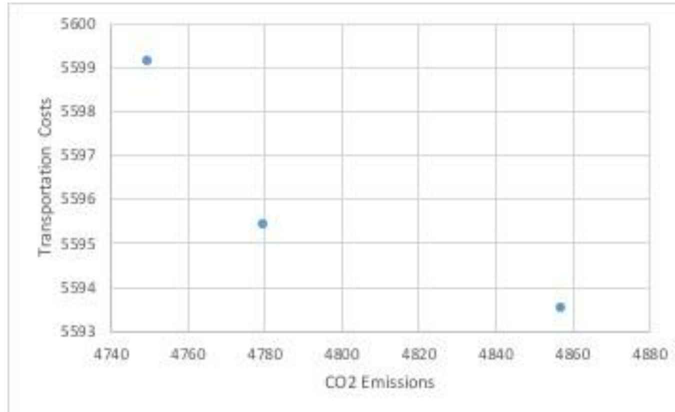

Figure 7. Pareto-Frontier

As can be seen we have 3 optimal points in the Pareto Frontier. This type of analysis is helpful for the decision maker to choose an appropriate level of cost and emission. The construction of the Pareto Frontier is important as each point in the set will give the optimal routing policy for that given cost and level of emission. We will present more details on the running times and size of the instances that we were able to solve to optimality with various neighborhood sizes $N_d^{\delta_{\max}}$. These results may help in guiding the implementation of these flow models for other transportation problems with similar settings or sizes.

C. Managerial Insights

Currently, cash distribution experts know the importance of supporting decisions using optimization models. Different enterprises and institutions tend to design their distribution routes in an empirical way, without intensive use of robust theoretical tools to minimize transport costs and maximize levels of customer satisfaction. Particularly, considering the case of the Central Bank of Mexico, the distribution of metallic coins is a legal requirement and mandatory process for the institution. We believe there are areas of opportunity in planning and scheduling distribution routes, which could avoid coin shortages and delays in deliveries to end users, reducing costs for the institution. The objective of this study is to propose and evaluate optimization models and algorithms for minimizing the cost of distributing metallic coins in Mexico. Mexico's coin distribution system consists of six distribution hubs and 86 demand points whose logistics is a challenging problem. We compare our proposed methodology with the operations and decisions that were taken by the Central Bank of

Mexico in a twelve-month period to show the advantages and savings of implementing our optimization solution. The Central Bank has a certification of “industria limipia” from PROFEPA (see [14]) for the printing of process in the Bank. The present study may help in the future to obtain additional certificates for the transportation operations of the Central Bank.

D. Future Work

At the present time the available inventory did not have a very important impact on the resulting routing. However, the model presented could also be used to explore scenarios where the inventory levels at the Regional Cashiers are tighter. We believe this model may also help in analyzing sensitivity of the solution when there are variations in the demand or in the capacity of the vehicles.

E. Disclosure

The work and results presented in this paper do not represent the views of the Central Bank of Mexico and are mainly for academic discussions.

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Transforming the BRT system for a greener future

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***Abstract* - Public passenger transport is the primary mode of urban mobility. However, it is highly dependent on fossil fuels, which represents a significant threat to the environment due to increased carbon emissions and air pollutants. This dependence contributes to the warming of the regions where these transportation systems operate. To address this challenge, energy efficiency measures must be implemented within urban transport infrastructures to ensure sustainable energy use. To mitigate pollutants and save energy derived from fossil fuels, wind turbines can be integrated into Bus Rapid Transit (BRT) System stations. This initiative requires a thorough characterization of the BRT system, including the identification of key variables to facilitate the implementation of such a solution.**

Keywords: Wind energy, wind turbines, public passenger transport.

I. INTRODUCTION

Approximately 80% of the world's energy is derived from non-renewable fossil fuels, including coal, oil, and natural gas [1]. In urban areas, public transportation is a significant contributor to air pollution, responsible for more than one-third of CO2 emissions from end-use sectors. Recent data from 2022 indicate a concerning trend: global CO2 emissions from the transport sector increased by over 250 Mt CO2 to nearly 8 Gt CO2, representing a 3% increase compared to 2021 [2]. Technological advances play a pivotal role in addressing environmental concerns in transportation, particularly in the development of energy and pollutant reduction systems for private vehicles. Nevertheless, public passenger transport has not received the same level of attention. Consequently, two significant challenges emerge: the promotion and evaluation of the adoption of renewable energy sources and the improvement of transportation efficiency in order to achieve sustainability goals.

One potential solution is to utilize wind energy, which has emerged as a significant contributor to global power generation. The utilization of wind energy not only reduces CO2 emissions but also contributes to the mitigation of climate change by promoting the use of clean, renewable energy sources. The conversion of wind energy into electrical power enables its effective utilization in the operation of transportation infrastructure, thereby providing a sustainable and environmentally friendly alternative.

This article thus examines the potential of integrating wind turbines into BRT system stations as an alternative solution to achieve energy savings. The article is structured as follows: Section 2 provides a literature review on wind energy, wind turbines, and transport energy consumption; Section 3 provides a characterization of the transport system, detailing the utilization of wind turbines and the essential implementation variables; Section 4 presents a theoretical proposal for the integration of wind turbines in a key corridor of Mexico City for the BRT System; and finally, conclusions drawn from the implementation of wind turbines are presented.

I. LITERATURE REVIEW

A. Energy consumption in the transport sector

Global energy consumption reached 422,117.52 petajoules (PJ) in 2021, representing a significant increase of 5.04% over the previous year. While efforts were made to reduce the carbon footprint, there were mixed trends in the consumption of energy sources. Consumption of coal and coal derivatives decreased by 0.54%. However, crude oil consumption increased by 14.18% over 2020, followed by natural gas with an increase of 6.09%. Petroleum products and electric power experienced significant increases, rising by 5.85% and 5.79%, respectively. In contrast, renewable energies experienced the smallest increase, rising by 4.20% over the previous year. [3] (Figure 1).

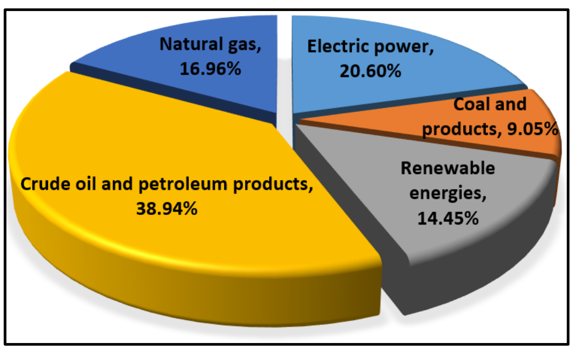

Figure 1. Global energy consumption by energy, 2021 [3].

In terms of energy consumption, the transportation sector accounted for a significant share, amounting to 26.68% (112,628.35 petajoules or PJ), which was largely driven by the combustion of fossil fuels. This increase can be attributed to the post-confinement recovery following the SARS-CoV-2 virus outbreak, which resulted in a 7.71% increase compared to the previous year, 2020 (see Figure 2). In the transportation sector, the transportation engine accounts for the largest share of energy consumption, representing 90.63% of the total [3] (see Figure 3).

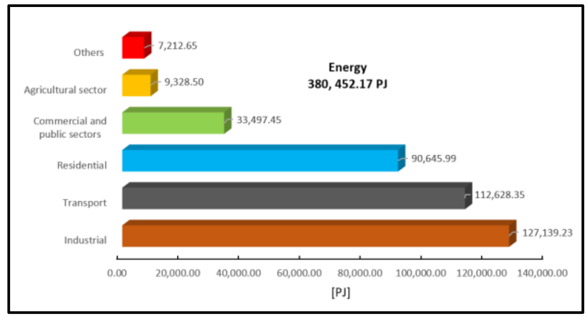

Figure 2. World energy consumption by category, 2021 [3].

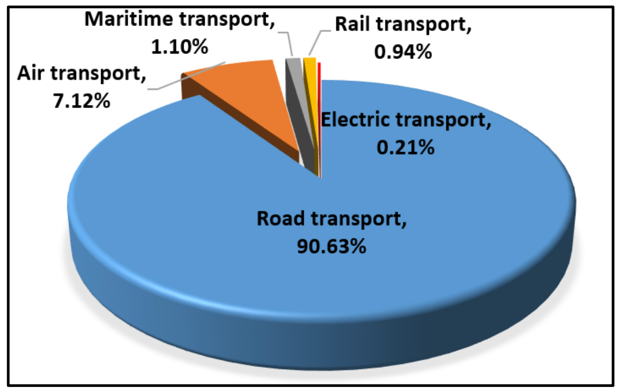

Figure 3: Energy consumption in the transportation sector [3].

The analysis of energy consumption is closely related to greenhouse gas (GHG) emissions, with transportation being a significant contributor to both. As indicated by [4], transportation is accountable for 38% of global energy consumption and 37% of GHG emissions. Mexico is ranked eighteenth in the international ranking of nations with the highest energy consumption [3], with its transportation sector consuming 46% of the energy produced and contributing 42% of GHG emissions, exceeding the world average [5]. In 2021, fuel consumption in Mexico's transportation sector reached 2,784,644 petajoules (PJ), representing a 63.45% increase over 2020 and accounting for 51.98% of the country's total energy consumption. A mere 0.2% of the total energy consumed in the transport sector is attributed to electricity supplied to electric transport, amounting to 5,693 PJ [6]. This underscores a significant obstacle in the transition to a more sustainable and energy-efficient transportation system in Mexico. Consequently, it is of the utmost importance to implement strategies that will result in a reduction in energy consumption if the United Nations' Sustainable Development Goals are to be achieved. The utilization of alternative energies, such as wind energy, appears to be a promising avenue for reducing energy consumption and associated emissions.

B. Wind energy.

Wind energy is a renewable energy source that harnesses the kinetic power of the wind using wind turbines. The energy is then transformed into electrical energy, which results in a significant reduction of polluting emissions by operating without generating greenhouse gases. Wind turbines are strategically installed onshore and offshore, featuring ingenious structures composed of large rotors equipped with blades. The wind exerts a force on the blades, causing them to rotate and thereby activating an internal electric generator. The efficiency of a wind turbine in converting energy is contingent upon several factors, including wind speed and the turbine's characteristics, such as generator capacity, hub height, and rotor diameter. These elements collectively determine the turbine's ability to capture and convert wind energy into electricity. Wind power technology is becoming a cornerstone in the transition to a sustainable energy future. It provides a clean, renewable alternative that diversifies energy sources and helps combat climate change [7].

Currently, energy recovery systems are employed to capture and transform the energy generated during braking or deceleration into a form that can be utilized as electrical energy. The integration of these systems into buses and trains allows for the reinvestment of otherwise wasted energy, thereby enhancing the overall energy efficiency of the system. Empirical evidence indicates that these systems can reduce energy consumption by up to 20%, thereby becoming a pivotal element in the optimization of the sustainability of transportation networks [8].

In the global effort to identify sustainable energy alternatives to fossil fuels, wind power has emerged as a significant contributor to electricity production. The widespread adoption of wind power contributes to the diversification of the energy mix and plays a pivotal role in the global effort to combat climate change. Wind power offers a renewable energy source that mitigates greenhouse gas emissions and facilitates the transition to a resilient, low-carbon energy economy. There has been a notable global expansion in the installed capacity of wind power, with substantial investments being made in both onshore and offshore wind farms. China, the United States, Germany, and Spain are leading nations that have made significant commitments to the energy transition, with notable installed wind power capacity [9].

These collective endeavors serve to illustrate the potential of wind energy to mitigate climate change. It is estimated that a rapid expansion of installed wind power capacity could significantly delay the 2°C warming threshold relative to pre-industrial levels [10].

In 2017, Mexico had an installed electricity production capacity of 75.69 gigawatts (GW), of which around 29.5% came from clean energy plants, including wind power. It is worth noting that the Isthmus of Tehuantepec region in Oaxaca is home to one of the highest densities of onshore wind turbines in the world. La Guna Sicarú wind farm in this region comprises 96 turbines generating 252 megawatts (MW), making it an important site for wind energy development in Mexico [11][12].

These developments underscore the abundance of sites in Mexico with substantial complementarity with energy sources. Although some locations are already in use, there are still untapped areas in the central to northern regions of the country that offer opportunities for the development of renewable energy generation systems. This underscores Mexico's substantial potential for integrating solar and wind energy into its energy matrix [13].

C. Wind turbines

In order to reduce the emission of polluting gases resulting from the combustion of fossil fuels, it is necessary to transition towards an industrial model and a lifestyle that prioritizes the use of sustainable and environmentally friendly energy alternatives. This necessitates the adoption of cleaner primary energy sources and their conversion to usable energy in an efficient manner, while simultaneously safeguarding the health of the planet and promoting a responsible energy future.

In this endeavor, extensive research has been conducted on the utilization of wind turbines. A wind turbine, also known as a wind generator, is a device designed to convert the kinetic energy of the wind, a natural and renewable source, into electricity. In contrast to a fan, which consumes electricity to generate wind, a wind turbine functions in reverse by harnessing the energy of the wind to generate electricity [14].

Wind turbines can be classified according to two key criteria: their power generation capacity and the position of their shafts. In terms of their capacity to generate power, wind turbines are classified into three categories: low-power, medium-power, and high-power turbines. The shaft position allows for the classification of wind turbines into two categories: vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT). The Savonius type of VAWT comprises two half-cylinders of equal diameter positioned parallel to the vertical axis of rotation. The Darrieus type of VAWT features two or three oval-shaped blades with an aerodynamic profile and offers minimum starting torque. Both types of wind turbine rely on differential wind forces to induce rotation. HAWT includes slow wind turbines that are equipped with a large number of multiple blades, which cover a significant portion of the rotor surface. Due to their relatively slow rotational speed, wind turbines of this type are more suitable for tasks such as water pumping than for electricity generation. In contrast, fast wind turbines are designed for the specific purpose of electricity generation, while intermediate-speed wind turbines, which typically have three blades, are used for electricity production by coupling with an alternator.

Vertical axis wind turbines (VAWT) exhibit several advantages over horizontal axis turbines. The vertical symmetry of these turbines obviates the necessity for orientation systems to align the turbine axis with the wind direction. Furthermore, VAWTs necessitate less complex maintenance procedures due to their reduced ground clearance. Furthermore, if they operate at a constant speed, there is no need to incorporate pitch change mechanisms, which translates into lower installation costs.

However, it should be noted that each wind turbine is adapted to specific environments and needs (Table 1). In urban settings, mini-wind turbines are the most prevalent and adaptable wind turbines due to their compact size and inherent safety features. Figure 4

TABLE 1. CLASSIFICATION OF WIND TURBINES

	Types of Wind Turbines			
	Horizontal Axis	***Vertical Axis***	***Offshore***	***Mini wind turbine generators***
Advantages	High efficiency	Less space	Increased energy production	Easy Installation
Disadvantages	Requires a lot of space	Less efficiency	High cost	Limited production
Ideal Use	Large wind farms	Urban areas	Offshore	Individual use or small quantities
Estimated power in (kw)	2000 8000 kW	10 – 100 kW	Up to 10000 Kw or more	5 50 kW

Source: Own elaboration

Figure 4: Mini wind turbine generation

Source:(Ovacen, 2024) [15]

D. BRT Systems

The Bus Rapid Transit (BRT) system represents a public transportation solution designed to enhance urban mobility. It encompasses several features, including dedicated bus lanes, high-quality stations, and efficient fare collection systems. These components function in concert to provide dependable and expedient transportation services, while requiring less investment and implementation time than rail or subway systems. The BRT system is renowned for its capacity to enhance urban mobility by reducing congestion and travel times. In the case of Mexico, BRT systems such as the Metrobus in Mexico City have implemented analogous strategies to enhance public transportation and concurrently diminish vehicular congestion and pollution [16].

The paper entitled 'A study on Bus Rapid Transit (BRT) system' focuses on economic and air pollution analysis in Tehran [17]. It investigates the efficiency of Tehran's BRT system by simulating ten different scenarios using Aimsun software. The scenarios aim to improve the efficiency of the system by implementing bus-only lanes, reducing bus intervals, activating traffic signals, and revising bus stations. The study demonstrates that converting shared lanes to dedicated lanes can generate significant benefits. These benefits include a 2.95% reduction in travel time, a 9% decrease in CO emissions, a 1.13% decrease in PM emissions, a 3.45% decrease in NOx emissions, and a 5.3% reduction in fuel consumption per kilometer. In addition, replacing fixed signs with activated signs along the route resulted in even greater improvements. Travel times were reduced by 6.31%, CO emissions by 25.9%, PM emissions by 3.42%, NOx emissions by 6.2% and fuel consumption by 5.26%.

This analysis offers insights into the potential of bus rapid transit (BRT) systems to optimize public transportation, enhance efficiency, reduce pollution, and contribute to sustainable urban development. These findings are pertinent to the Mexican context and present potential strategies for enhancing transportation systems while mitigating environmental impacts.

The study, entitled "Performance Evaluation in BRT Systems: An Analysis to Predict BRT System Planning," provides a comprehensive examination of the BRT system. Stochastic Petri Nets (SPN) are employed to assess the performance of the system, with a particular focus on key metrics such as the average system size, average queue size, average queue waiting time, and the probability of a user missing the bus. The model evaluates a variety of scenarios to optimize BRT planning and operation. This is achieved by incorporating variables such as bus intervals and the number of vehicles on the route.

The scenario identified indicates that the use of 300-second head intervals with five vehicles on the route results in a reduction in passenger waiting times. This approach offers a valuable tool for public transport system managers to evaluate and improve BRT performance. By considering a range of configurations and operational conditions, it is possible to achieve significant improvements in terms of efficiency, customer satisfaction, and sustainability. This analytical framework provides decision makers with the information necessary to optimize BRT systems, resulting in more efficient operations, enhanced service quality, and greater sustainability in urban transport networks.

II. BRT SYSTEM AND VARIABLE WIND TURBINES CHARACTERIZATION

For the generation of the proposal of the present project, a quantitative methodology of 4 stages is followed:

1. Characterization of the system, where variables of the urban wind turbine and transport variables are determined.
2. Characterization of the energy consumption in the system: to recognize the energy consumption in the station.
3. Determine the type of wind turbines: the specific characteristics of the wind turbines are considered, as well as the feasibility of their implementation in urban areas.
4. Planning of the special distribution of the wind turbines.

For which several variables must be considered for the implementation of wind turbines. These include:

A. Variables Influencing Energy Production

In the context of wind turbine-based energy production, the primary variables that impact the process are wind speed, air density, and blade radius. It is of the utmost importance to gather pertinent data on these variables [18].

B. Wind turbine characteristic variables.

For wind turbines, the essential variables required are the following [19]:

- Power: represents the main characteristic parameter of a wind turbine and denotes the amount of energy it can generate per unit time. Small-scale turbines for domestic use usually start with 1 kilowatt, while offshore turbines can reach up to 10 megawatts.
- Wind response curve: This curve illustrates the relationship between the power output and wind speed of a wind turbine. It generally consists of three regions: the region where wind speed is insufficient for production, the range of speeds from synchronization with the grid to maximum power production, and the range of speeds within which the turbine can operate effectively in both gusty and sustained winds, as well as the range where the turbine must be shut down.
- Wind turbine/generator type: Wind turbines use generators to convert the mechanical energy of the rotor into electrical energy. Generators can be either synchronous or asynchronous, and this distinction significantly affects the overall turbine design.
- Gearbox type: The gearbox inside a wind turbine plays a crucial role in transmitting power from the rotor to the

generator. There are several types of gearboxes, including single and multi-stage parallel shaft gearboxes, single and multi-stage planetary shaft gearboxes, and mixed gearboxes, which are commonly used in high-power wind turbines.

- Number of blades: Wind turbines can have one, two or three blades, although smaller models occasionally have more than three (always an odd number).
- Nacelle height: Refers to the height of the nacelle measured from its base to the center of the nacelle or the height of the rotor shaft. Nacelle heights vary significantly and depend on the turbine power, which determines the length of the blades.
- Blade length: The blades are crucial for converting the kinetic energy of the wind into rotating mechanical energy. The length of the blades is determined by the turbine power.
- Maximum height: This is the sum of the nacelle height and the blade length.
- Efficiency: The efficiency of the wind turbine depends on the speed curve and varies accordingly.
- Swept area: This denotes the area covered by the rotating blades, resembling the area of a circle.
- Rotational speed (range): In most cases, this is presented as a range. For high-power, grid-connected turbines, the rotational speed is typically around 15 revolutions per minute (rpm) and fluctuates between 10 and 15% depending on wind speed. Larger turbines tend to have lower rotational speeds.
- Blade orientation system: This can include turbines with no orientation system, those with hydraulic orientation systems, and those with electric orientation systems.
- Generation voltage: Wind turbines generally generate electricity at low voltages, with the common voltages at the generator terminals being 400 volts and 690 volts, both in three-phase current.
- Wind turbine output voltage: While domestic or low-power generators can generate directly at low voltage, medium or high-power generators usually require a transformer to raise the voltage to the substation connection voltage.
- Type of transformer: Possible transformers to step-up the generation voltage to transport voltage include integral fill transformers and dry transformers, the latter being the most common.
- Transformer location: The step-up transformer can be located at the rear of the nacelle, on top of the wind turbine or at the foot of the tower.
- Nacelle dimensions: Parameters such as height, length and width of the nacelle are crucial for transport to the site and erection.
- Nacelle weight: understanding the weight of the nacelle, along with its dimensions, is critical in determining the proper transportation method for its movement and installation on top of the tower.

*C. **Transport system variables.***

The Bus Rapid Transit (BRT) system comprises a dedicated bus lane, along with bus-level boarding platforms and the collection of fares at stations, which collectively facilitate the boarding process. To implement wind turbines, it is necessary to determine the number of stations along the route, the distance between each station, the number of traffic lights along the route, and the average speed of the buses.
Figure 5 and Table 2, illustrates the system configuration, where node A represents the number of stations along the route and node B represents the number of traffic lights along the route.

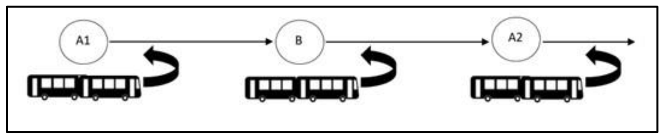

Figure 5: BRT system in nodes. Source: Own elaboration

TABLE 2. TABLE OF NODES IN THE BRT SYSTEM

Node type	**Definition**
Type A	= Number of stations on the route
Type B	= Number of traffic lights on the route

Source: Own elaboration

Once this information has been obtained, step 4 of the methodology proposed for this study can be carried out, which is detailed below.

III. TRANSFORMING THE BRT SYSTEM FOR A GREENER FUTURE (PROPOSAL FOR THE IMPLEMENTATION OF WIND TURBINES FOR THE BRT SYSTEM)

It is therefore proposed that wind turbines be integrated into the BRT system. The proposed solution entails the installation of vertical wind turbines at each station and traffic light, with the objective of maximizing the efficiency of power generation. Each turbine is connected to a substation, which boosts the voltage to power the station lighting system (Figure 6 and Table 3). Furthermore, the proposal includes the deployment of batteries to store surplus energy. The stored energy can then be transported to charging centers to power the lines equipped with all-electric buses.

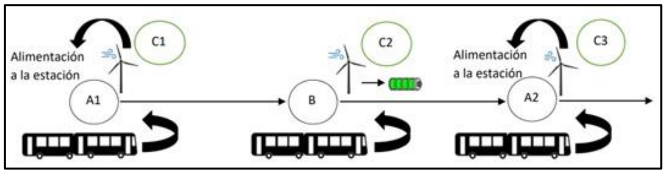

Figure 6: BRT system proposal Source: Own elaboration

TABLE 3. PROPOSED NODE TABLE IN THE BRT SYSTEM

Node type	Definition
Type A	Number of stations on the route
Type B	Number of traffic lights on the route
Type C	Number of wind turbines on the route

Source: Own elaboration

In consideration of the physical attributes of the BRT system infrastructure, the Savonius turbine is a suitable option for urban applications due to its simple microturbine design and its ability to operate at relatively low wind start-up speeds.

For the current analysis and implementation of wind turbines to be carried out correctly, it is necessary to link them to those agencies with decision-making power within the country's electricity sector. This implies that:

1. Implementing the requisite legal and regulatory changes to facilitate the development of wind energy in the country.
2. To conduct the requisite studies to ascertain the impact of the implementation of urban wind turbines in the BRT system.
3. It is recommended that the preparation and specialization of technical personnel in wind energy development and implementation be promoted.

The proposal is currently in its initial planning phase, during which the conceptual model and the necessary data collection variables are being outlined. Subsequent phases will entail the calculation of turbine placement distances, the determination of battery specifications for energy storage, the design of the necessary voltage lines, and the estimation of the energy yield of the wind turbine system. The objective is to quantify the potential energy savings that would result from the implementation of the system.

IV. CONCLUSIONS

Public transportation represents a vital component of urban infrastructure, providing daily mobility for millions of individuals. However, the sector is heavily reliant on non-renewable fossil fuels, such as coal, oil, and natural gas, which present significant sustainability challenges. To address this problem, innovation and the adoption of clean technologies are essential for the transition of public transport towards greater sustainability.

Wind turbines appear to offer a promising solution in this context, particularly in the context of bus rapid transit (BRT) systems. The integration of wind turbines in BRT systems not only reduces dependence on fossil fuels but also promotes an efficient, reliable, and environmentally friendly transportation model aligned with long-term sustainable development goals.

This represents a significant step towards energy autonomy and cost reduction, while simultaneously demonstrating a commitment to innovation and environmental stewardship. BRT systems play a pivotal role in alleviating traffic congestion and enhancing air quality in urban areas. The investment in the retrofitting of public transport infrastructure with solar panels and wind turbines has the potential to generate clean, renewable energy, to reduce dependence on fossil fuels, and to promote sustainability goals.

The definition of variables for the implementation of wind turbines in Bus Rapid Transit (BRT) systems serves as the foundation for the development of simulation models. These models are of critical importance in guiding decisions regarding the adoption of clean energy to enhance the autonomy of transportation systems and to mitigate dependence on fossil fuels. This approach represents a significant advance towards achieving the sustainability goals set by the United Nations.

These preliminary steps serve to establish the foundation for the development of a comprehensive simulation. The simulation will be employed to assess the current energy consumption of the BRT system in comparison to the anticipated consumption following the integration of the wind turbine system.

Consequently, future work will entail the simulation of the system and its energy consumption, as well as the reduction of consumption once the proposal is implemented.

ACKNOWLEDGMENT

We thank Arturo Moreno Arriaga for his assistance.

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Urban Transportation and Infrastructure

Articles

- **Navigating Mexico's Interoceanic Corridor: Exploring Challenges and Opportunities via Simulation Modeling**

  Miguel Mujica, Abdel El Makhloufi

- **Improvement of a last-mile delivery service using a descriptive analytics approach: a megacity case study**

  Carlos David Cadena Martínez, Ricardo Torres Mendoza, Jenaro Nosedal-Sánchez and Susana Casy Téllez Ballesteros

- **Intelligent Transport Systems Applications in Public Transport: a Review**

  Carmen Angelina Garcia-Cerrud, Adrielly Nahomee Ramos Alvarez and Idalia Flores-De-la-Mota

- **Leveraging Deep Learning for Enhanced Traffic Counting and Efficiency in Morelia México: An Artificial Intelligence Approach**

  José Alberto Guzmán Torres, Francisco Javier Domínguez Mota, Gerardo Tinoco-Guerrero and José Gerardo Tinoco-Ruíz

Improvement of a last mile delivery service using a descriptive analytics approach: a megacity case study

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***Abstract*— The following article presents the improvement of the arrival time of the units of a company in the energy sector to the service stations; used a database to design a dashboard to control of the transports, operators, transport lines and stations, to know the estimated time of arrival, as well as the exact time at which they began to operate, download the product contained in the unit, all using the ETL (Extract, Transform, Load) methodology. Performance evaluation, time is used which allows us to know the operational efficiency of program for assigning units to stations to deliver product (gasoline, diesel), which aims to be below 15% in the delay of deliveries to stations, and therefore, reduce customer complaints. Once the diagnosis and evaluation were completed, an analysis was carried out that determined the percentages by carrier lines, units and operators that arrive on time versus that arrive late. In addition to showing a dashboard with relevant information, such as: total trips by Storage and Dispatch Terminal (S&DT) and by carrier line, as well as the percentage of effectiveness of arrival at the station on time, which allows the logistics and transportation area to make decisions supported by data in terms of the assignment of units and operators to deliver to stations.**

Keywords-dashboard; delivery time; ETL; distribution; transport efficiency

I. Introduction

"Due to their large population and extensive commercial establishments, urban areas require large quantities of goods and services for commercial and domestic use. The increasing importance of urban freight transport is related to the increase in urban population and continued economic growth in urban areas. This results in increasing levels of demand for freight services" [1].

The last mile is the final leg of the supply chain that involves high frequency, low volume, and short-distance distribution of goods to end consumers. This last section is the most important, although the least efficient, part of the supply chain. Transportation planning and infrastructure controls are among the key factors contributing to the severity of last mile delivery (LMD) problems in large cities [2].

This is why in megacities; transportation becomes a colossal challenge due to population density and high demand for mobility. Access roads become congested and transit times lengthen, affecting the efficiency of last-mile deliveries. Vehicles intended for this crucial phase of the logistics process become stuck in traffic, resulting in delayed deliveries and customer dissatisfaction. In addition, environmental pollution worsens, as vehicles spend more time on the road. To address this challenge, it is essential to develop sustainable urban logistics strategies that optimize last mile management and reduce the impact.

The last mile problem is magnified in megacities, where space is limited, and congestion is the norm. Relatively short distances between warehouses and final destinations become a significant obstacle due to traffic density and access restrictions. The lack of specialized infrastructure for parking and loading and unloading goods in densely populated urban areas further complicates the delivery process. This not only increases operating costs for logistics companies, but also contributes to street saturation and polluting gas emissions.

This article explains how a multinational company in the energy sector has managed to implement a time control system, through data extraction and the development of a control panel for monitoring units and operators, carried out with the help of the ETL(Extract, Transform, Load) methodology, the impact it has had on its operational efficiency and how this initiative aligns with its vision of leading the transition towards a more sustainable energy future.

In the company's fuel transportation area, two major problems are detected in the process of monitoring units carried out by this company in the energy sector with each transport line at the time of delivering the product to each station: the first is the lack of monitoring of the unit in terms of estimated and actual arrival times at the station and the second is the little control of the requests attended to per week, that is, knowing if there were changes in the program (additions or cancellations)", which directly affect negatively on the productivity of the areas involved, since there is no clear visualization of the process in general, which causes decisions to be made based on the empirical knowledge of the analysts and not with a solid basis of data to makes the right decisions.

It is for these reasons that we seek to know directly what is the origin of the deviations in the weekly programs and based on this, take action on it, to improve the productive time of the area and help it to have a more detailed control and monitoring of the process that allows you to make decisions based on real data, all this through the creation of a visual control board, trying to obtain useful and accurate information for the development of the case.

II. METHODOLOGY

A. *Literature Review*

There are various investigations about time control in the last mile transportation of products, but these investigations do not cover the visualization of data for decision making using the ETL methodology.

One approach reported in the literature was about the problems of routing with real-time traffic information [3]. Another topic is the order picking and delivery planning both are essentials and interrelated problems for [4] are examined the optimal scheduling of pickup and delivery zones; however, the influence of real-world factors was ignored. On this basis, [5] considered the transportation time between collection areas and variable driving speed. Furthermore for [6] they optimized order allocation by predicting delivery time. Finally, [7] established a model to combine the location of warehouses with a timely delivery strategy.

In summary, there is a large amount of literature on the joint optimization of order allocation and distribution, however, few studies have considered the strategy of a data visualization dashboard for making on-time delivery decisions. Therefore, this article will be based on the ETL methodology for data management and its subsequent visualization in a tool (Power Bi®) that allows it to be visualized in a clear and dynamic way.

B. *Extract, Transform & Load Methodology*

ETL is a type of data integration that refers to the three steps (extract, transform, load) used to mix data from multiple sources. It is often used to build a data warehouse. During this process, data is taken (extracted) from a source system, converted (transformed) into a storeable format, and stored (loaded) into a data warehouse or other system. Extract, Load, Transform (ELT) is an alternate but related approach designed to pipe processing to the database to improve performance.

Extract, Transform, and Load (ETL) procedures are essential in a variety of actions, from basic database transfer to more complex tasks such as building a data warehouse. These processes are divided into various phases or activities, as defined [8].

The methodology of Extract, Transform, and Load (ETL) consist of six activities, see Figure 1. These activities are listed below:

1. First activity: identification of the data sources from which the extraction will be carried out, generally characterized by their heterogeneity.
2. Second activity: transformation of sources; Once the data is extracted, it is possible to perform transformations to generate derived data, involving actions such as filtering, conversion, calculation of derived values and key generation, among others.
3. Third activity: union of sources, which involves the consolidation of various sources into a single repository.
4. Fourth activity: selection of the destination to load the data.
5. Fifth activity: association of the attributes of the sources with the attributes previously stored in the destination.
6. Sixth activity: data loading, which covers the population of the data warehouse with the data already processed and transformed.

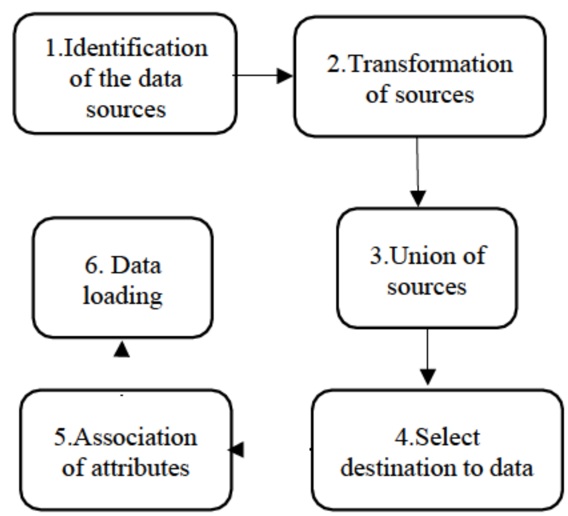

Figure 1. Extract, Transform, and Load (ETL) methodology Source:[9]

C. Case Study- Process delivery in megacities

In the context of a KPI (Key Performance Indicator) for controlling gasoline transportation times, the ETLmethodology can be applied in the following way:

Extraction: Is the first activity of the ETL methodology, data is extracted from the estimation program shared daily by the transportation area managers to control gasoline transportation times. This includes the following fields:

- Loading and unloading dates for deliveries to stations.
- SDT [Storage and Dispatch Terminal], (i.e. the cargo terminal: SDT 1, SDT 2, SDT3, SDT 4).
- Permit for the transportation of the material from the Energy Regulatory Commission (CRE).
- Name of the Station where the delivery will be made.
- Type of product to be delivered (Product 1, Product 2, Product 3).
- Volume requested to be delivered.
- BOL (Unique Identification Number for Station Delivery).
- Carrier Line that will make the trip.
- Type of unit and identification name of the unit that will be used.
- Name of the driver who will make the trip.
- Distribution center by area where the unit will be protected in case of circulation restrictions.

As well as support from GPS systems, planned route databases and other relevant sources. In addition, scheduled queries are used to extract data periodically (working with information older than a day), ensuring that the information is updated and accurate. Likewise, verification and validation mechanisms are implemented to guarantee the integrity of the extracted data.

Transformation: Once the data has been collected, it undergoes a transformation process to prepare it for KPI analysis. This includes data cleansing to remove duplicate or inconsistent records, as well as normalizing date and time formats to ensure consistency in time calculations. Specific algorithms and business rules are also applied to calculate key performance indicators, such as the following:

a. Each trip is given an hour of tolerance to make its delivery after of Earliest Time Arrival (ETA) provided by the carrier, for example, if you have an ETA of 2:00 p.m. and the download strip indicates a time of 2:59 h, then, it is said that it is "on time" with its delivery, after that time it is indicated that it has arrived "late".
b. It is necessary to know the conformity according to the weekly program vs. what was actually attended throughout it, and to do so, a comparison of the total trips by SDT will be made, verifying which station, what type of product and volume was delivered, with the BOL, that is, the unique identification number of delivery to station; since it gives us all the data requested to make the comparison.
c. In addition to this, it is necessary to know how many and which deliveries have been delayed for two days or more after the unit has entered to load the product. To do this, a subtraction is made from the delivery date of the product minus the date on which the loading was made, and a comment is added with the causes, as appropriate in accordance with the following standards:
   - Errors by Transportation managers: late sending of loading orders, error in the documentation of loading orders, addition of loading order requests and errors in the SAP platform.
   - Errors on the part of the transport line: they did not consider traffic, traffic restrictions on roads due to schedule, delay due to previous delivery (since the same unit is normally used to deliver to stations close to each other), road closures (accidents, demonstrations, etc.), mechanical failure of the unit and various problems with the operators.
d. Finally, it is necessary to know the behavior of the average time in minutes of arrival at stations, considering the two items of "On time" and "Late", since, although it is true that the vast majority of deliveries are made on time It had been observed that the ETA given by the carrier lines greatly exceeded the actual delivery time, so the decision was made to consider the following intervals in minutes to understand this behavior and make decisions based on consensus with each carrier line:
   - Interval of 0-10 minutes
   - Interval of 11-30 minutes
   - Interval of 31-60 minutes
   - Interval of +60 minutes

Load: The transformed data is then loaded into a storagesystem designed specifically for the purpose of everyone having access to said information. In this case, a data warehouse in SharePoint is used, specifically saved as an Excelfile that allows efficient and quick access to the information. The data is organized in relational tables that facilitate itsconsultation and subsequent analysis. It is important to establish a scheduled and automated upload process to ensure that information is always available and up to date.

Analysis and Visualization: Once the data is stored and updated in SharePoint, we proceed to the analysis and visualization phase. Microsoft's Power BI ® tool is used to explore the KPIs related to the control of gasoline transportation times.

The use of BI (Business Intelligence) applications today depends on the features and benefits offered by the different software applications, highlighting flexibility, friendly interface, extraction capacity, data processing and consolidation, as well as the presentation through its interface [9].

Microsoft Power BI is a service for the processing and visualization of data in an interactive way and with a simple interface, allowing the user to prepare reports, graphs for decision making [10]. In the context of time control in gasoline transportation, Power BI plays a fundamental role by transforming the data processed and calculated through the ETL methodology into graphs, pivot tables and interactive visualizations. This allows users to efficiently explore key performance indicators (KPIs) related to transportation times, providing a clear and detailed understanding of logistics performance. Additionally, Power BI offers the ability to create custom dashboards that enable real-time monitoring, as well as automated reporting that facilitate informed decision making and identification of areas for improvement in gasoline transportation management.

III. RESULTS AND DISCUSION

After designing the dashboard and feeding it with data from the database, with the tool indicated for the analysis of information and implementation of Business Intelligence and Data Analytics applications, we proceeded to create dashboards, which will serve as support to strategic decision making.

Data analytics applied to transportation monitoring processes allowed the implementation of a control panel, with which information can be articulated in relation to the structure of the queries that the user wishes to make and thereby represent or design the requirements. requested by the Transportation and Logistics area. The following indicator boards were prepared with the application of ETL Methodology.

“General Summary” Dashboard

This dashboard contains information by date in months for each SDT and Carrier, showing the number of total trips, arrival status KPI (on time, late), and the comparison of the projected program vs. the actual one.

Figure 2 and 3, shows the general dashboard for the month of July and November, showing a marginal improvement from 977 time trips (of a total of 1,152) in the month of July 2023 to 1,170 time trips (of a total of 1340) in the month of November, that is, an improvement of 193 trips in time, and an improvement of 3.64% with respect to the total trips that suffered an increase of approximately 16%.

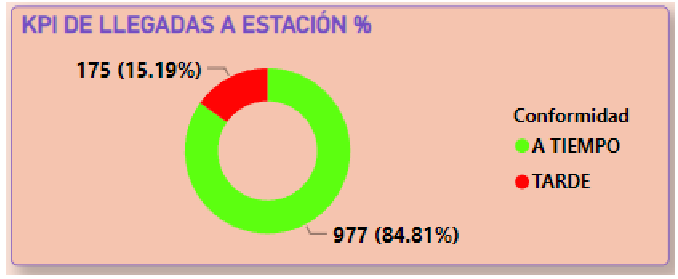

Figure 2. “General Summary” Dashboard july 2023. Source:Own elaboration

Figure 3. “General Summary” Dashboard november 2023. Source: Own elaboration

“Units and Operators” Dashboard

Shows a summary of how many times an operator is arriving late and the unit they have been using. This information is quite useful since it is complemented with another KPI from the Quality and Service area to be able to carry out audits on said operators and take action to solve this late delivery problem. Figures 4 show the top ten of operators arrived late in November 2023, and the Figure 5 show the top ten transports (with an identifier) arrive late.

“Download Delays” Dashboard

Shows why there are delays in product unloading and is broken down by carrier line, station, reason for the delay and scheduled unloading date vs actual unloading date. In Figure 6 and 7, show the Download Delays for July and November 2023 respectively. The number of download delays in July 2023 was 98 and in November 2023 decreased to 17 a reduction of 82.65%

Figure 4. "Units and Operators" Dashboard top ten operators arrived late in november 2023. Source: Own elaboration

Figure 5. "Units and Operators" Dashboard top ten units-transport arrived late in november 2023. Source: Own elaboration

Figure 6. "Download Delays" Dashboard july 2023. Source: Own elaboration

Figure 7. "Download Delays" Dashboard november 2023. Source: Own elaboration

"Unit Usage" Dashboard

Shows the % utilization of the units by each carrier line in all the trips made per month, since previously there were many units stopped and this represented a loss of money. Figure 8 show the percentage of utilization to July 2023, in this month the enterprise used 73 transport units with 6 carriers, for November 2023 the enterprise used 59 transport units and 5 carriers, see Figure 9. It must be taken into account that the decision was made to dispense with a transport line since its units generated a high cost and did not contribute great value to the operation. Furthermore, this analysis is complemented by point 1 mentioned in the "general summary" dashboard, although it is true that demand has increased in recent months and one might think that more units would be needed to meet said demand, this is not the case, since it has been demonstrated that the "download delays" KPI has been improving despite the decrease in unit availability.

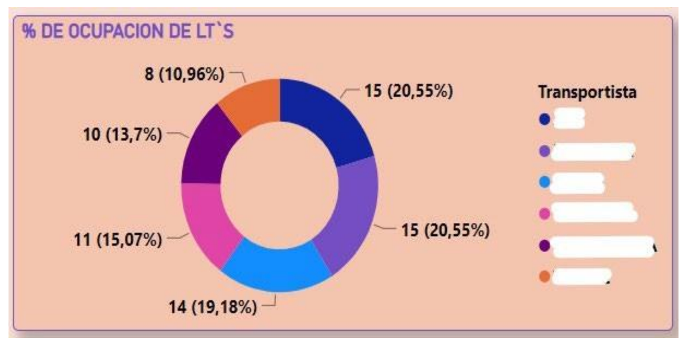

Figure 8. "Unit Usage" Dashboard july 2023. Source: Own elaboration

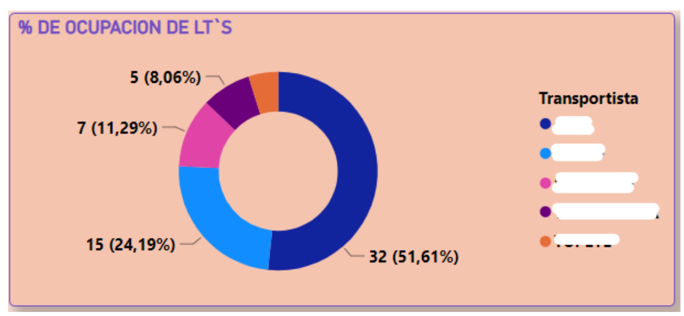

Figure 9. "Unit Usage" Dashboard november 2023. Source: Own elaboration

IV. Conclusions

In the energy sector, where operational efficiency and accurate time management are crucial, the use of ETL to address the challenges associated with the last mile in service delivery. The inherent complexity of the supply management of heterogeneous data, makes the effective

(Extract, Transform, Load) emerges as a fundamental tool chain in this sector, which involves the coordination of various resources and the implementation of ETL essential to optimize processes.

ETL's ability to extract data from multiple sources, transform it into consistent formats, and load it into a centralized warehouse provides a unified view of information related to lead times. This not only improves decision making, but also facilitates closer-to-real-time monitoring of events in the last mile. By integrating location data, traffic conditions and vehicle status, energy companies can identify bottlenecks and take proactive measures to optimize routes and minimize delays.

In conclusion, the strategic application of ETL in the energy sector is revealed as a catalyst for the effective resolution of the challenges associated with the last mile in service delivery. By providing robust data management and enhanced visibility, ETL provides the foundation and contributes to improving overall supply chain efficiency, thereby ensuring timely and effective delivery in an environment where time is a critical resource.

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Intelligent Transport Systems: Applications in Public Transport a Review

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***Abstract*—Intelligent Transport Systems (ITS) seek to provide a more efficient mobility through the integration of smart technologies into transport infrastructure, dynamics, and services. This integration has shown several improvements in the overall transport experience with resource optimization, congestion reduction, pollution decline, route enhancement, network update by giving data-driven solutions to complex problems. Specifically in Public Passenger Transport these improvements have been significant and due to the need to provide more efficient transport to the increasing population it has become of pivotal importance to incorporate these systems into cities. As a result, the objective of the present paper is to present a state-of-the-art review about ITS in Public Passenger Transport to give an outlook of the latest advancements and trends.**

Keywords-component; ITS; Public Passenger Transport, intelligent systems, optimization.

Introduction

Technological advances in transport aim to provide safer, more efficient, and environmentally friendly transport systems. Intelligent Transport Systems (ITS) integrate technologies such as computer networks, sensors, artificial intelligence, and the Internet of Things (IoT) into transport infrastructure and vehicles to address traffic congestion, road safety, and air pollution, creating smarter and more sustainable urban infrastructure and transport systems.

Intelligent Transport Systems (ITS) have facilitated the automated collection and seamless transmission of transport data, enabling better, more informed decisions, especially in real-time operations. ITS data have characteristics of significant volume and consistent continuity over time that can be used for strategic planning in public transport. This includes the collection of information on public transport performance, ridership, and demand patterns.

It is therefore essential to analyze the current applications of ITS in public transport, identify key trends and their practical implementations, and understand the specific characteristics and requirements necessary for successful implementation. This assessment will help detect existing limitations hindering ITS adoption in developing countries.

Literature Review

Public Passenger Transport

Public passenger transport is a comprehensive system of transport that provides a solution to people's travel needs through widespread use. Public passenger transport includes various modes of transport such as buses, taxis, bicycles, trams, trolley buses, trains, commuter rail, and ferries [1].

Satisfying the customer's need for high quality, flexible, fast, and safe transport of passengers is ITS' primary goal [2].

The accessibility of destinations and the frequency of connections are important factors for passengers when considering public transport [3]. Consequently, the primary objective of transport services is to provide a variety of travel options that meet these criteria, while infrastructure aims to facilitate the provision of a comprehensive service within a given state, specific geographic cluster, or area of interest [4] [5] [6].

For this reason, the use of ITS has become very important, as it provides real-time information that can be used to plan and manage public transport in a more efficient way, with an impact on both users and the environment, as well as providing data-driven solutions to current problems. Therefore, ITS represent a valuable tool for Smart Cities

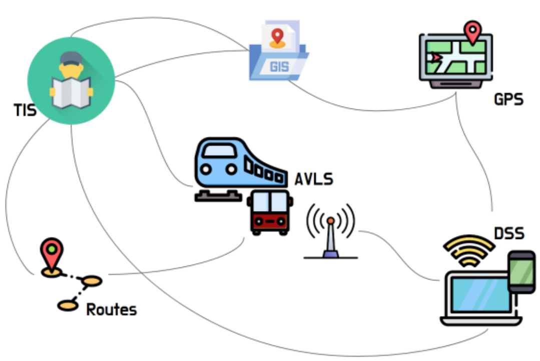
Intelligent Transport Systems (ITS)

ITS encompass wireless, electronic, and automated technologies. Having the ability to integrate different vehicles (such as transit, trucks, and personal vehicles), system users, and infrastructure (including roads and transit networks) [7].

A variety of ITS technologies can improve the travel experience by optimizing routes, reducing unnecessary vehicle miles traveled, promoting alternative modes of transport, reducing congestion, reducing dependence on foreign oil, and improving air quality. In addition, when applied to system management (such as transit and highways) and vehicle design, these technologies can reduce fuel consumption.

Intelligent Public Transport Systems (IPTS) are a subset of ITS. Their goal is to monitor public transport networks and ensure their optimal performance, while providing users - both passengers and decision-makers - with timely information about trips and the operational status of the network [8].

For example, Geographical Information Systems (GIS) help plan new routes and shuttle services. Automatic Vehicle Location Systems (AVLS) use Global Positioning Systems (GPS) to track the location of transit vehicles. Traveler Information Systems (TIS) provide users with real-time updates on network conditions. IPTS also allow for the integration of Decision Support Systems (DSS) that suggest control strategies and control measures to maintain network performance, as it is shown in Figure 1. These information systems and technologies collectively process, analyze, and exchange different types of data from various detection devices and advanced technologies such as global positioning satellites (GPS) and sensor networks [9].



Relationships among GIS, AVLS, TIS and GIS

ITS APLLICATIONS ON PUBLIC PASSENGER TRANSPORT STATE OF THE ART

Rajbhandari, Bidur (2002) investigate the impacts and benefits of specific ITS measures within urban bus networks. It examines potential influencing factors and critiques the evaluation methods used to measure the impact of these measures. A comprehensive review of modeling techniques is conducted to delineate the prerequisites for effectively assessing the impacts of selected ITS measures in public transport. It is concluded that there is a need for application-specific evaluation techniques due to the different impacts and influencing parameters of different ITS measures. Results from illustrative modeling efforts demonstrate significant benefits associated with individual measures and their potential to influence perceived change and patronage. Combined measures can have impacts comparable to those of conventional measures, often with less disruption to other modes [10].

Hounsell, N., & Wall, G. (2002) summarize several examples of ITS implemented in Europe, such as automatic vehicle location (AVL), bus priority in traffic control systems, automated ticketing systems, automated camera enforcement systems, and variable message signs. The focus is then narrowed to AVL systems and their integration with Urban Traffic Control (UTC) systems, which are particularly prominent in Europe [11].

N.B. Hounsell (2004) explores various ways in which ITS can support bus operations, particularly in ensuring efficient bus movement. However, while the potential benefits are significant, their realization depends more on factors such as organizational structures, funding, and commitment than simply the availability of technology, and to fully realize the benefits of ITS, there is an urgent need for stronger partnerships between local authorities and operators, as both parties stand to benefit along with passengers. In addition, as ITS technologies become more sophisticated, there is a growing need for enhanced skills in system specification, operations and management to ensure the realization of benefits in the long term [12].

Jakubauskas G (2006) analyzes two approaches to creating an intelligent ticketing system for urban public transport: electronic ticketing and e-ticketing, and the outcomes associated with the implementation of smart cards and e-ticketing and concludes that predicting technological trends is difficult and that conducting a comprehensive cost-benefit analysis is essential. Nevertheless, ITS holds great promise for improving urban transport ticketing systems. Contactless smart cards and e-ticketing are fast track approaches to making urban public transport systems intelligent, and efficient payment systems are fundamental to seamlessly integrating different modes of urban public transport [13]. As a result, leading public transport operators are tending to adopt contactless smart card-based ticketing systems and e-ticketing, which offers passengers a highly convenient and attractive solution.

N. Lathia, et al. (2010) propose and evaluate methods to predict personalized trip durations for system users and prioritize stations based on expected mobility patterns, facilitating the identification

Identify applicable sponsor/s here. *(sponsors)*

of stations of greatest interest to users and thereby enabling the provision of valuable travel updates using traveler information, route planning, and service updates have become indispensable features of public transit systems, helping individuals navigate urban environments by providing pertinent details about delays and service interruptions [14].

Maria Visan, et al. (2010), propose a definition for the maturity levels of capabilities within the mobility ecosystem and outlines a functional architecture for a collaborative decision-making system for the implementation of C-ITS in future Smart Cities, contributing by increasing the awareness and understanding of the Capability Maturity Model (CMM) for all stakeholders within the mobility ecosystem, emphasizing the essential capabilities required at each maturity level [15]. Encouraging collaboration between public and private companies operating in the mobility ecosystem, promoting the assessment of existing capabilities and striving for higher maturity levels in mobility processes, leading to stable and repeatable results, and defining a C-ITS functional architecture tailored for future Smart Cities, facilitating collaborative decision making specifically for the implementation of public transport in large Smart Cities. The goal is to improve the quality of life for citizens by optimizing public transport systems within Smart Cities.

Phil Blythe et al., (2010) examine the technologies and methodologies aimed at improving the integration of public transport modes and services, both within urban areas and on interurban routes. With a primary focus on the use of ITS solutions, to facilitate a seamless travel experience for users of the transport system. Covering a wide range of measures, from smart card ticketing and bus priority systems to automatic vehicle location, trip planning, on-board information systems, and emerging public transport services offering on-demand travel and integration with taxi services and highlighting their role in making fixed public transport networks more attractive and competitive compared to the door-to-door convenience offered by private cars [16].

Młyńczak, J. (2011) presents various examples of ITS, with a particular focus on systems that facilitate the development of public transport. The study highlights several ITS applications aimed at improving the operational efficiency of public transport. Despite the reluctance of some decision-makers to implement such solutions, the studies demonstrate effective measures that, when combined, offer potential solutions to traffic-related problems [17].

Janecki, R., Krawiec, S. (2011) examine the interplay between fostering sustainable mobility within cities and employing Intelligent Transport Systems (ITS) applications revealing that local authorities possess a diverse array of options for pursuing the objectives of a burgeoning mobility culture [18].

Janecki, R. (2011) aims to delineate the role of ITS within the transport policy of the city. Stating that territorial cohesion and economic growth depend on the presence of advanced transport infrastructure and related ITS technologies. Sustainable mobility in urban areas is also central to this sector strategy. Activities that support these objectives will increasingly be included in urban transport policy documents, evolving from mere instruments to overarching goals due to their spatial and technological dimensions [19].

Susan Grant-MullerMark (2014) addresses two primary research questions: first, whether there is sufficient evidence to support the deployment and operation of Intelligent Transport Systems (ITS) in a way that generates environmental benefits, and second, whether policy priorities among national and international stakeholders reflect a tendency to prioritize ITS deployment for such benefits. The results indicate that variables such as vehicle density and high technology exports significantly influence the propensity for ITS to be considered a high priority policy tool in future transport strategies. This research not only positions ITS as a valuable policy tool capable of delivering economic and sustainability benefits, but also has relevance for policy analysts and transport strategists at international, national, and regional levels [20].

Weber, K. Matthias & et al., (2014) explore the conditions, determinants, and instruments crucial for effectively managing ServPPINs, by examining four cases of ServPPINs involved in ITS. These cases all share the common objective of fostering system innovations within the transport sector. by establish a conceptual and analytical framework for examining public-private innovation networks in transport services, dissecting the factors influencing system innovations, categorizing them based on their location and stage within the innovation diffusion process. and conduct a comparative analysis of four instances implemented in Austria and Norway. Concluding that the models provide a promising framework and first step for future research but should be considered working hypotheses that require further refinement. More case studies are needed, including examples of ServPPINs that experienced failures at different stages of the process. These failures provide valuable insights into potential barriers and obstacles that should be considered in any revised process model [21].

Agostino Nuzzolo & Antonio Comi (2016) analyze several methodological issues related to the development of the collection and processing of "Big data" from the transit system, and two-way communication between transit travelers and information centers, are improving the tools that support short-term prediction of network status for transit operations control and traveler information. These issues include the application and refinement of methods for real-time short-run vehicle load forecasting, real-time best path advice, real-time transit assignment modeling, individual path choice modeling, and real-time updating and upgrading of demand and supply model parameters [22].

Kalupová, Blanka & Hlavoň, Ivan (2016) state that the integration of ITS and services into road transport has been shown to reduce accidents, increase the capacity of existing infrastructure, and reduce congestion. In addition, the implementation of tolling systems generates the necessary resources for the construction and maintenance of new road networks. Furthermore, tolling systems contribute to the improvement of public transport, cycling and pedestrian infrastructure, facilitating their multimodal integration with the private car. Concluding that it's important to note that the financial investment to purchase and implement these systems requires long-term planning. While immediate savings may not be realized within weeks, the benefits will be realized over months or years and that the initial challenges, economic benefits can be realized through improved work organization, communication, socio-economic conditions within the organization, coaching opportunities, reporting capabilities, and most importantly, gaining control over expenses, vehicles, and personnel [23].

D. Vakula & B. Raviteja (2017) propose to implement a system to inform passengers of bus locations and arrival/departure times via displays at bus stops or a smartphone application, using the latest technology integrated into existing bus systems. This technology includes a GPS system to track bus locations and sensors to monitor the number of passengers. With which passengers can access this information via WiFi or the Internet at the bus terminal. Overall, the integration of ITS allows passengers to conveniently access public transport information through a smartphone application [24].

Mangiaracina, Riccardo, et al. (2017) undertake a comprehensive analysis of the role of ITS in facilitating smart urban mobility, with the aim of identifying key shortcomings in the existing literature and suggesting avenues for future research. Evaluate prevailing research methodologies used to measure the benefits available to logistics operators, city administrations, and city residents in the areas of traffic management, public transport, parking management, and city logistics [25].

Iliopoulou, C. & Kepaptsoglou, K, (2019) examine potential models and methodologies in public transport planning and operations, focusing on how they can leverage ITS data. The success of ITS-based public transport planning depends on the seamless integration of traditional transport planning methods with advanced computer science algorithms and data mining techniques. Overall, data-driven public transport planning is expected to become the dominant approach in the coming years, especially with the widespread deployment of ITS systems in urban centers under the sustainable mobility paradigm [26].

Marcin W. Mastalerz et al. (2020) explore the automation of the Check-In/Check-Out (CICO) process for public transport fare collection systems, using modern IoT tools such as Beacon and Smartphone. It introduces the idea of an integrated passenger identification model that utilizes machine learning technology to reduce the risks associated with misclassifying a smartphone user as a vehicle passenger. The purpose of this model is to simplify the creation of an intelligent fare collection system that operates using the Be-In/Be-Out (BIBO) model [27].

Issam Damaj, et al., (2022) provide a comprehensive analysis of recent literature on Machine Learning (ML)-driven Intelligent Transport Systems (ITS), with a focus on the integration of Mobile Health Devices (MHDs) and their performance indicators. Acknowledging the challenges in selecting suitable machine learning techniques and model-based health diagnosis methods for ITS across diverse complexity levels, this paper introduces a novel performance evaluation framework [28].

Yong-Hong Kuo, et al. (2023), examine the various models and methodologies used in the planning and operation of public transport systems. It examines the effectiveness and applicability of these tools in optimizing public transport networks and improving service quality, as well as the influence of big data and Internet of Things (IoT) technologies on existing and new public transport services. It assesses how the integration of these technologies can improve operational efficiency, passenger experience, and overall system performance [29].

Liu, Chenchen, Ke, Li ((2023) design a Cloud-assisted Internet of Things Intelligent Transportation System (CIoT-ITS) addresses the challenges of traffic management. The system deploys IoT sensor-integrated cameras at each traffic signal corner, effectively monitoring vehicle flow.A simulation analyses confirm the CIoT-ITS's capability to autonomously monitor and manage vehicle flow, showcasing its effectiveness. The proposed CIoT-ITS is designed to enhance smart city transport management by improving vehicle speed calculation. This is expected to result in reductions in fuel consumption (31.5%), energy utilization (23.8%), and traffic congestion (27.1%). It is also anticipated that predictions related to green transportation (93.1%) and traffic management (94.2%) will be enhanced [30].

Bharadiya, J. (2023) investigated the pivotal role of machine learning (ML) and artificial intelligence (AI) in the evolution of smart cities to comprehend how these technologies contribute to the management of expanding metropolitan areas, the stimulation of economies, the reduction of energy consumption, and the enhancement of residents' living standards. Additionally, the research delved into the analysis of the information flow associated with information and communication technology (ICT) within smart city infrastructures. Demonstrating the profound impact of ML and AI across a multitude of facets of smart cities, particularly within intelligent transportation systems (ITS). These technologies are pivotal in tasks such as modeling and simulation, dynamic routing, congestion management, and intelligent traffic control [31].

Oladimeji D, et al. (2023) provide a comprehensive examination of the contemporary technologies employed in smart transportation and the associated challenges. The review addresses three key areas of focus: data privacy and security concerns, network scalability, and enhancing interoperability among diverse Internet of Things (IoT) devices deployed in smart transportation ecosystems. The objective is to contribute to the advancement of smart transportation technologies by identifying critical issues and suggesting avenues for further investigation and innovation [32].

Yong-Hong Kuo, et al. (2023) address the intricacies associated with network design, operations planning, scheduling, and management of smart public transport systems. Their objective is to provide insights into these challenges while also offering a concise overview of recent research and innovations in the field [33].

Zhihan Lv, Wenlong Shang, (2023) examine the impact of intelligent transportation systems (ITS) on energy conservation and emission reduction (ECER) within transportation networks. They underscore the diverse effects of ITS on ECER across different transportation sectors. Their findings reveal a transition from conventional video surveillance to more intelligent systems, which significantly contribute to traffic management by providing real-time data to alleviate congestion and enhance vehicle efficiency. Moreover, optimizing vehicle specifications is essential for realizing energy conservation within the transport system. However, the successful implementation of these energy-saving strategies hinges on robust government policies that promote and incentivize ECER transportation initiatives. Such policy measures are imperative to fully harness the potential benefits of ECER within transportation networks [34].

Adewopo, V.A., et al. (2023) examine the utilization of augmented reality (AR) systems in conjunction with various traffic video sources, including static surveillance cameras at traffic intersections, highway monitoring cameras, drones, and dash-cams, identifying key techniques, taxonomies, and algorithms employed in AR for autonomous transportation and accident detection. Finding a promising research direction for developing and integrating accident detection systems for autonomous vehicles and enhancing public traffic safety. These systems can promptly alert emergency personnel and law enforcement in the event of road traffic accidents, thereby reducing human error in accident reporting and providing swift assistance to victims [35].

Bibliometric Analysis

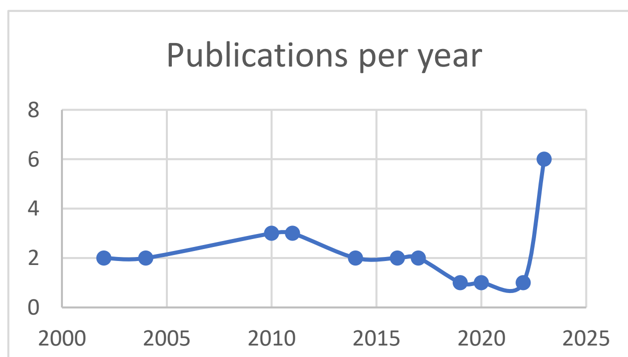
After the comprehensive analysis, a bibliometric analysis of the 25 publications was performed to show the importance of ITS in recent years.
Table 1 provides a summary of the publications reviewed, including title, authors, year of publication, editorials, and citations.
Figure 1 clearly shows that the number of publications per year has increased. This is because there is a growing tendency to use ITS in the current year. This implies that more studies need to be carried out to address its utilization and implications. Also, Figure 2 clearly shows that all editorials are high impact and that there are several publications regarding ITS, which shows its application is important.
Figure 3 definitively demonstrates the citation rate of each reviewed publication. As the ITS topic becomes increasingly crucial for achieving the goal of smart and sustainable cities, the overall citation rate is undoubtedly high.

Publications summary

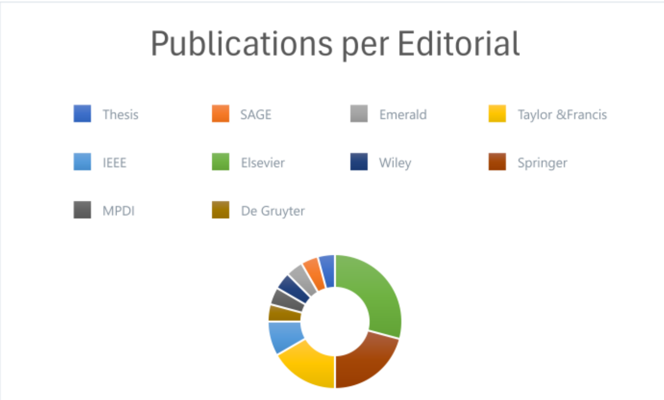
Title	Author	Year	Editorial	Citations
Modelling intelligent transport systems applications for public transport	Rajbhandari, Bidur	2002	Thesis	3
New Intelligent Transport Systems Applications in Europe to Improve Bus Services	Hounsell, N., & Wall, G	2002	SAGE	15
Keeping buses moving: role of intelligent transport systems	N.B. Hounsell	2004	Emerald	12
Improvement of urban passenger transport ticketing systems by deploying intelligent transport systems	Jakubauskas G	2004	Taylor &Francis	45
Mining Public Transport Usage for Personalised Intelligent Transport Systems	N. Lathia,et al.	2010	IEEE	33
Towards intelligent public transport systems in Smart Cities; Collaborative decisions to be made	Maria Visan, et al.	2010	Elsevier	13
ITS applications in public transport: Improving the service to the transport system.	Phil Blythe, et al.,	2010	Wiley	24
Analysis of Intelligent Transport Systems (ITS) in Public Transport of Upper Silesia.	Młyńczak, J.	2011	Springer	7
The Significance of ITS Applications for the New Mobility Culture in the Cities	Janecki, R., Krawiec	2011	Springer	2
Intelligent Transportation Systems in Transportation Policy of the Cities	Janecki, R	2011	Springer	6

ICT-enabled system innovations in public services: Experiences from intelligent transport systems	Weber, K. Matthias & et al.	2014	Elsevier	73
Intelligent Transport Systems: The propensity for environmental and economic benefits	Susan Grant-MullerMark	2014	Elsevier	108
Intelligent Public Transport Systems: A review of architectures and enabling technologies	Agostino Nuzzolo & Antonio Comi	2016	Taylor &Francis	35
Intelligent Transport Systems in the Management of Road Transport	Kalupová, Blanka & Hlavoň, Ivan	2016	De Gruyter	18
Smart public transport for smart cities	D. Vakula & B. Raviteja	2017	IEEE	44
A comprehensive view of intelligent transport systems for urban smart mobility.	Mangiaracina, Riccardo, et al.	2017	Taylor &Francis	124
Combining ITS and optimization in public transport planning: state of the art and future research paths	Iliopoulou, C. & Kepaptsoglou, K	2019	Springer	60
Passenger BIBO detection with IoT support and machine learning techniques for intelligent transport systems	Marcin W. Mastalerz et al.	2020	Elsevier	11
Intelligent transport systems: A survey on modern hardware devices for the era of machine learning	Issam Damaj, et al	2022	Elsevier	24
Public transport for smart cities: Recent innovations and future challenges	Yong-Hong Kuo, et al.	2023	Elsevier	69

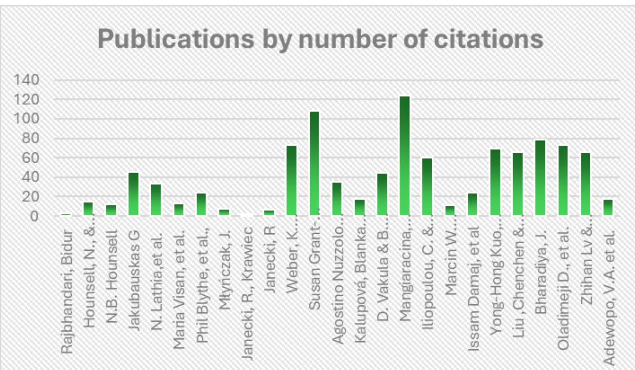
Cloud assisted Internet of things intelligent transportation system and the traffic control system in the smart city	Liu ,Chenchen & Ke ,Li.	2023	Taylor &Francis	66
Artificial Intelligence in Transportation Systems A Critical Review	Bharadiya, J.	2023	MPDI	79
Smart Transportation: An Overview of Technologies and Applications. Se nsors	Oladimeji D., et al.	2023	Elsevier	73
Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: A comprehensive review	Zhihan Lv & Wenlong Shang	2023	Elsevier	66
A review on action recognition for accident detection in smart city transportation systems.	Adewopo, V.A. et al.	2023	Springer	18



Publications per year



Publications per Editorial



Publications by number of citations

DISCUSSION

The advent of digital innovation (ITS) has emerged as a significant transformative factor for cities transport. Leading to the creation of smart cities and offering several key advantages: Firstly, autonomous transportation systems significantly reduce accidents caused by human error. Secondly, computers do not suffer from distractions, fatigue, or emotional factors that can impair human drivers. Thirdly, data collection plays a crucial role in responsible infrastructure management. Smart transportation systems provide detailed data on various aspects of the transportation network, enabling administrators to monitor operations effectively, track maintenance requirements, and pinpoint critical issues that require attention. This data can be used to improve efficiency and cost-effectiveness. For instance, adjusting train schedules slightly can optimize occupancy rates, and redistributing bus stops can better serve community needs. The implementation of smart transportation systems optimizes the utilization of resources, thereby reducing costs. Through the implementation of preventive maintenance, decreased energy consumption, and the reallocation of resources to address accidents, smart transportation systems offer cost savings. Additionally, the provision of efficient public transportation can compete favorably with private vehicle ownership, thereby reducing overall transportation expenses for users and finally City Traffic Management Centers (TMCs) benefit from rapid visibility and notifications regarding problem areas or city-wide issues affecting traffic congestion, public safety, and emergency response systems. This enables prompt action and effective communication with other agencies and emergency responders, ensuring a coordinated response to urban challenges.

Public policies have a great impact in ITS implementation since, it is necessary to modify federal and local regulations in order to facilitate the implementation and incorporation of ITS technologies into the design and operation of road networks, enabling the provision of greater road safety, greater security for assets, and the availability of information to travelers, thereby demonstrating the feasibility of large-scale intermodality, the competitiveness of the transport system. and the enforcement of regulations based on the data provided by these systems.

However, the implementation of ITS in developing countries is hindered by the characteristics of the population. For instance, the implementation of demand controls, which are essential for the success of ITS, is particularly challenging in public transport due to the high population density. This density can lead to the generation of risk factors when implementing ITS technology. Furthermore, the dynamic monitoring of transport units is also hindered by the existence of unregulated transport. Therefore, implementing these systems becomes complex without the appropriate control measures in place.

Consequently, it is imperative to conduct a thorough examination of the distinctive attributes of each urban area, encompassing institutional and governance structures, prior to the implementation of ITS. Otherwise, this could potentially result in a protracted and incremental integration of ITS, which has, in turn, led to a certain degree of disillusionment with the smart city concept.

CONCLUSIONS

ITS have improved mobility solutions by providing and analyzing data through the above-mentioned tools. Planning routes, tracking location, optimizing routes, creating paths, updating network conditions in real time, integrating decision support, enhancing stability, reducing risks are some of the benefits of ITS implementation.

The implementation of ITS not only enhances safety and management efficiency but also facilitates cost savings and the rapid response to urban issues through data-driven insights and technology integration.

Although many solutions have raised through Machine Learning, Artificial Intelligence and Big Data there are still challenges to fully implement ITS' tools, being some of them the collection, processing, and analysis of large amounts of information in real-time, evaluation metrics for changing circumstances, cybersecurity strategies implementation, methods validation for emergent economies.

In the aim to reduce lag times, system disruptions, congestion, air pollution and other severe problems, ITS have raised but concerns about their effectivity in environmental and operational issues are present. For this reason, further analyses are required to measure ITS impacts from a systemic approach.

ITS high initial costs of implementation and maintenance, potential security vulnerabilities, and non-intuitive technology are challenges that may delay ITS development and application in places where population grows faster than urban infrastructure, mobility strategies, and policies. For it is vital to build plans in accordance with the administrations' capacities and capabilities. Being the construction of Smart Cities and the deployment of Smart Mobility a larger challenge in developing countries.

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Leveraging Deep Learning for Enhanced Traffic Counting and Efficiency in Morelia México: An Artificial Intelligence Approach

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***Abstract*—The evolution of urban cities demands innovative solutions for traffic management and safety, particularly in culturally rich but rapidly urbanizing cities like Morelia, Michoacán, Mexico. Traditional traffic management systems, while foundational, often fall short in addressing the dynamic nature of urban traffic flows, leading to inefficiencies and wrong designs of road structures.**

This study presents a groundbreaking application of deep learning in Morelia's traffic counting, the YOLOR algorithm. It analyzes the efficiency of this approach, aiming to outperform traditional methods in both scope and effectiveness. This research comprehensively analyzes the number of vehicles that pass over primary avenues by leveraging extensive amounts of traffic data and employing state-of-the-art DL algorithms.

This work integrates real-time vehicle detection and classification across multiple monitoring stations, facilitating dynamic traffic management and supporting long-term urban planning. Comparative analysis with traditional traffic management approaches highlights DL's advantages in terms of scalability and accuracy.

Throughout this research, various model versions with different confidence levels were tested at two monitoring stations. The YOLOR_csp version achieved the best overall model performance in inference mode, achieving an accuracy of 83.81%. The outcomes of this research demonstrate significant improvements over traditional methods in traffic flow management and counting through AI-driven systems. (*Abstract*)

***Keywords*—Traffic monitoring; Deep learning; Artificial intelligence; Vehicle counting; YOLOR.**

I. INTRODUCTION

Nowadays, mobility in cities, independent of size, is a principal concern for the evolution of a nation or region. Mobility and city traffic management are crucial for maintaining adequate economic conditions and reducing severe injuries and fatalities [1]. México is a developing country whose towns and cities, according to their population, are classified as small, medium, and large. In almost all cases, the cities are proliferating. Therefore, it is natural to think that new roadways, widening the roads, and designing new roadway infrastructure capable of supporting and distributing the rising vehicular park are necessary.

One of the main approaches to consider in this analysis is urban traffic management because it strongly impacts the devel- oping level of urbanizing cities [2]. Urban traffic management involves significant challenges, particularly in rapidly urbanizing cities like Morelia, México. In a medium size city like Morelia, one of the primary challenges is the rapid growth of population and vehicle ownership, leading to increased congestion on road- ways. As cities expand, there often needs to be more infrastruc- ture to accommodate the growing number of vehicles, resulting in traffic bottlenecks, delays, and decreased overall efficiency of transportation systems. In Morelia, this challenge is magnified by the city's cultural richness and historical significance, which attract both residents and tourists, further intensifying the strain on transportation networks. Moreover, urbanization in cities like Morelia involves complex traffic dynamics influenced by diverse factors such as land use patterns, economic activities, and social behaviors. The lack of comprehensive urban planning strategies and adequate transportation infrastructure worsens these complexities, leading to efficient traffic flow and safety hazards [3].

Addressing these challenges requires innovative solutions integrating advanced technologies, data analytics, and holistic urban planning approaches to effectively manage traffic and ensure sustainable mobility in rapidly urbanizing cities like Morelia.

In México, traditional traffic management methods are employed to control the traffic system. Traditional traffic management systems often rely on static infrastructure and manual vehicle gauging, which present several limitations in addressing the dynamic nature of urban traffic and producing subjective and inaccurate methods. Moreover, traditional approaches typically lack real-time data and predictive capabilities, making anticipating and mitigating traffic congestion effectively challenging [4]. Today, there are various technological approaches to mitigate the lack of innovation in this field; one of the most novel is artificial intelligence (AI).

This research evaluates deep learning (DL) algorithm performance to check and test how to make the vehicle counting method more efficient in Morelia and expand this approach to different places in the country. The aim of leveraging DL for this task is to address the current challenges of urban traffic management by harnessing the power of advanced DL algorithms to analyze vast amounts of traffic data. In recent years, DL techniques have satisfactorily been used in different fields of civil engineering, from predicting behavior materials like concrete materials with significantly superior accuracy [5] to classifying and detecting damage over concrete and asphalt structures using complex convolutional neural networks [6]–[8].

The aim is to develop accurate and scalable solutions to automatically detect, classify, and count vehicles in real time from video footage captured at key monitoring stations across the city. This approach might enable transportation authorities to gain valuable insights into traffic patterns, identify congestion hotspots, and optimize the traffic flow in Morelia. This research combines the YOLOR (You Only Learn One Representation) algorithm with the DeepSort algorithm. The YOLOR algorithm was tested in two monitoring stations in inference mode to research and analyze the application of a computer vision system as a possible solution in building traffic monitoring systems.

The developed analysis includes a variety of confidence levels during the inference mode to ascertain the precision grade in terms of the vehicle-type classification. Also, during the analysis stage of the video footage, different pre-trained weights (a variety of the model's complexity) were employed, considering the most straightforward architecture to the more complex. Therefore, the research focuses on the evaluation of the model's performance during detecting, classifying, and counting vehicles in particular scenarios and conditions, as Morelia City offers.

II. Literature review

The literature review explores studies underscoring the necessity for advanced technological integration in traffic monitoring. Previous research highlight the challenges of increasing vehicular populations, which strain existing infrastructure and complicate traffic dynamics and management. Studies such as "A Real-Time Vehicle Counting, Speed Estimation, and Classification System Based on Virtual Detection Zone and YOLO" [9] have significantly contributed to the understanding and development of real-time vehicle detection and classification systems using convolutional neural networks like YOLO, demonstrating substantial improvements in traffic monitoring efficiency. Expanding on recent advances, the work "Towards Real-time Traffic Flow Estimation using YOLO and SORT from Surveillance Video Footage" [10] underscore the potential of leveraging surveillance video footage with computer vision techniques to estimate traffic flow accurately and efficiently. Their work effectively integrates the YOLOv4 and SORT algorithms to classify and track vehicles through various directions of movement.

Muhammad Azhad and Fadhlan Hafizhelmi demonstrate the integration of YOLO and DeepSORT for vehicle detection and tracking, noting improvements with the use of YOLOv4 for real-time applications in traffic management, achieving state-of-the-art results and substantiating the effectiveness of combining deep learning algorithms and video surveillance technologies to enhance vehicle counting and tracking capabilities [11]. Al-qaness et al. presented an enhanced YOLO-based vehicle detection system for road traffic monitoring [12], demonstrating improved detection and classification performance through training on diverse datasets and testing on real-world traffic video sequences, providing a foundation for intelligent traffic management solutions. The work "Detection and tracking different type of cars with YOLO model combination and deep sort algorithm based on computer vision of traffic controlling" [13] develops a traffic monitoring and control system using a combination of YOLOv4 and Deep Sort algorithms to effectively detect, track, and classify multiple vehicle types from CCTV footage, achieving a detection accuracy of 87.98% with mAP. Lin and Jhang developed an intelligent traffic-monitoring system that integrates YOLO and convolutional fuzzy neural networks for real-time vehicle classification and counting [14], demonstrating superior accuracy and performance on various datasets.

Azimjonov and Özmen enhanced YOLO-based real-time vehicle detection and tracking [15], significantly improving classification accuracy for highway traffic monitoring by integrating machine learning classifiers, ultimately boosting performance from 57% to 95.45%. Abbasi, Shahraki, and Taherkordi review the deployment of deep learning for Network Traffic Monitoring and Analysis (NTMA) [16], emphasizing its efficacy in managing complex network behaviors and significant data challenges, especially in cellular networks influenced by device mobility and heterogeneous network conditions. Zhu et al. introduce the MME-YOLO model, an innovative multi-sensor and multi-level enhanced convolutional network for robust vehicle detection in traffic surveillance [17], significantly improving detection performance under various conditions.

The integration of AI approaches in traffic monitoring has shown promising results in improving and addressing the challenges of cities with increasing vehicular populations. These studies also highlight the limitations of traditional traffic management methods and the need for more advanced solutions. In Mexico, where cities like Morelia are struggling with rapid urbanization and increasing traffic volumes, adopting modern technologies is becoming increasingly urgent to optimize traffic counting and design better road structures.

This research aims to optimize the registration of vehicle traffic and the estimation of the Annual Average Daily Traffic (AADT) through the application of DL techniques and data- driven approaches.

A. Management of traffic studies in México

Vehicle counting tasks in nations like México use traditional methods such as manual vehicle gauging and pressure sensors to measure vehicle quantities and estimate vehicular composition. These studies typically involve monitoring traffic flow at specific roadway points to ascertain daily traffic. However, traditional vehicle gauging encounters notable limitations, particularly in accuracy and reliability. For instance, permanent gauging en- tails measurements throughout the year, often conducted at toll booths, providing precise data but limited scope. Otherwise, weekly-based gauging offers broader coverage but relies on smaller sample sizes, leading to significant estimation errors. This discrepancy introduces challenges in accurately estimating average annual traffic, resulting in biased estimations that may deviate significantly from actual values.

The reliance on small sample sizes and limited temporal coverage in traditional traffic studies exacerbates the challenges of accurately estimating traffic volumes and compositions in Mexico. Furthermore, the inherent variability in traffic pat- terns across different seasons and regions compounds the issue of biased estimations. Corrective factors are often applied to mitigate these shortcomings and adjust estimations based on temporal variations observed at nearby master stations. While these corrections aim to improve accuracy, their effectiveness hinges on the similarity between traffic variations at master stations and the monitored locations. Thus, traditional methods encounter inherent limitations in providing precise and reliable data for traffic management and planning purposes, necessitating innovative approaches to overcome these challenges and enhance the efficiency of traffic studies in Mexico.

This research sets out to fill crucial gaps in the existing methodologies related to traffic management in Morelia México city. It does so by harnessing cutting-edge deep learning techniques, marking a significant departure from traditional approaches. The aim is to enhance the accuracy and reliability of traffic data collection and analysis. Additionally, this work proposes the development of a real-time traffic counting and analysis system, powered by the YOLOR algorithm. By implementing this approach in real scenarios, transportation authorities could swiftly identify congestion hotspots, optimize signal timings, and implement proactive measures to alleviate traffic congestion and improve overall road safety. As urbanization accelerates and traffic volumes continue to rise, the demand for scalable traffic management solutions that can adapt to diverse urban environments is on the rise.

III. METHODOLOGY

A. Data collection

For the data collection process, the authors identified two points of interest in Morelia city: the street “Calzada La Huerta”, near the Patzcuaro exit, which was called Monitoring Station 1 (MS1) and “Avenida Camelinas’, which was named Monitoring Station 2 (MS2). These two points were selected as monitoring points due to engineering factors; for instance, the significant amount of traffic these roadways store during certain hours of the day. These relevant avenues are starting points for going to different points in the city. Also, many vehicles circulate on these avenues, making them perfect for initializing a detailed study about traffic management and counting. The coordinates of the MS1 and MS2 are shown in Table I., and two screen-shots for each monitoring station are depicted in Fig. 1 and Fig. 2. Both figures were taken from the Google Maps application and show the area of interest for this study within the city.

TABLE I. COORDINATES OF THE MONITORING STATIONS

Monitoring Stations	Coordinates	
	Latitude	***Longitude***
MS1	19°40’52.8” N	101°13’02.3” W
MS2	19°40’54.9” N	101°11’42.0” W

Figure 1. MS1 pinned in color blue in “Calzada la Huerta Avenue”, Morelia City, México.

The data collection process consisted of taking videos at the selected monitoring station points. Videos were recorded at the same time of the day, 11:00 am. The recorded time was one hour for each monitoring station, i.e., beginning at 11:00 am to 12:00 pm. All the video data were recorded with a PIXEL cellphone camera with the following specifications: 12.2 MP

Figure 2. MS2 pinned in color blue in “Avenida Camelinas”, Morelia City, México.

1/2.55” sensor, 1.4 μm pixels, 77° field of view, f/1.7 aperture lens, Dual PDAF, OIS. The recorded videos were taken using a resolution of 1080p at 30 FPS (Frames per second).

The times of the day were selected because at 11:00 am, the flow of the vehicle traffic is constant, and for obtaining a complete analysis, it is necessary to consider data all the possible scenarios. During the video recording process, several traffic characteristics were observed. For instance, the average vehicle speed was around 20 km/hr. because each monitoring station was located after a traffic light. The camera positioning in MS1 was at street level to test the model’s capability of detecting and counting vehicles with a lateral perspective. On the other hand, the camera positioning in MS2 was 6 meters up of the road, specifically over a pedestrian bridge, getting an elevated and frontal view of vehicular traffic. For both cases (MS1 and MS2), a commercial tripod was used to ensure the stability of the videos collected.

The traffic density was high with clear changing zones and the typical vehicle compositions included passenger cars, trucks, motorcycles, buses, trailers, and bicycles. Also, there were no traffic pattern variations during the data collection process.

B. YOLOR algorithm

The YOLOR algorithm was chosen for its unique ability to provide a unified representation that integrates both explicit and implicit knowledge, which is essential for tackling the complexities of traffic analysis in Morelia. By incorporating both types of knowledge, YOLOR can effectively capture the intricate dynamics of traffic patterns, such as the interactions between vehicles, pedestrians, and environmental factors. This unified representation allows for more accurate and robust pre- dictions, enabling better decision-making for traffic management strategies.

One of the critical advantages of YOLOR is its flexibility and scalability across multiple tasks. Through its formulation that combines explicit and implicit errors, YOLOR can adapt to various traffic-related tasks, including vehicle detection, classification, and traffic flow analysis [18]. This versatility is crucial for addressing the diverse challenges faced in Morelia’s traffic conditions, where different traffic management aspects require simultaneous attention.

For a conventional network, the objective function is formulated as:

$$y = f_\vartheta(x) + \epsilon, \tag{1}$$

where x is the observation, ϑ represents the set of parameters of a neural network, f_ϑ denotes the operation of the neural network, ϵ is the error term, and y is the target of a given task. The goal is to minimize ϵ to make $f_\vartheta(x)$ as close to the target as possible. The YOLOR proposes an enhanced formulation integrating both explicit and implicit knowledge as is denoted in (2).

$$y = f_\vartheta(x) + \epsilon + g_\phi(\epsilon_{ex}(x), \epsilon_{im}(z)) \tag{2}$$

where ϵ_{ex} and ϵ_{im} model the explicit and implicit errors from observation x and latent code z, respectively. g_ϕ is a task- specific operation that combines information from both explicit and implicit knowledge.

C. DeepSort algorithm

DeepSort, an extension of the original SORT (Simple Online and Realtime Tracking) algorithm, significantly improves tracking accuracy by incorporating deep learning features. DeepSort combines motion and appearance information to track objects across frames in a video sequence.

DeepSort operates by following detection, feature extraction, prediction, association, update and track management.

This algorithm enhances tracking performance by effectively integrating appearance features extracted via a deep neural network with motion predictions made by the Kalman filter, while the Hungarian algorithm optimizes the tracking associations across frames.

The adapting capacity of the YOLOR and DeepSort algorithms for Morelia’s traffic conditions were tested during this research, considering the unique characteristics and challenges of the city. For instance, the types of vehicles commonly found on its roads, typical traffic patterns, and specific congestion points.

D. Vehicle classification

Generally, each country manages its vehicular classification type. México classifies the type of vehicles regarding the equivalent single axle load. This consideration produces a complete and detailed vehicular classification. For this research, we just used five vehicular classifications: cars, trucks, buses, motorcycles, and bicycles, to start with a general classification. Also, these four classes are present in the COCO dataset. This dataset stored 80 classes for different objects, and within these objects, the vehicular classification corresponds to the proposed by the authors.

It is important to remember that this research assesses the capabilities of the YOLOR algorithm in inference mode. Therefore, transfer learning and fine-tuning methods were used implicitly in this research to run the model with pre-trained weights. YOLOR was trained by considering various datasets to evaluate its performance. The COCO dataset is no exception, and due to the training process, five pre-trained weights are available for customized analysis. The pre-trained weights are related to the version of the model employed. This study explored three pre-trained models, considering their sizes and complexity. The pre-trained models are *YOLOR P6*, *YOLOR CSP*, and *YOLOR CSP X*, which are the small, large, and extra-large versions of the model, respectively.

E. Computational details

All the experiments and tests were performed in a personal workstation with the following features:

A processor of 13th Gen Intel(R) Core (TM) i7-13620H 2.40 GHz, 48 GB of Random Access Memory, a NVIDIA GeForce RTX 4060 Laptop GPU, CUDA cores: 3072, Max-Q Technology, 8,188 MB GDDR6. A GPU-acellerated Python environment was created following the next: CUDNN 8.2.1, CUDAToolkit 11.3.1, Keras 2.4.3, Keras-GPU 2.4.3, Tensorflow-GPU 2.5.0, Tensorflow 2.5.0, and Python 3.7.16.

IV. RESULTS AND DISCUSSIONS

A. Vehicle counting and classification

This section handles the results produced by the YOLOR and DeepSort algorithms for the monitoring stations MS1 and MS2, where each station was analyzed with different confidence levels and different model versions. Each video footage lasts one hour, i.e., each analysis involves the same time. The approach for developing this task is described in Table II. and Table III.. Moreover, a pair of computational details are added to these tables in order to get a more comprehensive scenario of the model's performance.

TABLE II. ANALYSIS DETAILS OF THE MS1

Model versions	*Confidence*	*FPS Average*	*Computing time*
YOLOR CSP X	0.35	10.65850	10,746.900 s
YOLOR CSP X	0.55	10.97416	9,972.058 s
YOLOR CSP X	0.75	11.89185	9,071.210 s
YOLOR CSP	0.35	16.23829	10,449.018 s
YOLOR CSP	0.55	15.83025	7,325.711 s
YOLOR CSP	0.75	16.72830	6,417.746 s
YOLOR P6	0.35	14.93275	10,236.872 s
YOLOR P6	0.55	15.35486	9,232.314 s
YOLOR P6	0.75	15.74308	7,237.114 s

From Tables II. and III., it is possible to appreciate for all the model versions that as the confidence level increases, the computing time reduces. This phenomenon occurs because while the confidence level is high, the algorithm does not need to disseminate in significant proportions about what class of object is detecting. Contrarily, the FPS average results improve

TABLE III. ANALYSIS DETAILS OF THE MS2

Model versions	*Confidence*	*FPS Average*	*Computing time*
YOLOR CSP X	0.35	11.08947	10,239.895 s
YOLOR CSP X	0.55	11.22915	10,602.192 s
YOLOR CSP X	0.75	12.20530	8,821.168 s
YOLOR CSP	0.35	14.49380	7,714.414 s
YOLOR CSP	0.55	15.687030	6,878.323 s
YOLOR CSP	0.75	16.99784	5,788.091 s
YOLOR P6	0.35	15.25878	7,720.355 s
YOLOR P6	0.55	14.28251	7,228.845 s
YOLOR P6	0.75	17.41921	5,285.749 s

as the confidence level increases. This behavior is strongly related to the computing time results; while the model takes into consideration lower operations, the velocity of processing each frame is superior. Therefore, the FPS increases when the confidence level follows the same trend.

One notable distinction among the YOLOR versions is their size and their effect on performance. The *YOLOR P6* is the lightest version of the architectures of the YOLOR algorithm, while the *YOLOR CSP X* is the biggest, and the *YOLOR CSP* is the middle version. For that reason, the FPS average results are higher in the lightest version of the model as the computing time.

Tables IV. and V. show each model version's number of vehicles computing to different confidence levels. Each class is abbreviated as follows: Cars (**C**), Trucks (**T**), Buses (**B**), Motorcycles (**M**), and Bicycles (**Bi**). These Tables depict the variety when a specific model version is employed. Even though the variety is wide, all the obtained results are within the 2% tolerance range by the standard deviation. Due to the varying scales in each class, the values were re-scaled in a range between 0 and 1. The standard deviation (STD) of each class by each inference was computed, resulting in:

- STD **C** = 0.36925
- STD **T** = 0.36299
- STD **B** = 0.29011
- STD **M** = 0.32064
- STD **By** = 0.31207

TABLE IV. NUMBER OF VEHICLES FOR EACH CLASS AT THE MS1

Model versions	Conf	C	T	B	M	By	Total
YOLOR p6	0.35	1396	241	19	87	4	1747
YOLOR p6	0.55	1319	122	35	94	3	1573
YOLOR p6	0.75	1152	127	53	94	6	1432
YOLOR csp	0.35	1369	284	38	84	7	1782
YOLOR csp	0.55	1306	136	33	95	5	1575
YOLOR csp	0.75	1092	127	59	95	4	1377
YOLOR csp x	0.35	1375	262	38	85	9	1769
YOLOR csp x	0.55	1352	101	36	100	8	1597
YOLOR csp x	0.75	1125	134	52	95	6	1412

TABLE V. Number of vehicles for each class at the MS1

Model versions	Conf	C	T	B	M	By	Total
YOLOR p6	0.35	1960	106	4	119	12	2201
YOLOR p6	0.55	1971	34	1	95	1	2102
YOLOR p6	0.75	1870	14	4	2	0	1890
YOLOR csp	0.35	1947	147	8	127	1	2230
YOLOR csp	0.55	1942	58	3	113	0	2116
YOLOR csp	0.75	1810	23	5	8	0	1846
YOLOR csp x	0.35	1952	178	6	134	6	2276
YOLOR csp x	0.55	1952	109	3	109	0	2173
YOLOR csp x	0.75	1815	19	2	6	0	1842

The Fig. 3 clearly depicts the proportion and distribution of each class regarding the number of vehicles.

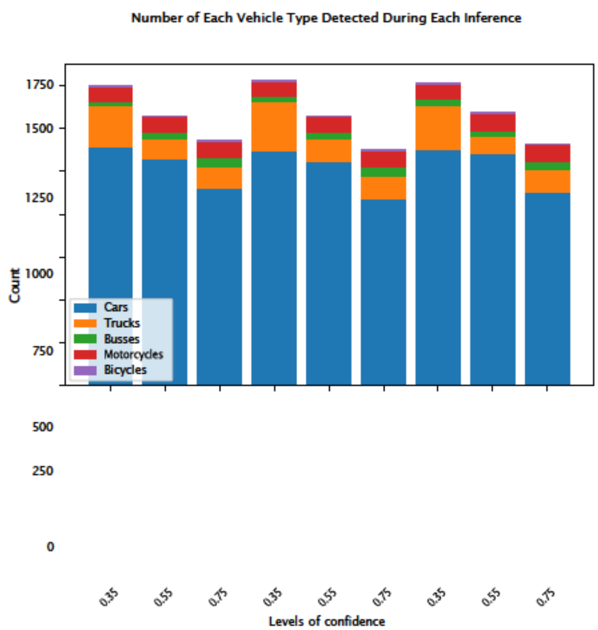

Figure 3. Number of vehicles at the MS1.

For this work, the type of vehicle 'Car' is the predominant class in the vehicular distribution. However, it is crucial to consider the 'Trucks' class because it considerably affects the roadway surface in greater proportions than the common Cars.

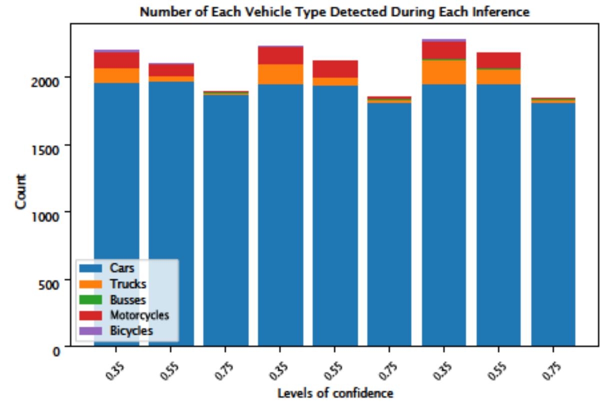

Figure 4. Number of vehicles at the MS2.

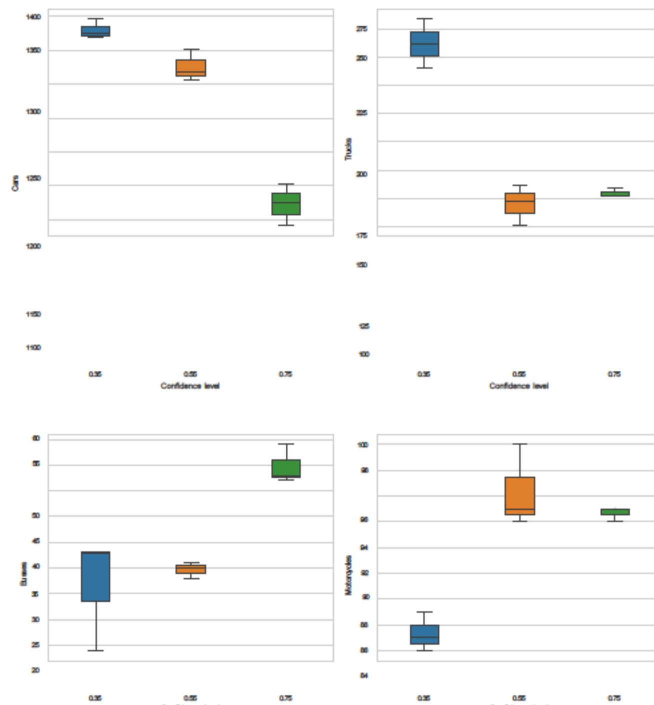

Figure 5. Number of vehicles counted at the MS1.

For Fig. 4, we can observe the same data distribution, with the 'Car' class acting as the predominant class and the 'Truck' class as the second one. The distribution of the number of vehicles is shown in a boxplot, which organizes its variety through the confidence level for the classes **C**, **T**, **B**, and **M**. This boxplot is shown in Fig. 5 and Fig. 6, where each inference considers the models' versions.

A pair of frames of the model's performance is shown in Fig.7 and Fig.8 corresponding to the monitoring stations, and two demos can be found in the https://www.youtube.com/watch?v=_uZjKpMID7Y and https://www.youtube.com/watch?v=VCo_rCulYsI

B. *Efficiency analysis*

Tables VI. and VII. show the ground truth for each monitoring station, detailing the actual number of each vehicle class registered in the video footage.

The number of vehicles was compared with the ground truth for each confidence level and each model's version. For this research, the average accuracy results were computed, considering the counted vehicles in each inference mode (confidence level and the model's version) as data. These results are enlisted in the Table VIII. and in the Table VII.

Tables VIII. and IX. show the overall performance of each model's version, considering all the classes (**C**, **T**, **B**, **M**, and

TABLE VI. Coordinates of the Monitoring stations

MS1 Calzada la Huerta					
	C	**T**	**B**	**M**	**By**
Number of vehicles	1217	260	29	117	7

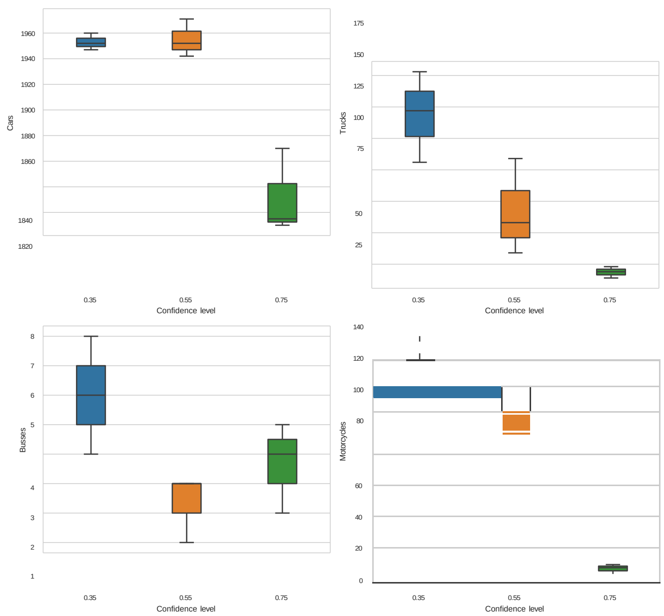

Figure 6. Number of vehicles counted at the MS2.

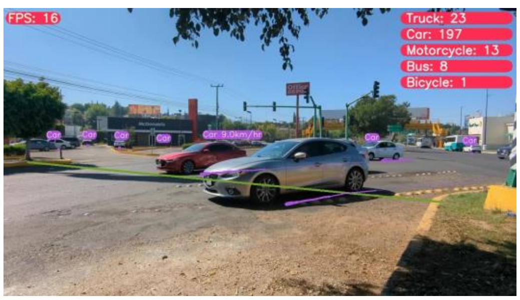

Figure 7. Number of vehicles counted at the MS1.

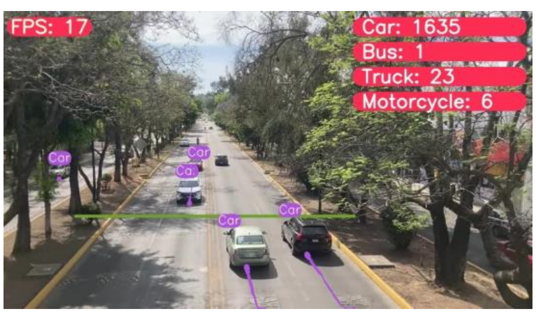

Figure 8. Number of vehicles counted at the MS1.

By). Generally, the model performs correctly in the classes **C**, **T**, and **M**. The model's performance in the classes **B** and **By** can be improved, being these classes are the reason why the model reduces its overall performance.

At the MS1, the better model's version was the *YOLOR_csp* set to a confidence level of 0.35. Similarly, in the case of MS2,

TABLE VII. COORDINATES OF THE MONITORING STATIONS

MS1 Av. Camelinas					
	C	**T**	**B**	**M**	**By**
Number of vehicles	1846	165	1	129	0

TABLE VIII. AVERAGE ACCURACY COMPUTED BY EACH MODEL'S VERSION AT THE MS1

Model versions	**Confidence**	**Average accuracy**
YOLOR p6	***0.35***	***75.00***
YOLOR p6	0.55	68.21
YOLOR p6	0.75	65.36
YOLOR csp	***0.35***	***83.81***
YOLOR csp	0.55	76.77
YOLOR csp	0.75	54.69
YOLOR csp x	***0.35***	***79.86***
YOLOR csp x	0.55	74.96
YOLOR csp x	0.75	66.32

TABLE IX. AVERAGE ACCURACY COMPUTED BY EACH MODEL'S VERSION

better results were obtained by the same model's version with

AT THE MS2

Model	Confidence	Average accuracy
YOLOR p6	0.35	56.72
YOLOR p6	***0.55***	***77.49***
YOLOR p6	0.75	46.74
YOLOR csp	***0.35***	***78.91***
YOLOR csp	0.55	70.17
YOLOR csp	0.75	47.63
YOLOR csp x	0.35	66.31
YOLOR csp x	***0.55***	***75.62***
YOLOR csp x	0.75	52.89

the same confidence level. Therefore, this model's version was configured with a confidence level of 0.35, which is the best in all the tests.

It is true that, in general, the YOLOR algorithm works well in the tested domains by this research; however, it can be noticed that the classes **B**, **M**, and **By** are better detected and classified in a lateral perspective. At the same time, the frontal and superior views do not perform adequately in these classes of vehicles.

Comparing the effort of counting the vehicles via the visual method and the AI approach, there are clear advantages, such as efficiency, velocity, and real-time adaptability for counting the vehicles. Therefore, there is a winner between the artificial intelligence and the traditional methods used by the city administration (visual and pneumatic); however, there is too much to improve the computational methods for making these differences more remarkable.

V. Conclusions and future work

Overall, the YOLOR algorithm's adaptability and robustness make it ideal for addressing Morelia's complex traffic management needs, ultimately leading to safer and more efficient transportation systems.

Implementing and evaluating the YOLOR and DeepSort al- gorithms within Morelia's traffic management framework marks a significant jump in leveraging artificial intelligence for urban traffic analysis. These technologies have proven to be highly effective in vehicle detection and classification, surpassing tra- ditional methods in terms of speed, accuracy, and scalability. This research not only demonstrates the potential of deep learn- ing models to enhance real-time traffic monitoring and urban planning strategies but also holds promise for your work in optimizing traffic flow, reducing congestion, and enhancing road safety. The integration of such AI-driven systems could lead to more informed decision-making, ultimately benefiting your role in urban traffic management and infrastructure development.

In future work, we will work with algorithm optimization, especially in improving the detection and classification accuracy of buses and bicycles. Research will continue to optimize these models to handle the diverse and complex traffic scenarios presented by urban environments like Morelia more effectively. Future studies could expand data collection to different times of day and additional urban settings within Morelia and other cities, helping refine the models to be adaptable to various traffic conditions and urban environments.

Acknowledgment

Authors thank to AULA-CIMNE MORELIA, CONAHCYT and CIC-UMSNH.

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Navigating Mexico's Interoceanic Corridor

Exploring Challenges and Opportunities via Simulation Modeling

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Abstract— ***The Interoceanic corridor of Mexico stands as a pivotal infrastructure project poised to significantly enhance Mexico's national and regional economy. Anticipated to start the operations in 2025 under the auspice of the national government, this corridor represents a strategic counterpart to the Panama Canal, which faces capacity constraints due to climate change and environmental impacts. Positioned as a promising alternative for transporting goods from Asia to North America, this corridor will offer a new transport route, yet its real operational capacity and spatial impacts remains uncertain. In this paper, the authors undertake a preliminary, informed analysis leveraging publicly available data and other specific information about infrastructure capacities and economic environment to forecast the potential throughput of this corridor upon full operationalization and in the future. Applying simulation techniques, the authors simulate the future operations of the corridor according to different scenarios to offer insights into its potential capacity and impacts. Furthermore, the paper delves into the opportunities and challenges that are inherent in this project and gives a comprehensive analysis of its potential impact and implications.***

[1] ***Keywords; Interoceanic corridor; port operations, regional economy; martitime sector; simulation; economic impacts; infrastructure project.***

INTRODUCTION

Recently, the federal government of Mexico has issued one of the most ambitious large infrastructural projects of the National Development Plan: “the development of the Interoceanic Corridor of Tehuantepec” (hereafter CIIT or ISTHMUS project) that connect the tow seaports of Salina Cruz (Oaxaca) and Coatzacoalcos (Veracruz), through an interoceanic Railroad transport network. Along the railroad networks of the Interoceanic corridor that connect the two regions of Veracruz and Oaxaca, the government has projected the construction of 10 industrial poles or industrial zones.

This big infrastructural project is considered by public authorities as a major port-rail multimodal transport project of North America’s trade corridor. The total investments in the CIIT infrastructure project are valued at around USD 12.9 billion, from which USD 5 billion expected to come from public funding and the rest from the private sector (Economic Outlook and Investment Environment, 2023). According to federal authorities, the realisation of the Interoceanic Corridor will generate 1.6% of the national GDP, will attract a total of 50 billion dollars of (private) investments, and is expected to generate about 550.000 jobs by 2050, mainly due to the development of various industrial zones along the interoceanic port-railroad corridor.

The main objectives of the CIIT corridor, as set by the federal government, is to; (1). Decrease the disparities between the states and regions in terms of economic development and growth i.e., increase employment opportunities and income for the population; (2). Promote a more balanced regional development integrating economic (reinforcement of the economic potential and increasing investments opportunities), social (social solidarity), and cultural aspects (i.e., respecting and preserving cultural identity of indigenous communities); (3). Preserving and improving natural capital i.e. natural resources, environment biodiversity and ecosystems, and (4). Increasing trust and credibility in federal authorities.

The railroad networks of the Interoceanic corridor will be used for both passenger and freight trains, through a 380 km railroad line, with a total of 10 stations (Ixtepec, Chivela, Matías Romero, Mogoñé, Donají, Jesús Carranza, Medias Aguas, and Jáltipan de Morelos). Compared to the 80-km Panama Canal that moves about 63.2 million tons (year 2022), it is expected that the CIIT corridor will have a total capacity of 300.000 cargo containers per year by 2028, and 1.4 million containers per year by 2033 (about 33 million tons).

Current improvements and extensions work on the Coatzacoalcos port include, among other things, dredging works to expand the port's depth to 12 metres, the construction and maintenance dredging of port access channels, the expansion of a pier (completed in March 2021) to enable the mooring of two vessels of up to 180 meters in length, as well as the widening of an access road to the port area from two to four lanesand, and the construction of a brand-new 940,000-square-metre container terminal valued at USD 248 million (Duhalt, 2021). Figure 1 below gives an overview of the development and extensions work at the port of Coatzacoalcos.

Figure 1. Development and extension work in the Port of Coatzacoalcos. ***Note:*** *<u>Completed work</u>: 1 (new dock), 2 (road access) and 3 (construction dredging). In progress: 6 (rail access), 7 (urbanisation service) and 8 (Ethane terminal). Not started: 9 (LNG terminal) and 10 (Specialized container terminal).*

Similarly, the port of Salina Cruz has also received large public investments to boost its operating capacity. The most important development and extension work are taking place at the multipurpose terminal, such as the expansion of the dredging and the docks in the port container terminal. Figure 2 below gives an overview of the completed and in progress of all extensions and development work in the port.

Figure 2. Development and extension work in the Port of Salina Cruz. ***Note:*** *<u>Completed work</u>: 1 (multiple use pier construction). <u>In progress</u>: 2 (reinforcement of pier and container terminal), 3 (enlarge the access and sheet piling of pier) and 4 (break water construction). <u>Not started</u>: 5, 9 (rail and road access to container terminal), 6 (dredging of navigation area), 7 (traffic control center and rearrangement of land access), 8 (specialized container terminal).*

Concerning the development of the railroad linking the two ports of Salina Cruz and Coatzacoalcos, it is worthy to mention that the total journey of cargo transport from port to port is expected to be less than six hours. In addition to this railroad line, additional railroads links have been planned and will be developed in the futures (such as FA Line connecting Coatzacoalcos and Palenque to Chiapas on the border with Guatemala (329 km) and the Line K connecting Ixtepec Ciudad Hidalgo with Central America (459 km)). The container cargo trains that will operate along the interoceanic corridor are expected to move 5,200 tonnes of cargo in 65 railcars (135 cars in double-deck train), in a total transit time of 6.5 hours, excluding loading time.

What is interesting in the studies focusing on the development of the CIIT corridor is the lack of quantifying the expected capacity, efficiency, in terms of costs and benefits, for providing economic evidence that justifies the benefits of implementing such big infrastructure project. To fully understand the true impacts of the provision and use of the interoceanic corridor's projected infrastructure for the (private) users, operators, businesses, regions, etc., a more elaborated technical analysis of the potential future economic and societal impacts, in terms of costs and benefits, is required (Cambridge Systematics, 2008).

This paper undertakes a preliminary analysis, using publicly available data and other specific information from official documents, about the potential (economic) effects of the Interoceanic Corridor of Tehuantepec project in terms of infrastructure capacities (i.e. potential throughput) and economic environment upon full operationalization in the future. The study applies simulation techniques to analyse and forecast the future operations of the corridor under different scenarios to offer clear insights of its potential capacity and economic and environmental impacts. Furthermore, the paper discusses the opportunities and challenges that are inherent in the execution of this big infrastructural project and gives a comprehensive analysis of its potential impacts and implications at regional and national level.

OPPORTUNITIES AND CHALLENGES OF THE INTEROCEANIC CORRIDOR OF TEHUANTEPEC PROJECT: OVERVIEW FROM THE LITERATURE

One of the key features in Latin America is the development of major markets around port cities, as result of relatively high geographical concentration of key industries and economic activities in coastal areas. Consequently, transport and logistics activities are dominated by road transport, compared to other transport modalities like rail connections for example. However, the last decennia's, many ports have upgraded their rail connections to hinterlands as strategic element of port competitiveness and port logistics. In this context, the Isthmus of Tehuantepec corridor project is viewed by the federal government as strategic in boosting economic growth and industrial development in the port regions of Coatzacoalcos and Salina Cruz.

The short distance (only 285 km) between the two Mexican ports of the Isthmus corridor, can be seen as important factor in improving operational efficiency of the port-rail connection, lower transit times and costs per kilometre, and stimulate the development of industries and logistic activities in strategic location sites or nodes along the corridors (Peyrelongue, 2012).

In terms of costs, expressed in rates per 40 TEU container, the advantage of CIIT corridor (maritime freight in dollars/kilometre) can reduce the gap between the North America and the CIIT ports, especially when the corridor will be able to increase the container volume that allow the realisation of greater economies of scale.

The competitive advantage of the multimodal trans-isthmic corridor for container cargo will depends on how well the ports are connected to the rail network system (i.e., in terms of reducing transit time at seaports by enhancing rail services), and to the locations of production and/or consumer markets (Leal, 2012).

The CIIT corridor can develop into a very sophisticated multimodal transport and logistic platform in international production and distribution network of goods and logistic value-added services. In this respect, Reynoso and Torres (2022) have examined the question whether the Interoceanic Corridor of the Isthmus of Tehuantepec will stimulate economic development of the cities and regions, and lead to improvement of well-beign of the population. The authors stress the fact that the main element of the Interoceanic corridor project that will promote economic activities is the development of industrial zones along the corridor because of the expected attraction of private investments and the integration of industrial clusters with logistics platforms.

Beside the application of a costs-benefits analysis quantifying the potential economic and societal impacts of the development of the Interoceanic Tehuantepec Corridor, application of simulation models is considered as valuable instruments providing insights on various aspects of the potential impacts of the development and improvement of different critical components of the interoceanic corridor project. One of the main benefits of using simulation models is to help stakeholders to improve decision making about infrastructure investments and operational strategies by providing them with analytically grounded solutions based on "wat-if" scenarios. In addition, simulation models are powerful tools for enhancing performance optimization of operations and system efficiency, by identifying inefficiencies of the system and providing different improvement solutions. Finally, simulation models are very appropriate to identify potential bottlenecks and risks that can help to improve risk management of investment projects and developing mitigation strategies for potential risks.

First, concerning the existing studies that focus on the application of simulation models in planning decisions and optimization of port operations and container terminal processes, we cite Budipriyanto et al., 2017; Wahed et al., 2017; Fajar et al., 2018; Tri Cahyono et al., 2019, Bin and Xin-qing, 2010; Garro et al., 2015; Muravev et al., 2021. For example, Legato and Mazza, 2001, present a simulation model to conduct a what-if analysis on the berth planning problem, while Wibowo et al., 2015 and Henesey et al., 2003 studies are focused on the application of simulation analysis in port expansion plans and port stakeholder management respectively.

Examples of the application of agent-based simulation models in analyzing port related operations and processes can be found Vidal and Huynh (2010) and Lee et al. (2003). The first authors applied an agent-based model (ABM) for simulating container crane operations in a seaport container terminal, while second authors used ABM based model to simulate a supply chain as a complex system to get grip on the multi-objective, interdependent business processes. Other applications of ABM models in analyzing port operations and processes can be found in Demare et al. (2017) and Gerrits et al. (2017) and Mazloumi et al. (2021). These last authors have developed an agent-based simulation model of a container terminal at the Port of Antwerp (Belgium) to evaluate the terminal overall equipment effectiveness and investigate factors that affect container handling processes. The results from the simulation model show that having information on further transportation mode significantly increase the container outflow and the container terminal's overall equipment effectiveness.

In the same vein, Guo et al. (2015) developed a simulation model of throughput[1] capacity of port container terminal to analyse the expansion of the port under required service level. Their analysis focus on the distribution of arrival interval of vessels in relation to the effective berth utilization rate, crane handling efficiency, and operation time per day. The results obtained from the simulation show that the distribution of arrival interval of vessels is determined by efficient use of existing equipment and the effectivity of handling port operations, such as berth utilisation rate, speed and rate of using cranes, and the time of handling inbound and outbound containers in terminals. All these mentioned factors are crucial for enhancing the capacity and efficiency of port operations.

Close to the study of Guo et al. (2015), Ding (2010) has built a simulation model to study the throughput capacity under different combinations of arriving vessels. The authors analyze the impact of various vessel arrival combinations on berth utilization and throughput capacity. The simulation results indicate that optimizing the combinations of arriving vessels can significantly improve berth utilization and increase throughput capacity of the port.

Longo, Huerta, and Nicoletti (2013) applied a simulation model to analyze the performance evolution of ship turnaround time. The obtained results of their analysis show significant improvement of ship turnaround time by optimizing various operational parameters, which has resulted into enhancement of the port's overall performance. These results confirm the results obtained from the application of a simulation model, using object-based computer animation simulation language, for the case of port of Tianjin (China) by Peng (2004). The results of this simulation model show that the yard capacity constraints can significantly limit throughput capacity, suggesting that improvements in yard management and capacity are necessary for enhancing overall terminal efficiency.

Similarly, Li, Yu, and Yang (2010) built a container terminal simulation model to analyse the influences of annual operating days, handling amount of a single vessel, service levels and other factors on throughput capacity at the container terminal. This simulation model provided insights

[1] Throughput capacity of a container terminal is defined by the authors as the number of TEUs that a terminal can handle in one year under a specific service level in terms of AWT/AST. AWT/AST denotes the ratio of the average waiting time of a vessel to the average service time of a vessel at berth. Design Code of Container Terminal for Sea Port (Guo et al., 2015., p. 3).

into how various operational factors influence terminal performance.

Using the case of the port of Jingtang (China), Tian et al. (2016) applied a simulation model to study how to operate and improve the fairway through capacity of the port with the increasing number of arrival ships. The simulation scenarios include the arrival process, service process and departure process of ships in the port area. The authors show that the fairway through capacity increase by 13.7% by changing navigation rules (from one-way to two-way) for the ships with a tonnage of not more than 50,000 tons. The obtained results provide a theoretical foundation for fairway construction and management of Jingtang port area.

Finally, Rusca et al. (2018) studied the relationship between the port container terminal and port transport and logistics e.g., connections between the land and sea transport networks. The simulation model focus on the transit capacity of throughput at port container terminal (i.e., load and unload containers quays, landside transport networks (rail, trucks), stacks, storage area, etc.), with a special attention to berths and quay cranes in the terminal. The simulation results reflect the close positive relationship between the distributions for arrival flows of the containers, the size of the container's input flow in the terminal, the time of handling process inside the terminal, and the size of the truck's arrival time in the port. The simulation shows that optimizing these components can significantly enhance transit capacity and improve the integration of land and sea transport networks.

Second, concerning research that apply simulation models in studying various aspects of rail container cargo transport related to port logistics operations, most of these studies focus on the enhancement of efficiency and performance of rail network system (i.e., throughput and Level of Services) and resource or asset allocation (velocity, infrastructure occupation time, or percentage).

Simulation methods are usually used in combination with other tools and objectives such as optimizing capacity through timetable or rescheduling. Borndörfer et al. (2018) or Boysen et al. (2012) give an extended overview of the main relevant research questions tackled by most of studies on rail network optimisation and rail-yard operations.

Abril et al. (2008) developed a decision support system tool that can analyze rail network capacity by considering train speed, stations, heterogeneity, distances between signals and robustness of timetable. The model can find the saturated timetable for achieving maximum capacity utilization and does several other analytical and practical evaluations.

Dingler at al. (2010), for example, studied the integration of port-rail container cargo transport in North America. Authors applied a discrete event simulation (DES) model that allow the optimization of the scheduling and routing of trains and improving network capacity and efficiency. The model simulated train movements across a large rail network, accounting for various factors such as track occupancy, train priorities, and maintenance schedules. The results of this study show that implementing more flexible scheduling and dynamic routing based on real-time conditions could increase network capacity by 15% and reduce delays by 20%.

Jeeva et al (2022) examine several issues related to the freight railway network affecting seaport competitiveness in Malaysia, especially the relationship between container transit time and rail freight performance. The study shows that container unloading and storing at the yard is one of the main activities that significantly prolongs transit time at the terminal (an average of 4 to 6 days). Furthermore, the study reveals that unavailability of rail connectivity in specific regions delays the container rotation from the destination back to the origin.

Other research on rail network capacity optimization focused on train scheduling problem which determines the route, stop plan and departure/arrival times of each train (Zhang et al., 2022; Wang et al., 2021; Frisch et al., 2021), or transshipment where containers in the yards are moved between port/trucks and trains (Schulz et al., 2021; Rupp et al., 2021).

METHODOLOGY

The methodology employed in this study is based on the framework devised by Mujica et al. (2018). This approach integrates various knowledge layers to construct the final model. For the study of CIIT, we combined a GIS layer containing information about the distances and locations of infrastructure, such as ports and train stations. Building upon this, we developed a network model that incorporates the logic and sequence of processes.

We used several inputs for the model, including the number of trains and a fixed demand. The model primarily focuses on the capacity of the train network, as we consider it a critical hurdle to achieving the government's projected goals. Assumptions were made based on public information regarding train speeds, capacities, and loading and unloading times, among other factors. Figure 3 illustrates the general methodology developed for this study.

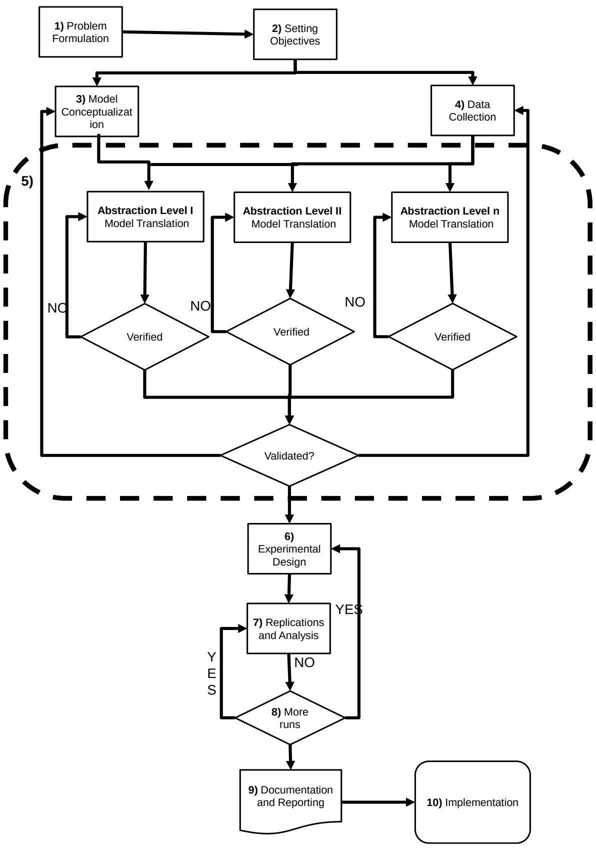

Figure 3. Multimodel Simulation Methodology

As with any simulation project, data is crucial for conducting subsequent activities. For this step, we used public information on the types of trains expected to be used, along with their anticipated speeds and capacities based on current global standards. The following table presents the main assumptions considered for the model.

Table 1. Assumptions for Model CIIT

Item	Value
Speed Train in Cruise mode	80 km/hr single stack
Speed train in cruise mode	60 km/hr double stack
1 entity	10 40'Containers = 20 TEUs
Train Capacity	60 wagons for 40'containers
Train Capacity	120 or 240 TEUs
Speed in City	10km/hr
Loading time	T(20,30,40) min/10 containers
Unloading Time	T(10,20,30) min/10 containers

The model was verified, but its validity cannot yet be fully confirmed since the project pertains to future operations. However, the assumptions made were sufficiently informed to meet the study's objectives. While the train stations already exist for passenger operations, the cargo project is still in its early phases.

The objective of the model is to conduct a preliminary analysis of the operational capacity of the CIIT. We assumed the availability of several trains, each with a capacity of 60 wagons, where each wagon can hold either one 40-foot container or two TEUs. The sequence of operations is depicted in the following diagram.

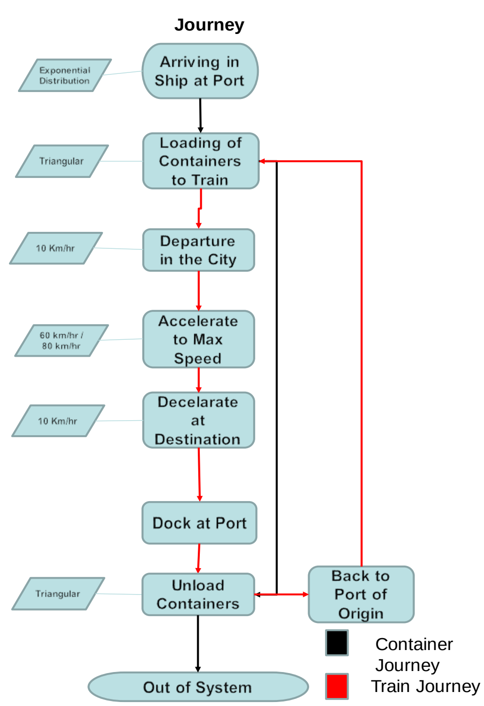

Figure 4. Conceptual Modeling

The trains load containers either from the ship or directly from the yard, taking the loading time into account. Once fully loaded, the trains depart at 10 km/hr. through the city. After leaving the city, they reach their cruising speed, which depends on the type of train (single or double decker). Upon arrival at the destination, the speed is again reduced to 10 km/hr, and the trains are unloaded in the port, considering the unloading time.

The simulations were run 30 times for the following scenarios:

Scenario A: Assumes single-decker trains with a maximum cruising speed of 80 km/hr. A total of 10 trains were used.

Scenario B: Assumes double-decker trains with a maximum cruising speed of 60 km/hr. A total of 10 trains were used.

RESULTS

The two initial scenarios were run, and the results are presented in the following table. These preliminary results indicate the potential number of containers transported by the system, the total amount of cargo transported, and the expected transit time, including loading and unloading.

Table2. Weekly & Yearly Values

Item	1 week Simulation	Yearly Value
Scenario 1 (Single Decker Trains)		
Containers Transported	144	7,488
TEUs transported	2878	149,656
Tons Transported (ton)	5324	276,848
Transport Time (hr.)	12.8	12.8
Transit Time (hr)	3.9	3.9
Scenario 2 (Double Decker Trains)		
Containers Transported	223	11,596
TEUs transported	4478	232,856
Tons Transported (ton)	8285	430,820
Transport Time (hr.)	17	17
Transit Time (hr.)	5.17	5.17

DISCUSSION

The results from the initial simulation-based approach to the CIIT system reveal intriguing contrasts with the government's plans. The data indicate that the projected number of containers transported falls short of governmental targets. It appears that to meet the expected demand of 1.3 million containers per year, it may be necessary to integrate the corridor with other transportation modes, such as road transport.

Regarding transit times, most of the processing time is consumed by the loading and unloading of containers, with transit time accounting for only 30% of the total duration from loading to unloading. Transit times range from 4 to 5 hours, depending on the type of trains used. These transit times could be reduced by increasing yard capacity and using multiple cranes working in parallel to load and unload containers, thereby enhancing throughput.

As this is a preliminary approach to the problem, some assumptions, such as the use of a single crane for all trains, might limit the findings. However, this study has already highlighted potential bottlenecks that the system could face once operational.

CONCLUSIONS AND FUTURE WORK

We have presented the initial results of capacity indicators for the CIIT, based on public information and the expected types of trains to be used. The results indicate the potential capacity of the system once operational, highlighting that the government's target figures are quite ambitious. One of the main hurdles identified is the capacity of the trains, which poses a significant challenge to moving 1.4 million containers per year.

This challenge can potentially be addressed by constructing parallel rail lines and supplementing rail transport with road transport along the corridor. Trucks could be used to transport containers between locations not served by rail. These plans are yet to be detailed by the government.

For future work, we plan to incorporate the road network into our analysis to determine the overall capacity of the system, assuming that the rail network alone will not be able to handle the expected container volume.

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Logistics and Suply chain Management

Articles

- **Location-Allocation Model of Facilities for an Integrated Medical Services Network**

  Alejandro Martínez Paniagua

  Idalia Flores De la Mota

- **Analysis of orthopedic surgery service applying queues and simulation**

  Adán Marín-Alquicira

  Omar Manuel Escamilla Orla

  Irma Cervantes-Galicia

  Patricia Balderas

  Idalia Flores-De La Mota

Enhanced Analysis of Orthopedic Surgery Services Using Queue Management and Simulation at a Hospital in Mexico City

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Abstract—

In this study, we analyze the arrival times of orthopedic patients at a hospital in Mexico City and their relationship with the demand for healthcare services. A simulation was conducted using the Arena® software to model the healthcare process based on queue theory with an infinite population, a limited number of servers, and limited capacity. A statistical study was carried out using R Studio to identify individual distributions. The purpose of this model is to analyze the behavior of various processes involved in both patient care and patient experiences. The achievement lies in providing a supplementary tool for decision-making aimed at improving orthopedic services, based on the validation of the simulation model under different scenarios.

Keywords- Orthopedic Patients, Orthopedic Surgeries, Simulation in Arena®, Queueing Theory, Time Series, Quality of Service, Probability Distributions.

I. INTRODUCTION

The incidence of hip fractures in older adults, the focus of this study, is rising exponentially worldwide, estimated at 1.6 million cases (Delgado et al., 2021) [11]. A hip fracture results from fragile bone conditions, and its significance is underlined by both its high occurrence rate and its severe impact on patients' mobility and functionality. From a social and economic perspective, the costs and mortality rates of hip fractures are comparable to those associated with cardiovascular diseases or cancer. It is projected that by 2050, hip fractures will number 6 million globally, leading to increased hospital demands (Rosas, 2023) [33] [26].

In Mexico, despite limited data due to the COVID-19 pandemic, it is estimated that musculoskeletal disorders among those aged 60 and older have a prevalence of 36.4%. Hip fractures, a serious complication of osteoporosis, increase in prevalence with age and have significant repercussions on quality of life and morbidity and mortality rates. After a fracture, 95% of patients require hospitalization, and the remaining individuals never regain their pre-fracture quality of life. Mortality rates can reach up to 10% during the hospital stay and 30% within the following 12 months. Consequently, this study focuses on the orthopedic surgery service at a hospital in Mexico City (IOF, 2023) [13].

Currently, the optimal treatment for hip fractures in Mexico is surgical, involving longer hospital stays and often incomplete recovery to the patients' previous functional levels. Surgical treatment requires metal fixation devices or bone prostheses. As per the Clinical Practice Guidelines (GPC, 2017) [21], to ensure successful outcomes, surgery should ideally be performed within 36 to 48 hours from the onset of the fracture.

There is a fragmentation phenomenon within the various organizations comprising the Mexican health system, which obstructs its sustainable development. This fragmentation arose due to the independent evolution of each entity. The challenge for the Mexican health system is to create a harmonization mechanism that lays the foundation for a universal health system, ensuring effective access to all processes and healthcare services (Mares, 2019) [25].

In this case study, the issue lies in a demand rate exceeding the maximum capacity for care, leading to patient dissatisfaction. Therefore, there is a need for optimal resource allocation, timely intervention, and a significant reduction in wait times to facilitate what is referred to as orthopedic surgery. This study aims to identify and address delays in the processes of waiting for implant and bed availability.

II. LITERATURE REVIEW

Research conducted in hospitals and clinics on the implementation of Operations Research tools has made significant strides in enhancing the quality, coverage, and efficiency of healthcare institutions. For instance, the work of Chan et al., 2017 [10], describes a framework for the successful application of this discipline, highlighting the ease of use due to the minimal data required to define a queue. However, it also addresses considerations such as the development of service measurement indices and hospital occupancy. This is crucial due to demand assessments based on waiting times, areas, and types of hospitals, as indiscriminate application of queuing could bias system evaluations (Vega et al., 2017 [33]).

Queueing has also been instrumental in developing prioritization models. Queiroz et al., 2023 [5] discuss using a series of queues and a heuristic method of the nearest neighbor with dynamic variables to conclude a service delivery model for patients considering their physical conditions such as morbidity, urgency, among others. The study determined the number of doctors and scheduling to minimize wait times and efficient methods for utilizing already available information. Another notable work is by Hassanzadeh et al., 2022 [14], which employed discrete simulation methods to properly distribute hospital beds to meet variable patient demand with finite hospital capacity. This article not only demonstrates the utility of queuing for diagnosing and improving this type of service but also emphasizes simulation as a crucial tool, given the complexity of many systems represented by hospitals. Simulation tools facilitate the treatment and analysis of information."

Similarly, there are studies that focus not only on describing or improving hospital waiting systems but also on the behavior of agents. As Gino et al., 2018 [11] stated, 'understanding human behavior in systems is critical for their analysis.' For instance, Bolandifar et al., 2023 [9] examined the timing and reasons patients abandon queues in a hospital setting, often due to dissatisfaction. This study provided valuable insights for discrete event simulation, highlighting the importance of modeling patient dropouts, which is commonly overlooked in favor of assuming a constant influx of patients.

Additional notable applications include the use of logistics improvements at the Sacré-Coeur Hospital in Montreal, Canada, where initiatives focused on clinical unit resupply and automation technology were implemented (Amaya et al., 2010) [4]. In Colombia, Hospital El Tunal was studied for short-term improvements in laundry, pharmacy, and emergency room operations using linear programming based on routing problems. In Cuba, the Holguin Hospital utilized queue theory in the orthopedic consultation process (Vega de la Cruz, 2017) [13][4], and Fortis Escorts Hospital in Jaipur, India, applied queue theory to optimize waiting times in hospital operations (Yaduvanshi, 2019) [33].

Hospital logistics is further explored in works such as that by Kumar et al., 2023 [27], similar to Hassim 2008 [31], where patient arrivals at a single-server system are scheduled using dynamic programming. The arrivals are modeled as a stochastic jump process. This research is significant for its advanced use of simulation functions that go beyond basic queue parameters and include feasible scheduling for these types of arrivals.

Amahand et al., 2024 [3] utilize blockchain technology to design smart city operations, supported by the capabilities of the Internet of Things (IoT). Noteworthy in this work is the application of queueing as an auxiliary methodology. The study developed a three-tier parallel server model with a FIFO discipline. The variables are stochastic, and the queueing model addresses the needs for logistic hubs, demand sizes for specific products, and aims to minimize response times to the requests of the data. Although this model targets smart city logistics, its objectives mirror those of hospital logistics, which also involve managing resources and demands for beds, operating rooms, diagnostic centers, goods, and medical supplies. This research contributes to resource distribution logistics and the transportation problem as tools to ensure successful hospital logistics management.

Improving customer service and thereby reducing wait times in hospital services can be addressed through the implementation of an efficient Supply Chain Management (SCM) process. The anticipated outcomes of this application are multifaceted, including a) shortened delivery times, b) increased reliability of shipments, c) cost reductions, and d) optimized scheduling of shipments. These benefits are highlighted as ambitious objectives in various studies and projects related to hospital care.

Additional research provides insights on how to model and guide a service process. Recurrently, Poisson models are utilized, such as in the work of Pandey et al., 2023, which predicts the number of patients in the queue, or the article by Benedetto et al., 2023 [7], where the primary focus is on validating the model due to its critical resemblance to reality, enhancing its utility as a decision-making tool. Furthermore, the article by Sarla et al., 2020 [31], using an M/M/1 model, represents the service provided in a COVID clinic. This article is of interest as, similar to the current document which focuses on an orthopedic surgery area, the situations often have a critical nature due to the delicate health conditions of the patients.

Other related articles that demonstrate benchmarks in the use of queuing systems in hospitals include the study by Ronnesrrande et al., 2020 [29], which aims to explore patient perception and decision-making, potentially leading to better resource distribution. Another significant work is by Canales et al., 2019 [8], which develops metrics and applies them to measure service quality, a crucial aspect for improvement and decision-making.

In the realm of simulation, the article by Askarian et al., 2016 [3] stands out for directly simulating the operation of a hospital's emergency area using Arena Simulation®. Additionally, there are manuals focused on simulation in Arena, published by Kelton [37].

The analysis of hospital data and the implementation of process improvement strategies across various health institutions in Mexico have been extensively researched within the fields of hospital logistics, statistical medicine, industrial planning, operations research, and medical care quality. Notable examples include the research by Medina in 2010 [28], who applied queuing models in a Bogotá hospital and identified factors that directly increase waiting times; similarly, the case studied by Rodríguez in 2005 [31] in an emergency department in Celaya, Mexico, also explores queue lines but through the application of simulation.

III. THEORETICAL FRAMEWORK

Queue theory aims to characterize the time a source spends within a system and in the queue. To achieve this, the theory requires minimal data input, including arrival rates and service rates, which indicate the number of customers served per unit of time. The theory examines various configurations of the fundamental system and their behaviors under different input parameter qualities.

Kendall's notation succinctly summarizes the characteristics of queues, including the distributions of arrival and service times, which are dependent on probability distributions. Kendall's notation can be represented by a set of letters separated by slashes in the format A/B/X/Y/Z, where A denotes the arrival time distribution, B represents the service time distribution, X the number of servers, Y the system capacity constraint, and Z the queue discipline.

The Poisson distribution is commonly used in this field, but other distributions can also be defined. The following equation 1 illustrates the probability distribution function of a Poisson distribution, using the average number of successes (λ) and the number of successes (k) [23].

$$f(X = k) = \frac{e^{-\lambda}\lambda^k}{k!} \qquad \text{Ec. (1)}$$

The exponential distribution is commonly used for service rates. In a queue, the most crucial metrics are the customer's waiting time in the queue and in the system, as these serve as key performance indicators (De la Mota, 2023) [19].

$$f(X = k) = \lambda e^{k\lambda} \qquad \text{Ec. (2)}$$

The occupancy level, the probability of there being no customers in the queue, the probability of having customers in line, and finally, the number of customers in the queue for an M/M/1 model are detailed in Equations 3 to 6, respectively (de la Mota, 2023) [19] [23].

$$\rho = \frac{\lambda}{\mu} \qquad \text{Ec. (3)}$$

$$p_0 = 1 - \rho \qquad \text{Ec. (4)}$$

$$p_n = (1 - \rho)\rho^n \qquad \text{Ec. (5)}$$

$$L_q = \frac{1}{\mu - \lambda} - \frac{\lambda}{\mu} \qquad \text{Ec. (6)}$$

A. *Probability Distributions*

In the application of queuing theory, it is essential to understand the distribution of customer arrivals and service rates. In addition to the data, these are considered part of a stochastic process involving both discrete states and continuous variables. It is necessary to individually verify the distributions of each variable. Among the most popular tests is the Kolmogorov-Smirnov test, which proposes that the null hypothesis asserts that the sample distribution matches the theoretical distribution, as shown in Equation 7 (Feller, 1948) [34].

$$S_n(X) \begin{cases} 0 \; para \; x < X_1^* \\ \frac{k}{N} \; para \;\; X_k^* \leq x \leq X_{k+1}^* \\ 1 \; para \; x \geq X_N^* \end{cases} \qquad \text{Ec. (7)}$$

The sample consists of $X_1, X_2, \ldots, X_n$ random variables representing a sum of increments, with a maximum allowable average variations of $|S_n(X) - F(X)|$ which must be less than the specified significance level. This study employs the *tidyverse* library and the *ks.test* function in RStudio for the test. (R Studio®, 2024)

B. *Simulation*

Simulation based on the discrete-event approach examines systems that function over time. This tool is widely used across various fields of study to observe subjects that would otherwise be too complex to analyze directly. A fundamental classification of simulation types includes:

- Discrete: This type studies events where the arrival units to a system are discrete and are commonly used to simulate queuing scenarios.
- Continuous: This type studies systems that change continuously over time and uses differential equations for analysis.

In simulation, it is necessary to define some basic concepts, as shown below:

• System: The object of study that is being recreated using the simulation tool.

• Model: The theoretical models used to determine the behavior of variables over the simulation period.

• State: The sum of all the system's characteristics. In the case of queueing systems, this can be defined by the expected times within the system.

• Performance: Defined as the system's output, which can be measured and compared in terms of a cumulative unit.

• Variable: These can be stochastic or deterministic, and their influence on the system can be either exogenous or endogenous.

IV. CASE STUDY

This case study describes a process at the General Hospital of Specialties APP in Mexico City, which is experiencing a backlog of pending surgeries, particularly in orthopedics for patients with hip fractures. This issue arises from factors such as an aging population increasing the demand for specialized services, staff shortages, and logistical problems in managing medical supplies, leading to patient complaints and a decline in service quality. These issues have resulted in complaints from patients, their families, and medical staff, affecting the hospital's reputation for quality and efficiency. If corrective actions are not taken, the problems could have lasting consequences on the hospital's operations and patient trust. It is crucial to conduct a detailed evaluation to identify the causes and develop comprehensive and sustainable solutions that improve resources and internal processes, thereby enhancing the quality of the medical services provided.

Figure 1 provides an illustrative basis for generating the queue model and gathering the necessary information, highlighting the number of servers, their configuration, and the involved parameters.

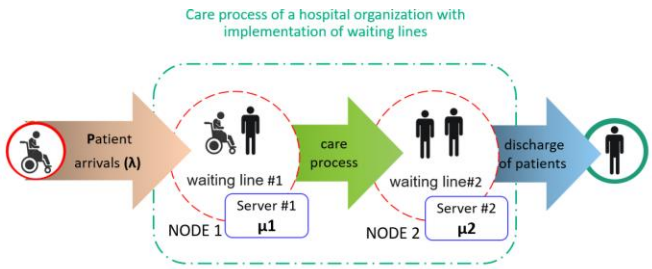

Figure 1 Representation of a queue network with servers in series, applied to a hospital care process, where the parameters µ and λ represent the service and arrival rates, respectively. (De la Mota, 2023)

A. *Information collection*

To develop the model, information on patient arrival and wait times was collected, which was then used to perform a statistical analysis to determine the data distribution from a sample of 309 patients.

Regarding wait times, data from the year 2021 to 2022 was examined concerning requests for hip prostheses and their tracking from inception to completion. Table 1 displays the processes and their codes used in the work comprising the surgical area.

TABLE I. PARTS OF THE ORTHOPEDIC SURGERY PATIENT CARE PROCESS

Code	*Process in the orthopedic surgery area*
A	Arrival time until implant request
B	Arrival of the implant and surgery
C	Surgery wait until patient discharge
D	Patient wait in bed for surgery

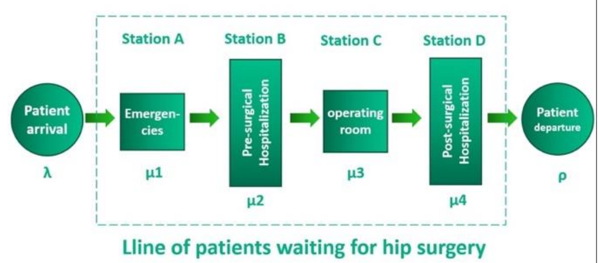

Figure 2. Graphic representation of the process, each part of them have a different size depending of the afluence of patients at the respective process. Own dessign

- Distribution of patient care times

Service times for each process were obtained from a record of entries in the processes described in Table 1. These times were calculated using the dates each patient was attended to and their entries into the system. The times (in days) underwent a Poisson distribution test using a 90% confidence level and a Kolmogorov-Smirnov hypothesis test. Subsequently, using R Studio®, the parameters for each of the distributions needed for the simulation were derived.

The only process that does not follow a Poisson distribution is the care times. However, when compared with a normal distribution, a P-value of 0.5 was obtained, which is acceptable. Therefore, this distribution is assumed for the care times. Subsequently, the parameters for each process will be summarized, but before doing so, the arrival distributions of patients to the surgery area must be established (Figures 3 to 6).

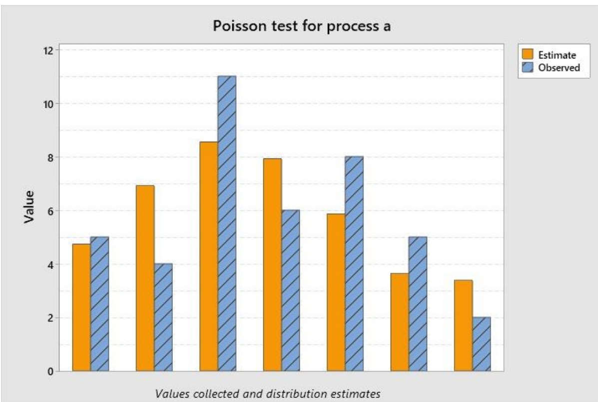

Figure 3. Poisson distribution test for process A

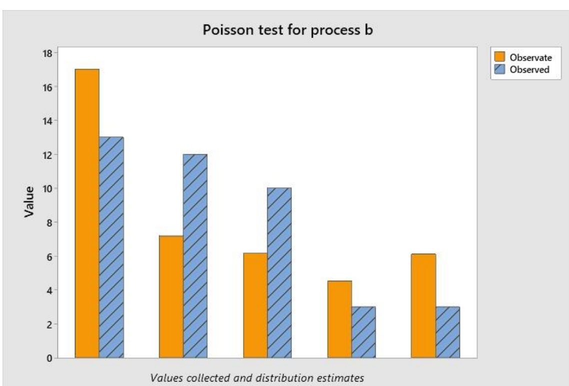

Figure 4. Poisson distribution test for process B

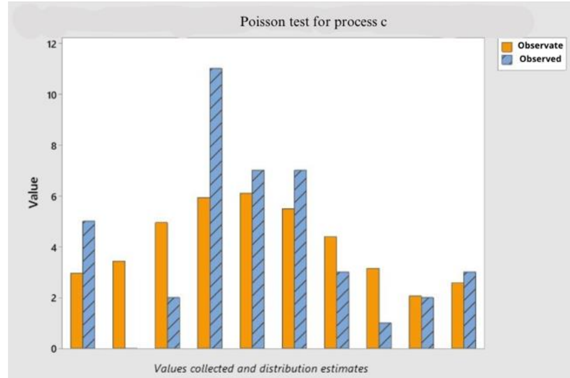

Figure 5. Poisson distribution test for process C

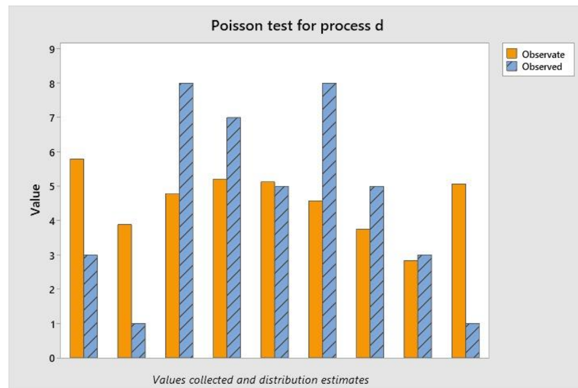

Figure 6. Poisson distribution test for process D

- Distribution of patient arrivals to the system

To determine the pattern of patient arrivals, a record of all admissions to the orthopedic surgery area during 2021 and 2022 was used. The arrival pattern is not uniform, as there were periods without any admissions. For this reason, the data were analyzed in a monthly series, but the daily arrival rate was used for the simulation. The images display normality test graphs and a box plot showing the distribution of monthly arrivals over the years (Figures 7 and 8).

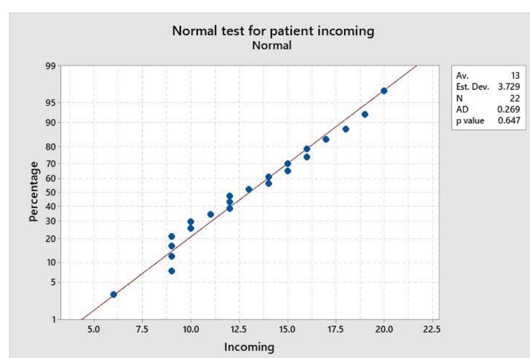

Figure 7. Normality test for arrivals to the surgery area

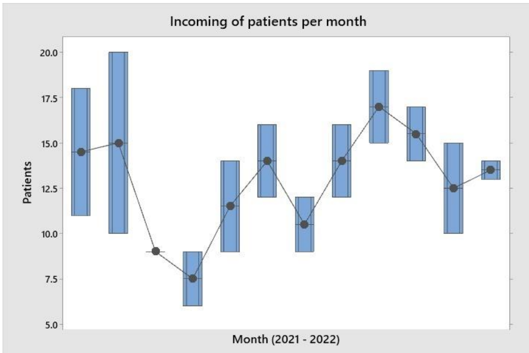

Figure 8. Normality test for monthly arrivals to the surgery area

B. *Generation of disbribution parameters*

For generating the parameters of the distributions, the *'findstr'* function available in the MASS library of R Studio® was used.

Through individual tests and Poisson distribution analysis, a time-based distribution was determined. The criterion for individual tests was that if the P-value was greater than the significance level (5%), the data were considered to fit a distribution, with higher values indicating a better fit. The same rule applies to the Poisson test as it is based on a hypothesis test where the null hypothesis asserts a distribution with these characteristics, and a significance level of 5% was used. Table 2 displays the results and parameters for the selected distribution; if more than one distribution is applicable for a time, their performance will be compared in the process simulation.

TABLE II. TABLE TYPE STYLES

Incoming	Queue parameter	Distribution	Parameter value
A	Average incomings	Normal	μ=1.21, σ=0.482
B		Normal	μ=1.21, σ=0.482
C		Normal	μ=1.21, σ=0.482
D		Normal	μ=1.21, σ=0.482
A	Attention time	Poisson	$\lambda = 3.87$
B		Normal	μ=5.2, σ=1.458
C		Poisson	$\lambda = 7.49$
D		Poisson	$\lambda = 10.16$

Source:

C. *Simulation*

The simulation was conducted using Arena Simulation® with the discrete simulation module. The setup consists of three "create" modules (Figure 9) representing the arrival of patients needing a specific type of prosthesis. The attributes of these modules are set according to the proportion of patients recorded in the time series used. These modules are then connected to an "assign" module that stores an attribute divided by prosthesis types.

The assign modules subsequently converge into a decision point, which represents the possibility of a patient deciding whether to stay in line or leave, as some may opt to seek treatment at a different institution due to the large number of people in line before this point. If the patient stays, they must then await the prosthesis request process and at the same time, wait in a bed, which is represented by the "process" module of the same name. It's possible that the patient may not need to wait in a bed; this potential is accounted for by a second decision point, although it is unlikely, thus the assigned value to this event is small. Once patients reach the waiting area, they must be attended to in surgery before moving to a recovery area, which coincides with the waiting beds. It is expected that the bed area will have the most waiting time, as two processes converge at this point.

The simulation covers a period of 30 days to analyze the process, considering that it operates 24 hours a day. As a result, the output specifies the queues in the process and the average time per patient for these queues.

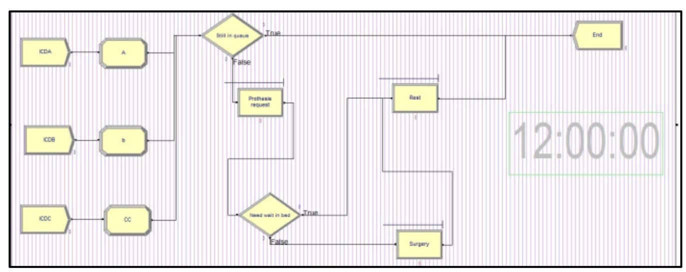

Figure 9.Process diagram for the surgery area

V. RESULTS

In Figure 10, it is evident that the majority of the waiting time is concentrated in the implant request and the wait in bed, with average times of 11.17 and 18 days, respectively. This helps validate the model, as experience has shown that these areas are where delays and patient complaints tend to accumulate. The excessive times in these processes suggest they could be reduced with an appropriate implant inventory policy using demand planning, as orders are only placed once a week before the cutoff day. The assignment of bed periods to patients from different areas is due to variable influx throughout the year and the shared resource of beds. Dynamic scheduling with conventional algorithms can efficiently manage this assignment.

ARENA Simulation Results
omar_orla@hotmail.com - License: STUDENT

Summary for Replication 1 of 2

Project: Unnamed Project Run execution date : 3/19/2024
Analyst: omar_orla@hotmail.com Model revision date: 3/19/2024

Replication ended at time : 30.0 Days
Base Time Units: Days

TALLY VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Observations
Pedido de protesis.WaitTimePerEntity	8.3201	(Insuf)	.00000	15.279	7
Cirugia.VATimePerEntity	--	--	--	--	0
Cirugia.TotalTimePerEntity	--	--	--	--	0
Pedido de protesis.TotalTimePerEntity	11.177	(Insuf)	2.0000	18.279	7
Recuperacion.WaitTimePerEntity	18.000	(Insuf)	18.000	18.000	1
Recuperacion.VATimePerEntity	9.0000	(Insuf)	9.0000	9.0000	1
Cirugia.WaitTimePerEntity	--	--	--	--	0
Recuperacion.TotalTimePerEntity	27.000	(Insuf)	27.000	27.000	1
Pedido de protesis.VATimePerEntity	2.8571	(Insuf)	.00000	5.0000	7
Paciente.VATime	2.7500	(Insuf)	.00000	11.000	4
Paciente.NVATime	.00000	(Insuf)	.00000	.00000	4
Paciente.WaitTime	4.5000	(Insuf)	.00000	18.000	4
Paciente.TranTime	.00000	(Insuf)	.00000	.00000	4
Paciente.OtherTime	.00000	(Insuf)	.00000	.00000	4
Paciente.TotalTime	7.2500	(Insuf)	.00000	29.000	4
Cirugia.Queue.WaitingTime	--	--	--	--	0
Recuperacion.Queue.WaitingTime	18.000	(Insuf)	18.000	18.000	1
Pedido de protesis.Queue.WaitingTime	10.613	(Insuf)	.00000	26.670	8

Figure 10. Variable reporting in Arena Simulation (r)

On the other hand, the report on discrete variables shown in Figure 11 indicates that the longest queue is for patients waiting for their implant. In terms of efficiency and operation, it is clear that this wait needs to be reduced. However, in terms of quality of life, there is a justification, as a patient waits while suffering from an ailment. The same report also highlights excessive utilization that needs to be reduced, as the hospital operates with a maximum permissible occupancy value of 0.8. The system outputs show a capacity to serve 4 patients per month, which could be improved with a redesign of the service and the work area.

DISCRETE-CHANGE VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Final Value
Paciente.WIP	34.628	(Insuf)	.00000	68.000	68.000
Anestesiologo.NumberBusy	.00000	(Insuf)	.00000	.00000	.00000
Anestesiologo.NumberScheduled	1.0000	(Insuf)	1.0000	1.0000	1.0000
Anestesiologo.Utilization	.00000	(Insuf)	.00000	.00000	.00000
PAT.NumberBusy	1.0000	(Insuf)	.00000	1.0000	1.0000
PAT.NumberScheduled	1.0000	(Insuf)	1.0000	1.0000	1.0000
PAT.Utilization	1.0000	(Insuf)	.00000	1.0000	1.0000
Cirugia.Queue.NumberInQueue	.00000	(Insuf)	.00000	.00000	.00000
Recuperacion.Queue.NumberInQueue	3.9333	(Insuf)	.00000	6.0000	6.0000
Pedido de protesis.Queue.NumberInQueue	29.694	(Insuf)	.00000	61.000	61.000

Figure 11. Reporting Discrete Variables in Arena Simulation.

VI. CONCLUSIONS

The results of the applied model are consistent with what was observed in the simulation, showing similarities to historical records. The elements of delay during the process appear in the administrative node, "prosthesis order," and in the waiting time in bed for patients "Patient," making it viable to continue analyzing the behavior of the orthopedic surgery service. Moreover, improvement options should be considered from the process of prosthetic requests and bed availability. In the future, it would be relevant to study the movement of patients in the healthcare sector using dynamic models, similarly, managing a section with limited space such as beds entails dynamic planning, which can be seen as a problem of combinatorial optimization. It is crucial that all these improvement options are always in response to demand and based on reliable, up-to-date data so that the hospital should develop areas and tools for independent decision-making.

Queue theory is a fundamental tool in operations research used to analyze situations where queues form due to service demand exceeding available capacity. This theory has significant applications in health care, particularly in managing patients waiting for hip surgery, as well as in the planning and operation of transportation systems.

Comparatively, in transportation systems, queue theory is used to analyze and improve the flow of vehicles, passengers, or cargo. For example, in a public transport system, this theory can help determine the optimal number of vehicles needed on a route to minimize waiting times without incurring excessive operational costs. Just like in hospitals, the effective application of queue theory in transportation can reduce congestion, improve user satisfaction, and optimize resource use.

Although the application scenarios differ—patients in a hospital versus passengers in a transportation system—both share the common challenge of managing limited resources against variable and often unpredictable demands. In both cases, the implementation of queue theory can lead to more effective planning and resource allocation that maximizes efficiency and minimizes wait times.

A connecting point between these two areas is the importance of forecasting and real-time management. In both hospitals and transportation systems, it is crucial to have systems that can quickly adapt to unexpected changes in demand to maintain a steady flow and avoid congestions that could result in significant delays and reduced service quality.

Finally, it is necessary to integrate the patient into the decision-making process. Currently, only hospital and government authorities have a decision-making role, but the patient is an agent who provides more substantial information than the rest. For this, it is recommended that in the future they be part of real-time outcomes, presenting an opinion survey. This work aims to lead to more comprehensive research, for which patient satisfaction data would be collected, where the service would be rated while contrasting this rating with the root causes.

Other applications of queue theory can include:

Customer Services: Many businesses use queue theory to enhance customer service in areas such as call centers, banks, and restaurants. They analyze customer arrival rates, service times, and the number of servers to minimize waiting times and optimize resources.

Transportation and Logistics Operations: In inventory management, transportation route planning, port operations, and traffic management, queue theory is used to optimize efficiency and reduce waiting times.

Healthcare Services: In hospitals and clinics, queue theory is applied to manage waiting rooms, schedule appointments, and optimize medical resources to minimize patient wait times and maximize medical staff efficiency.

Computer Networks and Telecommunications: It is used to analyze and optimize the performance of computer networks and communication systems, such as managing queues in internet routers and scheduling data packets.

Manufacturing and Production: In the management of production lines, queue theory is utilized to optimize the use of machinery and minimize waiting times between processes.

Systems and Process Design: Generally, queue theory is applied in the design and analysis of systems and processes to understand their behavior under different load and capacity conditions, enabling informed decisions to improve efficiency and productivity.

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Location-Allocation Model of Facilities for an Integrated Medical Services Network

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Abstract— The growth of medical care across different treatment and surgery specialties has led to increased complexity in the healthcare supply chain. Institutions often subcontract specialized medical services, including certain surgical procedures, which present significant operational challenges due to their requirements of products and staff. This article discusses the challenge of identifying and assigning facilities as distribution centers for integrated medical services, particularly surgical services distributed by private companies and required by a network of public hospitals. We developed an optimization model based on the location theory. We propose a specific model tailored to the characteristics of integrated medical services by adapting classic model structures. The result is a model that offers decision makers a valuable tool for planning the distribution of integrated medical services. Our findings suggest that the model obtained can guide the distribution planning process, offering various solutions based on the company's time and cost requirements to meet quality standards for public clients.

Keywords-component; location-allocation, models; integrated medical services, facilities, distribution planning.

VIII. Introduction

The rise in demand for medical care has led to an expansion of various specialties catering to different diseases, diagnostics, and treatments. Simultaneously, this surge has brought about heightened complexity in meeting the supply chain requirements of medical services [1]. Consequently, some institutions have opted to subcontract specialized companies to provide certain medical services, particularly in areas such as surgery, which present significant operational challenges due to their integrated nature. These subcontracted surgical procedures are commonly referred to as Integrated Medical Services [1].

The Mexican Social Security Institute defines Integrated Medical Services as follows: "Integrated Medical Services represent an alternative for contracting services aimed at conducting comprehensive and specific diagnostic or therapeutic procedures. These services enable medical units to meet the demand for medical attention while mitigating unforeseen errors that may impact the procurement process [2]. They encompass medical equipment and its accessories, disposable and no disposable instruments, and technical personnel for user support and training [2]. Private companies that offer Integrated Medical Services are contracted by public institutions through strict sale processes. In these sale processes, interested companies submit proposals outlining their capabilities, pricing, and operational plans to fulfill the requirements specified by the public institution [3]. During these processes, the winning company must fulfill all the stipulated requirements at the most competitive price. Companies must submit a comprehensive proposal that includes an operational plan detailing resources, legal documentation, and pricing. As an initial step, companies must develop a distribution operational plan for the service, prioritizing the needs, standards, and characteristics of their clients as swiftly as possible. This urgency is crucial because pricing is contingent on this plan, which must be submitted approximately one week after the publication of the bidding notice [2].

The distribution planning process is often reliant on empirical experience, which can occasionally lead to issues during the execution phase. Therefore, it is imperative to identify distribution problems and propose changes during the planning phase to solve or mitigate potential issues. By proactively addressing these challenges, adjustments can be made to the distribution strategy to enhance its effectiveness and ensure smoother implementation.

IX. Literature review

[37] Distribution planning of Integrated medical Services

The operational distribution service plan must consider various customer characteristics, such as the date of launching, contract duration, number of hospitals to serve, location addresses, estimated or required number of services, available resources (both material and human), transportation logistics, inventory management, and necessary facilities. In addition, it is essential to consider the customer service policies, which define the quality parameters for service delivery [1]. These parameters typically include delivery times and the hours during which service requests can be made.

Most customers of such services require round-the-clock availability for both delivery and service attention requests. Similarly, hospitals typically require service 365 days a year because of the urgent nature of patient needs. Failure to provide timely delivery or service requests may result in accusations of contract neglect. In such cases, the company could face penalties ranging from a 10% deduction of the contract amount for minor infractions to complete loss of the contract and potential inability to provide services to any public health institution for several years [2]. Therefore, adherence to service commitments is crucial to maintaining contractual obligations and reputation in the industry.

Thus, the company must select all necessary facilities, transport, staff, and resources to fulfill distribution requirements. However, adequate tools are lacking to make decisions encompassing all the unique characteristics of healthcare services [1]. As a result, distribution plans are often developed empirically in many cases.

[38] *Performance Issues at distribution.*

The distribution of Integrated Medical Services faces significant challenges, including unforeseen costs in transport and quality issues in delivery services. Nowadays transportation costs often exceed initial estimates due to factors like fuel expenses and vehicle maintenance [4]. The inadequate workload estimation may lead to breakdowns in the float of vehicles, needing temporary rental or outsourcing of delivery services. These unexpected costs can diminish project profitability. The Quality issues in services are mainly caused by delays in delivery of services on urgent requests for emergency surgery. Timely transport of equipment and staff is crucial, and any delays can have serious consequences for patient care [4].

After conducting various analyses of the problems related to increased costs and poor-quality service, a common underlying cause emerges inadequate planning strategies due to the absence of quantitative data tools for making key decisions in distribution [5]. This includes factors such as facility locations, transportation logistics, and demand assignment, all of which require robust planning supported by data-driven insights [5].

[39] *Solution proposal*

Historically, the health care industry has viewed itself as being operationally different from other businesses. Executives and logisticians state that they cannot predict their supply consumption based on patient performance [6]. To address and mitigate the problems encountered in the distribution of Integrated Medical Services, it is essential to formulate a strategy based on the following steps:

1. Minimize transport costs and delivery times by locating distribution centers closer to hospitals.

2. Optimize the allocation of facilities by assessing their proximity to hospitals and service demand.

3. Use quantitative data analysis to explore alternative distribution options.

To develop this strategy, we review existing literature and research articles on similar applications to gather insights and best practices. This process will inform the design of an effective distribution strategy tailored to the unique challenges of Integrated Medical Services.

[40] *Location-allocation facility models*

Location-allocation models are mathematical tools used to find optimal facility locations, considering specific characteristics and distribution needs [7]. These models can be used prescriptively or descriptively and are typically described as integer linear programing problems. Different types of location models cater to various demand configurations and geographic references [7]. The principal approaches are:

- Analytic Models: These assume a uniform distributed demand in an especial region with a specific form and the facility can be in any point of the region. The demand density is constant over all region form. To find the best location for facilities is needed just to find the geometric center of the form. Such approaches make hard suppositions so it can´t be recommended for non-uniform distributed demand applications like neighborhoods, states, or countries [7].
- Continuous models: These models assume that the demand occurs in specific points and the facilities can be in any point inside of this continuous region. The location and level of demand are previously known by experience or happened values of stochastic variables [7].
- Discrete models: In these models, the demand is in specific points and the facilities can be located only in selected candidate points in the region of interest. The distances between the candidate points and where

demand occurs do not follow a specific form or parameter. However, there exists a sub-group of discrete models in which the distance between facilities and demand points follows specific forms and parameters, these models are known as location-discrete models in networks [7].

[41] *Location-allocation discrete models for networks.*

In this model approach, the space is fully discrete, where the demand and candidate facility locations are in specific nodes of the space and are represented by a network. The distances between demand points and the possible facility locations are represented by the links of the network that follow parameters like flow, direction, and sense [7]. The network abstract is made with the proposal of simplifying the problem characteristics and its comprehension. Of the different approaches of location models, location-allocation discrete model in the network has the most common elements with the characteristics of the Integrated Medical Services network of distribution. Therefore, it is important to consider review the classic model of this approach.

- Total Cover Model: The objective of this model is to select the minimal number of needed facilities that every demand node can cover among a range of distances desired to the nearest facility [7].
- Maximum Cover Model: This is an alternative version of the total cover model, with the difference that the objective is to maximize the demand cover by selecting locations of several known facilities [7].
- P-center Model: This model suggests an objective function to minimize the maximum response time or distance between the demand node and the nearest facility using a known *P* number of possible facilities [8].
- P-median Model: The P-median model minimize the relationship between the demand level and the distance traveled for attention using a known number of P facilities. This relationship is minimized by assigning demand nodes at the facilities selected to provide services based on distance and weight of demand in the nodes [9].

All these network models have the common restriction that all facilities must be located only at the demand nodes [8], which is a problem for real-life applications. These models were the most used in research articles on location-allocation applications in public health [10]. However, integrated medical services are provided by private companies to a public health institution, that´s because we need a specialized model focused on the company objectives of cost and quality service in delivery. This is the reason why we need to propose a mathematical model in location-allocation that includes more specific characteristics of this type of private health services with the restrictions of public institutions.

To address and alleviate the challenges in distributing Integrated Medical Services, it is essential to implement changes during the planning phase. Therefore, a strategy based on the following steps and a mathematical model is proposed:

- Transport costs and delivery time reduction by minimizing the distance between hospitals and distribution centers. Strategically locating distribution centers closer to hospitals can shorten transportation distances, decreasing fuel costs and delivery times.
- Evaluation and optimization of the facilities required number and their assignment to the nearest hospitals ensures efficient coverage and timely service provision.
- Operational costs associated with excess facilities or inefficient assignments minimization.
- Incorporation of quantitative data analysis to explore various options and make informed decisions regarding distribution. By leveraging data-driven insights, alternative distribution strategies can be identified and evaluated, leading to more effective changes in the distribution process.

X. PROPOSAL OF A MATHEMATICAL MODEL

In accordance with our distribution planning strategy, the goal is to reduce the overall transportation expenses and delivery times associated with distributing Integrated Medical Services to hospitals. To ensure adequate coverage of demand and adherence to quality service standards through constraints by determining the best locations to become for distribution centers, assigning hospitals to these centers, and establishing transportation routes that minimize distance and time while meeting service quality requirements.

The key requirements and characteristics of the problem include the following:

- Determining the minimum number and locations of facilities to serve as distribution centers for Integrated Medical Services.
- Selecting facilities from a predefined set of available locations that meet operational requirements.
- Assigning hospitals to specific distribution centers to minimize the cost of demand fulfillment.
- Considering distance restrictions associated with delivery time limits.
- Ensuring that the selected facilities cover a minimum area to store all necessary goods for service provision.
- Optimizing the cost efficiency of facilities.

Based on these requirements, we can select mathematical structures such as optimization techniques, graph theory, and

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network modeling to develop a mathematical model tailored to Integrated Medical Services. These structures will enable us to shape the problem and devise an optimal solution that meets the specified objectives and constraints.

[42] *Model and problem variables identification.*

The problem at hand is a location-allocation problem that can be solved using linear programing, depending on the number of variables involved. The objective function, denoted as *Z*, minimizes distribution costs. Some important components of the model are the finite set demand nodes (hospitals) *I, and* the finite set of offer nodes (candidate facilities) *J*. Each individual component set of *I* is denoted *i*, and each individual component set *J* is denoted *j*. The function *Z* depends on the two sets of decision binary variables x_j and y_{ji}. The first one x_j represents the set of selected facilities, and the second y_{ji} represents the assignment set of hospitals *i* to each selected facility *j*. Because candidate facilities and demand nodes (hospitals) are in specific areas of the city, characterized by streets, avenues, highways, and various terrestrial pathways with distinct lengths, directions, and speed restrictions, the discrete network model is the most appropriate approach for this location-allocation problem. This model considers the network structure of urban environments, considering the complexities of transportation routes and the limitations of city infrastructure.

[43] *Math structures needed.*

Once the model and problem variables are identified, the mathematical structures needed are proposed as follows.

The objective function to minimize the cost of facilities is taken from the total cover model [3] defined by (3.1) :

$$Minimize\ Z = \sum_{j \in J} f_j x_j \qquad (3.1)$$

With the following constraints [3]:

$$x_j \in \{0,1\} \qquad \forall j \in J \qquad (3.3)$$
$$d_{ij} \leq S \qquad \forall i \in I, \forall j \in J \qquad (3.4)$$
$$y_{ji} - x_j \leq 0 \qquad \forall i \in I; j \in J \qquad (3.5)$$

i= Set of demand nodes.
j= Set of candidate locations.
x_j *= Binary decision variable that select the locations to use.*
y_{ji} *= Binary decision variable that assign each demand node i to a facility selected j.*
f_j *= cost of locate a facility in the candidate* $j \in J$.
d_{ij} *= Distance between the demand node i and the facility j.*
S= Cover radius. [7]

The transport cost for each demand node that is attended must consider the distance associated with the assignment to the nearest facility. We can use an adaptation of the objective function of the P-median [3] model is required:

$$Minimize\ Z = c * \sum_{i \in I} \sum_{j \in J} h_i d_{ij} y_{ji} \qquad (3.5)$$

c= Cost per traveled kilometer

h_i *= expected value of services demand in the hospital i*

This objective function considers the following restrictions of the maximum number of facilities (3.6) and ensures that each hospital is assigned to one distribution center (3.7):

$$\sum_{j \in J} x_j \leq P \qquad (3.6)$$
$$\sum_{j \in J} y_{ji} \geq 1 \quad \forall i \in I \qquad (3.7)$$

To calculate the cost of distributing service products internally between distribution centers each month, while factoring in both internal distribution and external delivery with a fixed cost for freight within the city, the following function (3.8) is used:

Minimize z = $t * (\sum_{j \in J} x_j - 1)$ (3.8)

t = unit freight cost in the city.

The model can integrate a constraint that ensures that the selected set of facilities covers at least the minimum area required to store all goods needed for service provision. This requirement can be expressed as follows:

$$\sum_{j=1} a_j * x_j \geq A \qquad (3.8)$$

a_j *= The storage area of each candidate facility j.*
A = The minimum total area required for storage all products of the service at month.

The objective of the model is to consider cost of facilities, cost of transport for attending services in each hospital, and the internal cost of distribution of products between distribution centers. Is needed to sum the functions (3.1), (3.5) and (3.6), resulting in the following expression to minimize (3.9):

$$z = c * \sum_{i \in I} \sum_{j \in J} h_i d_{ij} y_{ji} + \sum_{j \in J} f_j x_j + t * \left(\sum_{j \in J} x_j - 1 \right) \quad (3.9)$$

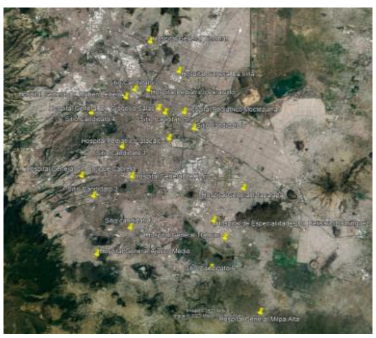
Once the mathematical model has been defined, it is possible to apply and validate it using a case study.

XI. CASE STUDY

In this case study, a company provides integrated medical services to 15 public hospitals in Mexico City. The company operates from a central distribution center at Uxmal Street 494, with a postal code of 03600. This facility offers a storage space of 40 m2, equipped with basic services available 24/7, and costs $25,000.00. Moreover, the company can choose from eight potential facilities, each with its own costs and storage areas [11], to optimize its distribution plan. To determine the best selection, a mathematical model that integrates this data is required, extracting, and organizing relevant information from the problem statement for input into the model.

[44] *Geographic data of distribution network.*

To obtain geographic data, Google Earth Pro version 7.3.6.9346 was used, which is a geographic data system that allows the visualization of different cartographic layers based on satellite imagery. This software offers the possibility of creating maps and polygons [13]. Using this tool, each hospital as a demand node and candidate facility can be accurately located (Figure 1). It also generates a layered map showing the locations of the service network.



Map of locations of facilities and demand nodes [12].

B. Recorded Demand Service Data at Each Node.

Historic demand data for each month were collected from an anonymous company in 2019. Unfortunately, it was not possible to obtain data from previous years because the company did not provide services previously and the hospitals did not keep records. Demand levels for each hospital in each month are shown in Table 1.

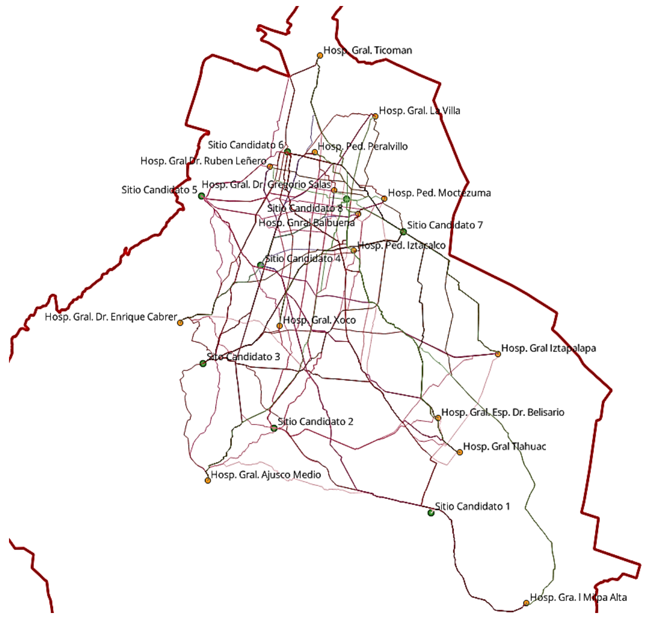
EXPECTED DEMAND VALUE AND LOCATION

N° demand node	Parameters of demand nodes		
	Hospital Name	***Demand at month***	***Latitude and Longitude***
1	Ticoman General H.	45	19.51, -99.13
2	La Villa General H.	65	19.43, -99.12
…	…	…	…
15	Milpa Alta General H.	99	19.20, -99.01

a. Average demand value at hospitals (Company data and Google EARTH [12])

[45] *Distance data of the network and cover radius.*

QGIS version 3.32.2-Lima software is used to calculate distances between nodes in the city network. QGIS offers capabilities for data visualization, management, editing, analysis, and printable map design [14]. By employing layer maps from Google Earth Pro and the QGIS geodatabase (NetGis Team), the shortest distribution routes between all facilities and hospitals in Mexico City can be determined using road layer maps. These routes provide distances, facilitating the construction of the Integrated Medical Service distribution network, as depicted in Figure 2. Accessing the attribute table of the layer enables the creation of a distance matrix (Table 2) which is essential for network construction.



Distribution Network for the Medical Integrated Service [14].

DISTANCES MATRIX

i, j	Candidate facilities distances km.			
	j1	**j2**		**j15**
i1	33.961	25.762		14.928
i2	29.134	22.948		12.978
..	...	...		...

i	2	1		6.
1	7.	8.		9
5	8	5		0
	6	8		3
	9	4		

a. QGIS distance routes [7].

According to hospital requirements, service requests should be made at least 2 hours before scheduled surgery, with service staff present at the hospital at least 1 hour prior to surgery to ensure readiness. With these constraints, service staff have only 1 hour to prepare and transport all necessary goods. The model establishes a coverage radius for facilities associated with a 1-hour travel radius within the city. Using data from INRIX [8], the average speed in Mexico City is approximately 12 mph or 19.3121 km/h, which the model adopts for the parameter *S* representing the average distance traveled in 1 h.

[46] *Cost and area parameters of candidate facilities*

The data required for the square footage and cost of candidate facilities for the model were obtained from rental facility advertisements available on the Internet. These publications provide information on the storage area and the cost of the facilities (Table 3). To establish the constraint on the minimum storage area parameter, we considered the total area of the initial facility used in the service, which was $40m^2$.

CANDIDATES FACILITIES TO SELECT.

N° Candidate facility	**Candidate facility parameters**		
	Latitude and Longitude	***Area m²***	***Cost of facility at month (U.S DLS)***
1	19.41, -99.08	220	$625.00
2	19.338, -99.21	19	$600.00
…	…	…	…
15	19.43, -99.08,	45	$400.00

a. Sample of a Table footnote [5][6].

[47] *Parameter of displacement cost in the network.*

The model must consider two important factors to determine the cost of transportation: the fuel for the vehicles and the maintenance associated with their use over the distances traveled. The vehicles used for distribution have a fuel efficiency of 11 km/l and an associated maintenance cost of $8,000.00 to be performed every 15,000 km [9]. By summing these two costs, parameter *c* can be defined as follows:

$$\boldsymbol{c} = (fuel\ cost\ \ + mainteinance\ cost)(\frac{\$}{km})$$

The model incorporates the freight cost for distribution between the selected facilities based on the economic proposal for an external delivery service, which is denoted as t = $5,000.00 [10]. This price applies regardless of the distance between any two points within Mexico City.

XII. RESULTS

With the problem definition, the proposed mathematical model, and the relevant data the location-allocation optimization problem can be described as follows:

The objective of this study is to determine the minimum number and location of facilities to serve as distribution centers for Integrated Medical Services for 15 hospitals in Mexico City. These facilities must be selected from a set of 8 available locations, to ensure that they meet the necessary operational requirements. In addition, hospitals must be assigned specific locations for each distribution center to provide service while minimizing the cost of meeting demand. Candidate locations should be selected with a distance constraint combined with a 1-hour delivery time limit as required by the customer. In addition, the selected facilities must cover at least the minimum area required to store all the goods needed to provide the services, and the cost of the facilities should be as efficient as possible.

Using the proposed model with the data provided for the problem, the objective function aims to minimize the monthly distribution cost for the integrated medical service which is defined as follows:

Choice binary variables:

$$\boldsymbol{x_j} = \begin{cases} \boldsymbol{1 ... if\ locate\ a\ facility\ at\ candidate\ \ j} \\ \boldsymbol{0} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \boldsymbol{if\ not} \end{cases}$$

$$\boldsymbol{y_{ji}} = \begin{cases} \boldsymbol{1} \quad \boldsymbol{if\ the\ node\ i\ is\ attended\ by\ the\ facility\ j} \\ \ \boldsymbol{0} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \boldsymbol{if\ not} \end{cases}$$

The objective function is defined as follows:

Minimize:

$$z = c * \sum_{i \in I} \sum_{j \in J} h_i d_{ij} y_{ji} + \sum_{j \in J} f_j x_j + t * (\sum_{j \in J} x_j - 1)$$

(5.1)

And the model considers the restrictions commented in section III.

$$y_{ji} - x_j \leq 0 \quad \forall i\ \in I; j\ \in J \qquad (5.2)$$

$$\textstyle\sum_{j \in J} y_{ji} \geq 1 \quad \forall i\ \in I \qquad (5.3)$$

$$\sum_{j \in J} y_{ji} \geq 1 \quad \forall i\ \in I \qquad (5.4)$$

$$\sum_{j=1} a_j * x_j \geq 40m^2 \qquad (5.5)$$

$$\boldsymbol{d_{ij} * y_{ji} \le 19.312\ km} \quad \forall \boldsymbol{i} \in \boldsymbol{I}, \forall \boldsymbol{j} \in \boldsymbol{J} \qquad (5.6)$$

$$\sum_{j \in J} \boldsymbol{x_j} \le \boldsymbol{8} \qquad (\boldsymbol{5.7})$$

$$x_j \in \{0,1\} \quad \forall j \in J; \quad y_{ji} \in \{0,1\} \qquad \forall j \in J \quad (5.8)$$

Definitions:

i = (1, 2,…,15) demand nodes (hospitals)

j= (1, 2,…,8)candidate facilities to distribution centers

a_j= *Storage area of each candidate facility* $j \in J$

f_j= *Cost of locate a distribution center at candidate* $j \in J$

c= 2.5($/km) transport (Combustible + Maintenance by km.)

S= 19.312 km Cover service radius.

d_{ij}= *Distances between facilities and hospitals*

h_i= *Expected demand value associated to node i*

t = $5,000.00 unity cost freight of products between distribution centers.

The process involves using the GAMS IDE 27723-27726 software as a solver to address a linear mathematical problem, which is then coded and solved using the CPLEX Solver [11]. Subsequently, QGIS was employed to visualize the results as a geographic distribution network. Various optimal solutions are generated for different parameter *S* values, representing the cover radius of the service.

[48] *Solution with delivery time [60-120) min*

For the initial result, the model used a parameter *S* ranging from 28.995 km (equivalent to 1.5 h travel time) to 19.312 km (equivalent to 1 h travel time). The solution indicated the selection of two facilities as distribution centers (Figure 3), with a distribution cost of $43,474.90 (Table 4).

RESULTS REVIEW SOLUTION A

Results	
Distribution cost Z =	$ 43,474.90
Facilities selected	2
Average transport time:	24.8 min
Average traveled distance	7.982 km
Total storage area:	67m^2

Distribution Network for Solution A

[49] *Solution with delivery time [45-60) min*

For the second solution, the model uses a parameter *S* ranging from 19.312 km (equivalent to 1 h of travel time) to 14.4975 km (equivalent to 45 min of travel time). The solution indicates the selection of three facilities as distribution centers (Figure 4), with a distribution cost of $56,054.99 (Table 5).

RESULTS REVIEW SOLUTION B

Results	
Distribution cost Z =	$56,054.99
Facilities selected	3
Average traveled distance	6.601 km
Average transport time	20.5 min
Total storage area	86m^2

Distribution Network for Solution B

[50] *Solution with delivery time [37-45) min*

For the third solution, the model uses a parameter *S* ranging from 14.4975 km (equivalent to 45 min travel time) to 12.07 km (equivalent to 37min travel time). The solution indicates the selection of four facilities as distribution centers (Figure 5), with a distribution cost of $56,054.99 (Table 6).

RESULT REVIEW SOLUTION C

Results	
Distribution cost Z =	$70,106.64
Facilities selected	4
Average traveled distance	6.44 km
Average transport time	20.0 min
Total storage area	111m^2

Network of distribution of Solution C

XIII. CONCLUSIONS

A review of the results obtained from the proposed model of location allocation facilities for the distribution of Integrated Medical Services led to the following conclusions:

Although the model does not perfectly mirror the real-world scenario, it effectively identifies crucial decision variables and parameters essential for the distribution plan.

The model produces various optimal solutions by changing the values related to distance, time, and cost. This flexibility enables comparisons between different solutions, facilitating decision making that considers both customer and company needs.

Solutions generated by the model rely on quantitative data, eliminating the need for empirical justifications for variables or parameters. In summary, the proposed model successfully achieves the objectives and expectations set for this investigation.

In future work, we could consider a simulation of the distribution of services using the results of the location-allocation model. The speed in the city changes a lot because of road restrictions such as traffic lights, speed limits, and road complications such as accidents or closed ways by social meetings. We could consider a simulation by software of the transport of the integrated medical services with these elements to have a better analysis of the obtained results of the model.

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Technology and Transportation efficiency

Articles

A review of Machine Learning Techniques on Transportation Systems

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***Abstract*— This paper reviews how machine learning (ML) impacts transportation systems, focusing on traffic flow, public transport, and freight logistics. It discusses the opportunities that ML must change transportation systems by improving real-time traffic management and enhancing decision-making. However, there are risks like privacy data and ethical considerations, not only in autonomous technology, trying to avoid any kind of segmentation. These opportunities and risks must be addressed with interdisciplinary groups and regulatory frameworks to integrate ML into transportation systems.**

Machine learning; Transportation systems; Transport decision Making; Real-Time Traffic Management

I. Introduction

In the actual world, transportation systems are crucial in the economic and social, development. The ability to move people and goods efficiently, safely, and sustainably is fundamental to the development and prosperity of nations. As urbanization accelerates and the demand for transportation grows, the challenges of managing and optimizing these complex systems have become increasingly evident. Traditional methods of planning, operating, and managing transportation infrastructure are being reevaluated in the face of evolving urban dynamics, environmental concerns, and the rapid advancement of technology.

The intersection of transportation with technologies like ML and artificial intelligence (AI), represents a change in the way transportation systems are designed, operated, and experienced. ML, with its ability to analyze large volumes of data and uncover patterns that human cannot detect, offers unprecedented opportunities for enhancing the efficiency, safety, and sustainability of transportation. From optimizing traffic flow and improving public transit systems to enhancing freight logistics and predicting transportation trends, ML applications are reshaping the transportation sector.

This paper delves into the literature about transportation systems, focusing on the impact of ML in advancing transportation solutions. It reviews recent studies, projects, and theoretical discussions to highlight the current state of ML applications in transportation, the challenges faced in integrating these technologies, and the future directions of this field. The exploration covers many facets of transportation, including traffic management, public transit, freight logistics, and intelligent transportation systems (ITS), providing insights into the innovative approaches being adopted to address the complex challenges of modern transportation. These include Extreme Randomized Trees (Extra Trees), Adaptive Boosting (AdaBoost), and Support Vector Regression (SVR), Random Forests (RF), Long Short-Term Memory (LSTM) and Artificial Neural Networks (ANN).

II. Transport

Transport is an essential sector for economic and social development, facilitating citizens' mobility needs related to commuting to work, shopping, leisure activities, and more Dirección General de Industria, Energia y Minas, 2012 [1].The term "transportat sector" encompasses the various means used to move people or goods from one place to another. Within this sector, there are two main categories: freight transportation and passenger transportation. In addition, there are three main modes of transportation: Road Transportation, which includes all road transportation systems, both private and public (such as cars, buses, trucks, motorcycles), railways, and pipeline transportation (for gas and oil); Maritime Transportation, which includes vessels (such as passenger ships, ferries, cargo ships, oil tankers), and includes foreign navigation, cabotage, and navigation through canals and inland waterways; and Air Transportation, which includes the movement of people and goods; and air transport, which includes the movement of passengers or goods by airplanes, helicopters and light aircraft, including scheduled and non-scheduled flights [1]

These transport services have different characteristics, such as the fact that their demand is of a derived nature, i.e. travel is not demanded, but is made with the aim of carrying out an activity localized in space and time, and to satisfy it, the infrastructure or network, the set formed by the different services and a management system are necessary. On the other hand, its supply is a mixture of public and private capital through the infrastructure and the different transport operators. These characteristics form a transport system [2]

Due to its characteristics the transportation system is transitioning from being technology-driven and independent to becoming a data-driven integrated network of interconnected systems. J. Zhang, et al, 20211, [3].

The increased accessibility of data has made it possible to identify real-time traffic flow patterns and individual driver behavior in different traffic conditions. This capability significantly improves the efficiency of current transportation system operations and enables prediction of future trends improving its performance Bhavsar, et al, 2017 [4]. However, the access to the data poses several challenges that have been addressed with the use of ML techniques.

III. MACHINE LEARNING (ML)

ML is a set of techniques that enable computers to automatically construct data-driven models and algorithms by systematically identifying statistically significant patterns in given data. The synthesis of intelligence—its implications [5].

ML encompasses a variety of methods and algorithms that can be classified by the type of "learning" involved. There are several basic types of learning methods, including: The synthesis of intelligence—its implications [5] which uses pre-labeled data to guide the learning process; Some studies in ML using the game of checkers [6] uses both labeled and unlabeled data; and Mining association rules between sets of items in large databases [7] relies on a series of feedback or reward cycles to guide the learning process.

IV. ML APLLICATIONS ON TRANSPORT STATE OF THE ART

To do the review we are going to use the next principal insights: Sustainable and inclusive transportation, Enhanced decision-making, Interdisciplinary collaboration, Challenges in data and integration and Future directions.

A. Sustainable and inclusive transportation

A detailed analysis of the use of Machine Learning in public bus transportation was provided in Machine Learning Applied to Public Transportation by Bus: A Systematic Literature Review [24]. It describes the modeling techniques used in these solutions, including the data types and ML algorithms employed.

Skhosana, et al, 2020, An Intelligent ML-Based Real-Time Public Transport System [25] propose a system in which bus managers can use a web application that incorporates a neural network trained to forecast ridership numbers per route. The neural network is fed with ridership data collected by an Android application used by bus drivers. Concluding that the system is effective, since it shows a decrease in total mileage for commuter transport, leading to lower fuel costs. Furthermore, the system increases profits for bus operators and improves the fulfillment of ridership requests, resulting in higher satisfaction levels among commuters with a 95% accuracy when the model is trained with standardized data.

A ML framework to examine the impact of land use patterns on predicting aggregate public vehicle speeds, a crucial aspect of public transportation by training gradient-boosting tree models with road properties, temporal factors (such as day and time), and land use data as input features to predict vehicle speeds on different roads in the city to gain insights into urban transportation dynamics, especially in developing cities aiming to inform urban planning and policy-making efforts to improve transportation efficiency and infrastructure development by clarifying the interplay between land use patterns and public transportation metrics. This framework was presented in the paper Use of ML in understanding transport dynamics of land use and public transportation in a developing city. The ML techniques show an accuracy of 95 % [26].

In Simulation, Optimization, and ML in Sustainable Transportation Systems: Models and Applications [27] reviews the scientific methodologies used to advance Sustainable Transportation Systems (STS), including simulation, optimization, ML, and fuzzy sets. It explains how each methodology is used in designing and improving the efficiency of STS, providing insights into their respective applications and contributions. Since STS has multifaceted aspects combining economic, social, and environmental sustainability considerations, the necessity of utilizing hybrid models is addressed.

A comprehensive exploration of the current state-of-the-art in the development of ML models for various aspects of international freight transportation management (IFTM) was provided in ML for international freight transportation management: A comprehensive review [28]. It explores potential data sources for developing ML models, expanding the understanding of available resources for model training and validation. Concluding that Artificial Neural Networks (ANN) are a prominent ML method that has gained attention for its effectiveness in addressing various challenges within IFTM and that the increasing prevalence of Big Data in international freight transportation and recent advancements in ML, there is a renewed opportunity to conduct data-driven research and leverage ML techniques to enhance decision-making processes and operational efficiency within IFTM.

The paper Emerging Technologies for Smart Cities' Transportation: Geo-Information, Data Analytics and ML Approaches [29] present a comprehensive review and discussion of emerging technologies relevant to transportation in the supply chain, from various data-driven perspectives covering geoinformation, data analytics, ML, integrated deep learning, and artificial intelligence (AI) approaches, demonstrating the efficacy of data-driven approaches in shaping smart cities and transportation architecture.

Identify applicable sponsor/s here. *(sponsors)*

A Fusion-Based Intelligent Traffic Congestion Control System for Vehicular Networks (FITCCS-VN that leverages ML techniques to gather traffic data and efficiently route vehicles through available pathways to mitigate congestion in smart cities was introduced in Smart cities: Fusion-based intelligent traffic congestion control system for vehicular networks using ML techniques [34]. The system offers drivers innovative services, allowing them to remotely monitor traffic flow and vehicle volume on roads, facilitating avoidance of traffic bottlenecks. The proposed model significantly enhances traffic flow and reduces congestion levels with 95% accuracy and a 5% miss rate when using ML techniques.

The principal contribution of some reviews for this insight are in the next table.

Table 1. Sustainable and inclusive transportation contributions

Author	Principal Contribution	Year	Technique	Metric
Alexandre, T., et al.	ML in public bus transportation.	2023	Literature review methodology	NA
Skhosana, M., et al.	ML for real-time public transport.	2024	Neural Networks	Mean Squared Error
Dorosan, M., et al.	ML in transport dynamics and land use.	2024	Gradient-boosting tree	R^2
de la Torre, R., et al.	ML in sustainable transportation.	2021	Literature review methodology	NA
Barua, L., et al.	ML in freight transportation management.	2020	Literature review methodology	NA
Ang, K. L.-M., et al.	Emerging technologies in smart cities.	2022	Literature review methodology	NA
Saleem, M., et al.	Intelligent traffic control in smart cities.	2022	Neural Networks and support Vector Machine	R^2 and Mean Squared Error

B. Enhanced decision-making

In the paper Study of ML Techniques for Transport. [9] used ML and simulation methods, focusing on neural networks for optimizing transportation routes. As a result, they developed software to automate critical transportation tasks using ML approaches. Their work also included assessing the sustainability of transportation solutions using ML methods and exploring the integration of ML with digital control systems.

Zhiyuan Liu, et al, 2019 [10] conducted a study focusing on the estimation of traffic flow in urban transportation networks using Cell Phone Location (CL) and License Plate Recognition (LPR) data. Proposing two methods to filter CL data and extract spatio-temporal traffic features for a given road segment and a tailored ML approach consisting of two components: a concrete multi-grained scan ensemble learning model and a novel two-stage zero-shot learner to estimate traffic flow on a single link using filtered CL data, extracted spatio-temporal traffic features of these links and relevant land-use information, and LPR data, integrating their unique advantages with an MAPE from 13% to 29.5%.

In the paper ML-based traffic prediction models for Intelligent Transportation Systems [11] aim to provide a comprehensive review of different ML models, analyzing their respective strengths and weaknesses. To achieve a categorization of different ML models based on the underlying ML theories used. A comparison across categories to gain a macroscopic understanding of which types of ML methods excel at prediction tasks based on their unique model features is performed and applied to traffic prediction.

The paper Inferencing hourly traffic volume using data-driven ML and graph theory [12] present an innovative spatial prediction method for estimating hourly traffic volume at the network scale employing Extreme Gradient Boosting Tree (XGBoost) and incorporating spatial dependencies between road segments into the proposed model using graph theory. Concluding that the numerical results not only demonstrate the high computational efficiency of the proposed model, but also show a significant improvement in the prediction accuracy with the highest R^2, and the lowest values of MAE and MAPE for the hourly traffic volume compared to benchmark models.

Müller-Hannemann, et al, 2022, Estimating the robustness of public transport schedules using ML [14] present a novel approach to approximate scenario-based robustness using ML regression models, using key features to train regression models to approximate robustness and integrating black boxes into local search algorithms to improve schedule robustness showing an improvement about 60%.

Time Prediction in a Multimodal Freight Transport Relation Using ML Algorithms. Logistics [15] use ML algorithms: Extreme Randomized Trees (ExtraTrees), Adaptive Boosting (AdaBoost), and Support Vector Regression (SVR), with different combinations of features extracted from the dataset to predict travel time. Showing that SVR has superior performance in accurately estimating travel time compared to the other algorithms, with a mean absolute error of 17 h which is better than average-based approaches.

An in-depth exploration of state-of-the-art ML-based technologies, organized into a three-tier solution taxonomy was provided in ML-based traffic scheduling techniques for intelligent transportation system: Opportunities and challenges [16]. The first tier includes a variety of tools and technologies used for traffic data collection. The second tier focuses on ML algorithms and their accuracy in identifying patterns within the collected data, thereby extracting critical insights about traffic flow, congestion levels, and related factors. In the third tier, the research delves into various traffic enforcement planning strategies, which are the most important layer of the taxonomy.

A novel approach was introduced in Predicting drivers' route trajectories in last-mile delivery using a pair-wise attention-based pointer neural network [19] for predicting delivery routes using historical driver trajectory data based on a specific neural network designed to capture local pair-wise information for each pair of stops and introduction of a new iterative sequence generation algorithm applied to a case study with real operational data from last-mile delivery operations. The proposed model outperforms traditional optimization-based approaches and other ML methods by increasing the average prediction accuracy by 0.229 to 0.312 and reducing the disparity between routes by around 15%.

The study Short- & long-term forecasting of multimodal transport passenger flows with ML methods [20] addresses the prediction of passenger flow in multimodal transportation, including train stations, bus stops, and tram stops. Long-term and short-term forecasting models are developed using ML techniques, including Random Forests (RF), Long Short-Term Memory (LSTM) neural networks, and calendar models to predict the volume of passengers entering each station or boarding at each stop. Demonstrating the effectiveness of ML methods in these forecasting tasks, providing reliable results across all modes of transportation (train, tram, and bus).

Table 2. Enhanced decision-making contributions

Author	Principal Contribution	Year	Technique	Metrics
Degtyareva, V.V., et al.	ML techniques for transportation.	2021	Neural Netwoks	NA
Liu, Z., et al.	ML for urban transport flow estimation.	2019	Tailored machine learning approach	Mean Absolute Percentage Error
Boukerche, A., & Wang, J.	ML-based traffic prediction models.	2020	Literature review methodology	NA
Yi, Z., et al.	Traffic volume inference using ML.	2021	Extreme gradient boosting tree	Mean Squared Error Mean Absolute Percentage Error R^2
Müller-Hannemann, M., et al.	ML for public transport schedules.	2022	Neural Networks	Mean Absolute Percentage Error
Servos, N., et al.	ML for travel time prediction.	2020	Extremely Randomized Trees, Adaptive Boosting and Support Vector Regression	Mean Absolute Error
Nama, M., et al.	ML in traffic scheduling.	2021	Literature review methodology	NA
Mo, B., et al.	Predicting drivers' route trajectories.	2023	Neural networks	R^2
Toqué, F., et al.	Forecasting transport passenger flows.	2017	Random Forests, Long-Short Term Memory neural networks	Root Mean Square Error Median Absolute Error

C. Interdisciplinary collaboration

The paper A Review of Artificial Intelligence and ML for Incident Detectors in Road Transport Systems. Mathematical and Computational Applications. [18] explore the role of artificial intelligence (AI) and ML in improving automatic incident detection systems to mitigate road traffic accidents. Examining the incident detection using ML and AI, and road management using ML and AI by incorporating wireless communication technologies such as 5G networks, and the application of ML and AI in road transportation system planning and highlights the importance of route optimization, freight volume forecasting, predictive fleet maintenance, real-time vehicle tracking, and traffic management in securing road transportation systems.

In the paper ML applications in activity-travel behavior research: a review [21] examines the literature on activity travel behavior, focusing on the application of ML techniques for empirical analysis and modeling. Observing that there is a lack of interpretability. However, most studies comparing ML techniques to conventional methods note that ML methods perform at least as well, if not better, than conventional approaches.

An overview on the integration of Artificial Intelligence (AI) and ML in Transportation Systems. Focusing on ML techniques aimed at detecting road anomalies to anticipate obstacles and predict real-time traffic flow and AI-based approaches for ensuring road safety through the implementation of management systems was provided in Applications of Artificial Intelligence and ML [22].

In the paper Exploring the Application of ML Algorithms to the City Public Bus Transport [31] use supervised ML algorithms to identify the main factors affecting on-time performance in a bus system , applying various algorithms to create predictive models that can determine whether a bus route adhered to standards on a given day and determine the most influential factors contributing to on-time performance, shedding light on the critical features that influence bus route performance. Thus, improving the understanding of the dynamics within the transportation system, facilitating informed decision-making and potential service delivery improvements.

The use of supervised ML algorithms to analyze the factors that affect the punctuality of Bus Rapid Transit (BRT) system using publicly available datasets and developing accurate predictive models to determine if a bus route will adhere to prescribed on-time performance standards on any given day was shown in Advantages of ML in Bus Transport Analysis since decision trees give on average 93.5% accuracy and K-Nearest neighbor a 91.18% accuracy rate[32].

Table 3. Interdisciplinary collaboration contributions

Author	Principal Contribution	Year	Technique	Metrics
Olugbade, S., et al.	AI and ML for incident detection.	2022	Literature review methodology	NA
Koushik, et al.	ML in activity-travel behavior.	2020	Literature review methodology	NA

Choudhary, et al.	AI and ML applications in transportation.	2021	Neural networks	Mean Squared Error Mean Absolute Percentage Error
Alicea, M., et al.	ML algorithms in city bus transport.	2020	Literature review methodology	NA
Roshanzamir, A.	Advantages of ML in bus transport.	2023	Random forest K-Nearest neighbor.	R^2

D. Challenges in data and integration

In ML techniques applied to the determination of road suitability for the transportation of dangerous substances [13] present a methodology for assessing the level of remedial action required to make short road segments suitable for the transport of dangerous goods (DGT) considering thirty-one factors using multilayer perceptron networks (MLPs), classification trees (CARTs), and support vector machines (SVMs) .The results of these techniques outperformed those of traditional discriminant analysis, regardless of whether dimensionality reduction techniques.

In Intelligent Transportation and Control Systems Using Data Mining and ML Techniques: A Comprehensive Study [33] investigate the use of data mining and ML technologies in research and industry to address the challenges posed by traffic impacts on society. Focusing on traffic management strategies that rely on data mining and ML techniques to detect and predict traffic patterns. Concluding that there is a lack of consensus within the traffic management community regarding a standardized approach to traffic management, however, ML techniques consistently outperformed linear discriminant analysis, regardless of whether dimensionality reduction was applied since Linear discriminant analysis had an error rate of 25.34%, CARTs 15.06%, MLP 14.52%, SVM 14.49% and ordinal SVM 13.19%.

Table 4. Challenges in data and integration contributions

Author	Principal Contribution	Year	Technique	Metrics
Matías, J.M., et al.	ML for road suitability analysis.	2007	Literature review methodology	NA
Alsrehin, N. O., et al.	Data mining and ML in ITS.	2019	Multilayer perceptron networks Classification trees Support vector machines	R^2

E. Future directions.

In the paper A Review of ML and IoT in Smart Transportation [8] highlight the breadth of ML algorithms proposed and evaluated for smart transportation applications, suggesting the suitability of IoT data in these contexts for ML exploitation. Conversely, a comparatively limited ML coverage for smart lighting systems and parking applications is observed within the current IoT and ML landscape. The analysis reveals a potential lack of ML coverage for smart lighting systems and smart parking applications. In addition, route optimization, parking management, and accident detection emerge as the most common ITS applications among researchers.

Yuan, et al, 2021 [17] present a novel modeling framework called Physics Regularized ML (PRML), which is designed to embed classical traffic flow models that outperforms previous compatible methods, including calibrated traffic flow models and pure ML approaches, in terms of estimation accuracy and robustness to noisy training data sets with 15% to 18% in MAPE.

ML for next-generation intelligent transportation systems: A survey [23] examine the application of ML in intelligent transportation systems (ITS) like cooperative driving and road hazard warning since ML advances are a key for transformative change into perception, prediction, and management domains.

Issam Damaj, et al, 2022, Intelligent transportation systems: A survey on modern hardware devices for the era of ML [30] make a comprehensive review of recent literature on ML -driven Intelligent Transportation Systems (ITS), with a particular focus on the use of Mobile Health Devices (MHDs) and their associated performance indicators. Recognizing the challenges involved in selecting appropriate ML techniques and model-based health diagnosis methods for intelligent transportation systems (ITS) with varying complexity levels and propose a performance evaluation framework.

In the paper Deep learning methods in transportation domain: a review [35] analyze recent studies on the use of deep learning techniques in processing traffic data. The studies cover various aspects such as transportation network representation, traffic flow forecasting, traffic signal control, automatic vehicle detection, traffic incident processing, travel demand prediction, autonomous driving, and driver behaviors. Despite the growing interest, the use of deep learning systems in transportation is still limited, with potential constraints hindering their widespread adoption for enhancing prediction models.

An examination of the use of Deep Learning (DL) in Intelligent Transportation Systems (ITS), focusing on the methodologies used to address the challenges was presented inm Technologies for Intelligent Transportation Systems: Prospects and Challenges [36]. Emphasizing on architectural design considerations and problem-specific factors that inform the development of innovative solutions to a wide range of areas, including traffic flow prediction, vehicle detection and classification, road condition monitoring, traffic sign recognition, and autonomous vehicle technologies.

Balster, et al, 2020, Prediction Model for Intermodal Transport Networks Based on ML [37] outline the framework of an Estimated Time of Arrival (ETA) prediction model tailored for Intermodal Freight Transport Networks (IFTN), integrating both scheduled and unscheduled transportation using ML techniques. Demonstrating the reliability of ML-based ETA predictions for intermodal freight transportation, including processing times at logistics nodes such as inland terminals, as well as transportation times on road and rail, facilitating proactive communication of potential disruptions to stakeholders throughout the intermodal transportation chain, enabling timely action to mitigate critical delays in subsequent transportation stages.

Table 5. Future directions contributions.

Author	Principal Contribution	Year	Technique	Metrics
Zantalis, F., et al.	ML and IoT in smart transportation.	2019	Literature review methodology	NA
Yuan, Y., et al.	Traffic flow modeling with ML.	2021	Physics regularized machine learning	Root Mean Square Error Mean Absolute Percentage Error
Yuan, T., et al.	ML in next-gen transportation systems.	2022	Literature review methodology	NA
Damaj, I., et al.	Survey on devices for ITS.	2022	Literature review methodology	NA
Nguyen, H., et al.	Deep learning in transportation.	2018	Literature review methodology	NA
Khalil, R. A., et al.	Learning technologies in ITS.	2024	Literature review methodology	NA
Balster, A., et al.	ML-based ETA prediction for transport.	2020	Random forest Gradient boosting	NA

V. Conclusions

The exploration of ML applications within the transportation sector identifies an important transformation, leveraging data-driven insights to enhance efficiency, safety, and sustainability. The literature review shows a variety of ML applications, ranging from traffic flow optimization and public transit enhancement to advanced freight management and the development of intelligent transportation systems (ITS). These innovations mark a significant departure from conventional transportation management practices, offering a more adaptive, predictive, and integrated approach to addressing the complexities of modern transportation challenges.

From the principal insights explored we can summarize:

Enhanced Decision-Making. ML algorithms provide transportation stakeholders with powerful tools for informed decision-making, enabling the anticipation of traffic patterns, optimization of route planning, and the dynamic allocation of resources. This capacity significantly improves operational efficiency and user satisfaction.

Predictive Analytics for Future Trends. The use of ML in transportation goes beyond real-time analytics to include the prediction of future trends. By analyzing historical and current data, ML models can forecast demand, identify potential bottlenecks, and suggest preventive measures to mitigate traffic congestion and enhance the robustness of transportation systems.

Challenges in Data and Integration. Despite the promising applications of ML in transportation, challenges remain, particularly regarding the quality, accessibility, and standardization of data. Additionally, the integration of ML technologies into existing transportation infrastructure requires careful consideration of technical, regulatory, and ethical issues.

Interdisciplinary Collaboration. The successful implementation of ML in transportation necessitates interdisciplinary collaboration, bringing together experts in ML, transportation engineering, urban planning, policy-making, and other relevant fields. This collaborative approach is crucial for developing comprehensive solutions that address the multifaceted nature of transportation challenges.

Sustainable and Inclusive Transportation. ML applications offer pathways to more sustainable and inclusive transportation systems. By optimizing routes, reducing travel times, and enhancing the efficiency of public transit and freight operations, ML contributes to lower emissions and increased accessibility, supporting broader sustainability and inclusivity goals.

Future Directions. The ongoing evolution of ML technologies, coupled with advancements in data collection and analysis (e.g., through IoT devices), presents new opportunities for further enhancing transportation systems. Future research should focus on the ethical use of data, the scalability of ML solutions, and the exploration of novel applications in emerging areas such as autonomous vehicles and multimodal transportation networks.

Finally, the integration of ML into transportation systems may represents a solution to the actual transportation challenges. By using the power of ML, stakeholders can enhance the efficiency, safety, and sustainability of transportation networks. However, realizing this potential fully requires overcoming data-related challenges, fostering interdisciplinary collaboration, and ensuring the ethical application of these technologies. As the field continues to evolve, the continued exploration and adoption of ML in transportation will be critical for shaping the future of mobility.

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Use of dashboard service for optimization and measurement of Key Performance Indicators

An IT decision tool at Cross Docking of a Retail company

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***Abstract*— In the era of knowledge and information technologies, we need to identify strategies for the appropriate use of information and data extraction that allow us to be efficient in the operation of the supply chain. Several authors [4] refer to opportunities and challenges in data analysis, such as listening to data and measuring information.**

The present paper consists of a data analysis for the optimization of information within the operational area. The consolidation of this information was carried out within the processes that make up Cross Docking in a Distribution Center of a Retail company, to subsequently obtain the necessary Key performance Indicators (KPI'S) to identify the merchandise rotation.

A report was developed through the Looker Studio platform (Dashboard Platform), which will provide information in real time, graphically and easily accessible, seeking the ease of showing the indicators for each of the areas, which will support inventory rotation, optimization of times and movements and communication within the areas. We conclude that general performance indicators already exist for the control of the retail supply chain; However, the calculation of performance indicators and dashboard visualization should aim to control the supply chain process.

Keywords- dashboard, retail, cross docking, inventory

I. INTRODUCTION

In 2023 a retail company showed deficiencies in inventory rotation because the average minimum storage time of merchandise is two days, this to meet the needs of store supply and transportation use.

However, the information on the status and volume of parts to be distributed is fragmented throughout the Cross Docking process, which is why the information is sought to be consolidated, to have a structured and updated analysis of the Stock that is held in the Distribution Center.

The same data analysis will allow us to build and structure the KPI's to locate the improvement times to which we must focus for inventory turnover and reduce the age time of the pieces in Stock, the same areas of opportunity that will help us meet customer service goals, since the store will have an optimal supply, avoiding shortages and improving the shopping experience.

In the next part of the document, we will describe definition and classification of retail trade; definition of dashboards, methodology for constructing a dashboard and its evaluation; finally, a case study of the use of the dashboard service as a technological decision tool in the cross docking of a retail company.

II. DASHBOARD CONTEXT

Dashboard provides a means for managers to monitor, analyze, and perform planning and budgeting. Decision makers use a dashboard to visualize, analyze and compare historical behavior with budgets, and forecasts. And later follow up, through dashboard updates, they could analyze trends and variations of the real conditions [14].

A. Dashboard classification

We can find the follow dashboard classification:

If we are talking about the planning definition [14], there are strategic, tactical, and operational dashboards.

1. Strategic dashboards, which support organizational alignment with strategic goals.
2. Tactical dashboards, which support the measuring of progress in key projects or initiatives.
3. Operational dashboards, which support the monitoring of specific business activities.

If we are talking about KPI control decisions, there are short- and long-range dashboards.

1. Short-range dashboard, it is a dashboard that displays daily information. It is typically used to monitor week, month, quarter, or year progressions. This type of data is frequently displayed in operational dashboards.
2. Long-range dashboard, it is a dashboard that contains a longer time range is usually called a strategic dashboard. Such a dashboard would contain higher-level calculations and key performance indicators (KPIs).

B. Methodology for constructing a dashboard

1. Pre-Modeling activity

- Characterize the environment: To build a dashboard, it is important to focus on the environment where your analysis will be based, to identify the areas in which you will focus on the search for data information and cover only those that are involved.
- Map under study: Once you have considered your environment and focused on the areas of analysis, you must build an object map, where the areas will be studied to determine the important information for the analysis.
- Select the process entities of interest and formalize the measurement objectives: When localized areas of improvement opportunities are found, it is important to analyze what the measurement objectives will be that will help us in analysis and decision making. For this it is important to know the area, what its threats and strengths are.
- Ask measurable questions that address measurement objectives: By formulating quantifiable questions that address the objectives, it helps us know the analysis approach as well as the information we need to collect to address the answers.
- Identify indicators that answer quantifiable questions: With the help of methodologies focused on process analysis and improvement, we can identify those indicators that will help us answer quantifiable questions, so it is important to take the objectives into account when carrying out any improvement analysis.
- Conceptualize the scorecard: At this point we seek to focus the objectives within the area as well as define the indicators focused on decision making within the areas of opportunity to work on.
- To keep in mind to avoid errors: the problem of dashboard design, which is extremely important in the areas of data analysis and decision making. To avoid misleading business users, managers, and other stakeholders through inappropriately designed dashboards, which may contain inappropriate visualization charts and graphs that do not fit the data sets considered.

2. Modeling activity

- Identify the data elements to collect: Having conceptualized the scorecard, the data to be collected will focus on satisfying the information necessary to carry out the improvement analysis for the process or area, which allows focusing on the objectives established at the beginning.
- Collect data, implement, and refine the dashboard: This approach is based on the transformation of the data mart or data warehouse from the star schema, an extremely popular and simple data structure, into the flat data set, suitable for selection and projection operations that must be used to produce subsets of data. data. The dashboard design alternatives obtained can be chosen by analysts for later use or as proofs of concept for demonstration to business users.
- Model validation: The purpose of this stage is to verify that there is no lack of information and to evaluate the organization and representation of the format.

3. Post-modeling activity

- Continuous improvement, adaptability, integrate information from the areas: When the dashboards are finished, the update, as well as the maintenance, lend themselves to continuous improvements over time, which is important to consider to implement improvements, whether visual, graphic or information, to have a greater scope of analysis, On the other hand, this allows for adaptability throughout use over time, allowing for the integration of valuable information for decision-making.
- Changes to other elements of the dashboard model, such as breadcrumbs, and access control, are as simple

as updating the corresponding models, making dashboard maintenance an easy and manageable task.

III. RETAIL CONTEXT

Retail is the activity of selling goods to the public, usually in shops. It is a largely high-volume business, it has greater volume consolidation, and better purchasing conditions. In business management, the tasks of retail commerce are a) determine the needs of its market and b) satisfying more effectively than its competitors [18].

The retail sector includes the marketing of retail products and has two distribution channels: traditional and modern. This sector is important because it is a source of investment, job creation (especially in the modern channel) and tax revenue.

C. *Use of dashboard in retail*

Since 2014, Yesudas, M. et Al. have been documenting dynamic data analysis to create operational reports for retail companies. whose objective was to establish strategic business reports [19].

A. Gunawan described specific applications of using commercial panels for automobile sales [6]. The use of dashboards and business intelligence is documented in the online retail industry [1].

In 2023, different technological platforms have been used to create retail dashboards whose objective has been to reveal trends and evaluate business performance. These platforms are Power Bi [9], Tag Helpers [2] and Apache Superset [15].

The data analysis uses a panel that has the double objective of offering information on the best-selling products [9]. As well as customer segmentation with a recency, frequency and monetary (RFM) approach where the frequency and purchase amount per customer is evaluated, to suggest a classification of customers: loyal, promising and in need of attention, all this through K-Means algorithm [7].

Table 1 shows the dashboard development software documented in the literature review for monitoring the operation of retail companies.

1. TABLE. DASHBOARD DEVELOPMENT SOFTWARE

No.	**Literature review**	
	Autor	***Software***
1	Yesudas et Al. (2014)	IBM Sterling Order Management System
• 2	Gunawan(2020), Tungare, N. R.; Jha, D. G. (2023)	Mobile application (R and SQL)
3	Al-Omoush et. Al. (2022), Hilmy F. M. et. Al. (2023)	Python
4	Kanagaraj, K.; Venkatesh, R. (2023)	Power BI
5	Bataieneh et. Al. (2023)	Tag Helpers in ASP.NET
6	Soares, G. H.; Brito, M. A. (2023)	Apache Superset

a. Source: own elaboration.

D. *Retail dashboard Key performance indicator*

Mirabel et Al. describes a conceptual framework for a supply chain analysis. They establish three characteristics of visibility as automation, information, and transformational organization of consolidated reports [11]. They also establish the follow performance indicators:

1. A stockout rate (leading) is when items are not available upon the requested need date.
2. A gross inventory value (lagging) is an average inventory value.
3. An inventory turnover (leading) is the rate of how many times a company can replace the inventories it has sold in a given period.
4. An inventory day of supply (leading) is how many days it will take for the stock to run out if sales continue at the same rate as recent sales.

Natvig and Wienhofena establishes performance indicators for the construction of transportation dashboards, prototype performance indicators are described after area of interest [13].

- Routes: provides status for all routes/trucks (foreseen delays, available capacities, etc.)
- Truck-in/out: supports follow up of transport operations by providing truck status (foreseen arrivals, delays, faulty deliveries, temperature, etc.)
- Warehouse-in: supports cargo receptions and cross-docking
- Warehouse-out: support goods expeditions from warehouse
- Shops: supports goods receptions in shops.

The next part of the paper describes the process to build a dashboard for a retail company, the necessary performance indicator for the company's stakeholders and the feedback process must be identified.

IV. DASHBOARD DEVELOPMENT FOR A SERVICE AT RETAIL COMPANY

The transportation of Cross Docking merchandise to the different stores was carried out by observing the occupied capacity of the spaces assigned to each store. This information was controlled visually directly in the warehouse.

When the analysis of the database begins, it is identified that the replenishment of merchandise by store had an area of opportunity as seen in Figure 1. In which it is observed that there are stores with unstocked inventory for eight or more days. (visually you can see the bars shaded in yellow and red).

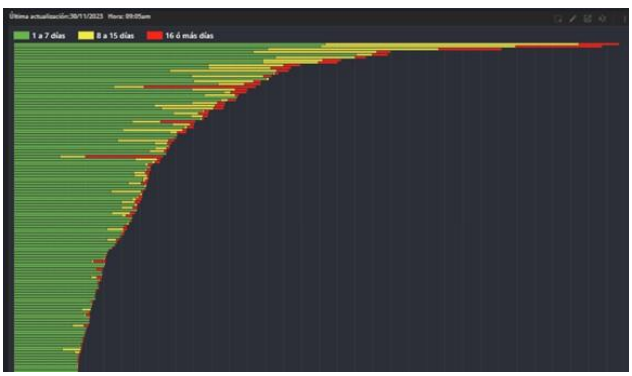

Figure 1. Number of merchandises at warehouse, Source: own elaboration.

Therefore, the replenishment strategy is changed to schedule the supply of those stores that had the longest inventory of unstocked parts, this is greater than eight days old.

A. *Objective*

Prioritize routing to stores, through the total Cross Docking process, to optimize inventory rotation and meet the company's objective of only retaining merchandise for a period of no more than one week.

By identifying all the questions that interested parties may have, the information to be presented on the dashboard can be determined. The relevant information that needs to be included in the dashboard is divided into the categories of:

B. *Pre Modeling activity for study case*

1. Situation: For the analysis of the stay time and average times of each process within the Cross Docking until its average Lead Time, the project was carried out since the month of September giving us an approximate average stay time of 5.33 days for a piece in the distribution center independent of its destination, as can be seen in figure 3. As well as a total Lead time of around 9.07 days, which reflects how low its inventory turnover was and the importance of having an indicator meter to prioritize destinations and pieces to send. Logistics: evaluation of available resources
2. Cartography: Monitor the 187 stores that are supplied in the interior of the Mexican Republic,
3. Activities: Download information on the number of units available in warehouses to supply stores in the interior of the republic via Cross Docking, daily. Generate the available inventory update and make the lead time heat map.
4. Communication: Share available inventory and heat map on the internal Google-locker studio portal.
5. Anticipation: The transportation area establishes priorities to carry out the routing and programming of units by size and type of load.

C. *Modeling activity for study case*

- Identify the data elements to collect: To carry out each of the control panels, information was collected from the logistics process area around the entire distribution center, in addition to the transportation area to be able to manage the replenishment frequency of the stores.
- Collect data, implement, and refine the dashboard: Database work was carried out to create a database that was fed daily to obtain both historical and real-time information. Measurement times were also implemented to regulate the age of parts in the

distribution center and the resupply of each one. Of the stores.

- Model validation: It is divided into three evaluations.

1. The first evaluation allows those involved to begin to familiarize themselves with the tool. For the analysis of the dwell time and average times of each process within the Cross Docking to its average Lead Time. The project has been running since September, giving us an approximate average time of 5.33 days for a part to remain in the distribution center regardless of its destination. As well as a total lead time of around 9.07 days, which reflects how low their inventory turnover was and the importance of having an indicator meter to prioritize the destinations and parts to be sent.

The results of October and November were updated to the date of the analysis that was carried out to reduce times within the merchandise transit zone; as well as reception time, which were prioritized to reduce the average Cross Docking time and Lead Time (see Figure 2).

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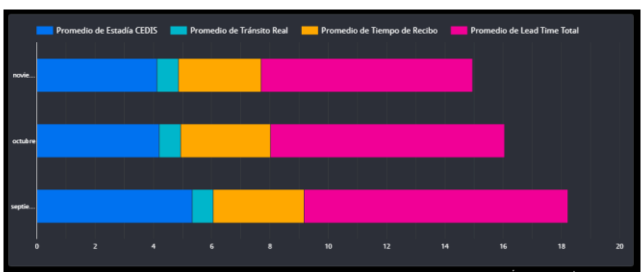

Figure 2. Traceability of lead time reduction within the warehouse. Source: own elaboration.

2. The second evaluation refers to the information in the interface according to their needs. At the figure 3 we can see the scale at the store level, to identify the destinations that should be prioritized. And measure the times that can be maintained or improved, which will allow us to provide a better restocking service and thus keep possible sales and always needs within the customer's reach.

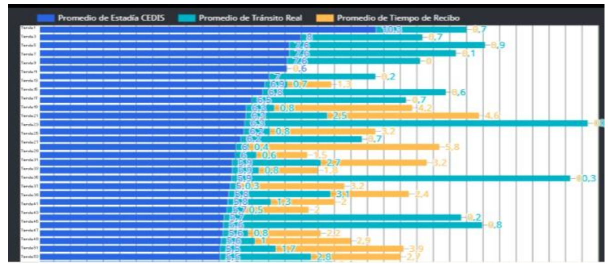

Figure 3. Stay, transit and in-store receipt. Source: own elaboration.

3. The third evaluation is a summary of historical data, this to be able to contrast the totals month by month, which helps us to measure them partially for the next few days or months.

	Mes	Promedio de Estadía CEDIS	Promedio de Tiempo de Recibo	Promedio de Lead Time Total
1.	noviembre	4,12	2,84	7,26
2.	octubre	4,19	3,1	8,03
3.	septiembre	5,33	3,11	9,07

Figure 4. Stay, receipt and lead time in store. Source: own elaboration.

Subsequently, problems were found in measuring store visits for each of the units. We did not have a measurement parameter that would provide us with information on the frequency of refills in stores in the republic. This caused shortages in stores that were located on the borders of the national territory, as they were the least frequented, and their growth was unknown. For this reason, store visit indicators were established to measure replenishment and improve commercial and logistics planning.

Figure 5 shows each of the stores and the number of times they are supplied is differentiated by color. This creates a heat map, which provides us with graphical and summary information about the status of each store. The heat map has filters to obtain information clearly, concisely, and quickly, in addition to allowing managers and the logistics area to interact with the information. Once the information is observed, action plans can be developed for those stores that fall within the red parameterization, which indicates one visit or less per month to the store.

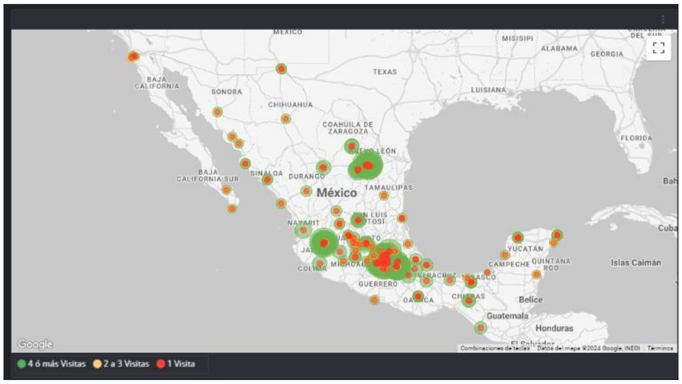

Figure 5. Store visit frequency dashboard. Source: own elaboration.

In addition to the above, a summary of the logistics area was carried out (see figure 6), which provides us with information segmented by the type of stores to be able to visualize the visits where we can concentrate.

Other KPIs are shown in Figure 6 as percentage of target by month, total number of store visits; top 10 stores with the most visits (4 or more visits with a green color block) and stores with the least visits (with a red color block).

Figure 6. Top 10 visit frequency dashboard. Source: own elaboration.

D. ¨Post-modeling activity for study case

Complementing the previous report, Irregularities were found for the assortment regarding imported merchandise, as it is a different merchandise from the national one, there is a different assortment and shipping process than the national product, which is why we seek to have control in the imported merchandise, as shown in figure 7, an analysis and dynamic dashboard was carried out regarding the stock held in CEDIS, particularly Import, in order to keep control.

Figure 7. Import in stock inventory dashboard. Source: own elaboration.

Each dashboard handles specific analyses, depending on the needs that arise throughout the interaction and joint work of each of the areas to be controlled.

It is important to see how each of the developed dashboards converge and support more than one area, this with the purpose of maintaining information communication, which supports decision making to optimize and streamline the cross docking of all the merchandise.

The logistics area is in a different state of change, which is why adaptability and updating is important daily, so the control boards continue to be improved, seeking to combine the information from each of the areas to have all the information in the decision making.

V. RESULTS AND CONCLUSIONS

Through the boards there has been greater control in each of the areas that make up the logistics of a retail company.

Based on the visibility of the data in the Cross Docking and Lead Time, as well as the age of the parts in the available stock, it has been possible to take an action plan to have a greater inventory rotation and greater profitability in transport. optimizing resources and allowing constant replenishment in each of the company's stores.

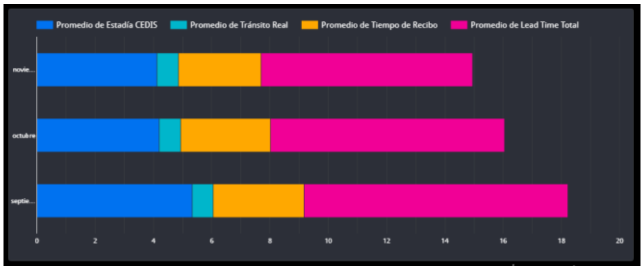

Figure 8. Traceability of lead time reduction within the warehouse. Source: own elaboration.

Figure 8 shows how it is made possible to optimize times and movements within the assortment and shipping processes throughout the cross docking of products, allowing for better inventory rotation within the warehouse, around the months of August, September, and October.

Product availability within each of the company's 187 stores plays an important role in meeting customer needs, since the construction of the transportation area dashboard, there has been a higher replenishment frequency to the stores than the previous month (see figure 9). Allowing us to monitor stores less or more frequently for optimal transportation routing.

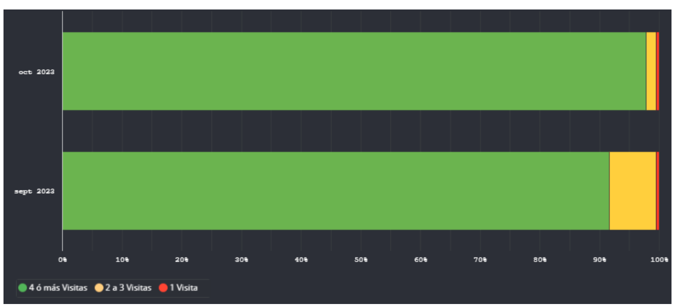

Figure 9. Recharge frequency for the months of October and September. Source: own elaboration.

In the literature review, general performance indicators for retail supply chain control are documented; However, the calculation of the performance indicator should aim to control the analysis process. Table 2 shows the performance indicators that provided a solution to the objective of the problem presented in warehouse of the retailer.

2. TABLE. COMPARISON OF PERFORMANCE INDICATORS

No.	**Performance Indicators**			
	KPI	***Mirabel et Al. [11]***	***Natvig et Al. [13]***	***Documented case***
1	Stockout rate	✓	●	✓
2	Gross inventory value	✓	●	●
3	Inventory turnover	✓	✓	✓
4	Inventory day of supply	✓	●	✓
5	Available capacities	●	✓	✓
6	Cross-docking support goods	●	✓	✓
7	Expeditions from warehouse	●	✓	●
8	Supports goods receptions in shops	●	✓	✓

a. Source: own elaboration.

Dashboards are a very useful tool for decision making because they provide us with important information thanks to the visual ease with which the data can be read. Likewise, updating or consulting it allows you to interconnect several areas, considering each of the data within your line of business.

That is why a dashboard will allow you to optimize information, connect areas and make decisions in real time.

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