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Operational Characterization of Multi-Stop Air Cargo Flights: A Data-Driven Analysis of a Mexican Dedicated Cargo Carrier

David-Leonardo Padilla-Georgge
Faculty of Engineering, Logistics
Manufacturing and Automotive (FILMA), UPAEP - SECIHTI
Puebla, 21 South 1103 Barrio Santiago C.P 72410, Puebla, Mexico
david.padilla@upaep.edu.mx

Diana Sánchez-Partida
Faculty of Engineering, Logistics
Manufacturing and Automotive (FILMA), UPAEP - SECIHTI
Puebla, 21 South 1103 Barrio Santiago C.P 72410, Puebla, México
diana.sanchez@upaep.mx

Patricia Cano-Olivos
Faculty of Engineering, Logistics
Manufacturing and Automotive (FILMA), UPAEP - SECIHTI
Puebla, 21 South 1103 Barrio Santiago C.P 72410, Puebla, Mexico
patricia.cano@upaep.mx

Santiago-Omar Caballero-Morales
Faculty of Engineering, Logistics
Manufacturing and Automotive (FILMA), UPAEP - SECIHTI
Puebla, 21 South 1103 Barrio Santiago C.P 72410, Puebla, Mexico
santiagoomar.caballero@upaep.mx

Abstract

This research analyzes the operation of a Mexican dedicated air cargo carrier operating a fleet of six Boeing 737-400F aircraft, whose primary market is domestic. The study is based on public data collected from August 2023 to December 2025. Data on flights and kilograms of air cargo transported per month were obtained from Mexico's Federal Civil Aviation Agency (AFAC), while fleet flight patterns were obtained from FlightRadar24. This information served as the foundation for a metaheuristic optimization model to guide Unit Load Device (ULD) distribution across multi-stop operations. Since cargo movement by station is not publicly available, a three-stage cargo disaggregation model was developed to estimate it. To verify this model's accuracy, estimated monthly cargo was compared against AFAC-reported figures using paired regression analysis, yielding a coefficient of determination of $R^2 = 0.9953$. Several relevant operational features were identified: the fleet averages 2.95 flight hours per aircraft per day; the highest-volume segment is Mérida–Cancún, averaging 16,013 kg per flight; October is the peak month of operations; and domestic segments carry an average of 5,583 kg while international segments carry 11,750 kg. Significant differences

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in cargo weight between consecutive segments within the same multi-stop rotation were also documented. These findings motivate the development of a Genetic Algorithm to minimize ground handling movements, subject to keeping the Center of Gravity (CG) within the certified safety envelope, incorporating the horizontal stabilizer trim setting as an operational resource.

Keywords
Air cargo, unit load devices, multi-stop operations, weight and balance, metaheuristic optimization.

1. Introduction
In the context of world trade, air cargo is characterized by two aspects: in terms of tonnage its participation is very modest, reaching barely 1% of total weight. However, in terms of monetary value, its participation reaches 33% (IATA, 2024; Kupfer et al., 2017). These attributes make this market have very particular characteristics; it is a service dedicated to goods with very short shelf life, such as flowers or some fresh foods. It is also used for products that need to be transported urgently, such as medicines, tissues for medical transplants, some automotive or aeronautical industry inputs involved in Just-In-Time processes (Kupfer et al., 2017). Another interesting sector is e-commerce, which offers its products with delivery times that would be impossible without the availability of air service. This sector has had very solid growth in recent years supported precisely by the air sector (Bombelli et al., 2020). A very particular aspect of this sector is the unidirectionality of cargo; unlike the passenger market where travelers usually start their journey at one place, travel and return to their starting point, in the air cargo sector, transported goods travel from an origin to a destination and very rarely return to the point of origin (Kupfer et al., 2017). This means that cargo logistics and marketing to sell capacity become complicated — some locations are predominantly cargo producers and others are consumers, so there is not necessarily a directional balance (Bombelli et al., 2020).

Multi-stop operations have more complex handling. Containers loaded at the origin airport can be offloaded at an intermediate stop or at the destination. This means that the weight configuration changes at every leg, and always it is mandatory to keep the center of gravity within the aircraft's certified safety envelope, considering that it shifts position during each leg due to fuel consumption (Zhao et al., 2021). To compensate for center of gravity displacement, the aircraft's horizontal stabilizer trim system can be used, which adds operational flexibility (Chaves, 2018). ULD positioning is relevant because in freighter aircraft the first ULD loaded will be the last to be offloaded — a rule known as FILO — and the ULD closest to the cargo door will be the first to be offloaded — known as the LIFO rule (Brandt and Nickel, 2019). If the arrangement is not optimal, it may be necessary at intermediate stops to offload and reload ULDs whose destination is not the current airport, which increases ground time and ground handling with a consequent rise in costs (Lange, 2019; Malandri et al., 2019).

Despite the growing interest in this type of problem, the review of recent literature shows that many studies are focused on operators with large fleets of wide-body aircraft (Brandt and Nickel, 2019; Zhao et al., 2024). The study of operators with small fleets using narrow-body aircraft is not as common; this finding is the main motivation of this research. In Latin America, air cargo operators do not have such large fleets and typically rely on smaller aircraft, which means this operational context is scarcely documented in the literature (Mesquita and Sanches, 2024). Few studies apply genetic algorithms to the ULD sequencing problem under the simultaneous constraint of keeping the center of gravity within the certified safety envelope, as well as the use of the trim system operating narrow-body aircraft (Brandt and Nickel, 2019; Zhao et al., 2024).

From this perspective, the purpose of this paper is to analyze the operation of a dedicated air cargo carrier in Mexico using public information, to characterize its operation and subsequently propose a Genetic Algorithm that optimizes ULD placement in multi-stop operations (Katoch et al., 2021; Rajwar et al., 2023).

It is relevant to note that this paper represents the first stage of a broader doctoral research effort. At this stage, two objectives are addressed: the first is the operational characterization of the fleet based on public data; the second is the development of a cargo disaggregation model that estimates the kilograms transported per segment and per month, derived from an analysis of publicly available information. Both results establish the empirical foundation upon which the Genetic Algorithm will be developed in a subsequent stage.

The operation of its fleet, composed of six Boeing 737-400F aircraft during the period from August 2023 to December 2025, was analyzed and complemented with information published by AFAC regarding flights and kilograms

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transported by route and month for all operators present in Mexico, as well as the monthly flight and cargo movement summaries published by each air carrier. This paper is structured as follows: Section 2 reviews recent literature; Section 3 examines the public data sources and the method used to estimate cargo transported per segment and per month by the airline under study; Section 4 presents the results of the analysis; implications are discussed in Section 5; and conclusions are presented in Section 6.

2. Literature Review

Regarding approaches focused on single-leg operations, the following sources were reviewed. The work of Zhao et al. (2021) analyzes the Weight and Balance Problem (WBP), using combinatorial optimization to select and assign the position of a set of ULDs subject to weight, volume, and center of gravity constraints. Among its relevant contributions, it formulates a mixed-integer programming model whose objective function maximizes payload while simultaneously minimizing CG deviation from an optimal position, incorporating the safety envelope as a constraint. However, it does not consider multi-stop operations. Zhao et al. (2023) addresses the case of two subproblems that are typically solved separately: on one hand, the Air Cargo Palletization Problem (ACPP), which analyzes how to pack cargo inside a ULD, and on the other hand, the Weight and Balance Problem (WBP), which focuses on the arrangement of ULDs inside an aircraft. Their analysis finds that solving both subproblems simultaneously yields better solutions while satisfying CG constraints, compared to treating them independently. Regarding the work of Brandt and Nickel (2019), it reviews the Air Cargo Load Planning Problem (ACLPP), providing an ordering and systematization of existing research on air cargo load planning. It divides the problem into four interrelated subproblems: deciding the aircraft configuration according to the type of operation, scheduling when and how ULDs are assembled before the flight, how to pack cargo inside the ULDs, and how to place the ULDs inside the aircraft while respecting CG constraints. Solving these subproblems jointly generates better solutions than addressing each one separately.

Extending the WBP to multi-stop flight operations adds further complexity to the problem. In addition to assigning the position of each ULD on each flight, the CG must be kept within the safety envelope, while also minimizing or eliminating ULD offloading and reloading operations at intermediate stops. Zhao et al. (2024) analyzed this problem for medium-sized aircraft, proposing ULD sequencing across the entire operational day based on a feasible loading and unloading sequence. Mesquita and Sanches (2024) identified the infeasibility of finding a deterministic solution given the size of the solution space, highlighting the need to resort to approximate methods such as genetic algorithms to find feasible solutions in reasonable timeframes. From an operational perspective, Lange (2019) demonstrated that cargo operations have a measurable negative impact on departure on-time performance, while Malandri et al. (2019) showed that the availability of ground resources is highly relevant to achieving adequate turnaround times.

Given the impossibility of finding deterministic solutions to NP-hard combinatorial problems, metaheuristic methods have been increasingly used, with genetic algorithms standing out among them. Katoch et al. (2021) provides a thorough review of genetic algorithm (GA) theory, explaining the main components such as chromosomal representation, the fitness function, and the three genetic operators: selection, crossover, and mutation. They document the types of problems that have been solved with GAs, highlighting combinatorial optimization, engineering, and logistics. Lee et al. (2018) reviewed GA applications in operations management, highlighting their effectiveness in sequencing, scheduling, and resource allocation problems with multiple simultaneous constraints, which reinforces their suitability for the purposes of this research. Rajwar et al. (2023) conduct a survey of 540 metaheuristic algorithms, confirming that GAs remain among the most widely used in logistics optimization given their capacity to incorporate hard constraints as penalty functions within the fitness function.

Following the literature review, no study was identified that simultaneously addresses the constraint of keeping the CG within the safety envelope, the use of the trim system as a resource for this purpose, and the efficient management of ULDs in multi-stop flights. This condition is particularly relevant in emerging markets such as Mexico, where dedicated cargo carriers serve their markets using narrow-body aircraft on multi-stop operations. This research aims to fill this gap with the following approach: first, public information is analyzed to characterize the carrier's operation, establishing the empirical foundation required for the subsequent development of a Genetic Algorithm to solve the problem.

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3. Data and Methodology

The study was based on three public documentary sources. Cargo statistics were obtained from AFAC in a document called Traffic Statistics by City-Pairs, which reports the number of flights and kilograms transported by all operators between airport pairs per month. The second documentary source, also from AFAC, is the Airline Statistics Summary, which contains a count of flights, passengers, and cargo transported by all airlines operating in Mexico, covering both domestic and international markets as well as regular and charter operations. The third source consulted was the FlightRadar24 portal, from which information on all flights operated by the carrier under study was obtained, making it possible to determine flight times, destinations visited, and multi-stop operations covering the period from August 2023 to December 2025 a span of 29 months.

Data processing was carried out using Microsoft Access for database management, descriptive analysis was performed in Excel, and the estimation of cargo volumes for the carrier under study was conducted in Python.

Actual cargo movement data by station were not available due to company confidentiality, so a disaggregation model was developed to estimate these values. The following steps were taken: first, the origin-destination pairs operated by the carrier under study were identified; then, an estimate of the kilograms moved per origin-destination pair and per month was calculated by combining AFAC and FlightRadar24 data at the flight level. In some cases, it was possible to calculate the average cargo transported per flight by the operator directly, since it is the only carrier operating certain pairs. For segments shared with other operators, an average competitor weight of 196.03 kg per flight was estimated, which made it possible to approximate the kilograms transported by the carrier under study. This value was derived from AFAC statistics for the four main competing airlines operating on shared routes: Aeroméxico (average of 440 kg, 22% market share), Aeroméxico Connect (131 kg, 13%), Viva Aerobus (75 kg, 34%), and Volaris (189 kg, 30%), weighted by their respective flight frequencies on the segments where they compete. A physical upper bound of 19,427 kg — corresponding to the maximum payload of the Boeing 737-400F — was applied to all estimates.

Once this stage was completed, a monthly adjustment was made by calculating correction factors to match the estimated values with the totals reported by AFAC. Finally, an iterative re-adjustment was applied to ensure that the cargo limit per flight segment was not exceeded in any case, distributing the excess among the remaining flights that could accommodate additional cargo. Through this process it was possible to estimate the cargo moved per month and per flight segment for the period from August 2023 to December 2025. The main limitation is that it is not possible to verify the estimates at the route level due to the impossibility of accessing the original operator data. However, the monthly cargo movement is at least characterized acceptably, and in no case is the maximum permissible payload exceeded measurements.

4. Results

4.1 Fleet Activity and Utilization

During the period from August 2023 to December 2025, the fleet of the carrier under study operated 13,120 flights, accumulating 15,195 block hours. Table 1 shows the number of flights and block hours for each aircraft, as well as the average flight duration in minutes.

Table 1. Fleet activity by aircraft (August 2023 – December 2025)

Aircraft	Flights	Block Hours	Avg. Flight Time (min)
Aircraft 1	2,402	2,660	67.8
Aircraft 2	1,808	2,296	75.2
Aircraft 3	2,282	2,554	67.9
Aircraft 4	2,895	3,208	67.5
Aircraft 5	1,723	2,174	75.1
Aircraft 6	2,010	2,304	74.3
Total	13,120	15,195	71.3

On average the fleet achieved 3.0 daily block hours per aircraft, with each flight averaging 71.3 minutes in duration. Fleet utilization was not uniform — Aircraft 4 accounted for 22.1% of total flights while Aircraft 2 accounted for 13.8%, a figure related to the fact that this aircraft ceased operations in October 2025, possibly due to maintenance reasons.

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4.2 Multi-Stop Route Patterns

Analysis of flight tracking records reveals that the operator's network is structured around a core set of recurring multi-aircraft daily rotation patterns, in which the same aircraft operates a sequence of consecutive flights forming a chained itinerary. It is important to note that each leg within these patterns constitutes an independent flight with its own departure and arrival, rather than a single multi-stop service. The ULD sequencing challenge arises precisely at the transition between consecutive flights, where cargo bound for downstream destinations must be managed across successive ground-handling events. Table 2 presents the most frequently observed chained rotation patterns identified in the dataset, where each pattern represents a sequence of consecutive flights operated by the same aircraft within a single operational day.

Table 2. Most frequent multi-stop itineraries (August 2023 – December 2025)

Route Pattern	Frequency
SLP–CUL–HMO–CUL–SLP	206
HMO–CUL–SLP	122
SLP–HMO–TIJ	116
TIJ–HMO–SLP	114
SLP–VSA–MID	91
MIA–MID–NLU–SLP	88
NLU–SLP–NLU–MID–CUN–MIA–CUN–MID–NLU	88
MID–MIA–CUN–MID–NLU	60
SLP–GDL–TIJ–GDL	56
SLP–CUL–HMO	53
MID–MIA–CUN–MID–VSA–NLU	52
SLP–GDL–TIJ	38

The most frequent multi-stop rotation is SLP–CUL–HMO–CUL–SLP with 206 occurrences, in which the same aircraft operates the San Luis Potosí–Culiacán–Hermosillo flight and subsequently operates the return flight in the opposite direction. The next relevant rotation is part of the previous operation but performed within a single day: Hermosillo–Culiacán–San Luis Potosí with 122 occurrences; however, the outbound direction recorded only 53 occurrences, which evidences the directional imbalance between multi-stop rotations. A more complex rotation is NLU–SLP–NLU–MID–CUN–MIA–CUN–MID–NLU, which in practice chains a first non-stop flight NLU–SLP, followed by NLU–MID–CUN–MIA, and concluding with the return flight MIA–CUN–MID–NLU.

4.3 Cargo Volume and Seasonal Variation

The kilograms transported per flight segment vary by route and type of operation. Domestic flights recorded an average of 5,583 kg, while international flights averaged 11,750 kg, representing an increase of 110%. The highest-volume segment is Mérida–Cancún (MID–CUN) with an average of 16,013 kg per flight. Regarding seasonality, the analysis was conducted for the years 2024 and 2025, determining that October is the peak month for cargo movement.

4.4 Payload Variation Across Multi-Stop Itineraries

To demonstrate the complexity of managing multi-stop flights, the average cargo moved per segment was analyzed. A revealing finding is the significant difference in payload between consecutive segments, which makes ULD management particularly relevant in the context of flights with multiple intermediate stops, considering that the CG position must be maintained within the safety envelope, market demand requirements must be met, and the cargo transported must remain within permissible operational limits (Table 3-Table 5).

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Table 3. Payload per segment — Itinerary 1: SLP–CUL–HMO–CUL–SLP (n=206)

Segment	Avg. Payload (kg)	Min (kg)	Max (kg)
SLP–CUL	10,948	8,736	13,449
CUL–HMO	274	11	1,163
HMO–CUL	3,009	2,236	4,701
CUL–SLP	3,717	2,821	5,885

Table 4. Payload per segment — Itinerary 2: SLP–HMO–TIJ (n=116)

Segment	Avg. Payload (kg)	Min (kg)	Max (kg)
SLP–HMO	7,951	4,090	15,929
HMO–TIJ	17,906	2,835	19,427

Table 5. Payload per segment — Itinerary 3: NLU–SLP–NLU–MID–CUN–MIA–CUN–MID–NLU (n=88)

Segment	Avg. Payload (kg)	Min (kg)	Max (kg)
NLU–SLP	5,982	4,015	11,572
SLP–NLU	10,500	6,852	13,612
NLU–MID	4,142	272	8,218
MID–CUN	16,013	9,915	19,427
CUN–MIA	7,778	2,402	19,381
MIA–CUN	6,052	4,548	9,048
CUN–MID	5,505	1,806	11,264
MID–NLU	1,683	2	3,703

This analysis shows that the kilograms of cargo transported vary significantly between segments of the same multi-stop flight. For example, in the SLP–CUL–HMO rotation, the first segment was estimated to carry 10,948 kg while the next carries barely 274 kg — undoubtedly a significant difference. In the case of Itinerary 2, SLP–HMO–TIJ, the first segment records 7,951 kg and the second 17,906 kg; in this case the average difference is not as large as in the previous example. Itinerary 3 contains four chained flights: NLU–SLP and its return (non-multi-stop), and NLU–MID–CUN–MIA and its return. Across the different segments, cargo volumes range from 1,683 kg (MID–NLU) to 16,013 kg (MID–CUN). These variations also imply significant shifts in CG management between one segment and the next, requiring a complete reconfiguration of ULD positioning.

4.5 Cargo Estimation Model Validation

The reliability of the three-stage cargo disaggregation model was assessed by comparing monthly aggregate cargo estimates against the figures officially reported by AFAC across all complete months in the observation period from August 2023 to December 2025. Figure 1 presents this comparison, plotting estimated cargo volumes against AFAC-reported figures expressed in millions of kilograms.

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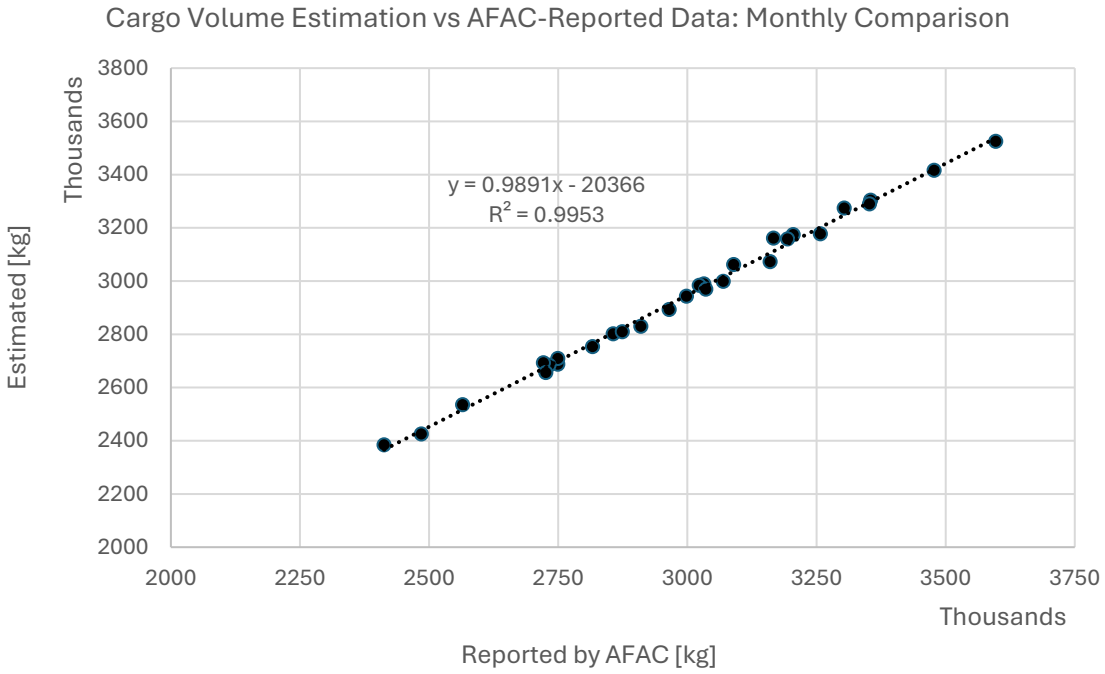

Figure 1. Comparison between estimated and AFAC-reported monthly cargo volumes (August 2023 – December 2025).

The regression analysis yields a coefficient of determination (R^2) of 0.9953 and a slope of 0.9891, indicating that the model explains 99.53% of the variance in officially reported cargo volumes. The slope close to unity confirms that the model neither systematically overestimates nor underestimates cargo volumes, with a marginal underestimation of less than 1.1% relative to AFAC figures. This level of fit validates the use of route-level estimates as a reliable empirical basis for the operational characterization presented in this study. It demonstrates and demonstrates that the three-stage disaggregation methodology can reconstruct flight-level cargo distributions from aggregate public statistics alone. To the authors' knowledge, this approach represents a replicable methodological contribution applicable to other regional cargo operators in emerging markets where internal operational data are not publicly available.

5. Discussion

The analysis of the information in this research reveals three relevant aspects of multi-stop flights regarding optimal ULD load planning.

First, the presence of multi-stop flights in daily operations is relevant in terms of ULD management. The position assigned to each ULD has implications for subsequent stops. A poor decision in this regard can lead to increased time and cost in ground handling, turnaround, and fuel consumption (Lange, 2019; Malandri et al., 2019).

Second, there are significant variations in cargo kilograms between consecutive flight segments, with some cases being extreme. This finding confirms that static loading rules are operationally insufficient to ensure that the CG remains within the safety envelope during all flight phases (Zhao et al., 2021; Chaves, 2018). Therefore, a Genetic Algorithm that simultaneously optimizes ULD loading sequence and trim configuration is critical, not merely convenient.

Third, cargo movement varies not only by segment but also by month, allowing for seasonality analysis. Sufficient disaggregation has been achieved to strengthen the analysis and provide elements for further research. October records the highest cargo movement, implying that during this period ground handling resources are under greater pressure and the operational cost of suboptimal ULD sequencing is proportionally higher.

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Additionally, the cargo disaggregation model developed in this research represents an independent methodological contribution. The comparison between estimated values and those reported by AFAC yielded a coefficient of determination of $R^2 = 0.9953$, validating its use as a reliable empirical foundation. This approach is replicable for other regional carriers in emerging markets where internal operational data is not publicly available.

6. Conclusions

This research estimates the cargo movement per month and per flight segment for a Mexican dedicated air cargo carrier, with a primary focus on the analysis of multi-stop flights. Data were collected over 28 months, encompassing 13,120 flights as well as cargo volumes by origin-destination pair and kilograms transported by carrier per month, all obtained from public AFAC statistics and the FlightRadar24 flight tracker. Using this information it was possible to determine fleet utilization patterns, multi-stop route structures, payload per segment, and seasonal variations.

A three-stage model was developed to estimate the average cargo transported on each flight segment from the consulted sources. As a precision assessment, a regression line was estimated between the global monthly observed values reported by AFAC and the estimated values, achieving $R^2 = 0.9953$, which confirms that the characterization is reliable.

The information derived has confirmed the complexity of multi-stop operations: the relevance of ULD position assignments and their potential effect on subsequent stops, wide variability in kilograms transported across consecutive segments, and seasonal variations. These arguments justify the development of a Genetic Algorithm for ULD management in multi-stop operations. The immediate follow-up to this first research stage will present the algorithmic formulation, chromosome encoding, fitness function design, application of the algorithm to representative cases, and verification that CG compliance within the safety envelope is achieved, incorporating the aircraft trim system as an operational resource under both constraints simultaneously.

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Biographies

David-Leonardo Padilla-Georgge is a doctoral researcher in the Logistics and Supply Chain program at Universidad Popular Autónoma del Estado de Puebla (UPAEP), where he also teaches courses in airport logistics, air navigation, airport pavements, and transportation engineering. He is a certified Airport Expert (Perito en Aeropuertos) accredited by the Colegio de Ingenieros Civiles de México. He is the founder of Metrovial, a transportation consulting firm, through which he has led studies in origin-destination matrix modeling, toll road demand analysis, and traffic engineering across multiple projects in Mexico. His doctoral research focuses on Unit Load Device (ULD) optimization for regional air cargo carriers, combining metaheuristic algorithms with weight-and-balance analysis. His broader research interests include air cargo network analysis, airport planning, and the application of genetic algorithms and simulation tools to transportation and logistics problems. He has presented his work at international conferences, including the IEOM Latin American Conference series.

Diana Sánchez-Partida is a Professor-Researcher in the Graduate Program in Logistics and Supply Chain Management at Universidad Popular Autónoma del Estado de Puebla (UPAEP), Mexico. She holds a doctoral degree in Logistics and Supply Chain Management and has received CONACyT doctoral and postdoctoral fellowships. She has authored or co-authored more than 161 scientific articles and is co-author and editor of two Springer books, Disaster Risk Reduction in Mexico and Humanitarian Logistics in the Disaster Risk Reduction Perspective. In 2023 she received Mexico's National Logistics Award, the "Galardón Tameme." She leads the Academic Body on Humanitarian Logistics and Resilience in Different Economic Sectors and has been a member of Mexico's National System of Researchers since 2018, currently holding SNI Level 2 status. Her research interests include disaster risk reduction, humanitarian logistics, resilience in economic activities and logistics operations, production planning, optimization, and warehouse and inventory management.

Patricia Cano-Olivos is a Professor-Researcher affiliated with the Faculty of Engineering, Logistics, Manufacturing and Automotive (FILMA) at Universidad Popular Autónoma del Estado de Puebla (UPAEP), Mexico. Her research spans logistics, operations management, and transportation, with particular focus on humanitarian logistics and disaster risk reduction. She has contributed to studies on the location of humanitarian response distribution centers in Mexico, risk assessment methods for humanitarian logistics networks, water resource availability and drought analysis, and pharmaceutical distribution planning. Her work also extends to freight transport optimization, vehicle and driver assignment problems, sustainable inventory management, and quality improvement methods for the automotive and textile industries in Mexico. She has co-authored chapters in the Springer volumes Disaster Risk Reduction in Mexico and Humanitarian Logistics in the Disaster Risk Reduction Perspective.

Santiago-Omar Caballero-Morales has been a Full-Time Professor-Researcher at Universidad Popular Autónoma del Estado de Puebla (UPAEP), Mexico, since 2015, where he is a member of the Graduate Department of Logistics and Supply Chain Management. From 2009 to 2015 he was a Titular Professor-Researcher at Universidad Tecnológica de la Mixteca (UTM) in Huajuapan de León, Oaxaca, within the Robotics and Advanced Manufacturing graduate divisions. He has also been a member of the Speech, Language and Music Group at the University of East Anglia (UK), where his research focused on improving automatic speech recognition for speakers with disordered speech using Hidden Markov Models, Weighted Finite-State Transducers, and Non-negative Matrix Factorization. His research interests include pattern recognition, human-robot interaction, industrial engineering, quality control, industrial analysis and simulation, speech and translation technologies for underrepresented languages such as Mixtec, and logistics planning and optimization.

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