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FLEET SIZING METHODS USED BY URBAN BUS TRANSPORT COMPANIES IN MANAUS: A THEORETICAL-EMPIRICAL STUDY

MÉTODOS DE DIMENSIONAMENTO DE FROTA UTILIZADOS POR EMPRESAS DE TRANSPORTE DE ÔNIBUS URBANO EM MANAUS: UM ESTUDO TEÓRICO-EMPÍRICO

MÉTODOS DE DIMENSIONAMIENTO DE FLOTA UTILIZADOS POR EMPRESAS DE TRANSPORTE DE AUTOBUSES URBANOS EN MANAUS: UN ESTUDIO TEÓRICO-EMPÍRICO

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ABSTRACT
This study aimed to understand the different fleet-sizing methods used by companies providing urban bus transportation services in Manaus. It used a survey method, with a purposive sample of five individuals responsible for planning and executing fleet sizing in their companies. Data were collected using a semi-structured interview guide, and the results were generated using semantic and content analysis techniques for each guiding question of the research. The results showed that a) the frequency and capacity methods are the most widely used; fleet size sizing is associated with route planning; quantitative and qualitative methods are used simultaneously; and the passenger-per-kilometer index and supply-demand analysis are the central indicators of the methods. b) The methods are employed to reflect the different perspectives on transport management in each company, almost always focused on determining the final fleet and financial and quality aspects. c) The main advantages of the methods are fleet optimization, route definition, and adherence to established schedules. At the same time, the predominant disadvantages are failure to meet service quality and failure to address user problems, and d) the main risks of method failure stem from technical limitations, lack of updating, subjectivity, lack of data, and operational problems. The conclusion shows that fleet sizing in the analyzed system is conducted through a hybrid strategy that combines operational indicators, demand analysis, and user experience assessment, highlighting the need for integration between technical methods and social analyses to improve the efficiency and quality of public transport.

KEYWORDS: *Fleet sizing, Urban transport. Urban bus transport. Fleet sizing methods. Urban transport in Manaus.*

RESUMO
Este estudo teve como objetivo compreender os diferentes métodos de dimensionamento de frota utilizados por empresas que prestam serviço de transporte de ônibus urbano em Manaus. Utilizou o método de levantamento, com uma amostra intencional de cinco indivíduos responsáveis pelo planejamento e pela execução do dimensionamento da frota de suas empresas, cujos dados foram coletados com o auxílio de um roteiro de entrevista

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semiestruturada, e os resultados foram gerados por meio da aplicação de técnicas de análise semântica e de conteúdo para cada questão norteadora da pesquisa. Os resultados mostraram que a) o método da frequência e o da capacidade são os mais utilizados, o dimensionamento do tamanho da frota está associado à roteirização, métodos quantitativos e qualitativos são utilizados de forma simultânea e o índice de passageiros por quilômetro e a análise oferta x demanda são os indicadores centrais dos métodos utilizados; b) os métodos são empregados para refletir as diferentes perspectivas sobre a gestão do transporte em cada empresa, quase sempre voltados para determinar a frota final e aspectos financeiros e de qualidade, c) as principais vantagens dos métodos são a otimização da frota, definição dos itinerários e atendimento dos horários estabelecidos, enquanto as desvantagens predominantes são não atender a qualidade dos serviços e não atender a resolução de problemas com os usuários e d) os principais riscos de falhas dos métodos são decorrentes das limitações técnicas, falta de atualização, subjetividade, falta de dados e problemas operacionais. A conclusão mostra que o dimensionamento de frota no sistema analisado ocorre por meio de uma estratégia híbrida, que combina indicadores operacionais, análise de demanda e avaliação da experiência do usuário, evidenciando a necessidade de integração entre métodos técnicos e análises sociais para melhorar a eficiência e a qualidade do transporte público.

PALAVRAS-CHAVE: Dimensionamento de frota. Transporte urbano. Transporte de ônibus urbano. Métodos de dimensionamento de frota. Transporte urbano de Manaus.

RESUMEN
Este estudio tuvo como objetivo comprender los diferentes métodos de dimensionamiento de flota utilizados por las empresas que prestan servicios de transporte urbano en autobús en Manaos. Se empleó una encuesta con una muestra intencional de cinco personas responsables de la planificación y ejecución del dimensionamiento de flota en sus empresas. Los datos se recopilaron mediante una guía de entrevista semiestructurada y los resultados se generaron mediante técnicas de análisis semántico y de contenido para cada pregunta guía de la investigación. Los resultados mostraron que: a) los métodos de frecuencia y capacidad son los más utilizados; el dimensionamiento de la flota está asociado con la planificación de rutas; se utilizan simultáneamente métodos cuantitativos y cualitativos; y el índice de pasajeros por kilómetro y el análisis de la oferta y la demanda son los indicadores centrales de los métodos empleados. b) Los métodos se emplean para reflejar las diferentes perspectivas de la gestión del transporte en cada empresa, casi siempre centradas en la determinación de la flota final y en aspectos financieros y de calidad. c) Las principales ventajas de los métodos son la optimización de la flota, la definición de rutas y el cumplimiento de los horarios establecidos, mientras que las principales desventajas son la falta de calidad del servicio y de atención a los problemas de los usuarios. d) Los principales riesgos de fallo del método se deben a las limitaciones técnicas, la falta de actualización, la subjetividad, la falta de datos y los problemas operativos. La conclusión muestra que el dimensionamiento de la flota en el sistema analizado se realiza mediante una estrategia híbrida que combina indicadores operativos, análisis de la demanda y evaluación de la experiencia del usuario, lo que destaca la necesidad de integrar los métodos técnicos con los análisis sociales para mejorar la eficiencia y la calidad del transporte público.

***PALABRAS CLAVE**: Dimensionamiento de la flota. Transporte urbano. Transporte urbano en autobús. Métodos de dimensionamiento de la flota. Transporte urbano en Manaus.*

1. INTRODUCTION

The improvement of logistics services has become a strategic factor in organizations' competitiveness, especially in a context marked by the intensification of global trade, the growth of e-commerce, and the need for greater operational efficiency in transportation systems. Improving logistics performance depends on integrating technological innovation, data analysis, and optimizing transportation operations, thereby reducing operational costs and increasing service reliability.

The efficient management of logistics resources, especially vehicles and transportation equipment, plays a central role in the sustainability and competitiveness of modern supply chains. Science shows that the efficiency of the logistics sector is directly related to the ability to plan and adequately utilize transportation assets, avoiding idleness, underutilization of capacity, and operational waste (Taran *et al.*, 2025; Nascimento-e-Silva *et al.*, 2019). Furthermore, advances in analytical methods and optimization models have enabled improved logistics planning by analyzing large volumes of operational data and simulating demand scenarios. In this scenario, fleet sizing emerges as a fundamental element for aligning operational capacity, transport demand, and customer service level.

Recent studies demonstrate that fleet sizing methods based on mathematical models, data analysis, and optimization algorithms contribute significantly to improving the efficiency and sustainability of logistics systems, allowing for a balance between operational costs, asset utilization, and service quality (Şahin; Yildiz, 2025; Jezequel; Boukherroub; Belmokhtar-Berraf, 2025; Al-Nabulsi *et al.*, 2025). Thus, the improvement of logistics services largely depends on the alignment between operational planning and fleet sizing methods, ensuring that transportation systems operate efficiently, sustainably, and competitively (Milenković; Bojović; Abramin, 2023; Zhang *et al.*, 2025; Wu; Liu; Du, 2024; Albuquerque *et al.*, 2023; Meßmer *et al.*, 2025).

In large cities, such as Manaus, which has approximately 2.5 million inhabitants, public bus transportation represents one of the main means of urban mobility, requiring efficient logistics systems to meet the high demand for mobility. The application of fleet-sizing methods is essential to balance vehicle supply with passenger demand, ensuring adequate service levels, reduced operating costs, and greater competitiveness of the public transportation system. Studies such as Tang, Shi, and Liu (2023) demonstrate that effective fleet size planning and vehicle scheduling can significantly improve the operational efficiency of urban transport systems by reducing waiting times, optimizing vehicle utilization, and minimizing energy and operating costs (Son, Im, and Kim, 2025).

Furthermore, research indicates that optimization models for fleet sizing enable the integration of trip scheduling, infrastructure, and energy-consumption decisions, contributing to more sustainable and efficient public transport planning (Son; Im; Kim, 2025). In large urban centers, the absence of structured sizing methods can lead to overcrowding, low trip frequency, and inefficient vehicle use, thereby compromising the quality of service provided to users. On the other hand, studies show that the application of analytical and optimization models in fleet planning makes it possible to improve the operational performance and sustainability of urban transport, allowing operators and public managers to make more efficient decisions about fleet size and the organization of the transport system (Wang *et al.*, 2023). Thus, in a large city like Manaus, the adoption of structured fleet-sizing methods is a fundamental element for guaranteeing logistical efficiency, service quality, and the competitiveness of the urban transport system.

In this sense, this study aimed to understand the different fleet-sizing methods used by companies providing urban bus transportation services in Manaus. Specifically, it sought to map the main methods used, when they are used, the main advantages and disadvantages, and the main risks of failure in their use. The survey method was used, with data collected through semi-structured interviews with professionals responsible for planning and executing fleet sizing in companies operating in Manaus. The results were generated using content and semantic analysis techniques and presented in summary tables.

2. LITERATURE REVIEW

Fleet sizing, in the context of transport logistics, refers to the process of determining the number and types of vehicles needed to meet demand for cargo or passenger movement, ensuring adequate service levels and operational efficiency. It is a strategic decision, as it directly influences logistics costs, customer service levels, and the use of company resources. According to recent studies, proper fleet sizing requires the integrated analysis of variables such as vehicle capacity, cargo volume and frequency, operational cycle times, and demand variability. In addition, optimization models and quantitative methods have been widely used to support decision-making in this process, allowing for the evaluation of different scenarios and the identification of the most efficient fleet configuration (Auad-Perez; Van Hentenryck, 2022; Kronmueller; Fielbaum; Alonso-Mora, 2024; Yatskiv; Tolujevs; Petrovs, 2024).

From a logistics planning perspective, fleet sizing is also associated with the tactical and operational decisions of the transportation system. This is because the size of the fleet needs to be aligned with the structure of the logistics network, distribution routes, and demand characteristics. Recent research highlights that mathematical programming techniques, stochastic models, and simulation methods have been applied to solve sizing problems in complex and dynamic environments. These approaches allow for consideration of operational uncertainties, such as variations in demand and transportation times, contributing to more robust and efficient planning of logistics operations. In this sense, recent studies show that integrating fleet sizing and operational planning can reduce costs and improve vehicle utilization in the transportation system (Hrušovský *et al.*, 2024; Truden; Hewitt, 2026; Kronmueller *et al.*, 2024).

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The topic has also gained prominence in research addressing sustainability and technological innovation in logistics, especially with the introduction of electric vehicles and on-demand transportation systems. In these approaches, fleet sizing now considers not only economic aspects, but also environmental and energy factors, such as fuel consumption, carbon emissions, and charging infrastructure. Recent studies indicate that integrated models that combine infrastructure planning, fleet sizing, and operations scheduling can significantly improve the efficiency and sustainability of transportation systems. Thus, fleet sizing is recognized as an essential tool for modern logistics planning, balancing operational performance, costs, and environmental impacts (Mancini; Gansterer, 2026; Yatskiv *et al.*, 2024; Truden; Hewitt, 2026).

Fleet sizing is crucial for all types of organizations, and various methods have been developed to improve efficiency and competitiveness in logistics. Recent literature shows that fleet sizing has evolved from simple deterministic models to hybrid and integrated approaches that simultaneously consider operational, economic, and environmental factors. Models based on mathematical programming (especially MILP) still predominate because they can represent complex logistical constraints. However, stochastic and multi-objective approaches have become more common for dealing with demand uncertainties and multiple logistical performance objectives (Karmanesh *et al.*, 2024). Recent research also emphasizes integrated models that combine fleet sizing with routing decisions, service scheduling, or energy infrastructure. These models are particularly relevant for urban transport systems, last-mile logistics, and electric fleets, where strategic and operational decisions are strongly interdependent (Mancini; Gansterer, 2026). Table 1 shows some possible groupings of methods, their main component variables, and their operational purpose.

Table 1. Main fleet sizing methods in recent literature

ethods	ey variables	urpose / Objective	studos recentes
Mixed Integer Linear Programming (MILP)	Number of vehicles, vehicle capacity, transport demand, fixed and variable costs, operational constraints, and routes	To determine the size and composition of the fleet that minimizes costs or maximizes operational efficiency in transportation systems.	Li; Shehaden; Tsang (2024); Silva; Wang; Soares (2024); Balac; Hörd; Axhausen (2020)
Two-Stage Stochastic Programming	Uncertain demand, probabilistic scenarios, fleet acquisition cost, operational costs, vehicle allocation	To size the fleet considering demand uncertainty and decisions at two points in time (planning and adjustment after demand is realized).	Karmanesh *et al.*, (2024); Zhang *et al.* (2025)

Multi-Objective Optimization Models	Fleet size, operational cost, service level, waiting time, emissions, or energy consumption	To find the fleet size that balances multiple objectives such as cost, logistics performance, and sustainability.	Truden; Hewitt (2026)
Integrated Sizing and Routing Models	Vehicle types, capacity, routes, demand by destination, and operating costs	To simultaneously determine fleet size and logistics route planning.	Xie; Wang; Duan, (2024); Kronmueller; Fielbaum; Alonso-Mora (2024)
Integrated Fleet and Infrastructure Sizing Models	Number of vehicles, battery range, charging stations, operating hours, transport demand	To simultaneously plan fleet size and the infrastructure needed to operate sustainable transportation systems.	Mancini; Gansterer (2026)
Data-driven and machine learning models	Historical demand data, temporal variability, fleet performance metrics, operational scenarios	To estimate the optimal fleet size through simulation, machine learning, and predictive models.	Truden; Hewitt (2026)

Source: data collected by the authors.

Mixed-Integer Linear Programming (MILP) is one of the most widely used methods for fleet sizing in logistics systems, as it enables mathematical modeling of discrete and continuous decisions regarding vehicle counts, transport capacity, operating costs, and logistical constraints. In this method, the operating logic consists of formulating an objective function, which is usually the minimization of the total system cost or the maximization of logistical efficiency, subject to a set of constraints that represent operational reality, such as vehicle capacity, transport demand, travel time, and operational limits. The main advantage of this method is its ability to find optimal or near-optimal solutions by simultaneously considering multiple variables and constraints.

Another relevant advantage is the model's transparency, which enables a clear interpretation of each variable's impact on the final decision. However, a significant disadvantage is the high computational cost, especially in large-scale problems such as urban transport systems or complex logistics networks. Furthermore, deterministic MILP-based models may not adequately capture uncertainties in demand or operating conditions. Among the main risks of method failure are oversimplifying the logistics system, errors in parameter estimation, and model instability when applied to highly variable data. Recent studies show that MILP performance strongly depends on the quality of the input data and the computational capacity available to solve the problem promptly (Silva *et al.*, 2024; Li *et al.*, 2024).

The Two-Stage Stochastic Programming method is widely used when fleet sizing must account for uncertainties in demand or operating conditions. Its operating logic involves two decision phases: in the first stage, the fleet size is determined based on forecasts or probabilistic scenarios; in the second stage, decisions are adjusted after the realization of random variables, such as effective demand or travel times. This structure allows the model to represent better the reality of logistics systems, where demand variability and uncertain operating conditions are critical factors. Among the main advantages of this method is the ability to produce more robust, adaptable solutions across different operational scenarios. Another important advantage is the ability to incorporate diverse probabilistic scenarios and evaluate their impacts on fleet efficiency.

The main disadvantage of the method is the high computational complexity, since the number of scenarios can grow exponentially, increasing processing time. Furthermore, the quality of the results strongly depends on the accuracy of the probability distributions used to represent uncertainties. Risks of failure include inadequate selection of probability scenarios, underestimation of demand variability, and difficulty obtaining reliable data to feed the model.

Recent research indicates that combining stochastic programming with decomposition techniques or heuristics can significantly reduce these problems (Karmanesh *et al.*, 2024; Li *et al.*, 2024).

Multi-objective optimization models represent an advanced approach to fleet sizing, especially in contexts where multiple goals must be met simultaneously, such as cost minimization, carbon emission reduction, service level improvement, and fleet utilization maximization. The logic of this method is to construct an objective function composed of multiple criteria or to generate a set of efficient solutions known as the Pareto frontier, allowing managers to choose the alternative that best balances the system's objectives. The main advantage of this approach is its ability to represent the complexity of modern logistics decisions, in which economic, environmental, and operational factors are equally relevant. Another advantage is the ability to analyze trade-offs among different objectives, providing a broader strategic view of the transportation system. However, multi-objective models can make results difficult to interpret, as they typically yield a set of possible solutions rather than a single optimal solution. Furthermore, the process of selecting the final solution may depend on the subjective preferences of the decision-makers. Among the main risks of failure are inadequate objective weighting, difficulty in correctly modeling relationships between variables, and increased computational complexity when many criteria are considered. Recent studies demonstrate that data-driven approaches and evolutionary algorithms have been used to overcome these limitations and improve the quality of the solutions obtained (Truden; Hewitt, 2026; Mancini; Gansterer, 2026).

The integrated fleet sizing and routing model, often associated with the Fleet Size and Mix Vehicle Routing Problem (FSMVRP), seeks to determine fleet size and distribution route planning simultaneously. In this method, the operating logic integrates strategic and operational decisions into a single mathematical model, accounting for variables such as vehicle types, load capacity, customer locations, distances between points, and operating costs. The main advantage of this approach is its ability to capture the interdependence between fleet size and logistics routes, producing more efficient solutions than those obtained when these decisions are treated separately. Furthermore, the model enables evaluation of different vehicle combinations and distribution strategies, thereby contributing to the optimization of the logistics system as a whole. However, this integration also significantly increases the problem's complexity, necessitating heuristic or metaheuristic algorithms to solve large-scale instances. Among the main disadvantages are the high computational cost and the need for detailed data on the logistics network. Failure risks include errors in estimating distances or travel times, inconsistencies in demand data, and limitations in the algorithms' ability to explore the solution space adequately. Recent studies indicate that hybrid approaches combining mathematical optimization and heuristics can significantly improve the performance of these models in real-world applications (Zhang *et al.*, 2024; Silva *et al.*, 2024).

The integrated fleet and infrastructure sizing model, especially applied to electric fleets or sustainable transportation systems, seeks to simultaneously determine the number of vehicles needed and the supporting infrastructure, such as charging stations or energy supply points. The logic of this method is to integrate strategic infrastructure investment decisions with operational decisions related to fleet use. Among the main variables considered are vehicle range, charging station locations, transportation demand, operating hours, and investment and maintenance costs. The main advantage of this model is its ability to support planning for sustainable transportation systems, enabling the evaluation of different fleet electrification scenarios and their economic and environmental impacts. Furthermore, the integrated approach reduces the risk of inconsistent decisions between fleet planning and infrastructure planning. However, the method poses significant challenges, including the need for large volumes of data and the complexity of the modeling process. Among the main disadvantages are the difficulty in accurately estimating technological parameters, such as energy consumption and battery degradation. Risks of failure include rapid technological changes, uncertainties about demand patterns, and limitations in available energy infrastructure. Recent research indicates that integrating energy planning and logistics is fundamental to reducing these risks and improving the efficiency of sustainable transport systems (Mancini; Gansterer, 2026; Yatskiv *et al.*, 2024).

3. RESEARCH METHODOLOGY

This study aimed to understand the different fleet-sizing methods used by companies providing urban bus transport services in Manaus. It is a qualitative study because the data collected were all nominal, in the form of phrases and sentences, with an individual unit of analysis, since the data and information were obtained by a professional from each company, with an inter-organizational level of analysis, so that the results achieved only cover the companies that provided the data and information for this study, which prevents its generalization to the entire business group. The analytical perspective was synchronic or transversal (also known as cross-sectional), since the researchers intended to generate a snapshot of reality at that exact moment (Nascimento-e-Silva, 2020; 2021a; 2021b).

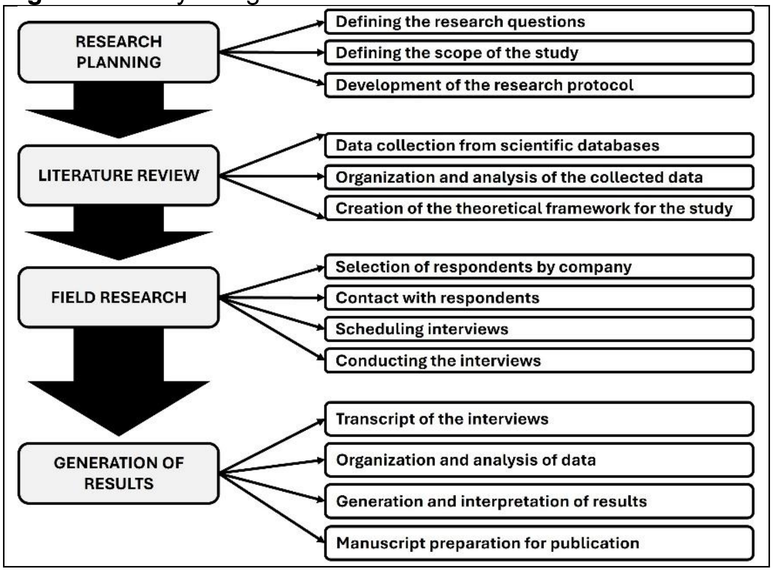
3.1. Guiding Questions

The general objective was divided into four specific objectives, transformed into the following guiding questions: 1) What are the main fleet sizing methods used by companies? 2) For what purpose are these methods used? 3) What are the main advantages and disadvantages of these methods? 4) What are the main risks of failure in the use of these methods? What can go wrong? The study design was developed to answer these questions, following the recommendations of Nascimento-e-Silva (2021c).

3.2. Study Design

The results of this study were generated in four stages. The first was the study planning, which consisted of defining the main and guiding research questions, defining the scope of the study (its breadth and depth), and developing the research protocol. The second stage was the execution of the literature review, which began with the collection of data from the scientific databases Scopus, Web of Science, and Google Scholar (Nascimento-e-Silva, 2023), continued with the organization and analysis of the collected bibliographic data, and culminated in the creation of the study's theoretical framework and its subsequent writing in report form. Figure 1 presents all stages and the respective activities developed for each stage.

Figure 1. Study design



Source: prepared by the authors.

The third stage was the field research, which began with the creation and testing of the data collection instrument, developed from the theoretical framework constructed with the literature review. This continued with identifying and contacting companies and their representatives to schedule and subsequently execute data collection on a predetermined day and time for each company. The fourth and final stage was the generation of results, which began with the transcription of interviews and continued with the organization and analysis of the collected data in spreadsheets to facilitate data handling in line with the guiding questions of the research. The results were generated through simultaneous semantic and content analyses, which were then compared with the study's theoretical framework to enable interpretation of each finding. The study concluded with the writing of the reports and the preparation of this manuscript for publication.

3.3. Population, sample, and research subjects

Five subjects were included in this research, chosen because they work with fleet sizing in urban transport companies. For three weeks, we searched for and contacted more than 30 companies and their employees, but only the five described in this study agreed to answer the questions in the research protocol. First, all the questions and their ethical implications were explained to them; then they were given time to decide whether to participate. During that time, those who agreed to participate were consulted about the day and time for the interview. Data collection took place during that time.

Respondent A is male, 31 years old, has a degree in logistics, has worked for a public transport company for 8 years, and has 14 years of experience in the field. Respondent B is male, 28 years old, has only completed high school, has worked for a public transport company for 3 years, and has 4 years of experience in the urban transport field. Respondent C is also male, 28 years old, studying Engineering, has worked for a public transport company for 1 year, and has only 1 year of experience in the field. Respondent D is male, 31 years old, holds a degree in business administration, has worked for a public transportation company for 13 years, and has 13 years of experience in the field. Respondent E is male, 25 years old, holds a degree in literature and journalism, has worked for the company for 6 years, and has 6 years of experience in the field.

The demographic characteristics of the sample indicate that the participants are adults, which presupposes adequate cognitive capacity to understand the challenges and implications of formalizing processes. The predominant level of education is higher education, considered adequate for roles that demand greater technical and managerial expertise. This characteristic may have contributed to the understanding of the benefits of standardization, especially regarding its applicability to simple and routine activities, which are significant for operational efficiency and consistency. The respondents' ages range from 20 to 35 years, and their experience in the field ranges from 1 to 13 years. This suggests that some employees have little experience, while others have significant practical knowledge.

3.4. Data Collection Instrument

Data was collected through interviews conducted using a questionnaire. Our first challenge was formulating the questions to ensure the best possible data collection. Our second challenge was the difficulty we faced in collecting data directly from company management, which led us to contact employees online through social media. Our third challenge was obtaining responses from employees contacted for in-person visits; only 5 of 30 responded. After collecting the data, we organized the interviews and formulated interpretations.

3.5. Data Collection Strategy

The data collection strategy used in this study was developed to obtain transparent, integrated data from respondents, aiming to ensure the study's replicability by any researcher, so that even those without prior experience in the transportation sector can understand and reproduce future studies in the area. Considering that the main objective of the study was to understand the fleet-sizing techniques used by urban public transportation companies in Manaus, it was essential to implement an organized methodology that would enable the collection of technical data and practical insights from the professionals involved to ensure the data's accuracy. To this end, it was necessary, even during the planning phase, to organize ourselves into stages to obtain as many respondents as possible, so that we could begin producing our data table with the final record of the responses. These stages included everything from researching transportation company locations to identify potential respondents to conducting face-to-face interviews with interested parties. This multi-phase structure made it possible to understand the methods employed and to identify how, when, and why each company chooses to use them, deepening the knowledge about the practices that influence the operational planning of public transportation in Manaus.

First, we defined the criteria for selecting participants. As the research focuses on the technical practices of fleet sizing, it was essential to interview professionals directly/indirectly involved in the planning, management, control, or operational monitoring of urban transportation. Thus, participants were selected based on their roles, years of experience, understanding of the companies' internal dynamics, and participation in fleet-related activities. The final sample included five participants from various companies in the sector. Secondly, we began collecting data in person, which ensured greater accuracy in the responses and a better understanding of the practices described. The interviews were conducted individually, in private locations within the companies or in suitable administrative spaces.

Before each interview, the objectives of the study were presented to clarify the academic nature of the research, the use of the information, and the guarantee of anonymity for the participants. After this explanation, the voluntary consent of each participant was requested. The interviews were conducted in two main sub-phases and followed a semi-structured format provided by our supervising professor. In the first, we sought to understand in detail which fleet sizing techniques each participant knew and used in their professional routine. The objective of the second stage was to deepen understanding of the practical situations in which these methods are employed, as well as their advantages, disadvantages, limitations, and failure risks. In both phases, the answers were documented in a field notebook with complete, immediate notes, ensuring the accuracy of the information provided.

In the third and final phase, after asking the initial questions, there was a second round of clarifications. In this phase, some previously recorded answers were presented again to the interviewee for confirmation. This direct validation technique ensured the absence of errors in the transcription of information or in the understanding of the practices described, giving us sufficient confidence to transcribe all the data provided in the field notebook into digitized Word files, organized for analysis.

3.6. Data Organization and Analysis Techniques

Initially, it is worth highlighting that data collection took place in person at the respective companies of each interviewee, using a semi-structured form that allowed us to more easily organize each person's response, categorizing them in detail by the sizing method used by each company, the situations in which it is applied, the criteria each company uses to apply the method, among other categories. For each question answered, the response was noted verbatim, followed by some additional questions to avoid any doubts. It is also worth remembering that some questions were not answered because the interviewee did not have the answers or chose not to answer them. In this way, we obtained the maximum number of responses, taking into account each interviewee's consent. This allowed each piece of information to be interpreted exactly as the respondent intended to communicate, avoiding erroneous or superficial interpretations.

Each interview was conducted individually, in a private setting within the company's facilities or in suitable administrative spaces. Before the start of each interview, a presentation of the study's purposes was given, explaining the academic nature of the research, the use of the information, and the guarantee of anonymity for the interviewees. After this clarification, the voluntary consent of each participant was requested.

The interviews were semi-structured and divided into two main stages. In the first, the aim was to understand in detail which fleet sizing methods each respondent knew and applied in their daily work. The second stage aimed to deepen understanding of the practical situations in which these methods are used, their advantages, disadvantages, limitations, and failure risks. In both stages, the responses were recorded in a field notebook with complete, immediate notes to ensure fidelity to the information provided. As mentioned earlier, the entire data collection process was meticulously recorded on a printed form, ensuring that each phase was documented accurately, chronologically, and contextually.

Subsequently, all these notes were converted into digital versions using a text editing tool to enable more reliable and systematic analysis. After transcription, each response was transformed into a table. In the table, the left side shows the respondents' names replaced by numbers 1, 2, 3... consecutively to ensure the security and anonymity of each respondent, while the right side shows the answers provided to each respondent. Due to the interviewees' literal responses, a wide range of information had to be synthesized and organized in the table.

The data analysis was carried out in accordance with the guiding question. For each question, we sought to find out what difficulties were faced, and the analysis also focused on a) the diversity of methods mentioned, b) which methods appeared only in specific situations, and c) the positive and negative points of each method used. Each question sought to investigate how these methods are implemented in practice, not only in the creation of their operational cores, but also in justifying their use in planning routines. For example, when a participant stated that IPK is used "to measure efficiency and profitability," the core identified was the indicator's function: it serves as an instrument for strategic decisions based on performance. The same occurred with another participant who, when stating that routing is "to determine routes and schedules," the analytical core pointed to the temporal and spatial organization of the operation, based on the structuring and predetermination of the route to be followed to carry out the activity.

The responses regarding the advantages, disadvantages, and risks of failure were analyzed to identify factors that reinforce or compromise the effectiveness of the methods. This process involved categorizing aspects such as weaknesses in the data used, dependence on external variables, limitations of precision, and direct impact on the quality of the service provided. Thus, whenever a respondent mentioned, for example, that a certain method could cause "fleet undersizing" or "inefficiency during peak hours," the analysis sought to understand the origin of this limitation, whether technical, operational, or structural. In general terms, the data analysis aimed not only to describe the methods used but also to explain the logic behind their use, the challenges encountered, the effects on operation, and possible actions to improve fleet sizing in the city of Manaus.

3.7. Techniques for Generating and Interpreting Results

From the answers to each guiding question in the research, results were generated and organized into structured tables, grouped by guiding question, enabling the conversion of raw data into solid, comparable results. Each of these tables served as the basis for the elaboration of a complete textual result, based on the approaches of each method employed, for example: their application times, their advantages and disadvantages, and the possible risks of failure for each of them, in addition to the creation of demographic and business profiles that related each participant to the company to which they belong. In parallel, the interpretation of the results was conducted through a two-pronged process: a) empirical interpretation and b) theoretical interpretation.

The empirical interpretation was based on respondents' answers, describing how each method is employed and viewed from the perspectives of those who work with it daily in their respective roles. The theoretical interpretation method sought to synthesize each response to find a line of reasoning that made sense, without losing coherence with the respondents' answers, thus ensuring greater data fidelity. Therefore, the interpretation of the results was based on comparing the reality observed by the respondents with the theoretical framework, enabling a robust understanding of the current state of fleet sizing in Manaus and the factors that influence the adoption and performance of each method. In short, the interpretation resulted from the combination of practice and theory, always based on the collected data and the analytical framework that guides the study.

4. RESULTS AND DISCUSSION

The presentation of the research results follows the logic of the guiding questions. Thus, the main fleet-sizing methods employed by companies are presented first, followed by their purposes, and then the main advantages and disadvantages of these methods, and the main risks of failure in their use. The section ends with a discussion of the results, in which the empirical findings are compared with the literature review.

4.1. Main fleet sizing methods employed

The analysis of responses from each respondent regarding the main fleet-sizing methods currently employed in Manaus identified 10 distinct methods used by companies. Respondent A reported the frequency method to measure service quality and the capacity method to measure service demand; respondent B reported the fleet size method, which measures the number of vehicles needed for each time of day, and the routing method, which determines the pre-determined times for each stop or region in which the line will travel. Respondent C reported using both the quantitative method, through which they carry out strategic planning, and the qualitative method, which involves providing feedback on the service provided by the company. Table 2 shows the findings for this question.

Table 2. Main fleet sizing methods employed

Respondents	Methods	Description
A	Frequency method	Ensures service quality
A	Capacity method (critical section)	Defines demand fulfillment capacity

B	Fleet size	Number of vehicles
B	Routing	Schedules
C	Quantitative method	Strategic Planning
C	Qualitative method	Feedback on the service provided
D	Passengers per Kilometer (PKI)	Measure efficiency and profitability
D	Supply vs. Demand	Assertiveness in service delivery
E	Variable analysis	Quantitative and comparative indicator
E	Behavioral analysis	Analysis to map behavioral patterns

Source: data collected by the authors.

Respondent D reported the IPK (Passengers per Kilometer Index) method, which measures the efficiency and profitability of the service, and the supply and demand method, which measures service delivery. Respondent E reported the variable analysis method for measuring a quantitative and comparative indicator and the behavioral analysis method, which aims to identify behavioral patterns among public transport users. These results indicate that respondents can be considered experts or knowledgeable about fleet sizing methods, and that their conceptions are shaped by their roles within their respective organizations.

4.2. When the methods are employed

The second analysis highlights the diversity of methods used by companies in the city of Manaus, based on results obtained when these methods are employed to size urban bus fleets in Manaus. The main finding is that each respondent adopts specific techniques for different purposes, showing that fleet sizing and management are not based on a single method. Respondent A uses the frequency method and the capacity method to determine the final fleet size. At the same time, respondent B works on fleet sizing, verifying availability, and route planning, and is responsible for defining routes and schedules. Respondent C uses the quantitative method in developing the company's action plan and the qualitative method to evaluate service quality. These results are shown in Table 3.

Table 3. When the methods are employed

Respondents	Methods	When are they used?
A	Frequency method	Determination of the final fleet

A	Capacity method (critical section)	Determination of the final fleet
B	Fleet size	Verification of the availability of each fleet
B	Routing	Determination of routes and schedules
C	Quantitative method	Development of the transport company's action plan
C	Qualitative method	Analysis of the quality of service provided
D	Passengers per Kilometer (PKI)	Measurement of efficiency and profitability
D	Supply vs. Demand	Analysis of supply and demand to ensure accuracy in the services provided
E	Variable analysis	Support for data-driven decisions, with a quantitative focus
E	Behavioral analysis	Identification of patterns, habits, needs, and reactions to changes

Source: data collected by the authors.

Respondent D reported using the IPK (Passengers per Kilometer Index), used to measure efficiency and profitability, in addition to Supply x Demand analysis, to ensure accuracy in the services provided. Respondent E uses variable analysis, focused on decision-making, and behavioral analysis to identify user patterns and habits. These data reveal that the methods employed reflect different perspectives on urban transport management. Some respondents focus on operational calculations, and others prioritize strategic analyses. Together, these approaches show that transport planning depends on both objective metrics and qualitative observations.

4.3. Advantages and Disadvantages of the Methods Used

The analysis of responses to this question reveals specific advantages and limitations, indicating that there is no single solution capable of meeting the demands of urban transport. The finding is that the methods complement each other: some offer greater operational efficiency, and others are more suitable for understanding passenger behavior. Respondent A highlights the use of the frequency method to optimize flow. However, it ignores real demand and can be inefficient during peak hours; the capacity method, efficient during peak demand times, has disadvantages such as low frequency and difficulties obtaining data. Respondent B uses fleet-sizing to ensure uniform service. Still, service quality can suffer, as can the routing method used to optimize routes and schedules, due to inconsistent data and unpredictability. Respondent C uses the quantitative method to define itineraries and schedules. However, it can result in overcrowding and long waiting times, and the qualitative method, which considers user perceptions, faces problems such as delayed responses. Table 4 summarizes these findings.

Table 4. Advantages and disadvantages of the methods employed

Resp	Methods	Advantages	Disadvantages
A	Frequency method	Easy to calculate. Optimizes workflow. Essential during low demand.	It ignores actual demand. It is inefficient at peak times. Risk of oversizing.
A	Capacity method	It is efficient during peak hours. It optimizes costs. It prevents overcrowding.	Difficult to obtain data. May lead to low frequency. Does not meet service quality standards.
B	Fleet size	Consistent service within established hours.	Poor quality of service provided.
B	Routing	Defining routes. Defining schedules. Time optimization.	Inconsistent data. Possible unpredictability. Information errors.
C	Quantitative method	Definition of routes and the number of vehicles in circulation. Definition of timetables. Formulation of new bus lines.	Overcrowding and a lack of buses. Long waiting times between buses.
C	Qualitative method	Customer satisfaction surveys. Direct communication channels. Analysis of complaints.	Lack of and/or delayed response. Dissatisfaction with the communication channel. Failure to resolve problems.
D	Passengers per Kilometer (PKI)	Assess the actual demand for a line or system. Optimize routes and travel frequency. Reduce operational and environmental costs.	Interconnection with other indicators. Not applicable to isolated communities. Easily affected by external factors.
D	Supply vs. Demand	Business profit strategy. Supports policies to improve service quality. Improves decision-making regarding networks and routes.	Accumulated inflation. Increased operating costs. Tariff increase.
E	Variable analysis	Fleet sizing based on demand by time slot. Fleet calculation based on passenger-kilometers (IPK) and occupancy rate. Fleet optimization through indicators.	Undersized fleet. Dependence on data quality. Risk of "over-optimization".

E	Behavioral analysis	Identification of actual passenger usage patterns. Analysis of quality perception. Availability of increasing or decreasing fleet sizes at specific times/days.	Slow and costly process. Difficult standardization. Lower quantitative precision. Oversized fleet.

Source: data collected by the authors.

Respondent D uses IPK, an indicator that assesses demand and reduces costs. This indicator improves decision-making and quality, but is affected by inflation and rising costs. Respondent E uses the variable analysis method, based on indicators such as IPK and occupancy rate, which depends on data quality, and the behavioral analysis method to identify patterns among passengers, but this can lead to oversizing.

The data show that the advantages and disadvantages of the methods employed also reflect the different perspectives and priorities of urban transport management. Frequency, capacity, and variable analysis methods are geared towards operational optimization, while qualitative and behavioral methods offer a deeper understanding of the passenger. In summary, the results show that efficiency and service quality can only be achieved by combining different methods for technical and user-perception analyses.

4.4. Main Risks of Failure of the Methods Used

Table 5 shows the methods used by respondents, along with the associated risks for each method. Each of the five respondents identified two specific methods, drawing on their empirical knowledge and experience in the public transport sector. The information exposes not only technical limitations but also operational and managerial risks, enabling a complete understanding of the weaknesses in the implemented practices. Respondent A indicates the dangers associated with two procedures: the frequency method and the capacity method. The frequency method presents risks, such as inaccurate cycle time calculations, which can lead to inadequate intervals between vehicles; intervals not adjusted to demand, which affect service efficiency for users; and undersized fleets, which can result in a lack of vehicles during peak periods. In the capacity method, the risks include inaccurate measurements of the critical section, which can compromise adequate service sizing; unforeseen seasonal variations, which complicate planning; and the exclusive prioritization of cost, which can reduce service quality by focusing only on operational savings.

Respondent B points out that fleet size and routing present risks. In the first scenario, risks mentioned include an increase in emergency maintenance resulting from poor planning; difficulties in fleet and driver allocation, affecting operational efficiency; and the lack of adoption of sequential methodologies, which can affect the logic of fleet growth or reduction. In route planning, risks include inadequate temporal configuration, disorganized time constraints, and outdated information. These elements hinder synchronization and the correct execution of trips, affecting both the user (who lacks updated route and schedule data, ultimately disrupting daily life due to bus uncertainty) and the transport company (which fails to correctly size entry/exit routes for fleets, ultimately overloading the driver).

Table 5. Main risks of method failures

Respondents	Methods	Risks of failure
A	Frequency method	Incorrect cycle time calculation, Time interval not aligned with demand. Underestimation of reserves.
A	Capacity method	Incorrect measurement of the critical section. Unexpected seasonal variation in demand. Exclusive prioritization of cost.
B	Fleet size	Increased emergency maintenance. Fleet and driver allocation problems. Failure to adopt a sequential methodology.
B	Routing	Problems with the timing of transportation. Disorganization regarding start and end time restrictions. Lack of up-to-date information.
C	Quantitative method	Difficulty in dealing with non-quantifiable variables. Superficial data excludes real user needs. Contextual limitations.
C	Qualitative method	Neglecting customer experience. Ignoring customer needs. Not providing personalized service. Not understanding the user's time frame.
D	Passengers per Kilometer (PKI)	It does not measure service quality. It disadvantages areas with low demand. It encourages concentration in areas with already high demand. It does not differentiate between short and long trips.
D	Supply vs. Demand	Discouraging the maintenance of long and sparsely populated routes. It may encourage the exclusion of outlying neighborhoods. It does not capture time variations. It encourages service cuts that worsen the service.
E	Variable analysis	Insufficient fleet during rush hour. High data dependency. Disregards social factors. Limited methodology.
E	Behavioral analysis	It depends on constant updating. It requires subjective interpretations.

Source: data collected by the authors.

Respondent C pointed out flaws in both the quantitative and qualitative methods. In the quantitative method, risks cited include difficulty handling non-quantifiable variables, which limit more complex analyses; superficial data, which may disregard the reality of users; and contextual limitations, which restrict the application of the results. In the qualitative method, the risks involve negligence regarding the customer's experience and needs, lack of personalized service (aggravated by using automatic message "bots" that impair the user's experience in obtaining information), and lack of understanding of each user's time, compromising the quality of the subjective analysis in relation to the real needs of each one.

Respondent D indicates dangers associated with the IPK (Passenger per Kilometer Index) and the Supply × Demand approach. The IPK may not assess service quality, harm low-demand areas, promote the concentration of supply in already saturated regions, or differentiate between short and long trips. On the other hand, the Supply × Demand method brings risks such as demotivation to maintain long and infrequently used routes, exclusion of distant neighborhoods, difficulty in capturing variations in schedules, and this method is also used to define the price of tickets in addition to defining the number of buses in circulation, which ends up not serving the population, dissatisfying users who use public transport.

Finally, Respondent E mentions flaws in the variable analysis, such as insufficient fleet during peak hours, high dependence on data, disregard for social factors, and methodological limitations; and in the behavioral analysis, which relies on constant updating, involves subjective interpretations, and is therefore susceptible to errors. In general, all methods are susceptible to errors, with weaknesses stemming from technical limitations, lack of updates, subjectivity, lack of data, and operational problems. This demonstrates that ongoing improvements are needed to ensure the efficiency and quality of public transport in Manaus.

4.5. Discussion of Results

The empirical results indicate that urban transport managers widely use the frequency and capacity methods to determine the number of vehicles needed at specific times and on specific sections of the network. These results are consistent with the international literature on public transport planning, which recognizes service frequency as a central variable for fleet sizing and defining the level of service offered to users. As observed in the research, the main advantage of this method is its operational simplicity and ease of calculation. However, it has limitations because it ignores real variations in demand at certain times of the day.

Recent studies confirm this limitation by showing that models based exclusively on frequency can lead to fleet oversizing or undersizing when they do not account for detailed demand data and urban mobility patterns (Li *et al.*, 2024; Karmanesh *et al.*, 2024; Truden; Hewitt, 2026). This research in transport planning indicates that traditional frequency-based methods need to be integrated with more robust demand forecasting and network optimization models to improve system efficiency. Furthermore, empirical analyses of urban transportation systems show that the lack of integration between frequency and demand variability can compromise service levels and increase operational costs. Therefore, the results obtained in Manaus reflect a pattern observed across several public transportation systems, in which traditional methods still coexist with more advanced operational planning approaches.

Another relevant finding of the research is the use of fleet sizing associated with route planning, which is used to determine vehicle availability, define itineraries, and organize operating schedules. According to respondents, this method enables better organization of system operations and optimization of vehicle use, although it is subject to data inconsistencies and the unpredictability of operating conditions. This finding aligns with the literature on the Fleet Size and Mix Vehicle Routing Problem (FSMVRP), in which decisions about the number of vehicles and route planning are addressed in an integrated manner. Recent studies show that integrating fleet sizing and route planning can significantly reduce operating costs and improve the efficiency of the logistics system (Silva *et al.*, 2024; Xie *et al.,* 2024; Kronmueller *et al.*, 2024). However, these models also face challenges related to computational complexity and the need for detailed data on the transportation network. The literature also highlights that errors in estimating travel times or forecasting demand can lead to distortions in route definition and fleet sizing. In this context, the empirical results observed in Manaus reinforce the importance of data quality and the continuous updating of information used in the operational planning of public transport.

The research also highlights the simultaneous use of quantitative and qualitative methods in urban transport management, indicating that fleet planning depends not only on operational calculations, but also on the analysis of user perception and the quality of service provided. This hybrid approach is widely discussed in contemporary literature on transport planning, which recognizes the importance of combining analytical methods with instruments for evaluating user experience. Recent studies show that quantitative models enable more accurate estimation of the number of vehicles needed to meet demand, while qualitative methods help identify problems related to comfort, accessibility, and service reliability (Balac *et al.*, 2020; Truden; Hewitt, 2026; Li *et al.*, 2024). However, this literature also highlights important limitations of these qualitative approaches, including the subjectivity of evaluations and the difficulty of translating user perceptions into quantitative parameters for fleet sizing. Furthermore, research indicates that the lack of integration between quantitative and qualitative indicators can lead to inconsistent operational decisions. Therefore, the empirical results obtained in Manaus confirm the need to integrate diverse data sources and methodologies to improve the efficiency of urban transport planning.

Another relevant aspect identified in the research is the use of the IPK (Passengers per Kilometer Index) and Supply × Demand analysis as central indicators for evaluating system efficiency and supporting fleet-sizing decisions. These indicators are widely used in public transport systems to assess line productivity and identify opportunities for network optimization. The scientific literature confirms that the IPK is one of the main performance indicators used by operators and regulatory bodies to assess the relationship between passenger volume and vehicle distance traveled. However, several studies point to limitations of this indicator, especially in low-density or peripheral areas, where demand tends to be lower (Mancini; Gansterer, 2026; Yatskiv *et al.*, 2024; Karmanesh *et al.*, 2024). Furthermore, the exclusive use of the IPK may encourage the concentration of services in high-demand regions, thereby reducing public transport coverage in less-dense areas. Recent research also highlights that analysis based solely on the relationship between supply and demand can lead to decisions that prioritize economic efficiency over social equity in transportation access. Thus, the empirical results observed in Manaus reflect a recurring dilemma in urban transportation systems between operational efficiency and universal service.

Finally, the research results demonstrate the use of analyses based on operational variables and behavioral analyses of users, used to identify mobility patterns and adjust fleet size according to demand behavior. This approach is consistent with recent trends in the literature on logistics and transportation planning, which emphasize the use of data and behavioral analyses to improve the operational planning of urban mobility systems. Recent studies show that incorporating data on travel patterns, user habits, and temporal variations in demand can significantly improve the accuracy of fleet-sizing models. However, these approaches also present important challenges, including the need for large volumes of data, difficulties with methodological standardization, and risks associated with the subjective interpretation of behavioral information. Furthermore, the literature points out that data-driven models can generate distortions when the available data is incomplete or outdated. Thus, the empirical results of the research confirm that behavioral analysis can contribute to improving urban transport planning when integrated with robust quantitative methods and reliable data collection systems (Truden; Hewitt, 2026; Xie *et al.*, 2024; Li *et al.*, 2024).

The empirical results indicate that fleet sizing in urban transport in Manaus is not based on a single structured method, but rather on a combination of operational, strategic, and behavioral approaches used by system managers. The data show that methods such as frequency, capacity, routing, and demand analysis, and indicators such as IPK, are employed in a complementary way to support decisions on the number of vehicles in operation, route organization, and the evaluation of service efficiency. This methodological diversity suggests that fleet planning is adaptive, responding to operational needs and the limitations of available data in the local context. At the same time, the results show that each method offers specific advantages but also important limitations, including dependence on data quality, difficulty in capturing demand variations, and risks of oversizing or undersizing the fleet. It is also observed that quantitative approaches are predominant in operational decisions, while qualitative and behavioral methods are used to understand user perception and support service adjustments. Thus, it is concluded that fleet sizing in the analyzed system is conducted through a hybrid strategy that combines operational indicators, demand analysis, and user experience evaluation, highlighting the need for integration between technical methods and social analyses to improve the efficiency and quality of public transport.

5. CONCLUSION

This study showed that fleet sizing in the urban transport system of Manaus is conducted using multiple complementary methods, reflecting the complexity of public transport management. The data collected from respondents indicate that methods such as frequency, capacity, fleet size, routing, IPK, supply and demand analysis, as well as quantitative, qualitative, and behavioral approaches, are used in combination to support operational and strategic decision-making. This methodological diversity shows that there is no single model capable of fully meeting the system's needs, and that integrating different indicators and analytical techniques is necessary to achieve greater efficiency. The results also demonstrated that each method has specific advantages, such as ease of calculation, support for operational planning, or understanding of user behavior, but also important limitations, including dependence on data quality, difficulty in capturing demand variations, and risks of oversizing or undersizing the fleet.

Thus, it is concluded that fleet planning in Manaus is adaptive and manager-driven, combining operational metrics and qualitative analyses to balance operational efficiency and service quality.

From both theoretical and practical standpoints, the study makes significant contributions to transport logistics and fleet management, particularly in the context of urban public transport. First, the research expands knowledge of the methods managers use for fleet sizing in real-world contexts, showing that operational practice often involves a combination of techniques rather than the isolated application of theoretical models. Second, the study contributes to the literature by demonstrating that traditional indicators, such as service frequency, capacity, and IPK, continue to play a central role in operational decisions, even amid advances in more complex optimization and modeling methods. Furthermore, the research highlights the importance of integrating quantitative indicators and qualitative analyses, showing that understanding user behavior and service quality perceptions also influences decisions about fleet size and operations.

Thus, the study helps bridge the gap between theory and practice in transport logistics, providing empirical evidence to support managers and researchers in evaluating and improving fleet-sizing methods. Due to the small sample size, the findings cannot be generalized.

Regarding future research, the study identifies promising avenues to deepen knowledge of fleet sizing in public transportation. The first proposal consists of developing quantitative research based on mathematical models or optimization methods, capable of comparing the performance of methods currently used by companies with advanced fleet-sizing models reported in the scientific literature. The second line of investigation involves expanding the scope of the research to a larger number of companies and cities, allowing the identification of regional patterns and the comparison of different fleet planning strategies in urban transportation systems. Finally, a third proposal calls for incorporating mobility data and digital technologies, such as electronic ticketing systems, GPS tracking, and urban mobility data analysis, to develop more accurate demand forecasting and dynamic fleet-sizing models. These lines of investigation can advance scientific knowledge and develop more efficient and sustainable solutions for public transportation planning.

REFERENCES

ALBUQUERQUE, V. et al. Sustainability measurement in a logistics transportation company. **Transportation Research Procedia**, v. 72, p. 48-55, 2023. https://doi.org/10.1016/j.trpro.2023.11.321.

AL-NABULSI, D. et al. Analyzing fleet efficiency and passenger delay in demand-responsive transit: A dual-model approach with CVRPTW and TAMOS. **Journal of Advanced Transportation**, v. 2025, n. 1, p. 6761411, 2025. https://doi.org/10.1155/atr/6761411.

AUAD-PEREZ, R.; VAN HENTENRYCK, P. Ridesharing and fleet sizing for on-demand multimodal transit systems. **Transportation Research Part C: Emerging Technologies**, v. 138, p. 103594, 2022. https://doi.org/10.1016/j.trc.2022.103594.

BALAC, M.; HÖRL, S.; AXHAUSEN, K. W. Fleet sizing for pooled (automated) vehicle fleets. **Transportation Research Record**, v. 2674, n. 9, p. 168-176, 2020. https://doi.org/10.1177/0361198120927388.

HRUŠOVSKÝ, M. et al. Integrated planning approach for fleet sizing and fleet management of freight railcars. **Flexible Services and Manufacturing Journal**, v. 37, n. 3, p. 869-903, 2025. https://doi.org/10.1007/s10696-024-09556-8.

JEZEQUEL, S.; BOUKHERROUB, T.; BELMOKHTAR-BERRAF, S. Dynamic electric vehicle dispatching problem: A simulation modelling framework. In: **2025 11th International Conference on Control, Decision and Information Technologies (CoDIT)**. IEEE, 2025. p. 2087-2092. https://doi.org/10.1109/CoDIT66093.2025.11321715.

KARMANESH, Y. et al. Two-stage stochastic programming approach for fleet sizing and allocating rail wagons under uncertain demand. **Computers & Industrial Engineering**, v. 188, p. 109878, 2024. https://doi.org/10.1016/j.cie.2023.109878.

KRONMUELLER, M.; FIELBAUM, A.; ALONSO-MORA, J. Fleet sizing for the flash delivery problem from multiple stores: A case study in Amsterdam. In: **2024 IEEE 27th International Conference on Intelligent Transportation Systems (ITSC)**. IEEE, 2024. p. 1159-1165. https://doi.org/10.1109/ITSC58415.2024.10919944.

LI, S.; SHEHADEH, K. S.; TSANG, M. Y. Stochastic programming models for a fleet sizing and appointment scheduling problem with random service and travel times. **Transportation Research Part C: Emerging Technologies**, v. 165, p. 104692, 2024. https://doi.org/10.1016/j.trc.2024.104692.

MANCINI, S.; GANSTERER, M. Infrastructure planning, fleet sizing, and scheduling for E-public transport. **Flex Serv Manuf J.**, p. 1-35, 2026. https://doi.org/10.1007/s10696-026-09658-5.
MEßMER, M. et al. Data-driven insights into truck utilisation challenges in freight logistics. **Research in Transportation Business & Management**, v. 60, p. 101373, 2025. https://doi.org/10.1016/j.rtbm.2025.101373.

MILENKOVIĆ, M.; BOJOVIĆ, N.; ABRAMIN, D. Railway freight wagon fleet size optimization: A real-world application. **Journal of Rail Transport Planning & Management**, v. 26, p. 100373, 2023. https://doi.org/10.1016/j.jrtpm.2023.100373.

NASCIMENTO-E-SILVA, D. et al. Influence of the external environment on the logistics strategies of industrial organizations. **International Journal for Innovation Education and Research**, v. 7, n. 12, p. 628-643, 2019. https://doi.org/10.31686/ijier.Vol7.Iss12.2117.

NASCIMENTO-E-SILVA, D. **Manual do método científico-tecnológico**: edição sintética. Florianópolis: DNS Editor, 2020.

NASCIMENTO-E-SILVA, D. **Handbook of the scientific-technological method**: Synthetic edition. Manaus: DNS Editor, 2021a.

NASCIMENTO-E-SILVA, D. **O método científico-tecnológico**: fundamentos. Manaus: DNS Editor, 2021b.

NASCIMENTO-E-SILVA, D. **O método científico-tecnológico**: questões de pesquisa. Manaus: DNS Editor, 2021c.

NASCIMENTO-E-SILVA, D. **O método científico-tecnológico**: coleta de dados. Manaus: DNS Editor, 2023.

ŞAHİN, M.; YILDIZ, E. A. The heterogeneous fleet drone delivery problem with total weighted lateness considerations: mathematical models and modified farmland fertility algorithm. **International Journal of Systems Science: Operations & Logistics**, v. 12, n. 1, p. 2566721, 2025. https://doi.org/10.1080/23302674.2025.2566721.

SILVA, L. M. R.; WANG, H.; SOARES, C. G. A strategic fleet size and mix vehicle routing model to analyze the impact of demand fluctuation on river-sea liner shipping. **Ocean Engineering**, v. 307, p. 118096, 2024. https://doi.org/10.1016/j.oceaneng.2024.118096.

SON, J.; IM, J.; KIM, D. Urban transit optimization: Efficient electric bus operations and vehicle-to-grid integration. **Computers & Industrial Engineering**, v. 205, p. 111169, 2025. https://doi.org/10.1016/j.cie.2025.111169.

TANG, C.; SHI, H.; LIU, T. Optimization of single-line electric bus scheduling with skip-stop operation. **Transportation Research Part D: Transport and Environment**, v. 117, p. 103652, 2023. https://doi.org/10.1016/j.trd.2023.103652.

TARAN, I. et al. Determining the optimal service area of a logistics center: A quantitative approach. **Transport Problems: an International Scientific Journal**, v. 20, n. 3, p 1-15, 2025. https://doi.org/10.20858/tp.2025.20.3.01.

TRUDEN, C.; HEWITT, M. Multi-objective, multi-attribute fleet sizing in a dynamic and stochastic environment: A data-driven approach. **Transportation Research Part E: Logistics and Transportation Review**, v. 207, p. 104585, 2026. https://doi.org/10.1016/j.tre.2025.104585.

WANG, Shiqi et al. Electrification of a citywide bus network: A data-driven micro-simulation approach. **Transportation Research Part D: Transport and Environment**, v. 116, p. 103644, 2023. https://doi.org/10.1016/j.trd.2023.103644.

WU, Y.; LIU, T.; DU, B. Fleet sizing and static rebalancing strategies for shared E-scooters: A case study in Indianapolis, USA. **Transportation Research Part A: Policy and Practice**, v. 190, p. 104287, 2024. https://doi.org/10.1016/j.tra.2024.104287.

XIE, F.; WANG, C.; DUAN, H. Optimizing fleet size in point-to-point shared demand responsive transportation service: A network decomposition approach. **Mathematics**, v. 12, n. 19, p. 3048, 2024. https://doi.org/10.3390/math12193048.

YATSKIV, I.; TOLUJEVS, J.; PETROVS, V. Framework for the sustainable modeling of electric truck fleet usage. **Logistics**, v. 8, n. 4, p. 95, 2024. https://doi.org/10.3390/logistics8040095.

ZHANG, H. et al. Joint optimization of fleet sizing, charging station planning, and operation for autonomous electric vehicle fleets in urban transportation networks. **Sustainable Energy, Grids and Networks**, p. 101946, 2025. https://doi.org/10.1016/j.segan.2025.101946.

ZHANG, Y. et al. A two-stage optimization framework for UAV fleet sizing and task allocation in emergency logistics using the GWO and CBBA. **Drones**, v. 9, n. 7, p. 501, 2025. https://doi.org/10.3390/drones9070501.