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The Influences of Elevator Traffic Flow under the Different Elevator Design

—Based on the Project of the Ak-Keme Hotel

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Abstract

Accompanied by the rapid development of society and the growing prevalence of high-rise buildings, vertical transportation has become a critical challenge in urban living and working environments. To address these challenges, advanced elevator control systems such as GCS (Group Control Systems) and DDS (Destination Dispatching Systems) have been developed, significantly enhancing the convenience and efficiency of elevator operations. In parallel, ETA (Elevator Traffic Analysis) has also emerged as an essential tool for tackling vertical transportation issues. By analyzing different elevator configurations tailored to specific building requirements, ETA facilitates informed decision-making during the design phase of elevator systems, ensuring optimized traffic flow and minimizing delays. This research leverages elevator traffic simulation to evaluate two distinct elevator configurations (CASE-1: Two large and three small-capacity elevators/CASE-2: Four large-capacity elevators) within the same building, specifically focusing on the actual remodeling project of the Ak-Keme Hotel in the Kyrgyz Republic. By comparing the mixed-capacity configuration and an all-large-capacity configuration, this research provides practical insights that are expected to serve as a valuable reference for actual elevator design in high-rise buildings, contributing to more efficient and effective solutions to elevator traffic challenges.

Keywords

Vertical Transportation, High-Rise Buildings, ETA (Elevator Traffic Analysis), Elevator Design, Elevator Capacity

1. Introduction

In contemporary urban society, due to the advanced development of foundational building engineering technologies, the quality of the living environment has become a focal point primarily. While structural concerns in modern buildings often fade into the background, receiving little attention from the general public, challenges associated with vertical transportation in tall buildings have emerged as a critical issue. The proliferation of skyscrapers in urban centers has underscored the importance of efficient vertical transportation systems, as frequent complaints about elevator congestion have grown into a pressing societal problem [1]-[3].

To address this issue, including GCS (Group Control Systems) and DDS (Destination Dispatching Systems), various innovative solutions have been proposed, while these systems leverage advanced algorithms and automation to alleviate elevator traffic and improve user experience [4]-[7]. Despite their effectiveness, the integration of such systems into building designs remains contentious due to their high implementation costs. Moreover, many building proprietors doubt the necessity of these advanced technologies, further complicating their adoption. In this context, ETA (Elevator Traffic Analysis) emerges as a pivotal tool. By evaluating elevator traffic flow and comparing the performance of different elevator control designs, ETA provides valuable insights for decision-making. It serves as a practical reference for building proprietors, helping them determine whether the integration of sophisticated elevator control systems is justified for their specific needs. Understanding the dynamics of elevator traffic not only facilitates the design of more suitable and efficient vertical transportation systems but also contributes to creating a more convenient and harmonious urban living environment. By addressing elevator-related challenges, complaints from passengers are expected to be reduced, ultimately enhancing the overall quality of life in densely populated urban cities.

Figure 1. Ak-Keme Hotel (Before remodeling).

The Ak-Keme Hotel, located in Bishkek City, Kyrgyz Republic, has been selected as the target building of this research on elevator traffic analysis, as illustrated in **Figure 1**. Originally constructed in 1996, the hotel has served the hospitality industry for 28 years. Over this period, including its elevator system, the infrastructure of the hotel has become outdated and increasingly inefficient, and these challenges have prompted the proprietor to initiate a comprehensive remodeling project aimed at modernizing the entire structure. The scope of this remodeling extends beyond aesthetic improvements, it also seeks to address critical operational issues, particularly those related to vertical transportation. Given the advancements in elevator technologies since the hotel's construction, the existing system struggles to meet the demands of contemporary users, leading to reduced efficiency and potential customer dissatisfaction. The remodeling project provides an opportunity not only to enhance the functionality of the hotel but also to apply and validate elevator traffic analysis methods to inform optimal design decisions.

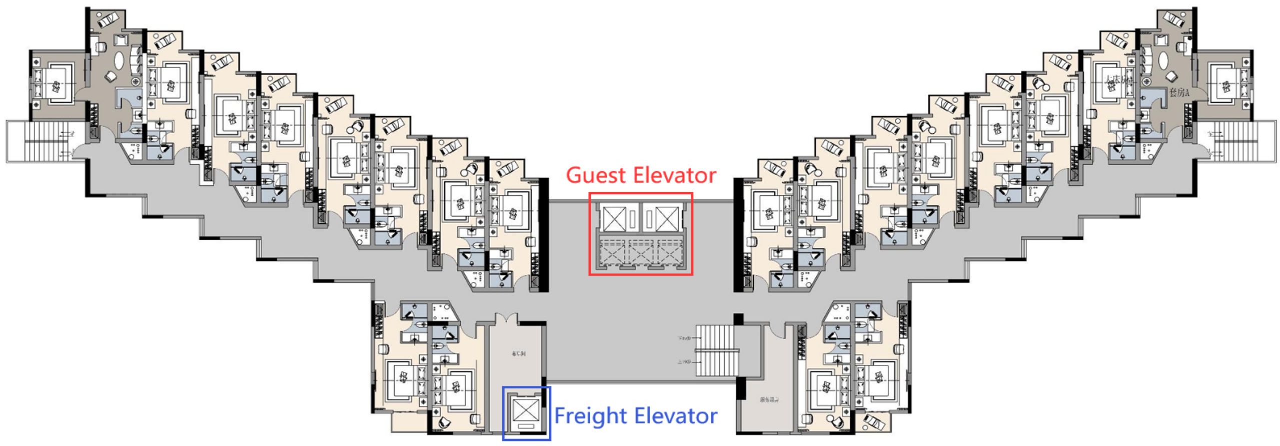

Figure 2. Layout of the bedroom floor of the hotel.

As depicted in **Figure 2**, the layout of the bedroom floors of the Ak-Keme Hotel reveals the original elevator design of the building. Aside from a freight elevator marked in blue in **Figure 2**, the hotel was initially equipped with a total of five guest elevators, and these include three smaller elevators with a capacity of 450 kg each and two larger elevators with a capacity of 1350 kg. This configuration has served the building since its construction, and it is now a point of consideration in the ongoing remodeling project.

For the renovation, the proprietor contemplates a significant redesign of the vertical transportation system. Specifically, the evaluation is focused on whether the current arrangement of three smaller and two larger elevators could be replaced with a system consisting of four larger elevators, each with a capacity of 1350 kg. This potential redesign aims to enhance the overall efficiency of the vertical transportation system by leveraging the higher capacity and improved performance of larger elevators. Despite the anticipated benefits, this decision poses challenges, because the proprietor is uncertain about whether the proposed configuration would adequately satisfy the diverse needs of hotel guests while maintaining optimal traffic flow during peak periods. Additionally, concerns regarding installation costs, spatial adjustments, and integration with the existing infrastructure of the hotel further complicate the decision-making process.

Preserving the original structural framework of the Ak-Keme Hotel while improving its vertical transportation efficiency is a fundamental objective of this research. By conducting a comparative analysis of two distinct elevator configurations, this research aims to evaluate the influences on elevator traffic flow without requiring structural modifications. The first configuration consists of two large elevators, each with a capacity of 1350 kg, complemented by three smaller elevators with a capacity of 450 kg. The second configuration replaces the mixed system in the first configuration with four large elevators, each having a capacity of 1350 kg. To ensure accuracy and consistency in the analysis, the simulation utilizes Elevator™, a specialized tool for elevator traffic modeling, allowing for precise evaluation of vertical transport dynamics. Additionally, to eliminate the potential variability in simulated results, fixed parameters such as passenger arrival rates and floor-based distribution are strictly maintained across both situations, ensuring that differences in performance are solely attributed to elevator configuration. Through comprehensive simulations, this research systematically examines key performance indicators, including average waiting time, transit time, queue formation, and overall passenger experience. By interpreting these results, this research highlights the influence of elevator capacity and system configuration on operational efficiency, offering valuable insights into the optimal elevator design for the Ak-Keme Hotel, while these findings are expected to provide a valuable reference for the ongoing remodeling project, offering insights into whether replacing the original elevator configuration would significantly enhance vertical transport performance.

Additionally, this research aims to contribute to a broader understanding of elevator traffic flow dynamics by exploring the comparative advantages of smaller versus larger elevators in a high-occupancy building. The findings of this research will not only inform the specific remodeling project but also serve as a meaningful reference for similar projects in other aging urban structures. By integrating a deep understanding of traffic flow into elevator system design, this research aspires to offer practical recommendations that balance efficiency, cost, and user satisfaction in vertical transportation planning.

2. Materials and Methods

2.1. Building Information of Ak-Keme Hotel

Including story height, passenger numbers, and floor area for each story, these key building parameters play a crucial role in the elevator traffic simulation for the Ak-Keme Hotel as summarized in Table 1. These parameters are integral to understanding the dynamics of elevator performance and traffic flow within the building.

Specifically, the height of each story is a particularly important factor, as it determines the travel distance for elevators between the departure and destination levels, and variations in story height directly influence travel time, energy consumption, and overall system efficiency. This parameter is critical for accurately modeling the vertical transportation system and assessing its performance under different design cases. Moreover, passenger numbers and floor area per story are equally significant because these parameters influence the density of occupants on each level, which in turn affects elevator demand and traffic patterns. By analyzing the ratio of area per person as presented in **Table 1**, it is possible to estimate the density of each floor and its impact on total elevator usage. Higher occupant density typically correlates with increased elevator demand, requiring more frequent trips and potentially longer waiting times during peak periods.

Table 1. Building information of Ak-Keme Hotel.

Floor	Height m	Passenger number Person	Passenger number Person	Area m^2	Area/person
PIT	−4.9	-	-	-	-
−1	−3.4	100	125	2490.38	19.92
1	4.3	0	0	2032.52	–
2	7.6	0	0	1870.46	–
3	10.6	0	0	1016.39	–
4	13.6	41	52	1016.39	19.55
5	16.6	41	52	1016.39	19.55
6	19.6	41	52	1016.39	19.55
7	22.6	41	52	1016.39	19.55
8	25.6	41	52	1016.39	19.55
9	28.6	41	52	1016.39	19.55
10	31.6	33	42	1016.39	24.20
11	34.6	33	42	1016.39	24.20
12	37.6	33	42	1016.39	24.20
13	40.6	33	42	1016.39	24.20
14	45.5	100	125	1016.39	8.13

As detailed in **Table 1**, including a single basement level, there are a total of 15 stories consisting of the Ak-Keme Hotel. The basement has a height of 3.4 m and a total area of 2490.38 m^2. The space of the basement is primarily designated for utilities such as laundry, a swimming pool, a spa, and a casino, and based on these functions, the basement is designed to accommodate up to 100 occupants under normal operating conditions. To ensure accuracy in elevator traffic simulation, a conservative estimate of the passenger number for the basement level is calculated by the equation as shown below:

$$POP_S = POP_R + \left(0.25 \times POP_R\right) \quad (1)$$

where, POP_R represents the real designed passenger number, which reflects the actual anticipated occupancy for elevator traffic flow based on the building's design and intended usage. This value accounts for factors such as the building's operational characteristics, the spatial allocation for various activities, and the occupancy limits established during the design phase. Conversely, POP_S denotes the simulated passenger number used in the elevator traffic analysis. This value is applied to the computational models and simulations to estimate elevator demand under different cases in this research.

Based on the calculated approach of Equation (1) in this research, the passenger number for the simulation for this simulation is determined to be 125 occupants. Given the total area of 2490.38 m^2 for the basement, the area-per-person ratio is calculated as 19.92 m^2/person, and this ratio provides a quantitative measure of the space allocated to each occupant in the basement, offering insights into the spatial distribution and comfort level for guests of this area. Conversely, the person-per-area ratio is calculated as 0.0502 person/m^2, indicating the number of occupants per square meter in the basement. This metric reflects the density of the space, serving as a key parameter in analyzing how the occupancy in the basement impacts overall elevator traffic.

The first three floors of the Ak-Keme Hotel have been excluded from the elevator traffic simulation due to their specific design and utilization. The first floor is an open space primarily serving as the check-in service center for hotel guests, covering an area of 2032.52 m^2. Additionally, this floor functions as the home floor for whole the elevators, meaning it acts as a central hub where elevators return to idle or begin their operations. Given its unique purpose and lack of continuous passenger occupancy, no occupants are allocated to this floor for simulation purposes. Moreover, the second and third floors are designated as equipment floors, with the second floor allocated for water systems and the third floor for electrical systems, while the areas of these floors are 1870.46 m^2 and 1016.39 m^2 respectively. These floors are solely functional and are not designed to accommodate hotel guests or staff beyond maintenance personnel, further justifying their exclusion from the passenger simulation.

The floor heights vary according to their design functions, while the first floor is 4.3 m high to accommodate its open layout, while the second and third floors have heights of 3.3 m and 3.0 m respectively, reflecting their technical utility roles, and the differences of the floors are detailed in **Table 1**. Since no passengers are assigned to these floors, it is not possible to calculate the area-per-person ratio or the person-per-area ratio for the first, second, and third floors, and this absence is noted in **Table 1** and emphasizes that these floors do not contribute directly to elevator traffic demand.

The design of the Ak-Keme Hotel from the fourth to the thirteenth floor is focused on accommodating guests, with these levels designated as bedroom floors. Each floor from the fourth to the thirteenth covers an area of 1016.39 m^2, providing consistent spatial allocation. According to Equation (1), floors four through nine are configured with 20 bedrooms per floor which is designed to house 52 occupants each. In contrast, floors ten through thirteen are configured with 16 bedrooms per floor, accommodating 42 occupants each. This variation in room count reflects the efforts of the hotel to offer a diverse range of accommodations, catering to different guest needs and preferences. Regarding the fourteenth floor, the design shifts to a restaurant space, which also spans 1016.39 m^2. According to Equation (1), this floor is designed to accommodate 125 occupants. The higher density of occupants on this floor is characteristic of restaurant settings, where shared dining spaces result in a greater concentration of people compared to individual rooms. This density highlights the different operational demands placed on the vertical transportation system of the hotel, particularly during peak dining hours. The transition from bedroom floors to the restaurant floor underscores the importance of adapting elevator systems to varying occupancy patterns across different floors.

Moreover, the calculated area-per-person and person-per-area ratios for these floors provide further insights into their functional characteristics. For bedroom floors, the area-per-person ratio is 19.55 m^2/person from the fourth to ninth floors and 24.20 m^2/person from the tenth to thirteenth floors, indicating more generous spatial allocations on the upper bedroom levels. In contrast, the area-per-person ratio of the restaurant floor is 8.13 m^2/person, reflecting its higher occupant density. Correspondingly, the person-per-area ratios are 0.0512 persons/m^2 for the fourth to ninth floors, 0.0413 persons/m^2 for the tenth to thirteenth floors, and 0.1230 persons/m^2 for the restaurant floor. These differences emphasize the distinct spatial dynamics and elevator traffic demands across these levels, providing a foundational understanding for optimizing the elevator system of Ak-Keme Hotel.

The height of each bedroom floor in the Ak-Keme Hotel plays a critical role in the simulation of elevator traffic flow because it directly affects the travel distance and operational efficiency of the elevators, while **Table 1** outlines the floor heights, highlighting a consistent height of 3 m for each of the bedroom floors from the fourth to the thirteenth floor. In contrast, the fourteenth floor features a greater height of 4.9 m as it is designed as a restaurant, reflecting the unique architectural and functional requirements of a dining space. Combining all these dimensions, the total structural height of the Ak-Keme Hotel amounts to 50.4 m, and the height of the building variations not only influence the vertical transportation dynamics but also underscore the need for tailored elevator strategies to accommodate the distinct demands of different floor types within the building.

2.2. Design of the Elevators

2.2.1. Design of CASE-1

The elevator design in CASE-1 for the Ak-Keme Hotel incorporates a total of five elevators, strategically configured to satisfy the vertical transportation needs of the building. As detailed in **Table 2** and **Table 3**, this configuration includes three small-capacity elevators, each with a load capacity of 450 kg, and two large-capacity elevators, each capable of accommodating up to 1350 kg. The inclusion of both small and large elevators reflects a balanced approach, aiming to handle a diverse range of passenger demands efficiently, and this mix is expected to be beneficial for a hotel, where elevator usage varies significantly depending on guest movement, housekeeping, and service requirements.

Table 2. Design of the small capacity elevator (CASE-1).

Number of Elevators	3
Capacity (kg)	450
Door Pre-opening Time (s)	0
Door Open Time (s)	2.3
Door Close Time (s)	2.5
Speed (m/s)	2
Acceleration (m/s^2)	0.8
Jerk (m/s^3)	1.2
Start Delay (s)	0.5
Home Floor	GF

Regarding the technical specifications of the small-capacity elevators as **Table 2** illustrates, the operational parameters are meticulously designed for optimal performance. The small-capacity elevators feature a door pre-opening time of 0 s, a door open time of 2.3 s, and a door close time of 2.5 s, ensuring swift yet safe passenger ingress and egress. The speed is set at 2 m/s, complemented by an acceleration rate of 0.8 m/s^2, enabling a smooth and efficient ride. Additionally, the jerk rate which influences the comfort of acceleration transitions, is designed at 1.2 m/s^3. A start delay of 0.5 s is also incorporated to enhance control and coordination during the operation of the elevators. These specifications collectively aim to provide a reliable and comfortable elevator experience, catering to both the guests and operational staff.

Table 3. Design of the large capacity elevator (CASE-1).

Number of Elevators	2
Capacity (kg)	1350
Door Pre-opening Time (s)	0
Door Open Time (s)	2.9
Door Close Time (s)	3.3
Speed (m/s)	2
Acceleration (m/s^2)	0.8
Jerk (m/s^3)	1.2
Start Delay (s)	0.5
Home Floor	GF

The design of the two large-capacity elevators in the Ak-Keme Hotel reflects considerations for their higher passenger load as detailed in **Table 3**. Similar to the small-capacity counterparts, two large-capacity elevators have a door pre-opening time set to 0 s, ensuring no additional delays during boarding or alighting. However, due to their increased size and capacity, the door opening and closing times are slightly longer at 2.9 seconds and 3.3 seconds respectively, while these extended times accommodate the anticipated higher volume of passengers, ensuring smooth and unhurried transitions. The large-capacity elevators maintain a speed of 2 m/s and an acceleration rate of 0.8 m/s^2, balancing efficiency and passenger comfort. Additionally, the jerk rate is set to 1.2 m/s^3, ensuring gentle changes in acceleration for a comfortable ride experience. The start delay, consistent with the small-capacity elevators, is 0.5 seconds, supporting coordinated operation and minimal wait times, and this design aims to effectively handle the demands of larger groups of passengers while maintaining reliability and comfort.

2.2.2. Design of CASE-2

The elevator design in CASE-2 for the Ak-Keme Hotel introduces a streamlined configuration consisting of four large-capacity elevators, which replaces the mixed design of CASE-1 that featured three small-capacity and two large-capacity elevators. This revised setup aims to optimize the vertical transportation system by standardizing all elevators to a uniform large-capacity model, each capable of accommodating up to 1350 kg as detailed in **Table 4**. This design is expected to simplify the operational logistics of the elevator system as all units have the same specifications and capabilities. The choice to transition to a homogeneous large-capacity design reflects a focus on enhancing efficiency by reducing the variability in passenger handling capacity across different elevators, and this configuration is expected to be particularly advantageous in managing peak traffic periods because the larger elevators can handle more passengers per trip, potentially reducing wait times and improving overall flow.

Table 4. Design of the large capacity elevator (CASE-2).

Number of Elevators	4
Capacity (kg)	1350
Door Pre-Opening Time (s)	0
Door Open Time (s)	2.9
Door Close Time (s)	3.3
Speed (m/s)	2
Acceleration (m/s^2)	0.8
Jerk (m/s^3)	1.2
Start Delay (s)	0.5
Home Floor	GF

The design specifications of the four large-capacity elevators in CASE-2 for the Ak-Keme Hotel as outlined in **Table 4**, mirror those of the two large-capacity elevators in CASE-1 detailed in **Table 3**, and this uniformity in design ensures consistency across all large-capacity elevators within the building. The door pre-opening time remains set at 0 s to eliminate unnecessary delays during passenger boarding and alighting. Meanwhile, the door open and close times are configured at 2.9 s and 3.3 s respectively, accounting for the large size and capacity of the elevators. The operational speed is maintained at 2 m/s, supported by an acceleration rate of 0.8 m/s^2 to ensure efficient vertical movement while prioritizing passenger comfort. Additionally, the jerk rate which governs the smoothness of acceleration changes, is designed at 1.2 m/s^3 ensuring a steady ride experience. A start delay of 0.5 s is also incorporated, allowing for synchronized elevator operations. These specifications collectively provide a reliable and efficient transportation solution, catering to the demands of a fully standardized large-capacity elevator system in CASE-2.

2.3. Simulation Design

The design of the elevator traffic simulation plays a crucial role in determining the accuracy and reliability of the analytical results, as it directly influences the simulation outcomes. In this research, the foundational setup for the simulation is presented in **Table 5**, which outlines several key parameters essential to the modeling process.

Table 5. Design of the simulation.

Analysis Type	Simulation
Measurement system	Metric
Dispatcher algorithm	Group Collective Traffic mode: 、Up peak 1
Time slice between simulation calculations (s)	0.1
No of time slices between screen updates	10
No of simulations to run for each configuration	10
Random number seed for passenger generator	1

As **Table 5** illustrates, these parameters include the type of analysis being conducted, which defines the analytical type of the simulation; the measurement system that is used to ensure consistency and precision in data collection; and the dispatcher algorithm, which governs the logic and efficiency of elevator dispatch operations. Additionally, the time slice between simulation calculations is specified to control the granularity of the simulation timeline, while the number of time slices between screen updates ensures the visual progress of the simulation is synchronized with the computational flow. The number of simulations to run for each configuration is also detailed, reflecting the iterative approach to achieve robust statistical reliability. Finally, the random number seed for passenger generation is included, providing a controlled randomness to replicate realistic passenger behavior patterns. These parameters all together form the backbone of the simulation design, enabling a comprehensive analysis of elevator traffic performance under various configurations.

The simulation setup for this research, as outlined in **Table 5**, establishes a detailed framework to analyze elevator traffic flow effectively. The analysis type is designated as the simulation that emphasizes a dynamic and iterative approach to evaluate elevator performance under real-world conditions. The measurement system is set to the metric that ensures consistency in units and alignment with international standards for accuracy and comparability. The dispatcher algorithm employed is the group collective strategy, which optimizes elevator allocation by considering the collective demands of passengers, and the traffic mode is defined as "up peak 1" focusing on peak upward traffic scenarios commonly encountered in high-rise buildings during morning rush hours. To maintain precision, the time slice between simulation calculations is configured at 0.1s, allowing for granular tracking of events within the simulation. The number of time slices between screen updates is set to 10, balancing real-time visualization with computational efficiency. Additionally, the number of simulations to run for each configuration is defined as 10, ensuring sufficient iterations for statistical reliability. Finally, the random number seed for the passenger generator is fixed at 1, providing controlled randomness to mimic realistic passenger behaviors while enabling the reproducibility of the simulation results.

Table 6. Design of the elevator traffic flow.

Arrangement	Conventional for Single Deck elevators
Template	Constant traffic (% building pop per 5 mins)
Total HC (% pop per 5 mins)	15
Incoming (%)	100
Outgoing (%)	0
Interfloor (%)	0
Start Time (mins)	0
End Time (mins)	60
Passenger Mass (kg)	75
Loading Time (s)	1.2
Unloading Time (s)	1.2
Stair Factor (%)	0
Capacity Factor (%)	80

The number of passengers and the simulated time are critical parameters in the elevator traffic simulation for this research, as they directly influence the accuracy and relevance of the results. **Table 6** provides an overview of the essential parameters used in this simulation setup. The arrangement is set as conventional for single-deck elevators, reflecting a standard design commonly found in hotels like the Ak-Keme Hotel. A constant passenger traffic template is applied with passengers arriving at regular intervals of 5 minutes. The total HC (Handling Capacity) is set at 15% of the total passenger count per 5-minute interval, ensuring a consistent flow of elevator demand throughout the simulation period. To simplify the model and control the variables, the simulation focuses exclusively on incoming passengers, set at 100%, while excluding passengers for outgoing and interfloor movements.

The simulation runs for a total of 60 minutes, as indicated by the start and end times in **Table 6**, offering sufficient time to observe traffic patterns and system performance. The passenger mass is standardized at 75 kg, aligning with common assumptions in elevator design [8]-[12]. Loading and unloading times are fixed at 1.2 s, reflecting realistic durations for passenger movement in and out of the elevator. Additionally, the stair factor is set at 0%, acknowledging that passengers in the Ak-Keme Hotel are more likely to use elevators over stairs due to convenience, particularly in a multi-story building. Finally, to account for safety and operational efficiency, the capacity factor is set conservatively at 80%, ensuring the simulation remains realistic while accommodating varying levels of elevator utilization.

3. Analytical Results and Discussion

3.1. Prime Results Discussion

The elevator traffic flow is analyzed through key operational metrics, including the number of up-and-down motor starts, the cumulative up-and-down motor running times, and the frequency of dispatches from the home floor [13]-[17]. These metrics are critical for understanding the performance and efficiency of the elevator systems. The simulated results for both CASE-1 and CASE-2 in the Ak-Keme Hotel are presented in **Table 7** and **Table 8**, providing a comparative analysis of the two configurations. By examining these cases, this research aims to identify how the differences in elevator design impact the overall vertical transportation efficiency, specifically using small-capacity versus large-capacity elevators.

Table 7. Analytical results of CASE-1.

Analytical types	Car 1	Car 2	Car 3	Car 4	Car 5	Total
Up Motor Starts	148	152	153	186	187	825
Down Motor Starts	60	60	61	35	35	251
Total Motor Starts	208	211	214	221	222	1076
Total up running time (s)	1365	1382	1390	1213	1225	6575
Total down running time (s)	1039	1038	1052	648	655	4433
Frequency of dispatch from home floor	37	38	38	23	23	159

The analytical results for CASE-1 provide a detailed understanding of the operational patterns and passenger preferences related to elevators of different capacities in the Ak-Keme Hotel as presented in **Table 7**. In this simulation, small-capacity elevators are assigned as Cars 1, 2, and 3, while large-capacity elevators are assigned as Cars 4 and 5. Over the course of the 60-minute simulation for CASE-1, the total number of elevator motor starts reached 1,076, comprising 825 up motor starts and 251 down motor starts. These results highlight a pronounced preference among passengers for larger-capacity elevator cars during upward journeys, as evidenced by the significantly higher number of up motor starts for Cars 4 and 5 compared to the smaller-capacity elevators. Specifically, Cars 4 and 5 recorded total motor starts of 221 and 222 respectively, surpassing the totals for Cars 1, 2, and 3, which registered 208, 211, and 214 starts respectively. This pattern strongly suggests that passengers prioritize the spaciousness and potential comfort of larger-capacity elevators when ascending. In contrast, the smaller-capacity elevators saw higher utilization for downward journeys, as reflected in their relatively greater number of down motor starts compared to Cars 4 and 5. This indicates a nuanced behavioral preference among passengers, likely influenced by the direction of travel, wait times, and perceived availability.

On the other hand, the simulated results in **Table 7** provide further insights into the efficiency of small-capacity versus large-capacity elevators in CASE-1, particularly when evaluating their total running times and dispatch frequencies. The findings indicate that small-capacity elevators exhibit lower efficiency in passenger transport utilization. This is evidenced by their significantly higher total running times (both upward and downward) compared to the large-capacity elevators as shown in **Table 7**. The extended operational duration of small-capacity elevators highlights their limited ability to accommodate a high volume of passengers in a single trip, necessitating more frequent trips to meet demand.

In contrast, large-capacity elevators demonstrate superior efficiency, as reflected in their shorter total running times and reduced frequency of dispatch from the home floor. These elevators can transport a larger number of passengers per trip, thereby minimizing the need for frequent dispatches. The data in **Table 7** reveal that the large-capacity elevators achieve greater operational effectiveness, handling more passengers while maintaining fewer dispatches from the home floor. This efficiency not only reduces the overall system workload but also contributes to shorter waiting times for passengers, enhancing the overall functionality of the vertical transportation system.

As presented in **Table 8**, the analytical results for CASE-2 offer valuable insights into the performance of the large-capacity elevators, highlighting significant efficiency improvements compared to CASE-1. Over the 60-minute simulation, the total number of elevator motor starts in CASE-2 is reduced to 810, comprising 664 upward motor starts and 146 downward motor starts. This is a marked improvement over CASE-1, where the total motor starts are significantly higher. To compare with the elevator design in CASE-1, the comparative analysis reveals that

CASE-2 experiences a 19.52% reduction in upward motor starts, a 41.83% reduction in downward motor starts, and a 24.72% reduction in total motor starts. These reductions underscore the superior operational efficiency of the all-large-capacity elevator design, which handles passenger demand with fewer activations and optimized usage patterns.

Table 8. Analytical results of CASE-2.

Analytical types	Car 1	Car 2	Car 3	Car 4	Total
Up Motor Starts	165	167	167	166	664
Down Motor Starts	36	36	36	38	146
Total Motor Starts	201	203	203	203	810
Total up running time (s)	1070	1081	1087	1081	4319
Total down running time (s)	593	595	600	605	2393
Frequency of dispatch from home floor	19	20	20	20	79

Further supporting the case for improved efficiency, the simulated results for the total up and down running times show substantial decreases in CASE-2 compared to CASE-1. Specifically, the total upward running time is reduced by 34.32%, and the total downward running time is reduced by an even greater margin of 46.01%. These reductions highlight the ability of the large-capacity elevators to complete their vertical transport tasks more swiftly and with fewer interruptions, further enhancing the overall effectiveness of the elevator system. Moreover, the frequency of dispatch from the home floor is reduced by 50.31% in CASE-2 compared to CASE-1, emphasizing the ability of large-capacity elevators to satisfy demand with fewer trips and reduced operational strain.

This comparative analysis between CASE-1 and CASE-2 demonstrates that transitioning to an all-large-capacity elevator system significantly alleviates elevator running stress. The lesser number of motor starts, shorter total running times, and reduced dispatch frequencies all contribute to improved system efficiency. These findings provide a compelling argument for adopting large-capacity elevator designs in situations requiring high vertical transport efficiency, as illustrated by the Ak-Keme Hotel simulation results in Table 7 and Table 8. This configuration not only enhances passenger convenience but also reduces mechanical wear and operational costs, presenting a sustainable and effective solution for high-demand environments.

An analysis of the hall calls throughout the elevator design process for the Ak-Keme Hotel provides further evidence of the improved efficiency of the large-capacity elevator configuration in CASE-2 compared to the mixed-capacity configuration in CASE-1 as presented in Table 9. Over the course of the simulation, the hall calls were recorded 267 times for CASE-1, while only 165 hall calls were observed for CASE-2. This significant reduction of 38.2% in hall calls underscores the enhanced vertical transport efficiency achieved with the all-large-capacity elevator design in CASE-2, as fewer hall calls reflect a smoother and more effective management of passenger traffic. Moreover, examining the specifics of the hall calls further reinforces these findings. For CASE-1, the total of 267 hall calls comprised 160 upward journey requests and 107 downward journey requests. In contrast, 165 hall calls were almost evenly distributed by CASE-2, with 82 upward journey requests and 83 downward journey requests. This balance in upward and downward journey requests in CASE-2 highlights a more uniform distribution of passenger traffic, indicating that the large-capacity elevators more effectively handle passenger movement in both directions compared to the mixed-capacity design of CASE-1.

Table 9. Analytical results of hall call.

		UP	DOWN	Total	Average
Numbers of Hall Calls	CASE-1	160	107	267	-
	CASE-2	82	83	165	-
Average Response Time (s)	CASE-1	13	12	-	12.5
	CASE-2	27	19	-	23

The discussion in these results demonstrates that the large-capacity elevator design in CASE-2 not only reduces the total number of hall calls but also achieves a more balanced and efficient utilization of elevator services. The reduced hall call frequency and improved directional traffic balance emphasize the advantages of an all-large-capacity elevator system, showcasing its ability to enhance overall transport efficiency while minimizing passenger wait times and operational strain.

The analysis of the average response time for hall calls in the elevator design at the Ak-Keme Hotel highlights a key difference between the mixed-capacity elevator system in CASE-1 and the large-capacity system in CASE-2 as presented in **Table 9**. In CASE-1, passengers experienced a highly efficient average response time of just 13 s for upward journey hall calls and even faster 12s for downward journey hall calls. This swift response reflects the effectiveness of the mixed-capacity elevator system in minimizing transport times by distributing passenger traffic between smaller and larger elevators. Conversely, the results for CASE-2 reveal a noticeable increase in response times with the all-large-capacity elevator design. Passengers wait an average of 27 s for upward journey hall calls and 19 s for downward journey hall calls. While the response time for downward journeys remained comparatively shorter, the overall average response time in CASE-2 was 45.65% longer than in CASE-1. This significant increase indicates that the large-capacity elevators, while more efficient in handling larger volumes of passengers, are less responsive to individual hall call requests, potentially due to fewer dispatches and longer transit times.

This trade-off highlights a critical consideration for elevator system design:

while large-capacity elevators improve overall transport efficiency and reduce the frequency of hall calls, they may compromise responsiveness, leading to longer transit times for passengers. The findings for the response time suggest that a mixed-capacity system might better balance transport efficiency and response time as CASE-1 shows, offering a more optimized solution in situations where passenger transit times are a priority.

Table 10. Fundamental results of the elevator traffic simulation.

	CASE-1	CASE-2	Ratio
Average Waiting Time (s)	515.9 (+62.4/−48.6)	328.9 (+54.8/−67.2)	36.25%
Longest Waiting Time (s)	1136.3 (+99.3/−92.2)	743.7 (+72.4/−138.6)	34.55%
Average Transit Time (s)	66.1 (+1.5/−1.1)	83.9 (+1.9/−2.6)	21.22%
Longest Transit Time (s)	182.2 (+10.1/−4.6)	182.6 (+9.7/−3.7)	0.22%
Average Time to Destination (s)	581.9 (+62.5/−49.7)	412.8 (+55.1/−69.8)	29.06%
Longest Time to Destination (s)	1273.5 (+104.4/−106.5)	888.2 (+86.9/−125.0)	30.26%

The simulated results for waiting time, transit time, and time to destination for the two cases in the Ak-Keme Hotel provide valuable insights into the efficiency of different elevator configurations as presented in Table 10. The waiting time is the parameter that measures how long passengers wait for an elevator car after making a hall call, and it is a crucial indicator of service performance. For CASE-1 which employs a mixed-capacity elevator system with three small-capacity elevators exhibits an average waiting time of 515.9 s. In comparison, CASE-2 which employs an all-large-capacity elevator design achieves a significantly shorter average waiting time of 328.9 s. This 36.25% reduction in average waiting time highlights the superior ability of large-capacity elevators to handle higher passenger volumes more effectively, reducing congestion and improving the overall user experience. Additionally, the results for the longest waiting time further underscore the advantages of the large-capacity elevator configuration. CASE-1 exhibits a longest waiting time of 1136.3 s, whereas CASE-2 reduces this to 743.7 s, a 34.55% decrease. This reduction suggests that the large-capacity design not only improves average performance but also minimizes extreme delays, ensuring a more consistent and reliable elevator service.

Although the large-capacity elevator exhibits a significant advantage in the aspect of the waiting time, the analysis of transit time reveals an interesting advantage of small-capacity elevators over large-capacity elevators in terms of passenger mobility as illustrated in Table 10. Transit time which measures the duration passengers spend inside the elevator traveling to their destination, and the simulated results demonstrate a clear benefit in CASE-1 that is designed with the mixed-capacity elevator configuration. Specifically, the average transit time for CASE-1 is significantly shorter at 66.1s compared to 83.9s for CASE-2, resulting in a notable 21.22% reduction. This highlights the agility and quicker response of small-capacity elevators in facilitating shorter trips, making them more effective for situations involving frequent and localized vertical movements. On the other hand, when examining the longest transit times, the difference between the two cases is marginal. CASE-1 records the longest transit time at 182.2 s, while CASE-2 has a slightly longer transit time of 182.6 s, marking a negligible 0.22% difference. This similarity indicates that for the most extended trips within the building, both small and large-capacity elevators perform nearly identically, suggesting that the primary advantage of small-capacity elevators lies in their ability to handle shorter journeys more efficiently.

While the small-capacity elevators show an advantage in transit time, the analysis of time to destination highlights the superior efficiency of large-capacity elevators in terms of overall vertical transport. Time to destination is a significant perimeter that encompasses the entire duration from the moment a passenger calls an elevator until they reach their intended floor, while the simulated results strongly favor the higher efficiency of CASE-2, the large-capacity elevator design. As shown in **Table 10**, CASE-2 achieves an average time to destination with 412.8s, significantly shorter than the 581.9s of CASE-1, representing a substantial 29.06% reduction. This reduction demonstrates the ability of large-capacity elevators to manage passenger flow more effectively, minimizing overall travel durations within the building. Furthermore, the advantage of large-capacity elevators is even more pronounced when considering the longest time to destination. CASE-2 records the longest time to destination as 888.2s, which is 30.26% shorter compared to the 1273.5s of CASE-1. This substantial difference highlights how the larger capacity of the elevators in CASE-2 reduces the likelihood of prolonged delays, ensuring a more streamlined and efficient vertical transportation experience for passengers.

3.2. Elevator Car Calling

The analysis of car calls for each floor provides valuable insights into elevator traffic flow patterns and system performance [18]-[20] within the Ak-Keme Hotel for the two distinct elevator configurations, CASE-1 and CASE-2. As illustrated in **Figure 3**, the number of car calls and the corresponding average response times across different floors reveal critical dynamics of elevator usage and efficiency. These results highlight the varying demand for elevator services on different floors, reflecting the unique passenger movement patterns throughout the building.

More importantly, the simulated results offer a quantifiable basis to evaluate the elevator traffic flow, as they detail not only how frequently elevators are called but also the responsiveness of the elevator system under different configurations. For instance, analyzing the distribution of car calls and average response times allows for an assessment of bottlenecks and peak traffic zones, enabling a clearer understanding of which floors experience higher elevator demand and whether the system can accommodate this demand effectively. Moreover, comparing CASE-1 and CASE-2 demonstrates how differing elevator designs impact operational efficiency and passenger experience.

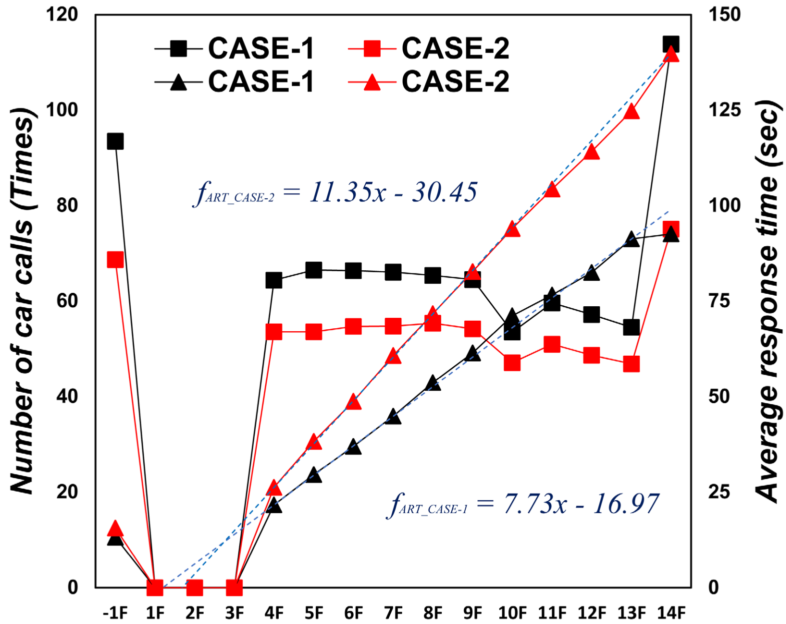

Figure 3. Car calls and response time.

The simulated results of car calls for the two elevator configurations (CASE-1 and CASE-2) offer a detailed perspective on the elevator traffic patterns within the Ak-Keme Hotel as shown in **Figure 3**. The analysis reveals that elevator activity is concentrated on specific floors, while certain floors experience no traffic due to their designated functions. Notably, the first floor serves as the hotel lobby, while the second and third floors are allocated for service areas, including equipment and storage, and are not accessible to hotel guests. In this research, the first-floor lobby activities are excluded from the elevator traffic analysis as the open area of the first floor is expected not to contribute to the flow dynamics of the vertical transportation system inside the Ak-Keme Hotel. This exclusion highlights a focused scope that prioritizes guest and operational movement in the service-related areas of the Ak-Keme Hotel. Regarding the service-related areas of the Ak-Keme Hotel, the basement sees a notable amount of activity, as it houses popular amenities such as casino rooms, a pool, a spa, and staff facilities, catering to both recreational and operational needs. Similarly, floors 4 through 13, which are dedicated to double rooms, exhibit high traffic due to guest occupancy. The 14th floor also contributes substantially to elevator calls as it functions as a restaurant, reflecting its role as a major destination within the hotel.

The patterns of car calls underscore the direct correlation between passenger presence and elevator activity, with more calls recorded on floors with higher occupancy and amenities as **Figure 3** illustrates for both CASE-1 and CASE-2. This relationship highlights the critical role that passenger distribution plays in shaping elevator traffic flow, while the concentration of elevator calls on specific floors reflects the natural usage patterns of guests and staff, with service-focused floors exhibiting minimal activity and guest-oriented floors showing higher demand. Additionally, the ratio of floor area to the number of passengers emerges as a key variable in understanding elevator traffic dynamics by the reference of **Table 1**. As **Figure 3** shows, larger floor areas with fewer occupants may result in lower call frequencies, while densely occupied floors could exhibit higher call volumes.

The simulated results presented in **Figure 3** reveal distinct patterns in elevator usage within the Ak-Keme Hotel, shaped by the different configurations of CASE-1 and CASE-2. Notably, the 14th floor which is designed as a restaurant with a floor area of 1016.39 m^2 and a design capacity for 125 passengers, exhibits the highest number of elevator calls in both cases. Specifically, the number of car calls reaches 114 in CASE-1 and 75 in CASE-2, demonstrating a significant 34.21% reduction in elevator calls when transitioning from the mixed-capacity elevator design of CASE-1 to the all-large-capacity design of CASE-2. This reduction highlights the superior efficiency of the all-large-capacity elevator configuration in managing vertical transportation demands, particularly for high-traffic destinations such as the restaurant floor.

In contrast, the basement which features a larger floor area of 2490.38 m^2 and serves as a hub for amenities such as casino rooms, a pool, a spa, and staff facilities, experiences fewer elevator calls despite being designed to accommodate the same number of passengers as the 14th floor. For CASE-1 and CASE-2, the basement registers 94 and 69 elevator calls respectively, representing a 26.6% decrease in CASE-2. The fewer number of car calls can be attributed to the larger spatial capacity and the shorter vertical distance of the basement from the home floor of the Ak-Keme Hotel, which facilitates smoother movement and reduces the frequency of elevator use. The comparison between CASE-1 and CASE-2 in the basement underscores how spatial layout, floor functionality, and elevator design influence usage patterns, further validating the operational advantages of the all-large-capacity elevator system in optimizing efficiency and minimizing elevator traffic across diverse hotel zones.

The simulated results provide valuable insights into the elevator call times for the double room floors of the Ak-Keme Hotel under different elevator configurations. Specifically, for floors 4 through 9, where each floor accommodates 52 passengers and houses 20 double rooms, the elevator call patterns exhibit a notable difference between CASE-1 and CASE-2. According to **Figure 3**, the average number of car calls is 66 for CASE-1 and 54 for CASE-2. This 18.18% reduction in car calls under CASE-2 underscores the superior efficiency of the all-large-capacity elevator design compared to the mixed-capacity configuration with three small-capacity elevators, highlighting its advantage in managing vertical transportation demands effectively on high-occupancy floors.

Similarly, for floors 10 through 13, where each floor is designed for 25 passengers with 16 double rooms, the simulated results indicate slightly lower elevator call frequencies compared to floors 4 through 9. The average number of car calls is 56 for CASE-1 and 48 for CASE-2, reflecting a 14.29% reduction in car calls with the all-large-capacity elevator design. This further demonstrates the enhanced operational efficiency of the all-large-capacity elevators, as they reduce the frequency of car calls while maintaining seamless transport for guests.

The analysis of average response times for elevator car calls at the Ak-Keme Hotel under the two different configurations (CASE-1 and CASE-2) highlights the significant impact of vertical distance to the home floor on elevator performance. As shown in **Figure 3**, the average response time increases proportionally with the vertical distance, indicating that the farther a floor is from the home floor, the longer it takes for elevators to respond to car calls. This trend is particularly evident when comparing the response times for the basement (CASE-1: 13.2 s & CASE-2: 15.6 s) and the 14th floor (CASE-1: 113.8 s & CASE-2: 139.8 s). The basement, which is closest to the home floor, records the shortest average response times: 13.2 s for CASE-1 and 15.6 s for CASE-2. The 15.38% shorter response time of CASE-1 demonstrates the superior mobility of the mixed-capacity configuration with three small-capacity elevators in vertical transportation. Conversely, as the vertical distance to the home floor increases, such as from the 3rd to the 14th floor, the average response time rises accordingly for both configurations. This increasing trend underscores the challenge of maintaining efficiency across greater vertical distances. The simulated results suggest that this relationship can be modeled with linear equations for both elevator configurations, providing a quantitative understanding for average response times based on vertical distance as below:

$$f_{ART\_CASE\text{-}1} = 7.73x - 16.97 \tag{2}$$

$$f_{ART\_CASE\text{-}2} = 11.35x - 30.45 \tag{3}$$

where, the values of 7.73 and 11.35 in Equations (2) and (3) represent the slopes of the increasing trend in average response time for CASE-1 and CASE-2 respectively, serving as quantitative indicators of how the response time escalates with vertical distance from the home floor. These slopes highlight the rate of increase in average response time for the two elevator configurations simulated in the Ak-Keme Hotel. The higher slope value of 11.35 for CASE-2 signifies a steeper increase in response time compared to CASE-1, where the slope is 7.73. This difference underscores a 31.89% slower average response time improvement for CASE-2 when compared to CASE-1, reflecting the superior performance of the mixed-capacity configuration with three small elevators in terms of mobility and responsiveness. The results emphasize that the small-capacity elevators in CASE-1 offer a significant advantage in reducing response times, particularly over shorter vertical distances, and this is attributed to their faster transit times and ability to serve requests more efficiently within the vertical range.

Referring to **Figure 4**, the distribution of response times provides further evidence that the vertical distance to the home floor significantly affects the response times of elevator car calls at the Ak-Keme Hotel. This trend is observed across both elevator configurations under the simulation as illustrated in **Figure 4(a)** and

Figure 4(b). Beyond average response times, the analysis in Figure 4 also examines how response times are distributed across various time intervals, offering deeper insights into elevator performance.

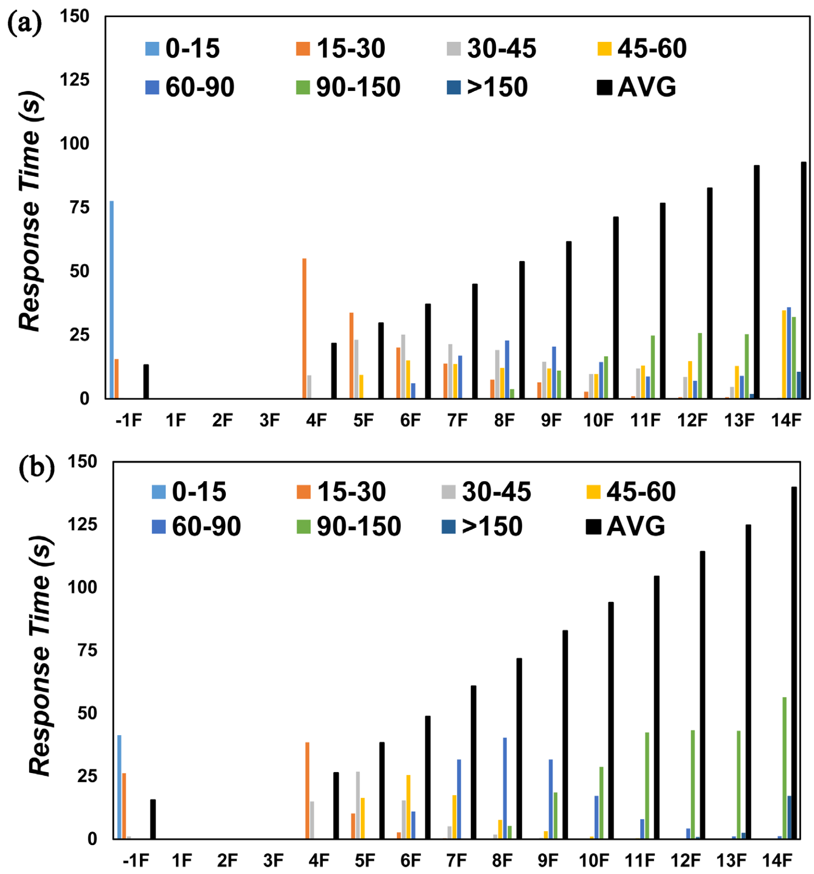

Figure 4. Response time distribution. (a) CASE-1; (b) CASE-2.

The results reveal that CASE-2 (all-large-capacity elevator configuration) shows longer response times within the 0 s to 15 s interval compared to CASE-1 for floors with double rooms. This highlights the superior mobility of the mixed-capacity elevator design with three small-capacity elevators for shorter response times in this situation, and similar trends are also observed in the longer intervals, including 45 s to 60 s, 60 s to 90 s, 90 s to 150 s, and beyond 150 s, where CASE-1 demonstrates better performance. These findings emphasize that the small-capacity elevators in the mixed configuration provide greater agility in responding to elevator car calls for short trips and frequent stops.

Conversely, CASE-2 outperforms CASE-1 within the 15 s to 30 s and 30 s to 45 s intervals, reflecting higher transport efficiency in these mid-range transits. This suggests that the all-large-capacity configuration is better equipped to manage vertical transportation over moderate distances, making it particularly suitable for handling larger passenger loads with fewer stops. Notably, the all-large-capacity elevators demonstrate exceptional performance for basement to home floor trips within the 0 s to 15 s interval, achieving faster response times due to their higher transport efficiency and reduced number of car calls.

Including the response times for each floor, as shown in Figure 4, the analytical results of the total response times across different time distributions offer valuable insights into the performance of the two elevator configurations—CASE-1 (mixed-capacity) and CASE-2 (all-large-capacity)—at the Ak-Keme Hotel. As Figure 5 illustrates, the longest response times for CASE-1 occur within the 15 s to 30 s interval, with a total response time of 157.8 s. Conversely, the longest response times for CASE-2 occur within the 90 s to 150 s interval, with a total response time of 237.9 s.

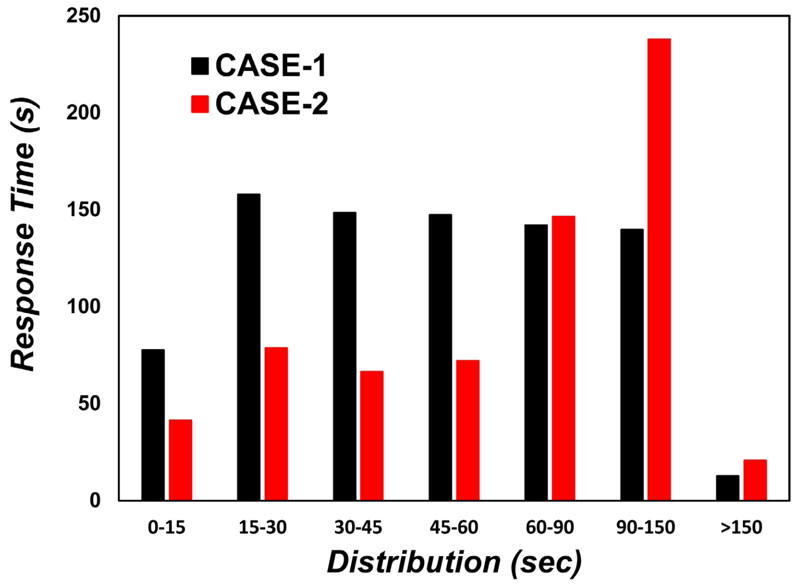

Figure 5. Total response time distribution.

These findings underscore the greater mobility of the mixed-capacity configuration, which demonstrates shorter response times for longer intervals, particularly from 60 s to 90 s, 90 s to 150 s, and beyond 150 s, as illustrated in Figure 5. The higher mobility of the three small-capacity elevators in CASE-1 allows it to handle long-distance transportation more effectively in certain cases. However, the results also reveal that CASE-2 excels in shorter response times within the earlier intervals, including 0 s to 15 s, 15 s to 30 s, 30 s to 45 s, and 45 s to 60 s, as shown in Figure 5. This performance reflects the efficiency of the all-large-capacity configuration in managing vertical transportation, particularly for larger passenger loads and fewer stops over shorter verticle distances.

Reflect the discussion on the response time distribution for each different floor of Ak-Keme Hotel, the comparison highlights the trade-offs between mobility and efficiency. While the mixed-capacity configuration (CASE-1) demonstrates superior agility and shorter response times for longer journeys, the all-large-capacity configuration (CASE-2) provides enhanced efficiency for shorter trips, indicating its suitability for high-demand situations with concentrated passenger traffic.

3.3. Time of Waiting, Transit, and Destination

Beyond the analysis of elevator car calls, it is equally critical to consider the dynamic factors that significantly impact passenger experience and operational efficiency [21]-[26]. These factors include waiting time, transit time, and time to destination, each of which provides crucial insights into the overall behavior of elevator traffic. By examining these factors, one can gain a more holistic understanding of vertical transportation performance and elevator mobility within the Ak-Keme Hotel.

The comparative analysis of the two elevator configurations within the defined analytical timeframe sheds light on their respective efficiencies and shortcomings as CASE-1 and CASE-2 show. As **Figures 6-8** illustrate, these metrics not only highlight the operational differences between the configurations but also emphasize their impact on the passenger experience. For example, the waiting time provides a measure of how quickly an elevator responds to a call, reflecting the responsiveness of the elevator configuration. Transit time quantifies the duration passengers spend traveling between floors, which speaks to the speed and stop efficiency of the elevator configuration. Finally, the time to destination captures the total journey time, integrating the effects of waiting and transit times to present a comprehensive measure of elevator performance.

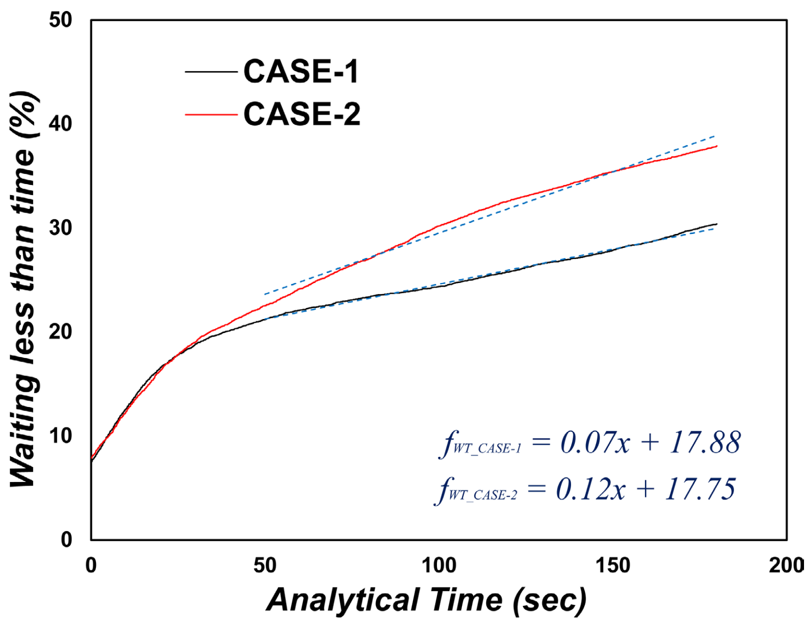

Figure 6. Time for waiting.

The analysis of waiting times provides a detailed understanding of the dynamic behavior of elevator performance at the Ak-Keme Hotel for the two configurations as illustrated in **Figure 6**. At the start of the simulation, only 8% of passengers experience waiting times shorter than the elevator response time for both different elevator configurations. As the simulation progresses, the number of passengers benefiting from reduced waiting times increases significantly during the first 50 s for both configurations. This trend indicates a rapid system adaptation to incoming passenger requests, where elevators begin to distribute traffic more efficiently across the hotel floors. Following this initial adjustment period of the first 50 s, the upward trend in passengers experiencing shorter waiting times continues but at a reduced rate, signaling a transition to a more stable state of elevator operation. The rates of increase for both configurations can be mathematically modeled, offering a quantitative framework to assess and predict elevator performance as below:

$$\sum_{x=50}^{x=180} f_{WT\_CASE\text{-}1} = 0.07x + 17.88 \tag{4}$$

$$\sum_{x=50}^{x=180} f_{WT\_CASE\text{-}2} = 0.12x + 17.75 \tag{5}$$

The analysis of the equations for the two elevator configurations (CASE-1 and CASE-2) provides critical insights into the passengers waiting less than the time of the elevator systems at the Ak-Keme Hotel, particularly during the time interval from the 50 s to the 180 s of the simulation. Referring to **Figure 6**, the slope of the curve in Equation (4) is calculated as 0.07 for CASE-1, while the slope in Equation (5) is determined to be 0.12 for CASE-2. These slope values represent the rate at which the number of passengers benefiting from reduced waiting times increases over the specified time period. The steeper slope for CASE-2 demonstrates that the all-large-capacity elevator configuration facilitates a faster improvement in passenger waiting times compared to the mixed-capacity configuration with three small-capacity elevators.

The comparison of these slopes reveals that 41.67% more passengers benefit from shorter waiting times in CASE-2 than in CASE-1, underscoring the superior vertical transportation efficiency of the all-large-capacity elevator system. This efficiency is further validated by the predictions of Equations (4) and (5) for the time required to ensure all passengers experience waiting times shorter than the elevator response time. According to the analysis, CASE-1 requires 1173.14 s to achieve this benchmark, whereas CASE-2 achieves the same result in just 685.42 s. The 41.57% reduction in time for CASE-2 highlights its enhanced performance and adaptability in handling elevator traffic.

The analysis of passenger transit times within the two elevator configurations (CASE-1 and CASE-2) at the Ak-Keme Hotel also reveals key patterns as illustrated in **Figure 7**. During the analytical time frame from 0 s to 180 s, the simulated results show a continuous increase in the proportion of passengers experiencing reduced transit times for both configurations. This upward trend culminates in both configurations reaching 100% near the 180s mark, indicating that all passengers benefit from minimized transit durations by this time point. However, the growth trajectories for CASE-1 and CASE-2 differ in their shapes and rates, as highlighted by the distinct curves presented in **Figure 7**. These variations in trends can be further analyzed and quantified through the equations provided for each configuration, which describe the increasing rate of passengers benefiting from reduced transit times, and the differences in the equations reflect the contrasting operational dynamics of the two elevator configurations as below:

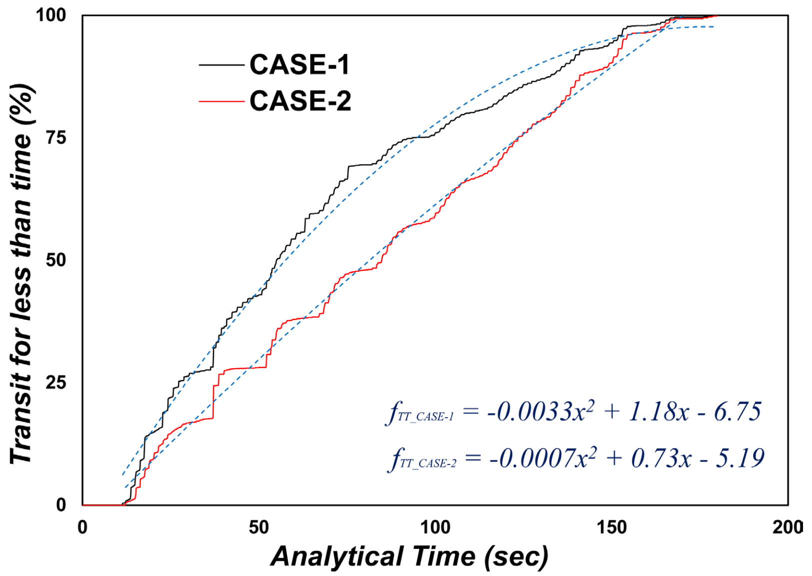

Figure 7. Time for transit.

$$\sum_{x=20}^{x=180} f_{TT\_CASE\text{-}1} = -0.0033x^2 + 1.18x - 6.75 \tag{6}$$

$$\sum_{x=20}^{x=180} f_{TT\_CASE\text{-}2} = -0.0007x^2 + 0.73x - 5.19 \tag{7}$$

The analysis of the provided Equations (6) and (7) highlights an analytical interval from the 20 s to the 180 s, during which the increasing trend of passengers benefiting from reduced transit times becomes apparent as depicted in **Figure 7**. Notably, during the first 20 s of the simulation, no passengers experience reduced transit times for either elevator configuration, making the subsequent interval the primary focus of the evaluation. Within this timeframe, the trends for both CASE-1 (mixed-capacity with three small elevators) and CASE-2 (all-large-capacity elevators) are distinctly characterized by their respective mathematical relationships outlined in Equations (6) and (7).

Based on the simulated results, both configurations demonstrate a steady rise in the percentage of passengers benefiting from reduced transit times, achieving 99.95% at 179.9 s for CASE-1, and 99.92% at 179.9 s for CASE-2. The equations further reveal that the intersection of the trends occurs at 169.54 s, where 98.45% of passengers benefit from reduced transit times. This point of intersection provides an insightful comparison of the performance of the two configurations. Although CASE-1 exhibits a steeper slope, reflecting the higher mobility and responsiveness of small-capacity elevators in the mixed-capacity configuration, the overall analysis still emphasizes the superior vertical transportation efficiency of the all-large-capacity configuration, particularly at and beyond the intersection point.

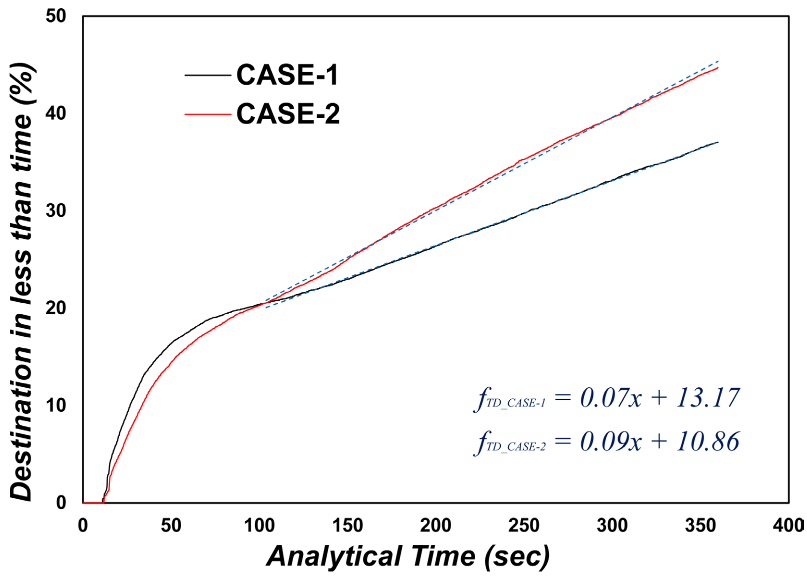

Figure 8. Time for destination.

The analysis of the dynamic behavior of the time to destination for the two elevator configurations uncovers significant trends and correlations as illustrated in **Figure 8**. Notably, the simulation results reveal that passengers begin to benefit from reduced time to destination at the analytical time point of 11 s for both CASE-1 (mixed-capacity with three small elevators) and CASE-2 (all-large-capacity elevators). This initial time point is strongly correlated with the starting time for the simulation of transit time, underscoring a close relationship between these two metrics. The observed correlation suggests that the time to destination begins calculation immediately after the transit process of vertical transportation is completed, with a slight lag of a few seconds.

As the simulation progresses, **Figure 8** demonstrates a distinct upward trend in the percentage of passengers experiencing reduced time to destination starting at 11 s. This pattern mirrors the trends observed in the analysis of waiting times as **Figure 6** shows, reinforcing the interdependence of these factors in evaluating the different elevator configuration performance. After the analytical time surpasses 50 s, the increasing trend slows down, highlighting the stabilizing benefits of the efficiency of both different elevator configurations over time. To capture these trends quantitatively as **Figure 8** shows, the increasing patterns for both CASE-1 and CASE-2 can be represented and summarized using the equations below:

$$\sum_{x=100}^{x=350} f_{TD\_CASE\text{-}1} = 0.07x + 13.17 \quad (8)$$

$$\sum_{x=100}^{x=350} f_{TD\_CASE\text{-}2} = 0.09x + 10.86 \quad (9)$$

The analysis of the time to destination highlights key observations regarding the dynamic performance of the two elevator configurations over specific time intervals as represented in **Figure 8** and detailed by Equations (8) and (9). During the initial period from 11 s to 100 s, both configurations exhibit faster-increasing trends in the percentage of passengers benefiting from reduced time to destination. However, the analytical focus from the 100 s to the 350 s provides deeper insights into the comparative performance of the mixed-capacity and all-large-capacity elevator configurations.

For CASE-1, which employs the mixed-capacity configuration with three small-capacity elevators, the slope of the increasing trend is calculated as 0.07, indicating a moderate improvement rate. In contrast, CASE-2, representing the all-large-capacity elevator configuration, has a steeper slope of 0.09, reflecting a significantly faster rate of passengers experiencing reduced time to destination. This comparative analysis underscores a 22.22% faster performance in CASE-2, emphasizing the operational advantages of larger-capacity elevators in optimizing vertical transportation efficiency.

Additionally, Equations (8) and (9) reveal that the time required for all passengers to benefit from reduced time to destination is 1240.43 s for CASE-1 and 990.44 s for CASE-2. This 20.15% reduction in total time for CASE-2 further highlights its superior efficiency, driven by the higher carrying capacity and reduced transit frequency of the all-large-capacity design.

3.4. Average Queue Lengths

In real-world elevator operations, the variability in passenger queues introduces a layer of complexity to elevator traffic analysis, as queues can range from a single individual to larger groups of two, three, or more. This randomness in passenger behavior directly impacts elevator efficiency and traffic flow, making it a crucial factor to consider in system design and evaluation [27]-[29]. In the simulation conducted for the Ak-Keme Hotel, the passenger queue dynamics under two different elevator configurations (CASE-1 with mixed-capacity elevators and CASE-2 with all-large-capacity elevators) are illustrated in **Figure 9**.

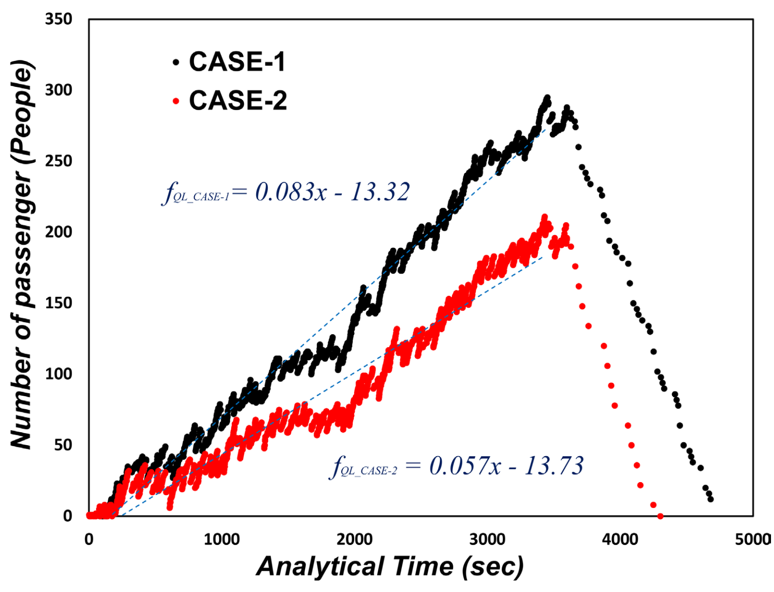

Figure 9. Queues of the passengers.

The analytical results illustrated in **Figure 9** reveal a pronounced correlation between the progression of analytical time and the proportional increase in total passenger queues. As the simulation unfolds, the cumulative number of passenger queues rises steadily for both elevator configurations. Specifically, **Figure 9** highlights that for CASE-1, a total of 730 passengers forming 295 queues were transported within a simulated timeframe of 4679 s. In contrast, for CASE-2, the same number of passengers formed only 211 queues, completing their transportation in a shorter time of 4300 s.

The comparative analysis underscores that CASE-1 results in 28.47% more queues than CASE-2, demonstrating the superior vertical transport efficiency of the all-large-capacity elevator configuration. Furthermore, the total analytical time required for all 730 passengers highlights a 8.1% longer duration for CASE-1, further emphasizing the time-saving advantage offered by the all-large-capacity elevator configuration.

Notably, during the main operational periods (0 s to 3451 s for CASE-1 and 0 s to 3431 s for CASE-2) both configurations exhibit distinct upward trends in total passenger queues. These growth patterns are further reinforced by the mathematical modeling, which provides a quantitative framework for understanding the performance dynamics of the two elevator configurations in the Ak-Keme Hotel as shown below:

$$\sum_{x=0}^{x=3451} f_{QL\_CASE\text{-}1} = 0.083x - 13.32 \quad (10)$$

$$\sum_{x=0}^{x=3431} f_{QL\_CASE\text{-}2} = 0.057x - 13.73 \quad (11)$$

Equations (10) and (11) provide a comprehensive mathematical model for the growth of passenger queues over the analytical time intervals for both elevator configurations at the Ak-Keme Hotel. Specifically, Equation (10) models the queue growth for the mixed-capacity elevator configuration with three small-capacity elevators (CASE-1) from 0 s to 3451 s, while Equation (11) models the same for the all-large-capacity elevator configuration (CASE-2) from 0s to 3431 s. The calculated slope values of 0.083 for CASE-1 and 0.057 for CASE-2 represent the rate at which queues grow per second. These slopes signify that for every second within the respective intervals, the number of passenger queues increases at a higher rate in CASE-1 compared to CASE-2. By substituting specific time values into the equations, one can precisely determine the total number of passenger queues at any given moment during the simulation period for both configurations. The comparative analysis highlights that the slope for CASE-1 is 31.33% steeper than that of CASE-2, while this result underscores the greater queue intensity under the mixed-capacity configuration, reflecting its relatively lower vertical transportation efficiency compared to the all-large-capacity configuration.

4. Summarization

In this research, the simulation of elevator traffic flow for the Ak-Keme Hotel is conducted using Elevator™ to evaluate the performance of two different elevator configurations. A key aspect of the simulation setup is the intentional exclusion of inter-floor elevator traffic, ensuring that the analysis focuses solely on vertical transportation efficiency between the main entry and destination floors. To enhance the realism of the simulation, the design incorporates a random number seed for the passenger generator as specified in **Table 5**, allowing for a stochastic yet controlled representation of passenger arrivals and movement patterns. This methodology ensures that variations in simulation results are due to inherent system dynamics rather than unpredictable external factors. Furthermore, by implementing a probabilistic approach to passenger flow, the model effectively captures the complexities of real-world elevator usage, where guest movements are often considered irregular and difficult to anticipate. The randomness in passenger generation accounts for fluctuations in demand, peak usage times, and variations in waiting times, thereby improving the accuracy of the traffic flow analysis. In conclusion, this simulation design enables a comprehensive assessment of how different elevator configurations perform under identical building environment and load conditions, while expected to provide valuable insights into operational efficiency, passenger experience, and the overall effectiveness of the elevator system in the Ak-Keme Hotel.

The comparative analysis of elevator configurations in this research highlights several critical factors influencing vertical transportation efficiency and mobility within the Ak-Keme Hotel. The results indicate that the all-large-capacity elevator configuration (CASE-2) demonstrates superior vertical transportation efficiency compared to the mixed-capacity configuration with three small-capacity elevators (CASE-1). This conclusion is supported by the observations of fewer motor starts, reduced up-and-down running times, and a lower frequency of dispatch from the home floor in CASE-2. Additionally, the reduced number of up-and-down hall calls further underscores the efficiency of the all-large-capacity configuration. Conversely, the mixed-capacity configuration exhibits higher mobility due to shorter average response times, enabling quicker service in situations requiring smaller passenger loads. Furthermore, analyses of average waiting time, longest waiting time, and average transit time reveal that the all-large-capacity configuration provides better overall efficiency for vertical transportation, whereas the mixed-capacity setup achieves greater mobility for rapid, localized trips. The metrics for the average and longest times to destination consistently highlight the advantage of the all-large-capacity configuration in handling large passenger volumes more efficiently. These findings underscore the trade-offs between mobility and efficiency, offering valuable insights into optimizing elevator configurations to satisfy the specific needs of high-rise buildings for urban society.

The comparative analysis of elevator performance further highlights the distinct advantages of large-capacity and small-capacity elevators in different aspects of vertical transportation. The higher efficiency of the large-capacity elevator is evident in its ability to handle larger passenger volumes with fewer car calls, shorter waiting times for significant passenger loads, and reduced time to destination for vertical transportation. These attributes make it particularly suitable for situations requiring the efficient transport of large groups, minimizing congestion, and maximizing throughput. Conversely, the small-capacity elevator demonstrates its strength in mobility, excelling in rapid service for localized trips and responding more quickly to car calls as the reduced transit time for verticle transportation. This higher mobility is reflected in shorter waiting times for individual passengers and faster response rates during periods of moderate traffic. Furthermore, the analysis of average queue lengths supports these findings, with smaller queue accumulations observed for large-capacity elevators in high-demand periods.

While small-capacity elevators demonstrate a clear advantage in terms of mobility and responsiveness for shorter and localized trips, their operational limitations pose challenges to overall efficiency in vertical transportation. The frequent motor starts required to handle multiple trips result in increased mechanical wear and higher energy consumption, reducing operational sustainability. Additionally, the lower capacity of small elevators means they can accommodate fewer passengers per trip, leading to a higher frequency of hall calls as they shuttle back and forth to serve the demand. This increased demand on the system contributes to longer cumulative waiting times for passengers, particularly during peak usage periods. Moreover, the limited capacity often necessitates multiple trips to serve the same number of passengers that a large-capacity elevator could handle in a single journey, thereby extending the total time to the destination.

5. Conclusions

Elevator traffic management has long been a pressing issue in modern urban design, attracting extensive research and technological advancements. Over the years, innovative solutions such as GCS (Group Control Systems) and DDS (Destination Dispatching Systems) have been developed to optimize elevator operations and improve efficiency [30]-[33]. Furthermore, the advent of artificial intelligence has opened new avenues, with neural networks like CNN (Convolutional Neural Networks) and LSTM (Long Short-Term Memory Networks) being applied to elevator traffic prediction and analysis [34]-[39]. In this context, the current research adopts a simulation-based approach to analyze elevator traffic flow for a real-world remodeling project at the Ak-Keme Hotel in the Kyrgyz Republic, utilizing the ElevatorTM software. By investigating two distinct elevator configurations (one featuring a mixed-capacity setup with three small-capacity elevators and the other comprising an all-large-capacity design), this research seeks to examine how these configurations influence elevator traffic under identical building conditions. Additionally, it aims to evaluate the vertical transportation efficiency of both small and large-capacity elevators, providing insights into their performance in terms of passenger flow and operational efficacy. This research highlights the practical implications of design choices in elevator systems, offering valuable recommendations for optimizing traffic flow in similar architectural settings.

1) The analytical results reveal that an all-large-capacity elevator system significantly enhances vertical transportation efficiency compared to a mixed-capacity system with three small-capacity elevators. This improvement is attributed to fewer motor activations, minimized travel durations, and a reduced number of dispatches from the home floor. By lowering the frequency of elevator operations, the all-large-capacity configuration ensures smoother and more energy-efficient transportation within the Ak-Keme Hotel. Consequently, the all-large-capacity configuration offers a more effective solution for handling elevator traffic flow, reducing wait times, and improving overall building mobility.

2) The mixed-capacity configuration enhances mobility by reducing average response times, allowing for faster service when accommodating smaller passenger loads. This configuration minimizes wait times and improves efficiency, particularly in cases with frequent but lower occupancy demands. As a result, the mixed-capacity configuration is well-suited for environments where prompt elevator availability is a priority over maximizing per-trip capacity.

3) Although the mixed-capacity configuration offers quicker response times, the frequent motor starts may lead to greater mechanical wear and increased energy consumption, ultimately reducing long-term operational sustainability. Also, the limit of the small-capacity elevator restricts the number of passengers per trip, necessitating more frequent trips to accommodate demand. As a result, the system experiences a higher volume of hall calls, causing elevators to shuttle back and forth more often. This increased activity not only accelerates component fatigue but also elevates overall energy costs, making the system less efficient in the long run despite its initial responsiveness.

This research underscores the critical role of elevator traffic analysis in optimizing vertical transportation for urban living and working environments. By employing elevator traffic simulations, this research provides a valuable methodological framework for understanding and addressing the complexities of elevator traffic flow. The comparative analysis of small-capacity and large-capacity elevators highlights their respective advantages in terms of mobility and efficiency, offering tailored insights for the specific demands of different building utilizations. The findings emphasize the importance of thoughtful elevator system design, where considerations of traffic flow, passenger needs, and operational efficiency can lead to significantly enhanced vertical transportation. Such improvements not only elevate user satisfaction by minimizing inconveniences but also offer a strategic reference point for future real-world elevator designs. In conclusion, this research emphasizes simulation-based approaches to achieve more effective, efficient, and user-friendly elevator systems, and provide a reference for improved functionality in urban infrastructures.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Putro, U.S. (2024) Decision Making in Social Systems. In: Novani, S., *et al*., Eds., *Social Decision Systems Science: Theory and Applications in Southeast Asia*, Springer, 1-15. https://doi.org/10.1007/978-981-97-5219-5_1

[2] Mansilla, J., Mabu, S., Yu, L. and Hirasawa, K. (2009) Adaptive Controller for Double-Deck Elevator System Using Genetic Network Programming. 2009 *ICCAS-SICE*, Fukuoka, 18-21 August 2009, 3870-3873.

[3] Luh, P.B., Xiong, B. and Chang, S.-C. (2008) Group Elevator Scheduling with Advance Information for Normal and Emergency Modes. *IEEE Transactions on Automation Science and Engineering*, **5**, 245-258. https://doi.org/10.1109/tase.2007.895217

[4] Ruokokoski, M., Sorsa, J., Siikonen, M. and Ehtamo, H. (2016) Assignment Formulation for the Elevator Dispatching Problem with Destination Control and Its Performance Analysis. *European Journal of Operational Research*, **252**, 397-406. https://doi.org/10.1016/j.ejor.2016.01.019

[5] Patiño-Forero, A.A., Muñoz, D.M., de Carvalho, G.C. and Llanos, C.H. (2012) Modeling of an Elevator Group Control System Using Programmable Logic Control and Destination Control System. *ABCM Symposium Series in Mechatronics*, Vol. 4, 433-441.

[6] Hanif, M. and Mohammad, N. (2023) Metaheuristic Algorithms for Elevator Group Control System: A Holistic Review. *Soft Computing*, **27**, 15905-15936. https://doi.org/10.1007/s00500-023-08843-0

[7] Sorsa, J., Ehtamo, H., Kuusinen, J., Ruokokoski, M. and Siikonen, M. (2017) Modeling Uncertain Passenger Arrivals in the Elevator Dispatching Problem with Destination Control. *Optimization Letters*, **12**, 171-185. https://doi.org/10.1007/s11590-017-1130-0

[8] Laine, T. and Sorsa, J. (2020) The Maximum Number of Passengers Boarding a Lift in Office Buildings Based on Automated Passenger Counts. 11*th Symposium on Lift and Escalator Technologies*, Vol. 11, 131-142.

[9] Escalada, A. and Abad, G. (2016) Elevators. In: Abad, G., Ed., *Power Electronics and Electric Drives for Traction Applications*, John Wiley & Sons, Ltd., 550-618.

[10] Han, L., Ali, S., Yue, T., Arrieta, A. and Arratibel, M. (2023) Uncertainty-Aware Robustness Assessment of Industrial Elevator Systems. *ACM Transactions on Software Engineering and Methodology*, **32**, 1-51. https://doi.org/10.1145/3576041

[11] Varma, V.K. (2022) Innovative Designs for Ultra-Modern Railway Stations, Elevated Greenfield Tracks, and Terminal Stations for Bullet and Inter-City Trains.

[12] Chen, L.Y., Zuo, Y.Y. and Yang, D.Q. (2023) Human-Induced Noise Study for Cruise Cabin: Numerical Analysis and Experimental Validation. *Ocean Engineering*, **286**, Article ID: 115498. https://doi.org/10.1016/j.oceaneng.2023.115498

[13] So, A., Al-Sharif, L. and Hammoudeh, A. (2017) Traffic Analysis of a Three-Dimensional Elevator System. *Building Services Engineering Research and Technology*, **39**, 5-20. https://doi.org/10.1177/0143624417710106

[14] So, A., Al-Sharif, L. and Hammoudeh, A. (2015) Traffic Analysis of a Simplified Two-Dimensional Elevator System. *Building Services Engineering Research and Technology*, **36**, 567-579. https://doi.org/10.1177/0143624414568728

[15] Al-Sharif, L. and Abu Alqumsan, A.M. (2014) Stepwise Derivation and Verification of a Universal Elevator Round Trip Time Formula for General Traffic Conditions. *Building Services Engineering Research and Technology*, **36**, 311-330.

https://doi.org/10.1177/0143624414542111

[16] Jalali Yazdi, A., Forsythe, P., Ahmadian Fard Fini, A. and Maghrebi, M. (2019) Optimization of Flexible Lift Processes on High-Rise Building Construction Sites. *Automation in Construction*, **107**, Article ID: 102939. https://doi.org/10.1016/j.autcon.2019.102939

[17] Yu, L., Mabu, S., Hirasawa, K. and Ueno, T. (2011) Analysis of Energy Consumption of Elevator Group Supervisory Control System Based on Genetic Network Programming. *IEEJ Transactions on Electrical and Electronic Engineering*, **6**, 414-423. https://doi.org/10.1002/tee.20677

[18] So, A., Al-Sharif, L. and Hammoudeh, A. (2016) Concept Design and Derivation of the Round Trip Time for a General Two-Dimensional Elevator Traffic System. *Journal of Building Engineering*, **5**, 165-177. https://doi.org/10.1016/j.jobe.2015.12.006

[19] Valdivielso, A. and Miyamoto, T. (2011) Multicar-Elevator Group Control Algorithm for Interference Prevention and Optimal Call Allocation. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, **41**, 311-322. https://doi.org/10.1109/tsmca.2010.2064766

[20] Swinarski, D. (2020) Modelling Elevator Traffic with Social Distancing in a University Classroom Building. *Building Services Engineering Research and Technology*, **42**, 82-97. https://doi.org/10.1177/0143624420966257

[21] Malapert, A. and Kuusinen, J. (2017) Estimation of Elevator Passenger Traffic Based on the Most Likely Elevator Trip Origin-Destination Matrices. *Building Services Engineering Research and Technology*, **38**, 563-579. https://doi.org/10.1177/0143624417707875

[22] So, A., Al-Sharif, L. and Chan, R. (2022) Universal Elevator Round Trip Time Calculation for General Traffic Conditions with Extension to Batch Arrivals. *Building Services Engineering Research and Technology*, **43**, 539-557. https://doi.org/10.1177/01436244221095195

[23] Wu, Y. and Yang, J. (2024) Directional Optimization of Elevator Scheduling Algorithms in Complex Traffic Patterns. *Applied Soft Computing*, **158**, Article ID: 111567. https://doi.org/10.1016/j.asoc.2024.111567

[24] Tartan, E.O. and Çiflikli, C. (2024) Esra (Elevator Simulation, Research & Analysis): An Open-Source Software Tool for Elevator Traffic Simulation, Research, and Analysis. *Journal of Simulation*, **18**, 868-885. https://doi.org/10.1080/17477778.2024.2330432

[25] So, A.T.P. and Al-Sharif, L. (2023) In-Depth Study on RTT-HC-MTT Relationship for Passenger Demand Beyond Elevator Contract Capacity by Simulation. *Transportation Systems in Buildings*, **5**, 1-24. https://doi.org/10.14234/tsib.v5i1.169

[26] Homchalee, R., Pitakaso, R. and Kumphon, O. (2023) Minimizing Energy Usage and Makespan of Elevator Operation in Rush Hour Using Multi-Objective Variable Neighborhood Strategy Adaptive Search with a Mobile Application. *Mathematics*, **11**, Article No. 1948. https://doi.org/10.3390/math11081948

[27] Wen, X., Si, B., Xu, M., Zhao, F. and Jiang, R. (2024) A Passenger Flow Spatial-Temporal Distribution Model for a Passenger Transit Hub Considering Node Queuing. *Transportation Research Part C: Emerging Technologies*, **163**, Article ID: 104640. https://doi.org/10.1016/j.trc.2024.104640

[28] Liu, J., Hu, L., Xu, X. and Wu, J. (2021) A Queuing Network Simulation Optimization Method for Coordination Control of Passenger Flow in Urban Rail Transit Stations. *Neural Computing and Applications*, **33**, 10935-10959. https://doi.org/10.1007/s00521-020-05580-5

[29] Su, G., Si, B., Zhi, K. and Li, H. (2022) A Calculation Method of Passenger Flow Distribution in Large-Scale Subway Network Based on Passenger-Train Matching Probability. *Entropy*, **24**, Article No. 1026. https://doi.org/10.3390/e24081026

[30] Fernández, J., Cortés, P., Muñuzuri, J. and Guadix, J. (2013) Dynamic Fuzzy Logic Elevator Group Control System with Relative Waiting Time Consideration. *IEEE transactions on Industrial Electronics*, **61**, 4912-4919. https://doi.org/10.1109/TIE.2013.2289867

[31] Gharbi, A. (2024) Exploring Heuristic and Optimization Approaches for Elevator Group Control Systems. *Applied Sciences*, **14**, 995. https://doi.org/10.3390/app14030995

[32] Jamaludin, J., Rahim, N.A. and Hew, W.P. (2010) An Elevator Group Control System with a Self-Tuning Fuzzy Logic Group Controller. *IEEE Transactions on Industrial Electronics*, **57**, 4188-4198. https://doi.org/10.1109/tie.2010.2044117

[33] So, A. and Al-Sharif, L. (2019) Calculation of the Elevator Round-Trip Time under Destination Group Control Using Offline Batch Allocations and Real-Time Allocations. *Journal of Building Engineering*, **22**, 549-561. https://doi.org/10.1016/j.jobe.2019.01.013

[34] Shi, M., Sun, E., Xu, X. and Choi, Y. (2024) Prediction and Analysis of Elevator Traffic Flow under the LSTM Neural Network. *Intelligent Control and Automation*, **15**, 63-82. https://doi.org/10.4236/ica.2024.152004

[35] Poon, K.H., Wong, P.K. and Cheng, J.C.P. (2022) Long-Time Gap Crowd Prediction Using Time Series Deep Learning Models with Two-Dimensional Single Attribute Inputs. *Advanced Engineering Informatics*, **51**, Article ID: 101482. https://doi.org/10.1016/j.aei.2021.101482

[36] Shi, M. and Choi, Y. (2024) Comparison of the Elevator Traffic Flow Prediction between the Neural Networks of CNN and LSTM. *Intelligent Control and System Engineering*, **2**, 1871-1871.

[37] Cao, Y. and Li, X. (2022) Multi-Model Attention Fusion Multilayer Perceptron Prediction Method for Subway OD Passenger Flow under Covid-19. *Sustainability*, **14**, Article No. 14420. https://doi.org/10.3390/su142114420

[38] Cheng, J.C.P., Ho Poon, K. and Kok-Yiu Wong, P. (2022) Long-Time Gap Crowd Prediction with a Two-Stage Optimized Spatiotemporal Hybrid-GCGRU. *Advanced Engineering Informatics*, **54**, Article ID: 101727. https://doi.org/10.1016/j.aei.2022.101727

[39] Han, W., Chen, A.Y., Chi, N. and Hsieh, S. (2024) Elevator Priority Scheduling with Deep Learning Based Image Analytics for People with Special Needs. *Advanced Engineering Informatics*, **62**, Article ID: 102794. https://doi.org/10.1016/j.aei.2024.102794