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REDESIGNING PASSENGER DISTRIBUTION SYSTEM OF KRL COMMUTER LINE: AN INTEGRATIVE APPROACH

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ABSTRACT
Commuter line electric rail (KRL) has become a critical mode of public transportation supporting urban mobility in densely populated areas. However, the rapid growth of urban populations and the corresponding increase in daily commuters have created significant challenges in delivering optimal and comfortable services due to overcrowding. This study addresses these challenges by enhancing passenger comfort on KRL commuter lines through the redesign of the passenger distribution system considering personal space along with passenger flow management. An integrative approach combining ergonomic approach in determining carriage capacity, passenger flow management, and simulation-based analysis was employed. Empirical data were collected through observation, empirical survey, and direct anthropometric measurement. Observations on passenger density were conducted on the Cikarang line during peak morning hours, focusing on mixed-gender carriages. Anthropometric measurements involving 238 subjects alongside carriage dimensions were analyzed to determine the capacity of carriage using ergonomic principles of personal space The results revealed that the carriage capacity of 150 passengers balancing comfort and efficiency. An innovative passenger distribution system deploying queuing system equipped with integrated sensors providing real-time number of passengers and innovative automatic door-closing mechanism at the carriages were proposed and tested under current passenger density and determined carriage capacity using discrete-event simulation implemented in Arena software. This study provides novel contribution both practically and theoretically demonstrating the application of ergonomics and sensor integration in public transportation system design for improving commuter comfort and safety in highly congested urban transport systems. Future researches are also discussed.
Keywords: *ergonomics, innovative passenger distribution system, integrative approach, KRL commuter line, personal space*

1. Introduction

Public rail transportation systems are integral to urban mobility in major cities worldwide, such as the Paris Métro in France, the London Underground in England, the U-Bahn in Vienna and several German cities, and the Shanghai Metro in China. These systems not only enhance urban mobility but also contribute significantly to reducing carbon emissions (Fageda, 2021; Lu et al., 2023; Welle, 2023; Zhang et al., 2019). Numerous studies have underscored the role of urban rail transit in alleviating congestion and improving environmental quality (Eboli & Mazzulla, 2012; Saw et al., 2020; Yuda Bakti et al., 2020). In recent years, the Indonesian government has made significant strides in improving public infrastructure, particularly through the development of inter-city toll roads and integrated public transport systems such as Transjakarta Bus, Commuter Line Electric Trains (KRL), Mass Rapid Transit (MRT), and Light Rail Transit (LRT) (Antara, 2023; Jati, 2024). These initiatives aim to mitigate congestion in Jakarta and its surrounding regions.

Among these transport modes, KRL, MRT, and LRT operate on dedicated rail lines, thereby not contributing to road congestion. According to MRT Jakarta's Annual Report (PT. MRT Jakarta (Perseroda), 2022), the MRT service has witnessed a rapid increase in ridership since its launch in 2019, with a customer satisfaction index ranging between 86% and 88%, accompanied by a zero-crime rate. Similarly, PT KAI, the operator of KRL, has maintained a high level of customer satisfaction, as indicated by studies on facilities at KRL stations such as Manggarai

(Manurung et al., 2023). The Indonesian government remains committed to further developing KRL and MRT systems to enhance public mobility (Cabinet Secretariat of the Republic of Indonesia, 2019). KRL, with its capacity of 8 to 12 carriages, serves a broader area, extending beyond Jakarta to cities such as Bogor, Cikarang, Rangkasbitung, and Tangerang, compared to the MRT, which operates primarily within Jakarta and has only six carriages. Given its longer routes and relatively lower fares, KRL is often more crowded than the MRT. Previous studies have indicated that high passenger density on KRL services forces commuters to adjust their travel times, leading to reduced satisfaction and comfort (Kumagai et al., 2021; Schneider et al., 2021).

This study aims to redesign the passenger distribution system considering personal space of ergonomics along with management of passenger flow. We hypothesize that redesigning the passenger distribution system based on ergonomic principles will improve passenger comfort on KRL commuter lines. The research focuses on commuter line KRL stations and proposes an integrated approach to enhance passenger comfort. This paper presents two contributions. Firstly, it advocated for a comprehensive methodology by utilizing the ergonomic dimensions of personal space to assess the carriage's capacity, proposing practical scenario, and appraising the efficacy of the scenario through simulation-based analysis. Secondly, the present study demonstrated a feasible practical solution for passenger distribution system to enhance both comfort and efficiency in KRL services.

This paper is structured into five sections. The introduction outlines the motivation and contribution of the study. The second section details the literature review. The third explains methodological approach, while the fourth presents results and discussion of the current state of passenger density and carriage preference, capacity of carriage using ergonomic principles of personal space, scenario development of innovative passenger distribution system, and scenario testing using simulation model. The final section concludes with the main findings and suggestions for future research.

2. Literature Review

As urban populations and daily commuting demands continue to rise, the challenge for rail-based public transportation lies in providing optimal and comfortable services. Passenger density has been identified as a key factor influencing the public's choice of transportation (Çelebi & İmre, 2020; Drabicki et al., 2023). High density within carriages often results in discomfort due to physical proximity, limited personal space, and restricted access to facilities such as seats, doors, and handles (Dwiatmoko et al., 2022; Hasibuan & Mulyani, 2022; Haywood et al., 2017; Hoogendoorn et al., 2007; Monsuur et al., 2021). In addition, a study from Kusmawan et al. (2021) found that commuting affects commuters' quality of life, impacting their physical, psychological, health, and environmental well-being, with prolonged commuting linked to musculoskeletal disorders (MSD), obesity, high blood pressure, and poor physical health. Based on a survey of 155 passengers, they also discovered that psychological factors function as a mediator between travel discomfort and health complaints. As a result, the problem of overcrowding is becoming increasingly recognized in metropolitan areas globally (Seriani et al., 2022). High passenger volumes during peak hours are a major cause of train delays (Ait Ali et al., 2022). Furthermore, it is expected that improvement in passenger comfort in public transportation could promote shift from using private vehicles to public transportation in the Jakarta area in which risky driving behavior remains a problem (Ho & Widaningrum, 2016).

In Jakarta, commuter line ridership reached an average of 848,195 passengers per day in 2022 (Santika, 2023). During peak hours, from 5:00 to 9:00 AM and 4:00 to 8:00 PM, approximately 88% of public transport users choose to travel, exacerbating the problem of overcrowding (Tjahjono et al., 2020). Prior studies have attempted to address the issue of train density through various approaches. For example, Luan & Corman (2022) proposed a mixed-integer nonlinear programming model to optimize train passenger distribution in the Zurich urban railway network. Their model combined train scheduling and passenger routing in order to reduce overall disutility and delays. Their study illustrated how taking crowding effects into account can result in more dependable train schedules and better passenger comfort because passengers may choose less crowded routes even if they take longer travel times. Peftitsi et al. (2021) used an agent-based simulation model to assess the passenger density in Stockholm's public transportation system. The results showed that more passengers are distributed more evenly among train cars during peak hours in which lessens the discomfort caused by higher volumes. Meanwhile, Aguayo et al. (2023) estimated platform density on urban railways using machine learning and image processing techniques. They developed a laboratory-based strategy utilizing computer vision techniques of neural networks and image processing. Their experiments used a mock-up of a train carriage and an adjacent platform to analysis the passenger distribution during boarding and alighting processes. Although the results are promising, using this technique to Jakarta's KRL is challenging considering crowd density, occlusion, inconsistent lighting, and outdoor conditions influencing image quality and algorithm performance (Hu et al., 2021; Hussein et al., 2024; Wang et al., 2023). In addition, data privacy regulations may limit large-scale implementation of surveillance technologies (Solihati & Indriyani, 2021; Susanti, 2022).

Numerous previous studies have proposed various strategies to improve passenger distribution and reduce congestion in urban rail systems. These methods used optimization models, real-time sensing technologies, behavioral incentives, and predictive analytics to better understand and respond to passenger flow dynamics. However, these studies have mainly focused on density optimization without specifically considering the ergonomic aspects related to personal space. For example, Yamauchi et al. (2023) suggested a Wardrop equilibrium-based model to optimize train stopping patterns on Tokyo's Keio Line. They adjusted stop schedules to balance passenger flow and reduce congestion using an efficient local search algorithm. Their approach alleviated overcrowding during peak hours with minimal effect on travel times. Next, Elhamshary et al. (2019) used CrowdMeter, a participatory system that uses data from users' smartphones to calculate real-time congestion levels in railway stations. This study utilized passengers' contexts to show congestion levels for each area, such as crowd density in passageways and queue lengths at ticketing machines. They highlighted each area of the station with specific colors (green, amber, red) corresponding to low, medium, and high congestion levels, respectively. Field tests carried out in 29 train stations in Japan demonstrated that CrowdMeter enables accurately estimate the levels of congestion.

Moreover, Shimizu et al. (2024) developed a reward-based crowd management system that offers passengers coupons redeemable at stores along the rail line. These coupons are provided to passengers who choose to travel during off-peak hours, so that they are directly incentivizing behavior that reduces congestion. In a three-month field experiment with Shizuoka Railway, 7.1% of passengers adjusted their commuting times to avoid congestion, and those who received coupons increased their disembarkation at specific stations by an average of 29%, indicating a positive impact on local economies. Meanwhile, Tuncel et al. (2024) introduces a method to predict instances where passengers are unable to board trains because of overcrowding using automated fare collection (AFC) and automated vehicle location (AVL) data. Their model estimates denied boarding probabilities based on factors such as passenger demand, train operations, and incidents. In Hong Kong's Mass Transit Railway. The model achieved an average prediction error of 6%-7% and it enables real-time crowding information, aiding passengers in making informed travel decisions and assisting operators in enhancing efficiency and safety without relying on costly manual data collection.

3. Method

This study employed an integrative approach combining ergonomic analysis to determine the capacity of carriage and a discrete-event simulation to examine the effectiveness of proposed scenario in adhering to comfort standards under various passenger density situations. The methodology section is divided into two main subsections: Data Collection and Data Analysis.

3.1. Data Collection

Empirical data with respect to passenger distribution and preference of carriages was collected through observations and empirical survey, respectively. The observational study focused on tracking the number of passengers boarding and alighting from KRL commuter line trains on the Cikarang line. The observations covered key stations, including Cikarang, Bekasi, Kranji, Cakung, Klender Baru, Buaran, and Klender, to assess passenger density. The observations were conducted on mixed-gender carriages (carriages 2 to 11) during peak hours (6:00 to 8:00 AM), focusing on identifying stations with the highest passenger density. The KRL system in the Greater Jakarta area operates trains with three different formations: SF8 (8-carriage series), SF10 (10-carriage series), and SF12 (12-carriage series). Two cellphone cameras were utilized to record the number of passengers entering and exiting each carriage. Data collection was conducted over three consecutive days during the same time frame (6:00 to 8:00 AM). The recorded data was then processed to quantify passenger density.

In addition, to acquire empirical data of passenger preferences in selecting carriages carriages, an empirical survey involving 157 current KRL users (85 women, 72 men; age range: <20 years: 26, 20–30 years: 96, 30–40 years: 17, 40–50 years: 11, >50 years: 7) was conducted. A similar survey was also administered to 110 prospective KRL users (61 women, 49 men; age range: <20 years: 24, 20–30 years: 73, 30–40 years: 9, >50 years: 4) from the same urban area.

Anthropometric measurements of 238 individuals (119 men and 119 women) in their 20s were taken to evaluate maximum carriage capacity based on body dimensions. The dimensions measured included chest thickness (the horizontal distance from the back to the chest), shoulder width (the maximum horizontal distance from the right to left deltoid muscles), and standing shoulder height (the vertical distance from the floor to the acromion). Train dimensions were measured using a Stanley Tylon tape measure (model: STHT30656). Currently, KRL commuter trains adhere to the Indonesian Ministry of Transportation's regulation PM 63 of 2019, which limits standing passenger capacity to 6 passengers per square meter (Kementerian Perhubungan Indonesia, 2019).

3.2. Data Analysis

The collected data was analyzed in four stages to design a passenger distribution system for the KRL commuter line.

1. Passenger Density and Carriage Preference: The first stage involved analyzing the number of passenger arrivals and alighting at the carriages. Statistical analysis was utilized to assess arrival rates for each carriage and the difference of the arrival rates across the carriages. Survey data on passenger preferences on carriage selection was also integrated to evaluate arrival distribution patterns.
2. Capacity of Carriage: The second stage focused on calculating the passenger capacity for a single carriage, incorporating the ergonomic principle of personal space. The results were based on anthropometric data and passenger density levels, aiming to determine the number of passengers that can be accommodated comfortably. Anthropometric data were used to quantify the physical dimensions of the human body, such as shoulder width, chest depth, and standing height, which are important for defining the minimum personal space required for comfort and safety in crowded environments. An empirical experiment was also conducted to verify the calculated capacity.
3. Scenario Development: Based on the specified carriage capacity, scenario was developed to ensure that the carriages are operated within their high utilization. Hence, passenger flow management employing queuing system equipped with integrated sensors and automatic door controls were proposed to facilitate more efficient passenger movement at station platform and within the carriage respectively. SketchUp software (Pro 2020, Trimble Inc) facilitating 3D design was deployed to visualize the design of carriage based on the proposed scenarios.
4. Scenario Testing using Simulation Model: The final stage aimed at evaluating the effectiveness of the proposed scenarios by developing a Discrete-Event Simulation (DES) model using Arena Simulation software (Version 16.2, Rockwell Automation). Arena was selected for this study due to its robust capabilities in modeling complex, discrete-event systems, which are essential for simulating passenger flow and distribution in public transportation. Its intuitive flowchart-based interface allows for efficient construction and visualization of intricate processes, such as queuing systems and boarding procedures, without the need for extensive programming knowledge (Oprea et al., 2024; Verawati et al., 2024). The DES processes beginning with passenger arrivals at the station and progressing through a First-In-First-Out (FIFO) queuing system at the platform entry. The DES focusing on the processes in a system was selected because the passenger distribution system is

regarded as a sequence of separate discrete events, i.e., a passenger arrives at the station, goes in a queue, enters the carriage, and departs. Parameters for the simulation were drawn from empirical data on passenger arrival patterns, a specified carriage capacity limit of passengers based on ergonomic principles, and the operational design of the innovative distribution system. Meanwhile, the key components modeled include digital display screens showing real-time carriage occupancy, sensor-based automatic door control, and designated exit buttons. The simulation included scenarios at both Buaran and Klender stations. Validation was performed by comparing simulated outputs (e.g., boarding counts, queue lengths, and carriage occupancy) against known empirical patterns and logical system behavior under consideration of capacity constraints. Performance indicators used in the analysis included passenger distribution per carriage, number of waiting passengers left in the queue, occupancy rates, and successful maintenance of the passenger capacity limit. Thus, under various passenger density situations, the simulation model examined the performance of the developed scenarios in terms of passenger distribution at the station and at each carriage, providing insights into the effectiveness of the proposed passenger distribution system.

4. Results and Discussion

This section is divided into four sections following the aforementioned research stages as the following.

4.1. Passenger Density and Carriage Preference

Figure 1 presents the density of passenger at various carriages in KRL commuter line across all stations for the Cikarang line. The figure highlights that the passenger density is various across the stations in which Klender Station and Buaran Station are experiencing the most densed passenger. As a result, these two stations became the focus for further analysis of passenger density. It is also worth noting that passengers are distributed unevenly across the carriages, resulting in overcrowded and passengers jostling within the carriages at some carriages particularly carriage number 6 and 7.

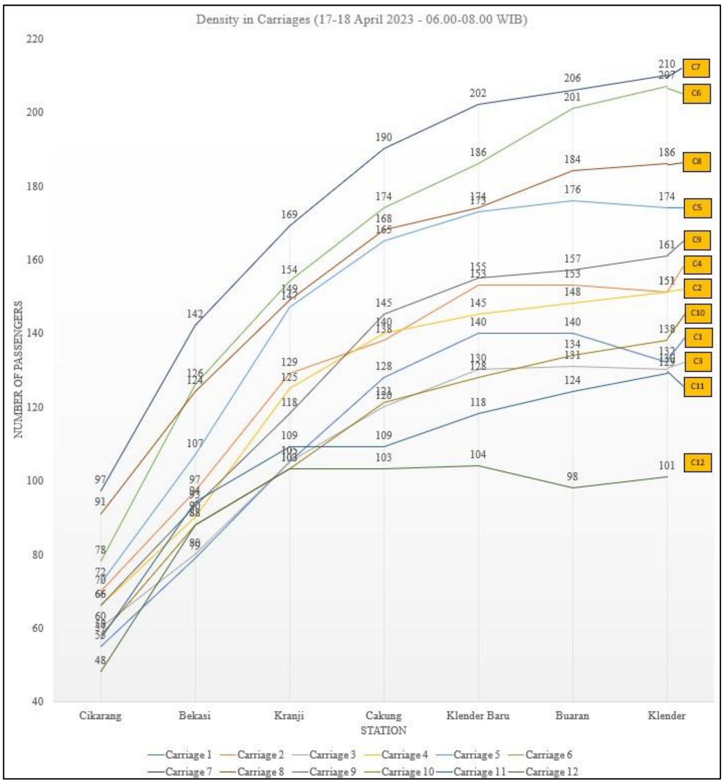


Fig.1. Passenger Density in Cikarang Commuter Line

Further observations were conducted over two separate days and revealed no significant differences in the distribution of passengers between the carriages ($t(53) = 1.36$, $p = 0.180$).

Similarly, no significant difference was found in the distribution of passengers boarding the train across all stations ($t(55) = 0.02$, $p = 0.982$).

Furthermore, in order to understand the preference of passenger selecting the carriages, the empirical survey was conducted. The survey results indicate distinct preferences among current KRL commuter line users regarding their choice of carriages. 23% users selected carriage number 1, primarily because it is designated as a women-only carriage (the first and last carriages). Additionally, many passengers considered it to be less crowded. 15% of passengers opted for carriage 2, while 12% passengers preferred carriages 3 and 7, and 10% passengers chose carriage 5. The reasons provided by these users included proximity to the stairs, fewer passengers, and ease of access. Notably, 39% respondents expressed no specific preference and chose any available carriage when boarding the KRL. The remaining respondents selected various other carriages. The distribution data on passenger preference in selecting carriages would then be used to parameterize the simulation model.

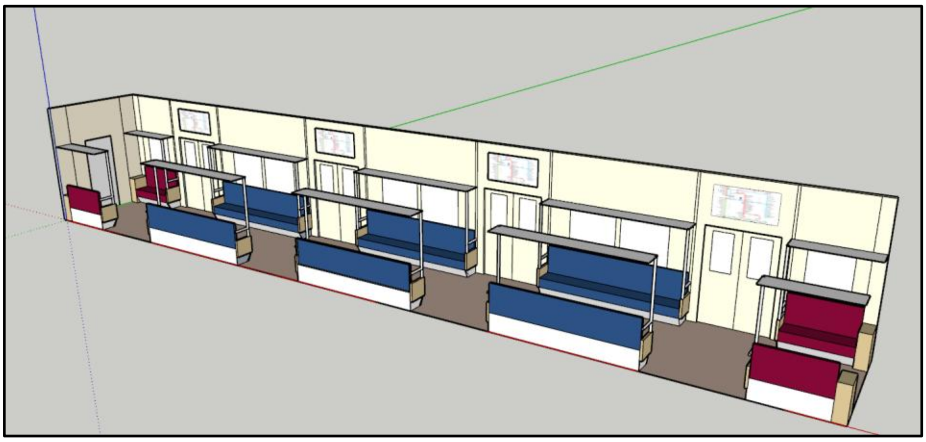
In a separate survey of prospective KRL users, the majority indicated their choice to use KRL for a variety of reasons, with 19% citing that the carriages were not overcrowded, and 19% choosing KRL because the stations were easily accessible from both their homes and destinations. Additionally, 13% of prospective users emphasized a combination of factors such as affordable fares, short travel times, minimal crowding in carriages, short waiting times for trains, and good integration with public transport at both the origin and destination points. In summary, prospective KRL users are willing to choose this mode of transportation for reasons that include affordable pricing, convenient access to stations, shorter travel times, and lower levels of crowding, alongside efficient integration with other public transport options. The findings support that low crowding is one of the influential factors to choose KRL commuter line, implying that managing the passanger distribution among carriages is necessary.

4.2. Capacity of Carriage

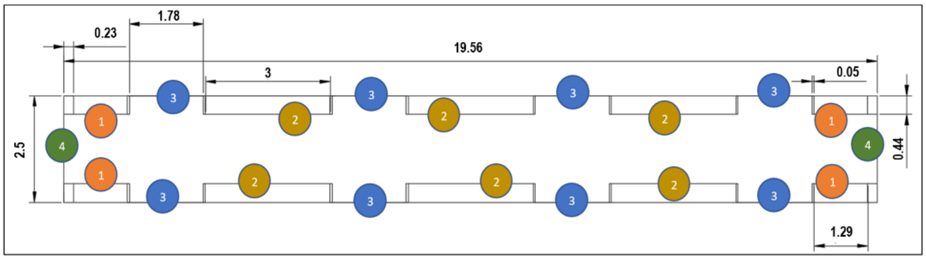
According to the Regulation of the Minister of Transportation of the Republic of Indonesia (PM 63 of 2019), the space allocated for standing passengers should not exceed 6 passengers per square meter. However, the implementation of this regulation might lead to discomfort (Ramadhanty & Maullana, 2024). Therefore, redesigning personal space is needed to enhance the ergonomic experience during commutes on KRL commuter trains. The total standing area in each carriage was calculated to be 37.95 m^2, derived by subtracting the area taken up by seating and other carriage components (10.95 m^2) from the total floor area (49.8 m^2), as shown in Table 1 and illustrated in Figure 2. Based on these regulations, the maximum allowable number of standing passengers is 227, with an additional 48 seated passengers (36 in general seats and 12 in priority seats), yielding a total capacity of 275 passengers per carriage. For a standard 12-carriage train (SF12), this equates to a total capacity of 3,300 passengers.

Table 1 - Dimensions of the Train Carriage

Train Carriage Area	Dimensions (Length × Width)
One train carriage	19.56 m × 2.5 m
Passenger seats	3 m × 0.44 m
Priority seats	1.29 m × 0.44 m
Others	0.76 m^2



(a)



(b)

Fig. 2. 3D (a) and 2D (b) Illustration of a Commuter Line KRL Carriage (in meters)
Note:
1 = Priority Seats   3 = Carriage door
2 = Passenger Seats   4 = Inter-carriage door

The passenger capacity in commuter line carriages is determined based on human body dimensions and carriage dimensions. To improve comfort, this study proposes the capacity of train carriages which is estimated based on the concept of personal space of ergonomics (He & Zhi, 2022; Küpper & Seyfried, 2023; Seriani et al., 2024; Sugiono et al., 2022). Table 2 presents the results of anthropometric measurements, including chest thickness, shoulder width, and standing shoulder height (Gumasing et al., 2022). These measurements are essential to determine the maximum passenger capacity in KRL carriages based on ergonomic principles to ensure adequate personal space. The standing shoulder height measurement is also used in the design of the door-closing system to ensure easy accessibility for passengers. The ergonomic considerations are aimed at improving passenger comfort while maintaining safety in high-density conditions.

Table 2 Results of Body Dimensions Measurements

Body Dimensions	Descriptive Statistics*	
	Male	Female
Chest thickness	20.61 (3.67)	22.14 (5.07)
Shoulder width	48.01 (5.65)	43.72 (5.26)
Standing shoulder height	143.61 (6.83)	131.24 (5.13)

* mean (standard deviation)

Previous research suggests that for standing passengers to maintain a comfortable amount of space, an area of 0.27 m² per passenger is required (Barney & Al-Sharif, 2015). This allocation helps prevent physical contact and allows for personal space. Similarly, Gray & Hoel (1979) observed that the shoulders of the 95th percentile male occupies 0.14 m², and that physical contact between standing passengers becomes unavoidable when the available space per person drops to 0.26 m². Space requirements in free standing lines or platform waiting areas are 0.5 to 1.0 m² per person. Matsika (2018) proposed an intermediate space allocation of 0.25 m² per passenger, balancing the needs between seated and standing densities. According to (Transportation

Research Board, 2013) at Level of Service E, the average space available per person ranges between 0.2 and 0.3 m². In these conditions, individuals are in constant physical contact with one another, making movement within the queue impossible. Queuing at this density can only be sustained for a short period without serious discomfort. Furthermore, Tillman et al. (2016) recommended personal space as of 0.66 m² per person to maintain intimate space boundaries, where intrusion is generally unwelcome unless in close relationships. Applying the principle of personal space of 0.27 m² and based on the anthropometric measurement, the proposed capacity for a single carriage is 150 passengers (including 102 standing and 48 sitting) as shown in Table 3 and Figure 3.

Table 3 Calculated Area and Proposed Passenger Capacity for Carriage

Carriage area and passenger capacity	Dimensions	Unit
Grey-shaded area representing standing passenger area	27.64	m^2
Standing area allocation per passenger	0.27	m^2/passenger
Maximum standing passenger capacity per carriage	102	passenger

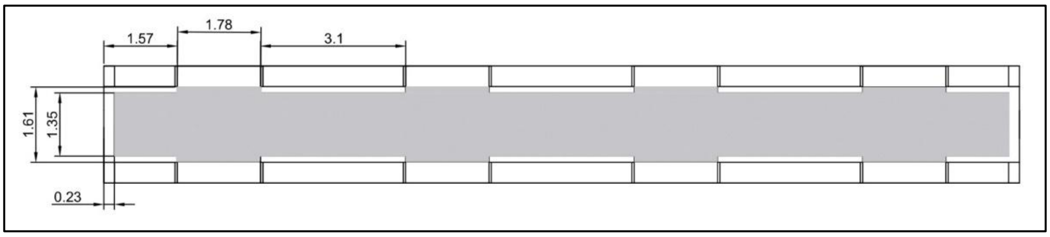


Fig. 3. Proposed Standing Passenger Area (in Meters)

When compared to the capacity of 275 based on the aforementioned regulation, the capacity calculated based ergonomics' personal space is much smaller, reduced by 45%. This reduction assures that passengers have sufficient room to perform light movements, such as reaching for personal items or adjusting their position, while minimizing discomfort (Peng et al., 2022; Stojanovski, 2020). To verify these findings, an empirical experiment was done where 4 adult passengers (both male and female) stood in an area of 1 m². As a result, it confirmed that passengers experienced a comfortable personal space with approximately 200 mm of space between individuals that aligns with ergonomic recommendations (Barney & Al-Sharif, 2015). In line with previous work, Matsika (2018) pointed out that standing passenger density standards vary across regions depending on design and operational needs. For example, new train design in Hong Kong accommodates up to 10 passengers/m^2 , and 8 passengers/m^2 for passenger planning. In the US, a baseline of 5 passengers/m^2 is regarded as the maximum acceptable for planning scenarios with 6 passengers/m^2 or above reserved for engineering considerations. In contrast, European standards typically allow for seating densities of 2.5 to 3 passengers per m^2, while standing densities generally range from 4 to 5 passengers per m^2.

4.3. Scenario Development: Innovative Passenger Distribution System

Based on the aforementioned finding, it is important to operate the carriage at its specified capacity of 150 passengers to improve passenger comfort. However, this reduction in capacity per carriage necessitates careful management to avoid potential trade-offs, such as increased waiting times and platform congestion. Fewer passengers per carriage could lead to longer queues and extended waiting periods if not properly addressed. Studies have shown that insufficient capacity not only causes local queues, leading to passenger discomfort and time wastage, but also train delays that reduce overall system efficiency (Erdei et al., 2023; Leurent, 2011; Sharma et al., 2023).

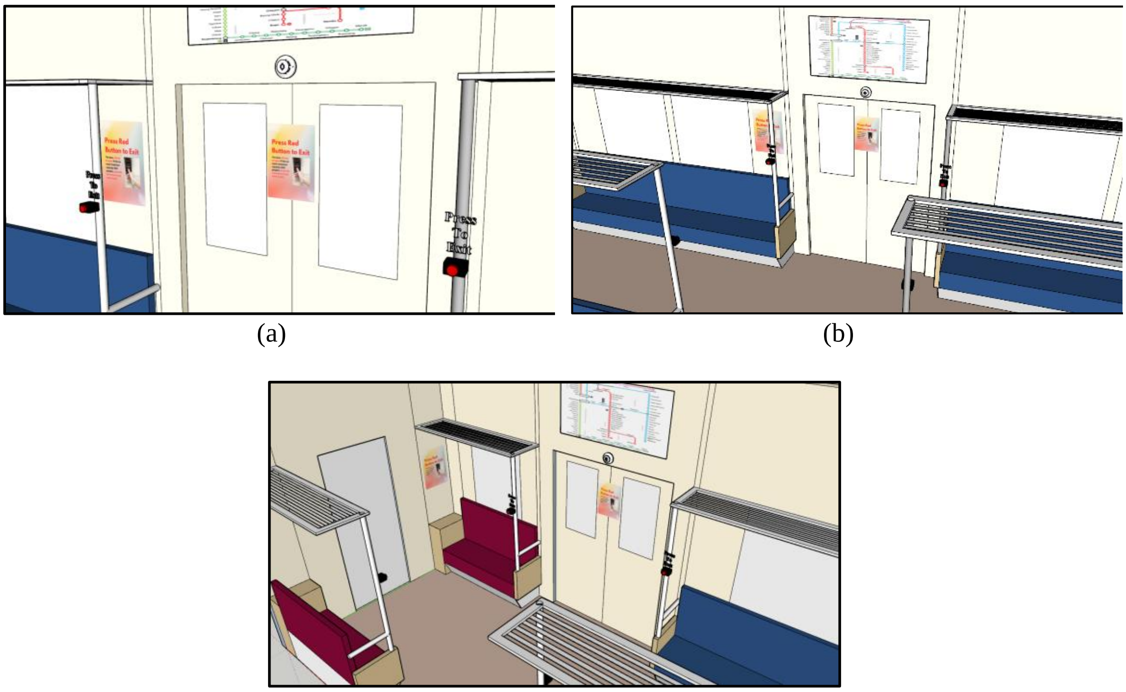
Moreover, passenger distribution among carriages is not uniform. The scenario of innovative passenger distribution system was then developed to ensure even passenger distribution at each carriage while operating at its high utilization. The suggested innovative passenger distribution system entails the management of passenger flow at the platform entry, facilitating systematic guidance prior to boarding, as well as the control of passenger within the carriage to ensure uniform load distribution.

With respect to passenger flow management at the platform entry, a queuing system is deployed. Security personnel may direct passengers to board them according to the remaining capacity in each carriage, which was displayed on a live digital report screen. In conjunction with the proposed capacity restrictions, an automatic system using innovative automatic door-closing mechanism and sensors to monitor the number of passengers in the carriage on a real-time basis is recommended, ensuring that overcrowding is prevented (Galliani et al., 2024; McCarthy et al., 2025; Roncoli et al., 2023). This system is designed to automatically close the carriage doors once the passenger count reaches the maximum capacity of 150 passengers, effectively preventing overcrowding and ensuring passengers have adequate personal space (BEA Sensor, 2024), in line with ergonomic principles. To facilitate efficient exits from fully occupied carriages, a strategically placed door-opening button system has been introduced near each door (on both the right and left sides). This innovative feature allows passengers in crowded carriages to exit without delay by reducing congestion near the exits and ensuring a smoother flow of passengers. The system also supports overall crowd management by providing a mechanism in which the doors open only when necessary and it contributes to the train’s operational efficiency and maintaining passenger safety. This innovation not only optimizes space utilization but also improves passenger comfort and safety by solving the issue of crowded exits during peak hours. By integrating this system with sensors that monitor carriage capacity in real-time, the train could assure that each carriage remains within the ergonomic limits and facilitate for better distribution of passengers across the train.

The location of the exit button was calculated using the 50th percentile of the standing shoulder height measurement, a commonly accepted ergonomic reference for hand reach (Freivalds and Niebel, 2014; Kroemer, 2017). The button was positioned 138 cm from the carriage floor so that it would be within easy reach for the majority of passengers. The button was designed in red color to improve visibility and consistent with established safety practices, where red is often used to denote notices that require attention (Kuniecki et al., 2015). Figure 4a provides an illustration of the button placement within the carriage.

In addition to the exit buttons, sensors are placed above each of the eight doors in each carriage. These sensors are utilized to count the number of passengers entering and exiting the train and providing real-time data on the current occupancy of each carriage. This data is then displayed on digital screens both within the carriage and at the station that allows passengers and station staff to monitor carriage capacity in real-time (Figures 4b and 4c). This sensor system not only helps in managing passenger flow but also ensures that the train adheres to the proposed capacity limits by automatically preventing doors from opening once the carriage is full.

The installation of sensors and digital screens in the train and station could be a cost-effective technique to improve operational efficiency and passenger experience. Advances in Internet of Things (IoT) technology have facilitated the development of affordable and scalable sensor systems that could monitor occupancy and environmental conditions in real-time. Likewise, modern digital display has become more economical, offering low-maintenance, dynamic content delivery while creating opportunities for advertising revenue. Although initial investments are required, the long-term benefits, such as better crowd management, enhanced comfort and safety, as well as improved service quality, make these technologies a worthwhile investment to support the growing demands of urban mobility (Pandey et al., 2025; Ryu et al., 2020; Sarp et al., 2024; Sivasubramaniyam et al., 2025).



(a) (b)

(c)

Fig. 4. Placement of Exit Buttons, Sensors, and Information in Carriage (a), Exit Button and Information Near Passenger seats (b), and at Priority Seats (c)

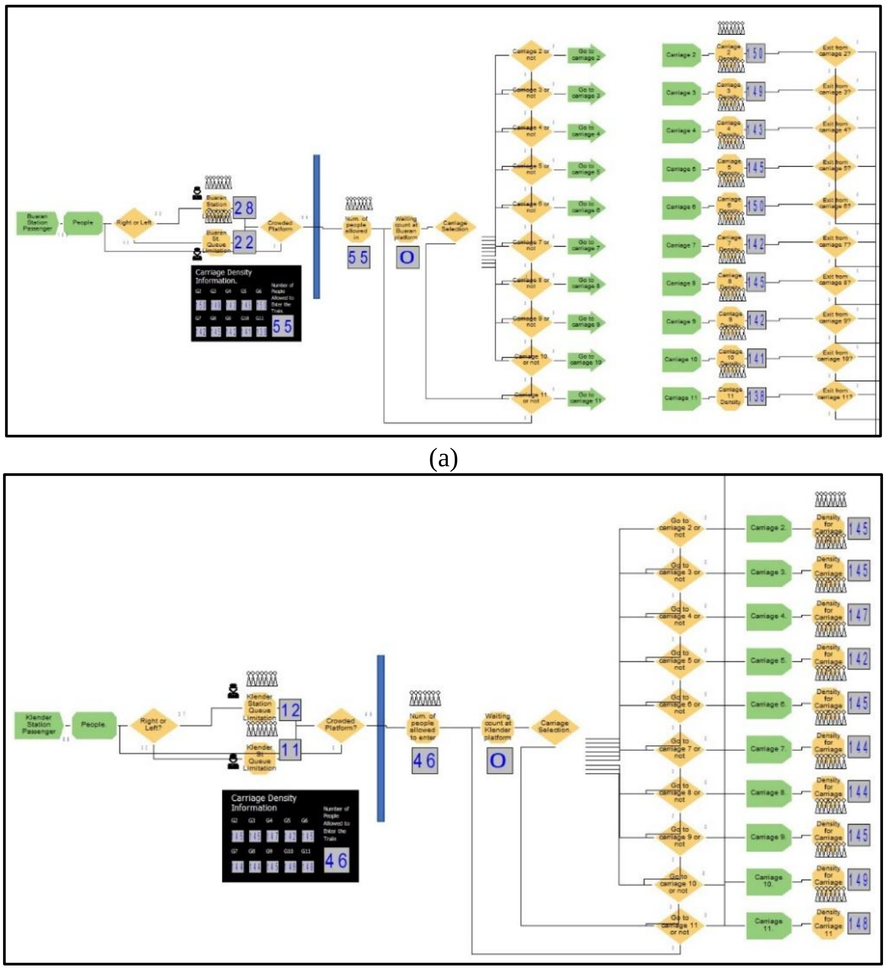
4.4. Scenario Testing using Simulation Model

To evaluate the effectiveness of the proposed scenario of innovative passenger distribution system given passenger density and specified carriage capacity, a discrete-event simulation model implemented in Arena was developed. The simulation model was parameterized using empirical data of passenger arrival presented in Section 3.1., maximum capacity of 150 passengers per carriage obtained in Section 3.2, and installed innovative passenger distribution system proposed in Section 3.3.

The simulation starts with passenger arrival which is then imposed on a queuing system before entering the platform. The queuing system followed a First In First Out (FIFO) principle, ensuring that passengers who arrived first were given priority to board. Passengers who could not board due to carriage capacity were required to continue queuing until the next train arrived. At the queuing station, a live digital report screen informing the available seats at each carriage is employed. Figure 5 illustrates the simulation model of the passenger distribution system.

Figure 5(a) shows the management of the passenger distribution system at Buaran Station, where carriages 2 to 11 were equipped with screens displaying their current occupancy. For instance, carriage 2 held 150 passengers, carriage 3 had 149 passengers, and carriage 4 had 143 passengers. The simulation revealed that carriages 1 and 6 had reached their full capacity, while the remaining carriages still had available space. The doors of fully occupied carriages remained closed, preventing further boarding. Passengers who wished to exit from full carriages were required to press the designated exit button to open the doors. The number of passengers allowed to board each train was determined by the remaining capacity in carriages 2 to 11, with specific limits shown on the live report screen (e.g., 55 passengers). Passengers who could not board continued waiting in a restricted area, where the numbers of waiting passengers were displayed (e.g., 28 and 22). Digital screens showing live reports of the carriage occupancy were placed both on the platform and inside the carriages to keep passengers informed.

The commuter line then traveled from Buaran Station to Klender Station as shown in Figure 5(b), where the simulation measured the number of passengers disembarking. 46 passengers exited at Klender Station, leaving sufficient capacity for additional passengers to board. Those who were waiting at the platform were invited to board the train, while others remained in the restricted waiting area for the next train. The live report screen at Klender Station also updated to reflect the new carriage capacities.



(a)

(b)

Fig. 5. Passenger Distribution Simulation at Buaran Station (a) and Klender Baru Station (b)

At Klender Station, the passenger distribution followed the same procedure as at Buaran Station. Figure 6 shows the exit of 46 passengers, with detailed figures for each carriage (e.g., 5 passengers from carriage 2, 8 passengers from carriage 5). After 46 passengers boarded, 23 passengers remained in the queue, awaiting the next available train.

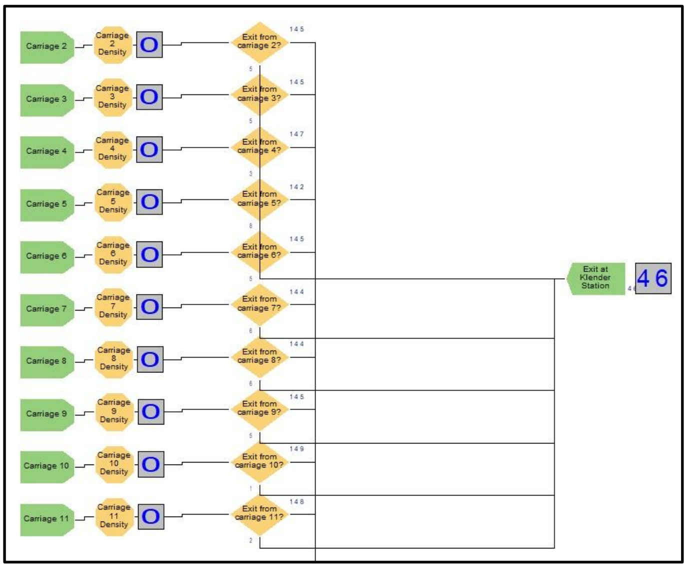


Fig. 6. Simulation of Passenger Exit Behavior at Klender Station

Based on the simulation results, it was concluded that the proposed limit of 150 passengers per carriage is feasible under current passenger density conditions. This limit, aligned with the personal space ergonomic concept, was successfully maintained, as evidenced by the simulation's demonstration of available capacity below the maximum limit in each carriage.

5. Conclusion

The present study has successfully demonstrated the feasibility of the proposed innovative passenger distribution system using an integrative approach. From the scientific point of view, the integrative approach involving the evaluation of carriage capacity following ergonomics aspect of personal space combined with the assessment of the proposed system using discrete-event simulation adds value to the body of knowledge by addressing passenger comfort, which is little explored in literature of public transportation. This study enhances passenger experience by ensuring a sense of safety, comfort, and spaciousness, hence attracting more individuals to use the KRL commuter line. It appears that the maximum capacity of train carriage of 150 passengers strikes a balance between comfort and efficiency, addressing the challenges of overcrowding and enhancing the overall commuter experience.

Furthermore, the developed scenario of innovative passenger distribution system involving queuing system at platform entry along with the adoption of integrated sensors for real-time passenger counting and innovative automatic door-closing mechanism, given current passenger density and limited capacity of train carriage of 150 passengers, was examined through the discrete-event simulation model. The simulation results demonstrated that this passenger distribution system can be effectively applied, particularly in stations experiencing the highest levels of passenger density, offering a practical solution for managing crowded urban transportation. From a policy perspective, Indonesian Railways Company could adopt these findings by considering the integration of ergonomic principles and real-time passenger management systems to improve commuter comfort and system efficiency. The successful implementation of such systems could encourage more people to use the KRL and potentially reduce the reliance on private vehicles in Jakarta.

While the current work offers both scientific and practical contributions, its limitation is in the fact that the feasibility analysis being limited to the virtual experimental phase and its focus on the Cikarang line. Therefore, future studies could further examine the proposed passenger distribution system by conducting field tests to examine the real-world effectiveness of the proposed system and ensure its feasibility and adaptability across different transit systems with diverse operational and demographic characteristics. Additionally, the model could be enhanced by integrating Discrete-Event Simulation (DES) with Agent-Based Modelling and Simulation (ABMS) to accurately model the various passengers with respect to preference, enabling a more comprehensive understanding of passenger behaviour and dynamics in a unified simulation platform. This would provide deeper insights into improving public transportation systems, contributing to sustainable urban mobility while enhancing the overall commuting experience. Next, another potential limitation lies in the possibility of sensor malfunctions or inaccuracies in real-time data collection, which could affect the overall effectiveness of the system. Solving this challenge is important for the successful implementation of sensor-based monitoring systems. Lastly, while this study focused on ergonomics and simulation-based feasibility, future studies could use statistical tests to rigorously validate the 150-passenger limit and assess its broader impact relative to current capacity standards.

Data Availability Statement

The data that support the findings of this study are openly available in https://zenodo.org/records/14065418

Author Contributions

Hwi-Chie Ho: Conceptual framework; Methodology; Formal analysis; Validation; Writing-original draft; Review & editing; Supervision; Project administration. Venessa: Investigation; Data collection and management; Statistical analysis; Software application; Data visualization.
Bertha Maya Sopha: Reviewing and Editing

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