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Optimizing Urban Metro Operations: A Simulation-Based Short Turning Strategy to Alleviate Overcrowding in High-Demand Areas

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Urban Metro; Reducing Congestion; Simulation Model; Rotating Trains; Increase Efficiency.

Abstract

The urban metro system is a high-capacity public transport mode aiming at providing convenient and efficient services for passengers, which plays an essential role in commuting traffic, especially in megacities. The urban metro system generally has to deal with intractable heavy passenger loading during peak hours, which demands are huge in certain stations. However, overcrowding doesn't ubiquitously exist for all stations, and mitigation measures must be carried out on purpose, respectively. Because of the restrictions on operational costs and avoiding transportation resources, simply increasing dispatch frequency is not a rational solution to solve the problem. Therefore, these overcrowding sections are the investigative focus of this study to provide rational and efficient short-turning operating policies. Short turning patterns need to be coordinated with the present operation strategies. As the cumulative demand in the short-turning zone is larger, the short-turning strategy could relieve overcrowding within the zone. To reduce overcrowding in a high-traffic demand area. So, the main aim of this study is to use a simulation model to determine peak times and the most crowded stations, thus increasing the capacity in that area by rotating trains, to reduce the occupancy rate. The model implementation is demonstrated through a case study for the first line Cairo Metro in Egypt. Managers will be able to use this model to identify and remedy underperformance in the urban metro system, as well as to design regulations intended to increase efficiency in the urban metro system.

1. Introduction

Urban metro systems form an integral part of modern public transport systems, offering high-capacity and efficient mobility solutions, especially in New York's megacities, London, Tokyo, and Shanghai, where they contain high-density populations. Urban areas are constantly plagued by problems regarding rapid urbanization in population and increasing travel demand worldwide, with capacity limitations against service efficiency. Chinese cities have extended their metro networks to accommodate this demand, which has sometimes increased so rapidly that reasonable conceivable may not be sufficient to cover the transport needs of cities like Shanghai. Shanghai had over 600 kilometres of subway and light rail infrastructure by 2016; however, this network remained inadequate to meet the

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transport needs of its over 24 million residents (Sun and Guan, 2016). The ridership boom has resulted in heinous peak-hour congestion. The figures presented by the operating company Shentong Inc. of the Shanghai Metro show over 10 million daily riders for five consecutive weekdays from February 29 to March 4, 2016, with the peak day reaching 10.82 million riders (Jin, 2016). Over levels of congestion have meant inconvenience for users, poor service delivery, and higher socio-economic impacts in lower productivity and living standards.

In metro system operation, an important consideration is that there is a poor distribution of passenger loads along any given section of a line. While some sections are extremely overcrowded, others carry far less traffic. For instance, the traffic demand may build up during the morning peak hours; however, the congestion will typically be situated within a certain section, with other sections operating well below capacity (Feng et al., 2020). When metro operators try to combat overcrowding by increasing train frequency, some drawbacks surface, for instance; Operational costs will increase, as more rolling stocks entering service imply higher maintenance costs. Wastage occurs because resources are inefficiently allocated, whereby low-traffic sections see capacity being increased beyond demand. Another distinguishing feature of peak-hour passenger flows in metro systems is directional non-uniformity. Lines that interface from suburban areas to the city center, as is the case for Cairo Metro Line 1, and those that cross an inner core of the city, like Cairo Metro Line 3, are thus typically those experiencing opposite direction imbalances in passenger flow. As such, a mere frequency increase may not be the best way to control congestion. From the observation of tidal nature with spatial and temporal variations of commuter travel patterns, transportation authorities need to adaptively respond both operationally and on an organizational basis to demand patterns (Li et al., 2021a).

In metropolitan systems in cities, short turning has been an effective strategic measure for alleviating peak-hour congestion. Short turning involves strategically allocating part of the metro line on which additional train services will operate between a segment of stations rather than on the whole route. Short-turning strategies in rail and bus transit systems have also been highlighted by previous studies as useful in increasing transport capacity in areas with excess demand without resource wastage on low-demand segments (Louwerse et al., 2014). Short turning is superior to frequency increase overall in the frequency of trains because it maximizes service quality to jammed sections through better efficiency. Different short-turning strategies, i.e., zoning services, limited and semi-limited services, express operations, etc., have been studied in the literature (Sun et al., 2017). Short turning may be effectively executed with balanced passenger distribution and minimum waiting times via proper coordination with existing full-length operations (Canca Ortiz et al., 2016). In addition to these economic matters, such as fare optimization and the cost-effectiveness of the operators, economic factors are key elements in developing strong short-turning scheduling tools (Ulusoy and Chien, 2015). This research, with its focus being the optimization of short-turning techniques on urban metro rail, is a continuation of the earlier knowledge and is for application in the application of these techniques with Cairo Metro Line 1 in particular. The simulation research aims to identify peak hours for congestion, identify areas best suited for short turning, and assess the effectiveness of short turning in congestion alleviation. This study will help transport planners and policymakers improve their metro operations from a data point of view, suggesting service effectiveness, passenger satisfaction, and operational cost improvement.

The rest of the paper is structured as follows: Section 2 provides a literature review of metro systems' overcrowding and short-turning strategies. Section 3 discusses the formulation of the simulation model.

Section 4 gives an account of Cairo Metro Line 1 as a case study. Section 5 concludes the study and gives recommendations for further research and improvements in metro systems.

2. Literature Review

In most cases, urban metros serve as an efficient means of mass transport in very densely populated cities. Overcrowding, directional non-uniformity, and inefficient allocation of resources are some of the challenges that have hindered optimal performance. Many studies have proposed ways of improving metro operations, ranging from short-turning policies and scheduling optimization to demand-responsive transit management. This section thus reviews major literature regarding urban metro system problems and short-turning strategies with a basis for the present study.

2.1 Challenges of Urban Metro Systems

Excessive urbanization and large populations have joined hands in shaking the whole structure of the meteoric cities worldwide. The number of studies that reveal how many times such a metro network becomes unable to provide for peak hour demand is too many, although they have a tremendous amount of infrastructure available. Such networks may include the metro networks of New York, London, and Shanghai; in the case of Shanghai, these over 600 kilometers added to the network and yet continue to have passenger demand exceeding its current capabilities (Shanghai Municipal People's Government, 2017). Such overcrowding generally translates into poor comfort conditions for the passenger with increased travel times and a continued decrease in service reliability (Jin, 2016). A core issue with the metro operation, concerning throughput, is the distribution of passenger flow at sections within the network: a few segments become extremely congested during peak hours while others are underutilized. This imbalance, often referred to as directional non-uniformity, appears much along metro lines between suburban areas and city centers, as well as cross-city routes (Soltani, 2017).

According to several studies, increasing the frequency of train dispatch will not suffice because of high operation costs and waste of resources in low-demand areas (Canca Ortiz et al., 2016). Rapid urbanization has brought about a phenomenal increase in metro ridership, causing overcrowded trains and stations during peak hours. The most recent analysis attests that by 2050, more than two-thirds of the world's population shall reside in urban areas, thus piling more demand on already pressured metro infrastructures (Navigate Mobility, 2024). As a result, such a surge in population in cities will need proper strategies to regulate passengers and maintain quality of service. Overcrowding decreases the comfort of passengers from different places or, rather, causes safety and operational problems. According to a report by the Design Division (2024), customary issues like traffic congestion, public transport deficiency, and negative environmental impacts marked most obstacles impeding efficient urban transportation systems. These represent reasons why modern techniques are necessary to enhance the performance of metro systems.

2.2 Short Turning as a Strategy for Overcrowding Mitigation

Short turning refers to an operational strategy whereby trains that would otherwise run the entire length of the route terminate early at a station along the route and return. This presents a mechanism for efficiently concentrating extra capacity where demand is highest. A wealth of prior research regarding short turning in metro systems has focused on how its effects relate to minimizing transport costs. Sun et al. (2015) argue that short-turning operations will optimize schedule performance by reducing passenger wait times in high-demand stations without requiring capital costs to purchase many more trains. Similarly, short turning incorporates high and low service levels to balance passenger distribution and improve service reliability in separately researched bus rapid transit (BRT) and railway systems (Sun et al., 2017). As well as zoning considerations, restrictions, and express services, short turning has been studied for trains operating only in designated high-demand corridors instead of across the entire network (Sun et al., 2017).

This way, short turning affords targeted service improvement, thus relieving congestion at key transfer nodes whilst not compromising system efficiency. Further noted by Canca Ortiz et al. (2016), timetable coordination is vital for short-turning systems; that way, different service patterns will interact when they're supposed to and mitigate passenger waiting times and disruptions. The European Transport Research Review published a study in 2018 that implemented a short-turn pattern of an urban metro system, mathematically determining the optimal parameters of a short-turning operation. The short-turning model used a load factor as a measure of overcrowding, proving its effective application to a case study carried out on Shanghai Metro Line 2 to relieve congestion in high-traffic zones. Louwerse and Huisman (2014) conducted further research that developed flexible semi-periodic timetabling based on short turning. This allows the reversal of trains before reaching terminal stations in schedules that are periodic for short-turning services with flexibility for full-length services. This improves frequency and minimizes wait times for passengers in congested areas. Canca Ortiz et al. (2016) also conducted a study on vehicle scheduling with the short turning of urban public transport to reduce passenger waiting times and operational costs. The research underscored how short-turning operations would benefit by being coordinated with existing schedules to ensure the overall good performance of the system.

2.3 Optimization of Short Turning Strategies

There are many parameters affecting the success of short-turning, and these include demand forecasting, schedule coordination, and operational restrictions. Many research studies that have developed simulation models have attempted to identify short-turning zones that are optimal and determine their impact on the performance of the metro system. For example, Louwerse et al. (2014) developed a scheduling model integrating short turns into full-length services, thus significantly reducing some passenger congestion and travel time. This idea is also present for data-driven decision-making in short-turning by Sun et al. (2015), emphasizing real-time passenger flow analysis for the most operational gain. Another consideration is the cost-effectiveness of short turns; that is, their diminishment in importance versus scheduling optimization. Sun et al. (2015) found that short turns could reduce passenger delays and enhance service reliability, but the application should be counterweighted with fare policies and operators' costs. The study argues that metro agencies should adapt schedule types flexibly to respond to the variations in peak-hour demand as a cost-minimizing approach (Canca Ortiz et al., 2016).

Short-turning plans should be formulated given other variable infrastructure capacity factors, patterns of passenger demand, and constraints in operation. Li, et al. (2021b) presented an optimization model that is robust for short-turning operation train timetable planning with stochastic terms added to the passenger demand as well as the train selections. The whole idea behind this model is to minimize total passenger waiting time at stops by co-optimizing timetable adjustment, rolling stock deployment, and short-running operations. Zhang et al. (2022) did, however, study the potential of performing short turning in combination with other operating schemes, including bus bridging in case of metro service disruptions. A synchronized plan was adopted that would optimize bus brigading schedules and metro short turns by responding to city metro disruptions and tracking lower passenger delays in such situations. These studies illuminate the possible capability that short-turning strategies possess in optimizing metro efficiency and passenger satisfaction. Alternatively, a highly complex comprehension of the system-specific dynamics in the operation and constant monitoring for changing patterns in demand will be required for effective implementation.

2.4 Research Gaps and Contributions of the Current Study

There are many more research studies on the topic of short-turning; however, very few have looked at the application of short turning in developing metro networks such as Cairo Metro. Impact studies on short turns are predominantly focused on long-standing metro systems, leaving an alternative realm unexplored on whether short turning can be beneficial to rapidly developing and directionally unbalanced transit networks. The other side of the coin of previous studies investigates short turning in rail systems and bus rapid transit, but only a handful of simulation-based endeavors have considered the ramifications on an urban metro system. This study will fill these gaps by simulating Cairo Metro Line 1 to improve short-turn operations. In this study, areas of peak congestion will be identified, and the effectiveness of short-turn strategies will be evaluated. The purpose is thus to give data-driven decision-making support to metro administrators for improving service efficiency. The results from this study will further engage the discussion on metro operations management by providing a case study on the short turn in a rapidly growing urban transit system.

3. Simulation Model Formulation

This section presents the formulation of the simulation model through which the impact of short-turning strategies is analyzed concerning the performance of metro systems. The need for deriving the model arises in response to addressing crucial operating concerns in the optimization of the short-timing point determination regarding demand variability, schedule coordination, and resource constraints (Varga, 2001). The scheme and methodology of the model are elaborated on in the following steps:

- **Step 1** - Objective: The simulation is trying to find optimal places where short-truing can be done and then analyze the changes in the system. The passenger wait times are also considered in the process, and the overall service reliability is evaluated by considering the operational parameters that set limits on delays and resource utilization.
- **Step 2** - Input Parameters: The model needs to know the following inputs to work: historical and current data on passenger demand; train schedules and headway; operational constraints (fleet size, track capacity, crew availability); and geographic parameters that serve to define possible short-turning locations.
- **Step 3** - Demand Forecasting: The model has a demand forecasting module, which is a part of the model that is responsible for the prediction of passenger flow patterns at stations over time using the data both from the past and from the current data that comes from the simulated demand scenarios; thus, it might lead to the adaptive response.
- **Step 4** - Short Turning Zone Identification: Optimization algorithms locate short-turning zones by the passenger load distribution, station proximity, and operational feasibility, as well as evaluate the zones' potential for congestion mitigation and service efficiency by balancing the metro system operation.

- **Step 5** - Performance Metrics: Key performance indicators have been designed to help in the estimation of the success of short-turn operations. Such indicators as average passenger waiting time, train occupancy, service frequency, operational reliability, and savings were considered for short-turn operations.
- **Step 6** - Simulation Framework: Simulation Framework: It is based on a discrete-event simulation model, where events represent real-life situations of a metro system and a comparative analysis of different short-turn scenarios is possible. Moreover, it involves an assessment of the trade-offs between different strategies.
- **Step 7** - Validation and Calibration: This was in agreement with the real data of the existing metro system to ensure accuracy and reliability. Calibration had the potential to adjust the model parameters to get similar outcomes of the simulation to the observed operational performance.
- **Step 8** - Scenario Analysis: Such a contrast utilizing possible deployment of short-turn operations in various operating conditions shows the best way to act in these scenarios. Comparing short-turning scenarios is carried out with peak versus off-peak demand patterns, with random disturbances included, and at different levels of demand.

3.1 Model Flowchart

The following flowchart describes the procedure behind simulation modelling, as shown in Figure 1. It starts with problem identification and then builds models from real data. Random numbers are generated and distributed to represent variability, followed by running the simulations and analyzing the outputs. Validation checks if the model reflects the actual process or not; if it does not, it will return for fine-tuning. After validation, assumptions are made, results are documented, and recommendations are made. This loop is a guarantee to improve the model until correct and actionable insights are achieved.

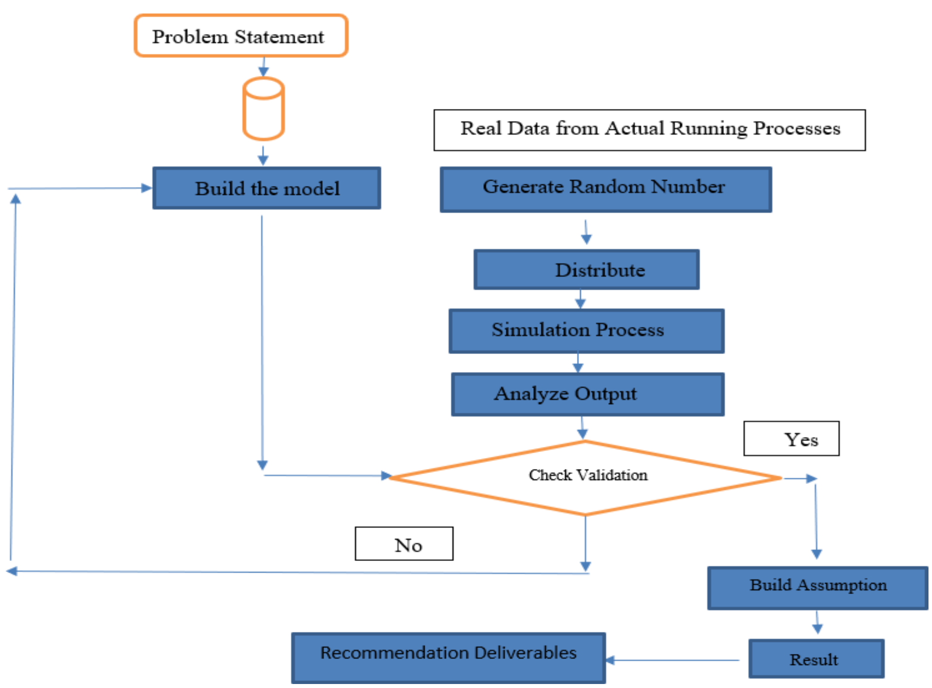

Figure 1. Simulation Model Flowchart

3.2 Model Assumptions

There are some assumptions that we must consider before building the model, and they are as follows:

1. For both full-length and short-turning services, all trains have to stop at every station in between and operate at the same speed with a fixed headway.
2. No turnaround constraints exist along a line since turnaround facilities can be built without any particular difficulties, although only a subset of stations containing short-turning facilities may be established.
3. All passengers waiting on the platforms take the recent arrival train and can board.
4. The type of real data obtained from the metro archive about passenger entry and exit for all Cairo Metro Line 1 stations distribution is normal.
5. The number of entries is divided equally in both directions.

4. Case Study

Cairo Metro Line 1 is the oldest and the longest, with the role of transport day more than all the other metro lines in Egypt and Africa. With the estimated number of passengers riding the metro, it has become one of the major commutes in the country. Way back in 1987, the first subway line in the Middle Eastern area (Cairo) was made as the result of the increased need for the urban population to be mobile efficiently. The route is designed between the northern and southern suburbs of the city, and it is approximately 44 kilometers long in total, running from the nearest terminus in El Marg to the southern end in Helwan with 35 stations, which are designed for different commuters, for example, workers, students, and tourists. The line stations are a combination of above-ground and underground systems, such that they contain 17 above-ground stations and 18 underground stations. Some stations are considered multi-level stations, such as Hospital El-Matar, El-Malek El-Saleh, and Sphinx.

In line 1, there are 35 stations, including 17 aboveground and 18 underground, through which various groups of people are served, including workers, students, and tourists. Because Cairo is one of the world's most densely populated cities with a metropolitan population of more than 20 million, the need for public transport, Line 1, has already become a major public transportation service that is experimental on this. Line 1, to be precise, is quite significant, as it is the line that connects the biggest residential pockets with the industrial areas. Therefore, it makes it one of the busiest metro lines with daily traffic of around 2 million passengers. However, the figure can be translated to some problems such as overcrowding, delays, and insufficient infrastructure. A lot of the forces are coming up from time to time, and they are not evenly distributed in the line. Most of the sections, which connect residential settlements to the city center, are overcrowded both in the morning and evening peak hours, while the majority of the sections are untapped during the said periods. Increasing the train frequency is additionally expensive for transportation companies, and constructors have to fix these issues. Potential resolutions such as the introduction of short-turning operations, in which some trains will only travel on the busiest parts, are also in the plan for improving service efficiency.

For our case study, we gathered data on how passengers entered and exited various Cairo Metro Line 1 stations for a specified number of months; daily traffic reports recorded every 10 minutes went into the archives of the metro. The metro runs in two directions at its stations: trains go to their destinations and come back. Different stations have different demand patterns. It can be seen from Figure 2 that the difference in average daily counts observed every 10 min from 01/10/2024 to 31/10/2024 between Station 50 and Station 27 is far more than the average counts for other stations during morning peak hours (07:40–10:30). Thus, the congestion created interferes with the travel experience, making such sections of interest from the focus of this study and therefore contributes towards developing rational and effective short-term operating policies. The great challenge is to determine the most favorable short-turn zone and synchronize schedules since short-turning patterns must integrate with existing operating plans. Although short-turning patterns will have to work on some additional trains and higher frequency, which usually are public costs, this budget restriction was removed for the sake of safety for passengers.

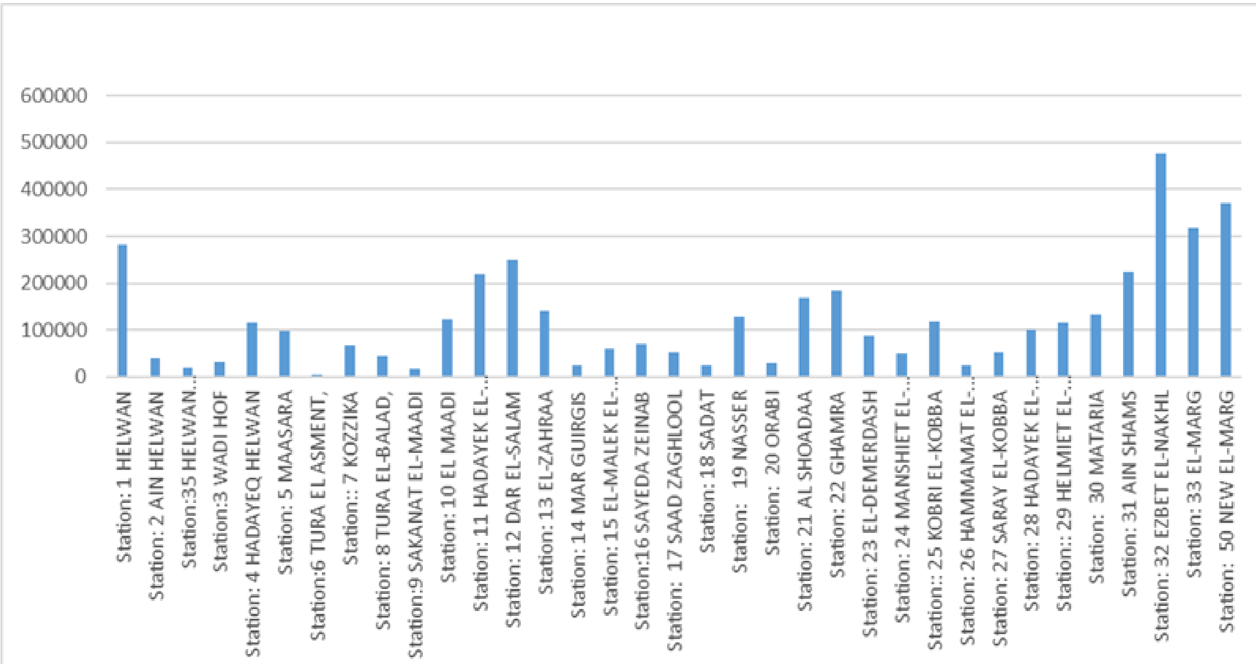

Figure 2. No. of Passengers During Peak Hours from 07:30 to 08:30

Before building the model, several points must be taken into consideration: For both full-length and short-turning services, all trains stop at every station, operate at a consistent speed, and maintain a fixed headway. There are no turnaround constraints along the line, as turnaround facilities can be constructed without significant challenges, though only certain stations may include short-turning facilities. All passengers were waiting on the platforms to board the most recently arrived train. The passenger entry and exit data obtained from the metro archive for all Cairo Metro Line 1 stations follows a normal distribution, with the number of entries evenly divided between both directions.

After that, we analyzed the data collected; we determined the peak times. Peak times were defined as periods with at least 2000 passengers at a given time slot or station, as shown in Figure 3. There are two peak times, from 06:50:00 AM to 10:10:00 AM and from 12:00:00 PM to 06:50:00 PM. At the time of the first peak, we determine which stations have the highest number of entries, as shown in Figure 4. The stations with the most entries are 7 stations (Station 1: Helwan, Station 11: Hadayek El-Maadi, Station 12: Dar El-Salam, Station 31: Ain Shams, Station 32: Ezbet El-Nakhl, Station 33: El-Marg, and Station 50: New El-Marg).

The simulation model builds along lines that would make the output match real-world data as accurately as possible. Only then can the accuracy in the simulation of this constructed model be validated and proven as believable. The methods involved historical data analysis to find out the significant patterns and use them to configure the simulation as shown in the following steps:

- **Step 1 -** Real-World Data Analysis (October): The first step of the process was to analyze actual data collected throughout October. The data undoubtedly included the bidirectional movement of entries at each station over the period of concern. Furthermore, examining such historical data makes possible the identification of actual peak hours of traffic and most congested spots (stations or sections of the line) at those hours. This serves as the benchmark for comparison with the simulation.
- **Step 2 -** Generation of simulation data and peak determination: Once these were established, the model was put into operation to forecast, as per its internal logic and parameters, the flow of passengers in terms of the peak time and crowded locations. The specifics of this internal logic (how passenger arrivals are, for example, modeled, how trains move, etc.) are not particularly fleshed out, but it was supposed to generate dynamics like those of the metro system. Here, what is key is the fact that the simulation has independently recognized its peak periods and congestion hotspots.
- **Step 3 -** Comparison and Validation: The most important step was to compare the peak hours and the most congested areas concerning the real-world October data against those identified by the simulation. Finding the two feigned similarities formed good evidence for establishing the veracity of the model. This congruence means that the underlying assumptions and logic of the simulation circumscribe the real-world patterns of passenger flow and congestion quite closely.

4.1 Building the Model by using Excel

A simple Excel approach for initial data analysis and peak identification was most likely thus given to have informed the simulations that were tried afterward in great detail. The overall assumption is that an Excel approach would be employed as follows:

- **Step 1 -** Averaging Data: Passenger data from three months at each station were collected (likely entries or total passenger counts). Data was processed in that for every time segment in the three consecutive months—August, September, and October 2024—between working hours of 5:15 A.M. and 01:30 A.M. for each station. We calculated their mean and standard deviation values for the entries and exits of passengers to obtain a model that would be able to predict daily traffic patterns for any given month in advance. The averages were calculated to smooth out daily variations and identify underlying trends.
- **Step 2 -** Visualizing Trends: The trend of the average data was plotted on line graphs in Excel. A plot was made for each station as a function of time on the x-axis versus the average number of passengers on the y-axis.
- **Step 3 -** Identifying Peak Times from Graphs: On looking at them visually, peak periods were identified through which a significant number of passengers were above average. This visual analysis thus gave two peaks.
- **Step 4 -** Validation Model: Validation of this model was performed by comparing the simulation output with real data for a different testing month. The model forecasted the same peak time slots and the top stations for passenger entries that were revealed by the actual data analysis. The consistency of this validates that the simulation model has successfully captured the underlying trends in passenger demand and is therefore reliable and valid for future prediction and scenario analysis.

- **Step 5 -** In the Focus of the First Peak: The study then proceeded to analyze the first-time window that was identified with a peak.
- **Step 6 -** Congestion Stations During the First Peak: The average number of passengers per station during this first peak time window was scrutinized. The stations with the highest average number of passengers during this peak were termed the most congested stations.

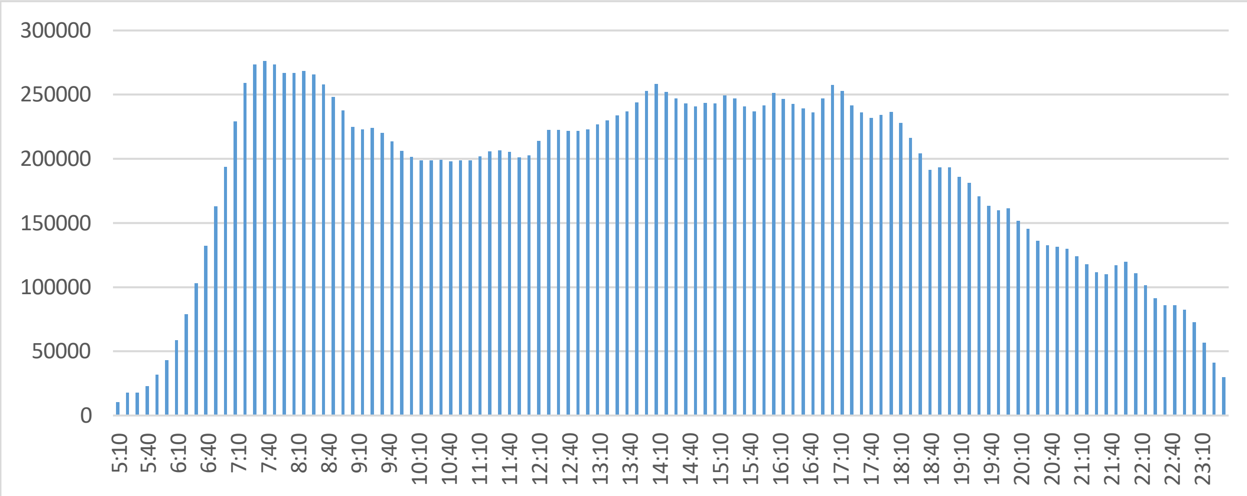

Figure 3. Peak time of demand

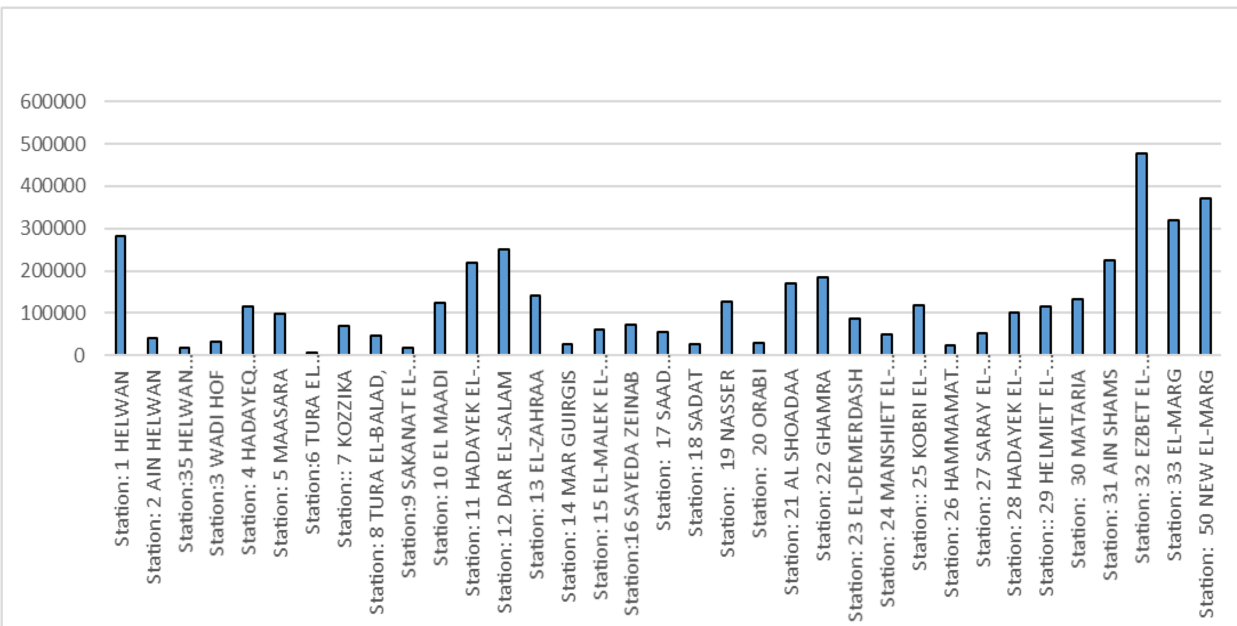

Figure 4. The station's demand in the first peak time

In order to reduce the occupancy index of Cairo Metro Line 1 stations, a simulation of passenger entry and exit data was run for a duration of one month. Hence, the occupancy index, meaning the utilization of available capacity, was calculated for each station during operating hours, with special emphasis on the peak time of 7:40 AM to 10:30 AM. The following steps were taken in the calculations:

- **Step 1** - Passenger Count: Counting passengers in the system at each given stop during the peak hour.

- **Step 2** - Train Determination: The number of trains in service for each station was determined at the peak times as per the operating schedule of the metro.
- **Step 3** - Capacity Calculation: Calculation of a station's capacity based on the number of trains available.
- **Step 4** - Occupancy Rate Calculation: Counting the number of passengers at each station and dividing by the total calculated capacity, the rate of occupancy was derived.

4.2 Phase 1: Current Train Timetable Model

To calculate system occupancy and identify congestion zones, we assumed an equal distribution of passenger entries and exits in both directions. During the morning peak period (7:40 AM to 10:30 AM), we analyzed the relationship between occupancy rate and station location to pinpoint areas of congestion. This analysis, depicted in Figure 5, revealed two distinct congestion zones: one spanning from Helwan to Tura El-Balad and another from New El-Marg to Saray El-Kobba.

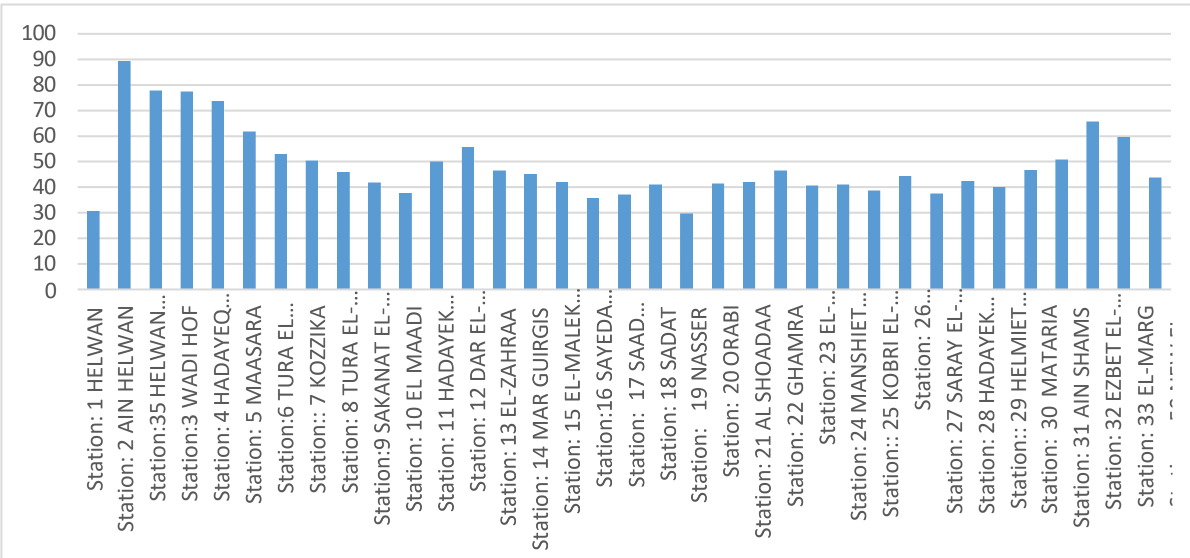

Figure 5. Occupancy Rate at First Peak Time

4.3 Phase 2: Modifying Train Timetable Model

There are thirteen stations, terminal stations included, and they possess turnaround train facilities as depicted in Table 1. Out of these, nine provide a third platform for the convenience of passengers alighting from trains during turnaround movement: Helwan, Maasara, Tura El-Balad, Dar El-Salam, Sayeda Zeinab, Saray El-Kobba, Mataria, New El-Marg, and El-Marg. As seen in Figure 5, the congestion problem was found to be confined to two main segments: Helwan to Tura El-Balad and New El-Marg to Saray El-Kobba. A short-turning policy has been introduced to address congestion in these two aforementioned sections. Train rotation from Tura El-Balad to Helwan occurs every 10 minutes for the first region and from Saray El-Kobba to New El-Marg in the second region. Sample results after incorporating this modification in the simulation model, which effectively increases capacity in the chosen congested areas, have observed reduced occupancy levels, which the co-author strongly affirms with his evidence as shown in Figure 6. This will be undisputed evidence that well-targeted short-turning operations can work wonders in overcoming congestion during peak periods as well as ensuring good system efficiency overall.

Table 1. Cairo metro Line – 1 Rotating Station

Station Number	Station Name	Station Number	Station Name	Station Number	Station Name
4	Hadayeq Helwan	12	Dar El-Salam	23	El-Demerdash
5	Maasara	16	Sayeda Zeinab	27	Saray El-Kobba
6	Tura El Asment	18	Sadat	30	Mataria
7	Kozzika	21	Al Shoadaa		
8	Tura El-Balad	22	Ghamra		

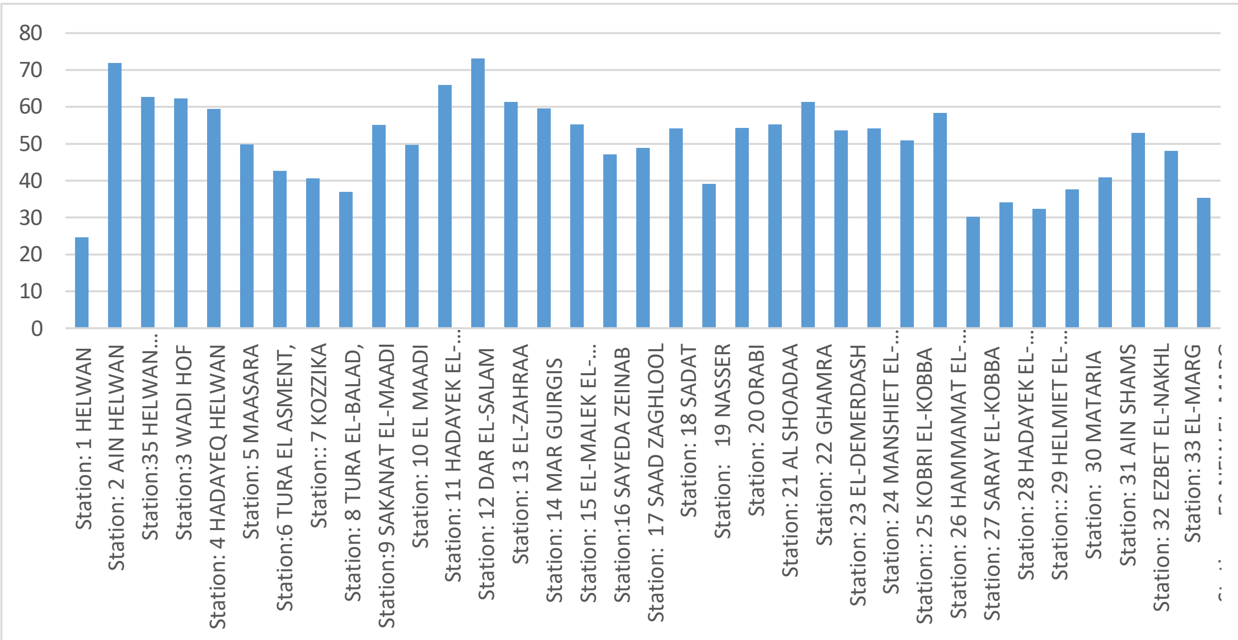

Figure 6. The Occupation Rate after Modification

5. Model Validation

Number crunching by a strict statistical approach, the simulation model was validated for its capacity to reduce congestion by short-turning interventions. To be precise, a paired sample t-test was used to ascertain whether a statistically significant difference in occupancy levels existed before and after a short-turn intervention was implemented in areas of identified congestion. This method was useful for comparing similar observations and was therefore used to examine the occupancy effect generated by the short-turn intervention. Now, contrasting the pre- and post-strategy mean occupancy levels of similar stations, a paired t-test provided a numerical estimate of the precision with which the model reproduced the actual effects of the alterations in operations.

Thus, the validation process encapsulated belief in the accuracy and trustworthiness of the simulation to anticipate the enhancement in metro system performance achieved through short turning tactics. As depicted in Table 2, the occupancy ratio in stations pre- and post-reform in the two zones is exposed. The 1st zone is Helwan and Tura El-Balad, and the 2nd zone is New El-Marg and Saray El-Kobba. Therefore, we can write the hypothesis test as:

H_0: There is no significant difference between the mean occupancy rate in stations before and after a short-turn intervention was implemented in areas of identified congestion.
H_1: There is a significant difference between the mean occupancy rate in stations before and after a short-turn intervention was implemented in areas of identified congestion.

Table 2. Occupancy Rate in Station After and Before Modification

Stations	Oc., Ratio Before	Oc., Ratio After	Stations	Oc., Ratio Before	Oc., Ratio After
Station - 1 Helwan	30.53	24.60	Station - 27 Saray El-Kobba	37.42	30.16
Station - 2 Ain Helwan	89.24	71.92	Station - 28 Hadayek El-Zeitoun	42.33	34.12
Station - 35 Helwan University	77.79	62.70	Station - 29 Helmiet El-Zeitoun	40.05	32.28
Station - 3 Wadi Hof	77.29	62.29	Station - 30 Mataria	46.67	37.61
Station - 4 Hadayeq Helwan	73.69	59.39	Station - 31 Ain Shams	50.70	40.84
Station - 5 Maasara	61.75	49.77	Station - 32 Ezbet El-Nakhl	65.56	52.84
Station - 6 Tura El Asment	52.90	42.63	Station - 33 El-Marg	59.61	48.05
Station - 7 Kozzika	50.28	40.52	Station - 50 New El-Marg	43.77	35.28
Station - 8 Tura El-Balad	45.77	36.89			

As shown in Table 3, the results of the paired t-test showed that the p-value is less than 1%. And that provides sufficient evidence to reject the null hypothesis in favor of the alternative hypothesis.

Table 3. Results of T-Test: Paired Two Sample for Means

Statistic	Oc., Ratio Before	Oc., Ratio After
Mean	55.60647412	44.8171524
Variance	270.5215393	175.7275136
Observations	17	17
Pearson Correlation	1	
Hypothesized Mean Difference	0	
df	16	
t Stat	13.93955449	
P(T<=t) one-tail	0.0000000001141156	
t Critical one-tail	1.745883676	
P(T<=t) two-tail	0.0000000002282311	
t Critical two-tail	2.119905299	

6. Conclusion

This research successfully developed and validated a simulation model that proved both authenticated and calibrated to the study on the metro system, whereby short-turning strategies were introduced specifically on the line one route in Cairo. The model was built by bringing together utilization fields, demand projections, and optimization methods, which were employed to distinguish short turns from other locations and measure their effect on passenger patronage. The study came up with the conclusion that with an engagement in the use of short turning in the congestion zones, such as Helwan-Tura El-Balad and New El-Marg-Saray El-Kobba, the occupancy rates plunged a lot, which was supported by the paired sample t-test.

The findings of the research imply short-turning interventions' effectiveness in addressing the peak-hour congestion, but the resulting enhancement of the system as a whole. The model as such presents metro operators with a very useful tool for optimizing strategies for operations, a way of improving service reliability, and an instrument for refining passengers' experiences. Although the research gives a good basis for understanding and implementing short-turning strategies, some additional areas of future research would be to the next level and thereby improve the model's performance and usage: A simulation model of this kind could be expanded to other metro lines while the impact on one train line operation of short-turning through different types of interline transfers and network congestion will be addressed. A formal sensitivity analysis can be conducted to reveal the conditions of uncertainty that the model operates under by testing the response to various inputs and identifying the parameters that are the leading causes of uncertainty.

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