Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (45) No. (2) October. 2023

A Proposal to Estimate an Appropriate Metro Headway Through Weekly Passengers' Flow Data

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الملخص العربي:

مترو أنفاق القاهرة الكبرى هو أول خط مترو في الوطن العربي وقارة أفريقيا ويعتبر واحدا من أهم وسائل النقل في المدينة، فهو يوفر وسيلة سريعة وفعالة للتنقل لملايين الركاب يوميا. ومع ذلك، يظهر جدول التشغيل الحالي أحيانا عدم توافقه مع تقلبات الركاب، مما يؤدي إلى الاكتظاظ والتأخير. بالإضافة إلى ذلك، لا يتوزع الركاب بشكل متساو على طول الرصيف أو داخل عربات المترو، مما يمكن أن يثير مخاوف السلامة. يهدف هذا البحث إلى تقدير فترة زمنية مناسبة لتقاطر المترو من خلال بيانات تدفق الركاب الأسبوعية التي تم الحصول عليها من آلة البطاقات التلقائية. في هذا البحث، قمنا بطرح وسيلة مبتكرة لإنشاء مصفوفة الأصل والوجهة لشبكة المترو، والتي من خلالها تمكننا من معرفة كثافة الركاب في الحالات التالية (على الرصيف، عند الأبواب، داخل عربات قطار المترو).
وبالتالي تمكننا التأكد من تحقيق الشروط الآتية:
- كثافة الركاب على الرصيف لا تزيد عن 2 راكب / المتر الطولي.
- زمن التوقف لا يزيد عن 30 ثانيه.
- كثافة الركاب داخل عربات قطار المترو لا تزيد عن 7 راكب/المتر المربع ولا تقل عن 3 راكب / المتر المربع .
ومن خلال تحقيق الاشتراطات السابقة تمكننا من الحصول على فترة زمنية مناسبة لتقاطر المترو تتناسب مع الطلب المستمر والمتزايد من الركاب.

الكلمات المفتاحية:
زمن تقاطر المترو، آلة التذاكر الأوتوماتيكية، بيانات الركاب الأسبوعية، عدد الركاب في كل رحلة، طريقة نموذج الجاذبية، مصفوفة الركاب [O-D]، كثافة الركاب على (الرصيف، أمام أبواب المترو، وداخل عربات المترو).

Abstract:

The Greater Cairo Underground Metro is one of the most important modes of transportation in the city, providing a fast and efficient means of travel for millions of passengers every day. However, the current schedule doesn't always comply with the passengers' fluctuations, leading to overcrowding and delays. In addition, passengers are not uniformly distributed along the platform or into the metro cars, which can lead to safety concerns. To address these issues, this research paper aims to estimate a suitable metro headway through the weekly passengers' flow data which obtained from the automatic ticket machine. In this research we proposed an innovative way to create an origin destination [OD] matrix for the metro network, through which it is possible to obtain an appropriate metro headway commensurate with the continuous and increasing demand for passengers.

Keywords:

Metro Headway, Automatic Ticket Machine, Weekly Passengers, passengers per trip, Gravity Model Method, [O- D] passenger matrix, Passenger density on (the platform, within the metro doors, and inside the metro cars).

Introduction:

Due to its multiple advantages, the Underground Metro is considered one of the most attractive means of transportation for passengers, therefore, it has a huge crowdedness specially at peak hours, for that it requires a lot of research and studies namely in large heavily populated cities. From this point of view, it's important to investigate the Optimal Operation of Greater Cairo Underground Metro (GCUM) taking into consideration safety and economy.

The research is driven by four key questions:

1. Estimating a suitable headway: Using detailed passenger flow data, we aim to establish a dynamic headway system that adapts to fluctuations in ridership throughout the week and across different times of day, ensuring efficient service while minimizing wait times.
2. Adapting to rising passenger numbers: The current schedule often falls short of accommodating the rapid surge in ridership. We explore solutions for optimizing existing infrastructure and scheduling to keep pace with this ongoing growth.
3. Prioritizing passenger safety: In crowded stations and trains, safety concerns become paramount. This research investigates measures to enhance passenger security and minimize risks associated with increased traffic.
4. Balancing economics and passenger needs: Achieving a financially sustainable Metro operation is crucial. We analyze how headway adjustments can contribute to economic feasibility while still prioritizing passenger comfort and safety.

Our hypotheses provide the foundation for our investigation:

-The proportionality of headway to passenger numbers suggests a dynamic approach to scheduling based on real-time demand.

-The gravity model helps us understand passenger distribution patterns across stations, informing platform design and resource allocation.

-Variations in platform and train car densities highlight the need for targeted solutions to optimize passenger flow and minimize congestion.

-Passenger behavior has a significant impact on operational efficiency. We assess strategies for mitigating behavioral delays and ensuring smooth platform and train movement.

Cairo is the most extensive city in both Africa and the Middle East, has been the capital of Egypt for more than a millennium. It stands as a crucial political and cultural focal point within the region [1] , which suffers from unplanned growth due to the high rate of both birth [2] and internal immigration [3],[4]. The present Greater Cairo metro network (GCUM) consists of three lines with a total length of about 96 km [5]. It is considered as the rapid transit system in Greater Cairo, Egypt [6]. It was the first of two full-fledged metro systems in Africa and four in the Arab world [7] .

This research paper is structured as follows: the second section is the literature review, we focused on previous studies, where we presented some local and international studies that closely related. In the third section, we reviewed the methodology and the case study, which is the peak hour scenario. This section was divided into three subsections: data collection, solution model, and finally analysis & results. Following that the fourth section was dedicated to extracting the conclusions.

Literature Review:

Eldeeb et al., 2018 [8] proposes a study on optimal metro operation that deals with optimizing optimal operation interaction for GCUM 1st and 2nd lines by proposing a methodology based on a field survey of travel time, actual headway, passenger waiting time, alighting, and boarding passengers. There are some shortages for the field survey as the data are collected during only one trip by counting the passengers who boarded or alighted from only one door for only one car, Accordingly, these records cannot be precisely utilized as a method to analyze the metro operation.

Another study reports by Eldeeb et al., 2019 [9] the results based on only one-day records. This can't be considered as a general case to be applied as they could cause misconceptions as regards the variations from day to another. Hence, it becomes crucial to consider the outputs of the Automatic Ticket Machine, capturing weekly, and daily passenger traffic from entry to exit at all stations. These accurate results will provide indispensable data for conducting an in-depth analysis of the phenomena and drawing appropriate conclusions regarding the optimal headway and important predictive recommendations.

For international studies: Wang et al., 2017 [10] This research investigates the use of metro smart card data to model the location choice of after-work activities for metro commuters in Shanghai. The study develops a gravity model based on smart card data and analyzes the influence of travel time, travel cost, and station characteristics on after-work activity location choices. Smart card data was collected from the Shanghai Metro, including passenger tap-in and tap-out timestamps, station information, and travel times. The data was preprocessed to clean and prepare it for further analysis. This included handling missing values, removing outliers, and correcting inconsistencies. A gravity model was developed to estimate the probability of an individual choosing a specific location for their after-work activity based on travel time, travel cost, and station characteristics. The gravity model was estimated using preprocessed smart card data, allowing for the quantification of the impact of each factor on location choice. The model's predictive accuracy was evaluated using a holdout sample of the data, demonstrating its effectiveness in replicating actual location choice patterns. The study concluded that: Smart card data can be effectively utilized to model the location choice of after-work activities for metro commuters. Travel time, travel cost, and station characteristics play significant roles in influencing location choices. The findings contribute to a better understanding of commuter behavior and provide valuable insights for urban planning and transportation system optimization.

Ekowicaksono et al., 2016 [11] uses the gravity model to estimate the number of trips between different zones in the city. The research concludes that the gravity model can be used to estimate the O-D matrix with reasonable accuracy, and it can be used to improve the transportation planning and management in the city.

Fang et al., 2019 [12] analyses the distribution of the passengers on the platform according to the boarding passengers’ choice. The author develops a model, taking into consideration the origin-destination of the passengers, their waiting time and the station platform layouts where the passengers’ boarding and alighting. The author calibrates the model by using the passengers’ weight for the London Underground Hammersmith-City (H&C) line , an airbag-based suspension system uses to obtain an accurate weight of the train, which is called load-weigh to calculate the number of passengers on each car of the train on the H&C line the load-weigh Divides by the standard average of passengers’ weight, which mentions in the Health Survey for England 2015. This study proposes two strategies. The first strategy is called the origin-based choice which demonstrates the behavior of boarding passengers who prefer the minimum platform walking distance where they board at the station, as well as a less congested area to stand. While the second one called the destination-based choice which demonstrates the behavior of alighting passengers who prefer the minimum walking distance of the interchange pathways where they alight, or platform exits at the station. The author recommended designing more than an entrance for the platform to ensure uniformly passenger distribution. The developed model presents good interpretation in predicting the distribution of passengers on the platform. This method estimates the number of passengers by weighing each train car, then dividing it by the average weight of the passenger. It’s considered more accurate than the smart card data method for several reasons, including that it gives us the number of passengers in each car, thus we can determine where passengers are crowded on the platform and in any car accurately. While the smart card data method estimates the number of passengers in all the train cars, which is assumed to be a similar distribution of passengers on the platform and in each train car, which is difficult to achieve in reality because we cannot control passengers' behavior and choices.

Lam et al., 1999 [13] divided the platform into six blocks, and noticed that the most congested block was the second-closest one to the entrance. studied the stopping time,

considering it a pivotal parameter for evaluating system performance, service reliability, and quality. The research attributed the main reason for the variations in dwell time to the boarding and alighting passengers.
Puong 2000 [14] The data collection process involved measuring stopping time, tracking passenger movements through entrances and exits, and assessing congestion levels from the platform, particularly focusing on the most crowded train cars. To gather the required data, four individuals were enlisted, each responsible for specific tasks, such as counting passenger movements through turnstiles. Notably, to enhance accuracy, it's advisable to conduct passenger counts at a car level rather than at the entrance/exit level, whenever sufficient labor resources are available. A mathematical model had been developed. It also highlights the influence of on-board congestion on boarding times for the non-Park Street Stations of the MBTA Red Line. The study's findings emphasize the consequential impact of dwell time's sensitivity to ridership variations, signifying the potential for inconsistent headways and running times, which could compromise service quality and capacity. The model introduced in this study establishes a fundamental framework for identifying critical stations necessary for supporting high-frequency service during peak hours.

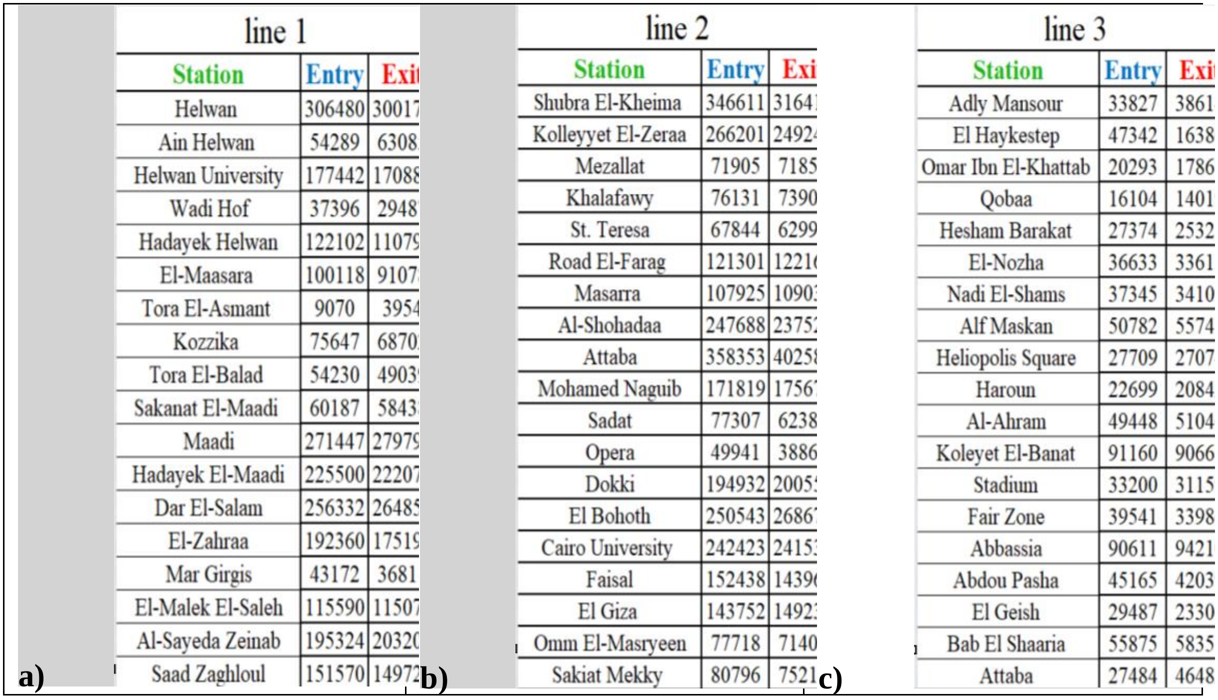
Seriani et al., 2016 [15] This study introduces a groundbreaking framework for evaluating passenger interactions at platform-train interfaces (PTIs), with the primary objective of understanding and quantifying the influence of various factors on passenger flow, safety, and comfort. The author employes a multifaceted approach to gather data on passenger movement patterns, interactions, and behavior. This includes video surveillance, passenger surveys, and sensor data. Mathematical models are then developed to represent passenger flow, safety hazards, and comfort indicators. The data collection and mathematical modeling components are seamlessly integrated into a comprehensive framework for evaluating PTI performance. Scenario analysis is conducted to systematically assess the impact of different factors, such as train scheduling, platform layout, and passenger demand, on PTI performance. The study Concluded that: The proposed framework presents a holistic approach to evaluating passenger interactions at PTIs. Its application holds immense potential for optimizing station designs, improving train scheduling, and enhancing passenger experience across various rail systems.

Luangboriboon et al., 2021 [16] This research undertakes an examination of how the density inside a train carriage influences the passenger boarding rate, offering valuable insights for optimizing boarding strategies and minimizing congestion. The research effectively illustrates a non-linear relationship between density and boarding rate, pinpointing an optimal density range for maximizing boarding efficiency. These findings offer valuable insights for refining boarding strategies, managing passenger flow effectively, and mitigating congestion in metro systems. This research contributes to the enhancement of metro system operations, fostering a more efficient and seamless travel experience for passengers.

Methodology & case study:

a- Data collections:

Table (1) Total Passenger Fluctuations during a week (From 1/3/2021 to 7/3/2021)



line 1

Station	Entry	Exit
Helwan	306480	30017
Ain Helwan	54289	6308
Helwan University	177442	17088
Wadi Hof	37396	2948
Hadayek Helwan	122102	11079
El-Maasara	100118	9107
Tora El-Asmant	9070	3954
Kozzika	75647	6870
Tora El-Balad	54230	4903
Sakanat El-Maadi	60187	5843
Maadi	271447	27979
Hadayek El-Maadi	225500	22207
Dar El-Salam	256332	26485
El-Zahraa	192360	17519
Mar Girgis	43172	3681
El-Malek El-Saleh	115590	11507
Al-Sayeda Zeinab	195324	20320
Saad Zaghloul	151570	14972

a)

line 2

Station	Entry	Exi
Shubra El-Kheima	346611	3164
Kolleyyet El-Zeraa	266201	2492
Mezallat	71905	7185
Khalafawy	76131	7390
St. Teresa	67844	6299
Road El-Farag	121301	1221
Masarra	107925	1090
Al-Shohadaa	247688	2375
Attaba	358353	4025
Mohamed Naguib	171819	1756
Sadat	77307	6238
Opera	49941	3886
Dokki	194932	2005
El Bohoth	250543	2686
Cairo University	242423	2415
Faisal	152438	1439
El Giza	143752	1492
Omm El-Masryeen	77718	7140
Sakiat Mekky	80796	7521

b)

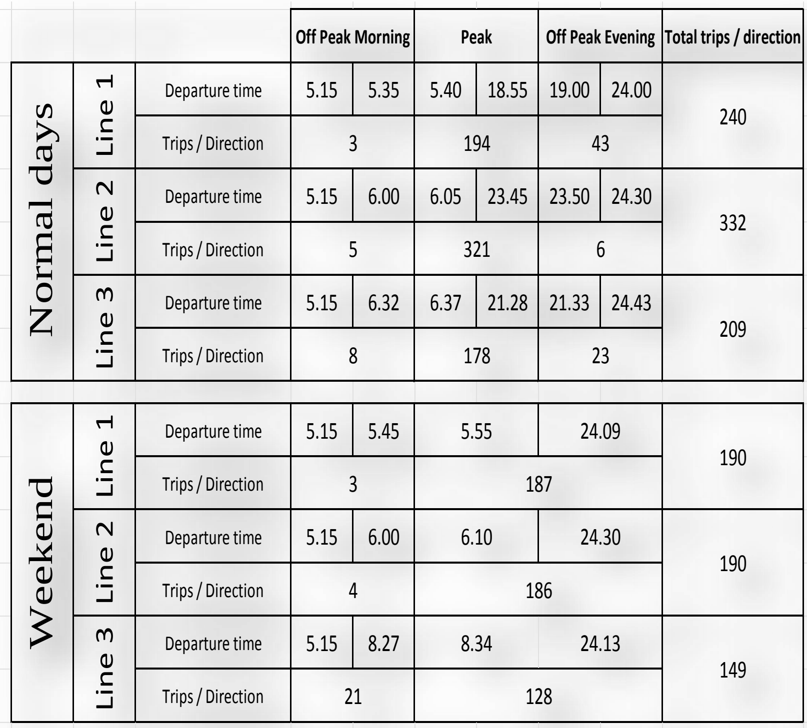
line 3

Station	Entry	Exi
Adly Mansour	33827	3861
El Haykestep	47342	1638
Omar Ibn El-Khattab	20293	1786
Qobaa	16104	1401
Hesham Barakat	27374	2532
El-Nozha	36633	3361
Nadi El-Shams	37345	3410
Alf Maskan	50782	5574
Heliopolis Square	27709	2707
Haroun	22699	2084
Al-Ahram	49448	5104
Koleyet El-Banat	91160	9066
Stadium	33200	3115
Fair Zone	39541	3398
Abbassia	90611	9421
Abdou Pasha	45165	4203
El Geish	29487	2330
Bab El Shaaria	55875	5835
Attaba	27484	4648

c)

Source: Greater Cairo Underground Metro Authorities.

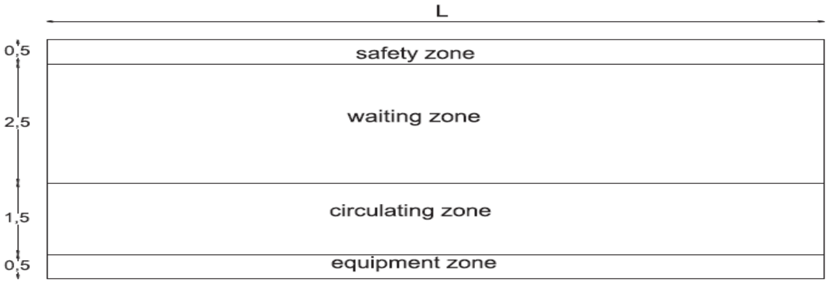
d) Table (2) The five official schedule operating times for the 3 lines.



			Off Peak Morning		Peak		Off Peak Evening		Total trips / direction
Normal days	Line 1	Departure time	5.15	5.35	5.40	18.55	19.00	24.00	240
		Trips / Direction	3		194		43		
	Line 2	Departure time	5.15	6.00	6.05	23.45	23.50	24.30	332
		Trips / Direction	5		321		6		
	Line 3	Departure time	5.15	6.32	6.37	21.28	21.33	24.43	209
		Trips / Direction	8		178		23		
Weekend	Line 1	Departure time	5.15	5.45	5.55		24.09		190
		Trips / Direction	3		187				
	Line 2	Departure time	5.15	6.00	6.10		24.30		190
		Trips / Direction	4		186				
	Line 3	Departure time	5.15	8.27	8.34		24.13		149
		Trips / Direction	21		128				

e)

f)

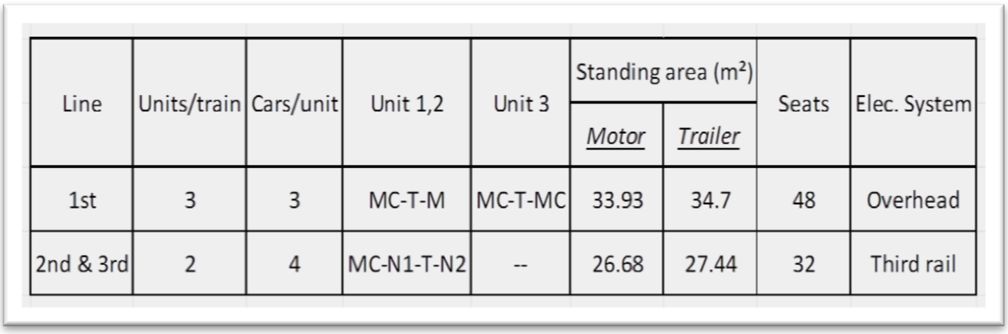


g) Figure (1) the underground metro platform dimension for line 1, and lines 2,3

h) (L = 200m for 1st line, L = 180m for 2nd and 3rd lines)

i) Source: Greater Cairo Underground Metro Authorities.

j) Table (3) rolling stock characteristics for the three lines.



Line	Units/train	Cars/unit	Unit 1,2	Unit 3	Standing area (m^2)		Seats	Elec. System
					Motor	*Trailer*		
1st	3	3	MC-T-M	MC-T-MC	33.93	34.7	48	Overhead
2nd & 3rd	2	4	MC-N1-T-N2	--	26.68	27.44	32	Third rail

k)

Source: Youssef M.

l)

m)

Where:
(MC): motor with a driving cabin.
(T): slip carriage (trailer) with longitudinal seats
(M): motor coach without a driving cabin (tapered end).
(N1): An intermediate motor car with one semi-permanent coupler at each end and with third rail collectors.
(N2): Intermediate motor car with a semi - permanent coupler at front end, fully automatic coupler at rear end, and with third rail collectors. The rear end is provided with an auxiliary driving cab.
Each car has 4 doors: two for alighting and two for boarding.

b- Solution model:

- Construction of [O-D] Matrix

Step (1): we converted the weekly passengers' data (P_w) Entry & Exit table (1) into passengers per trip (P_{ti}&P_{tj}) during a specific period. This was achieved by establishing a relationship with the official timetable shown in table (2), which divides normal days into three periods (off-peak morning, peak, and off-peak evening), and weekends into two periods (peak and off-peak). The total number of passengers during the week is calculated as follows: $P_w = N_d * P_{nd} + P_{we}$ .... (1), Where:
P_w=Total passengers during the week.

N_d = The total number of normal days of the week.

P_{nd} = Passengers on normal days during off peak morning, peak, and off-peak evening.

P_{we} = Passengers on weekends during peak and off-peak.

As the headway must be inversely proportional to the passengers' traffic, so it is easy to calculate the average corresponding headway for the five official schedules, i=(1,2,3,4,5) ,Where: {$(i=1)$ is for (off-peak morning), $(i=2)$ is for (peak) $(i=3)$ is for off-peak evening} for normal days & {$(i=4)$ is for (peak), $(i=5)$ is for (off-peak)} for weekend day.

$$H_i = \frac{Di}{N_{ti}} \text{ (min./trip) .... } (2),$$

Where:

H_i = Headway for i = (1,2,3,4,5)

Di = Duration for i = (1,2,3,4,5)

N_{ti} = Number of trips per direction i = (1,2,3,4,5)

For line 1:

$$H_1 = \frac{D_1}{N_{t1}} = \frac{5{:}35-5{:}15}{3} = 6.667_{\text{min./trip}} \qquad H_2 = \frac{D_2}{N_{t2}} = \frac{(18{:}55)-(5{:}40)}{194} = 4.098 \text{ min./trip}$$

$$H_3 = \frac{D_3}{N_{t3}} = \frac{(24{:}0)-(19{:}0)}{43} = 6.977_{\text{min./trip}} \quad H_4 = \frac{D_4}{N_{t4}} = \frac{(5{:}15)-(5{:}45)}{3} = 5.850 \text{ min./trip}$$

$$H_5 = \frac{D_5}{N_{t5}} = \frac{(24{:}09)-(5{:}55)}{187} = 10 \text{ min./trip}$$

According to the official timetable, we have five periods, resulting in five values for headway: (off peak morning, peak, and off-peak evening) for normal days and (peak & off peak) for weekends. To reduce the number of unknowns, we created the ratio between the peak headway and the headway for the remaining periods. This ratio is equal to one for the peak hour and less than one for the other periods.

$$R_i = \frac{H_2}{H_i} \text{ where } i = (1,2,3,4,5) \ldots. \ (3),$$

Where:

(R_i) is the ratio between the headway at peak hour (D_2) to any headway (H_i).

$$R_1 = \frac{H_2}{H_1} = 0.615,\ R_2 = \frac{H_2}{H_2} = 1,\ R_3 = \frac{H_2}{H_3} = 0.587,\ R_4 = \frac{H_2}{H_4} = 0.701,\ R_5 = \frac{H_2}{H_5} = 0.41$$

Then:

$$P_{t(i,j)} * \{N_d * \Sigma(R_1 * N_{t1} + R_2 * N_{t2} + R_3 * N_{t3}) + (R_4 * N_{t4} + R_5 * N_{t5})\} = P_{w(i,j)} \ldots (4)$$

Where:

$P_{t(i)}$ = entry for passengers per trip at peak hour.

$P_{t(j)}$ = exit for passengers per trip at peak hour.

$P_{w(i)}$ = entry for passengers per week.

$P_{w(j)}$ = exit for passengers per week.

N_d = The total number of normal days of the week.

$N_{t(i)}$ = Number of trips per direction for the five official schedules…. i = (1,2,3,4,5)

$$P_{t(i,j)} = \frac{P_{w(i,j)}}{6 * \Sigma(R_1 * N_{t1} + R_2 * N_{t2} + R_3 * N_{t3}) + (R_4 * N_{t4} + R_5 * N_{t5})}$$

$$P_{t(i,j)} = \frac{P_{w(i,j)}}{1405.289}$$

Applying the same way for the second and third lines.

n)

o) For line 2: p) $P_{t(i,j)} = \frac{P_{w(i,j)}}{2059.794}$

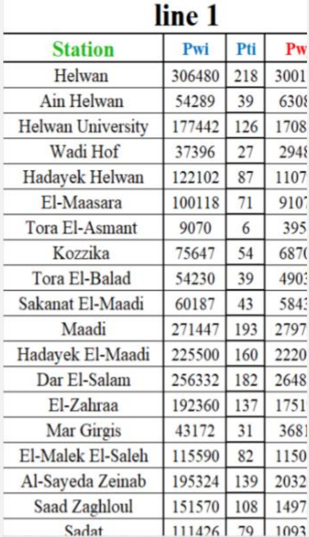
q)

r) For line 3: s) $P_{t(i,j)} = \frac{P_{w(i,j)}}{1275.392}$

In this research, we chose the peak hour as the case study.

Table (4) Passengers per train per direction at peak hour for line 1,2 &3.

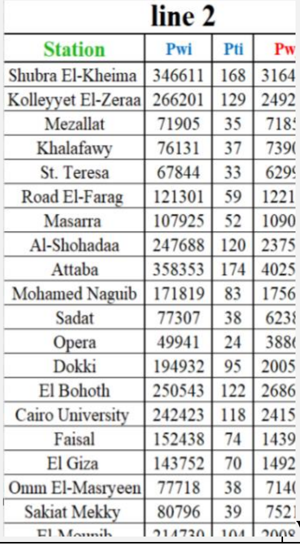
t)



line 1

Station	Pwi	Pti	Pw
Helwan	306480	218	3001
Ain Helwan	54289	39	630
Helwan University	177442	126	1708
Wadi Hof	37396	27	294
Hadayek Helwan	122102	87	1107
El-Maasara	100118	71	910
Tora El-Asmant	9070	6	395
Kozzika	75647	54	687
Tora El-Balad	54230	39	490
Sakanat El-Maadi	60187	43	584
Maadi	271447	193	2797
Hadayek El-Maadi	225500	160	2220
Dar El-Salam	256332	182	2648
El-Zahraa	192360	137	1751
Mar Girgis	43172	31	368
El-Malek El-Saleh	115590	82	1150
Al-Sayeda Zeinab	195324	139	2032
Saad Zaghloul	151570	108	1497
Sadat	111426	79	1093

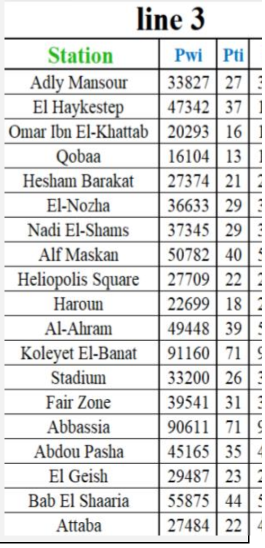
u)



line 2

Station	Pwi	Pti	Pw
Shubra El-Kheima	346611	168	3164
Kolleyyet El-Zeraa	266201	129	2492
Mezallat	71905	35	718
Khalafawy	76131	37	739
St. Teresa	67844	33	629
Road El-Farag	121301	59	1221
Masarra	107925	52	1090
Al-Shohadaa	247688	120	2375
Attaba	358353	174	4025
Mohamed Naguib	171819	83	1756
Sadat	77307	38	623
Opera	49941	24	388
Dokki	194932	95	2005
El Bohoth	250543	122	2686
Cairo University	242423	118	2415
Faisal	152438	74	1439
El Giza	143752	70	1492
Omm El-Masryeen	77718	38	714
Sakiat Mekky	80796	39	752
El Mounib	214730	104	2008

v)



line 3

Station	Pwi	Pti
Adly Mansour	33827	27
El Haykestep	47342	37
Omar Ibn El-Khattab	20293	16
Qobaa	16104	13
Hesham Barakat	27374	21
El-Nozha	36633	29
Nadi El-Shams	37345	29
Alf Maskan	50782	40
Heliopolis Square	27709	22
Haroun	22699	18
Al-Ahram	49448	39
Koleyet El-Banat	91160	71
Stadium	33200	26
Fair Zone	39541	31
Abbassia	90611	71
Abdou Pasha	45165	35
El Geish	29487	23
Bab El Shaaria	55875	44
Attaba	27484	22

Step (2): we employed an inventive method to establish the [OD] matrix for metro stations. Each row in the matrix was meticulously crafted by multiplying the volume of passenger entries at a given station by a calculated percentage, aptly termed the station's importance factor. This percentage, derived from the gravity model, inherently encapsulates the station's pivotal role in attracting a substantial number of passengers.

$P_{r(i)} = \frac{N_{p(i)}}{T_n}$ 100%.... (5), Where:

$P_{r(i)}$ = Percentage of total ridership for a station i

$N_{p(i)}$ = Number of passengers at station i

T_n = Total number of passengers for all the metro stations

Then:

$$P_{t(ij)} = P_{t(i)} * P_{r(i)} \dots (6),$$

Where:

$P_{t(ij)}$ = origin passengers per trip from the station *(i)* traveling to the station *(j)* at any case of the above five official scheduled.

This systematic approach was systematically applied to all stations across the three metro lines, totaling 74 stations. The outcome was a comprehensive square matrix [74*74] can be derivative into 9 smaller matrices.

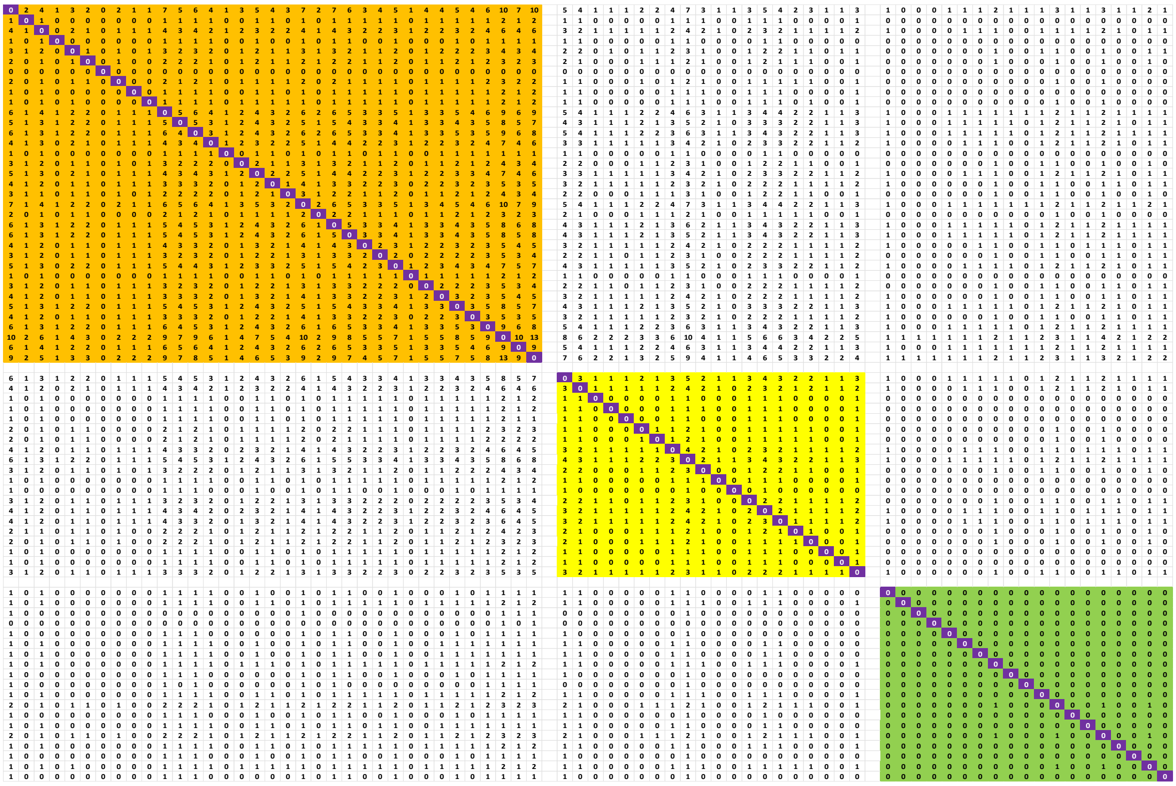
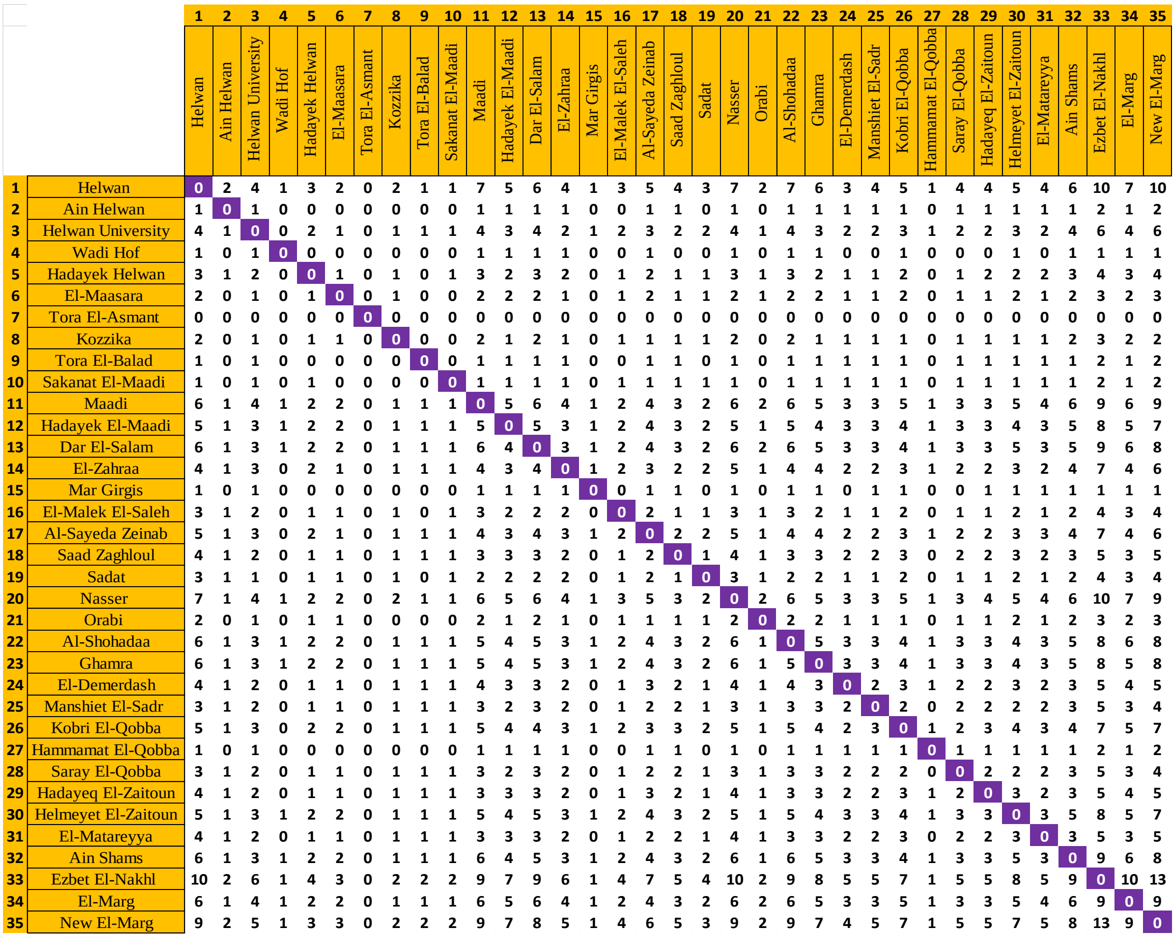


Figure (2) represents a part [35-35] of the whole [O-D] matrix which contains 9 parts of matrices.



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
		Helwan	Ain Helwan	Helwan University	Wadi Hof	Hadayek Helwan	El-Maasara	Tora El-Asmant	Kozzika	Tora El-Balad	Sakanat El-Maadi	Maadi	Hadayek El-Maadi	Dar El-Salam	El-Zahraa	Mar Girgis	El-Malek El-Saleh	Al-Sayeda Zeinab	Saad Zaghloul	Sadat	Nasser	Orabi	Al-Shohadaa	Ghamra	El-Demerdash	Manshiet El-Sadr	Kobri El-Qobba	Hammamat El-Qobba	Saray El-Qobba	Hadayeq El-Zaitoun	Helmeyet El-Zaitoun	El-Matareyya	Ain Shams	Ezbet El-Nakhl	El-Marg	New El-Marg
1	Helwan	0	2	4	1	3	2	0	2	1	1	7	5	6	4	1	3	5	4	3	7	2	7	6	3	4	5	1	4	4	5	4	6	10	7	10
2	Ain Helwan	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1	2	1	2
3	Helwan University	4	1	0	0	2	1	0	1	1	1	4	3	4	2	1	2	3	2	2	4	1	4	3	2	2	3	1	2	2	3	2	4	6	4	6
4	Wadi Hof	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	0	1	0	1	1	0	0	1	0	0	0	1	0	1	1	1	1
5	Hadayek Helwan	3	1	2	0	0	1	0	1	0	1	3	2	3	2	0	1	2	1	1	3	1	3	2	1	1	2	0	1	2	2	2	3	4	3	4
6	El-Maasara	2	0	1	0	1	0	0	1	0	0	2	2	2	1	0	1	2	1	1	2	1	2	2	1	1	2	0	1	1	2	1	2	3	2	3
7	Tora El-Asmant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Kozzika	2	0	1	0	1	1	0	0	0	0	2	1	2	1	0	1	1	1	1	2	0	2	1	1	1	1	0	1	1	1	1	2	3	2	2
9	Tora El-Balad	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1	2	1	2
10	Sakanat El-Maadi	1	0	1	0	1	0	0	0	0	0	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	2	1	2
11	Maadi	6	1	4	1	2	2	0	1	1	1	0	5	6	4	1	2	4	3	2	6	2	6	5	3	3	5	1	3	3	5	4	6	9	6	9
12	Hadayek El-Maadi	5	1	3	1	2	2	0	1	1	1	5	0	5	3	1	2	4	3	2	5	1	5	4	3	3	4	1	3	3	4	3	5	8	5	7
13	Dar El-Salam	6	1	3	1	2	2	0	1	1	1	6	4	0	3	1	2	4	3	2	6	2	6	5	3	3	4	1	3	3	5	3	5	9	6	8
14	El-Zahraa	4	1	3	0	2	1	0	1	1	1	4	3	4	0	1	2	3	2	2	5	1	4	4	2	2	3	1	2	2	3	2	4	7	4	6
15	Mar Girgis	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	1	0	1	1	0	1	1	0	0	1	1	1	1	1	1	1
16	El-Malek El-Saleh	3	1	2	0	1	1	0	1	0	1	3	2	2	2	0	0	2	1	1	3	1	3	2	1	1	2	0	1	1	2	1	2	4	3	4
17	Al-Sayeda Zeinab	5	1	3	0	2	1	0	1	1	1	4	3	4	3	1	2	0	2	2	5	1	4	4	2	2	3	1	2	2	3	3	4	7	4	6
18	Saad Zaghloul	4	1	2	0	1	1	0	1	1	1	3	3	3	2	0	1	2	0	1	4	1	3	3	2	2	3	0	2	2	3	2	3	5	3	5
19	Sadat	3	1	1	0	1	1	0	1	0	1	2	2	2	2	0	1	2	1	0	3	1	2	2	1	1	2	0	1	1	2	1	2	4	3	4
20	Nasser	7	1	4	1	2	2	0	2	1	1	6	5	6	4	1	3	5	3	2	0	2	6	5	3	3	5	1	3	4	5	4	6	10	7	9
21	Orabi	2	0	1	0	1	1	0	0	0	0	2	1	2	1	0	1	1	1	1	2	0	2	2	1	1	1	0	1	1	2	1	2	3	2	3
22	Al-Shohadaa	6	1	3	1	2	2	0	1	1	1	5	4	5	3	1	2	4	3	2	6	1	0	5	3	3	4	1	3	3	4	3	5	8	6	8
23	Ghamra	6	1	3	1	2	2	0	1	1	1	5	4	5	3	1	2	4	3	2	6	1	5	0	3	3	4	1	3	3	4	3	5	8	5	8
24	El-Demerdash	4	1	2	0	1	1	0	1	1	1	4	3	3	2	0	1	3	2	1	4	1	4	3	0	2	3	1	2	2	3	2	3	5	4	5
25	Manshiet El-Sadr	3	1	2	0	1	1	0	1	1	1	3	2	3	2	0	1	2	2	1	3	1	3	3	2	0	2	0	2	2	2	2	3	5	3	4
26	Kobri El-Qobba	5	1	3	0	2	2	0	1	1	1	5	4	4	3	1	2	3	3	2	5	1	5	4	2	3	0	1	2	3	4	3	4	7	5	7
27	Hammamat El-Qobba	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1	2	1	2
28	Saray El-Qobba	3	1	2	0	1	1	0	1	1	1	3	2	3	2	0	1	2	2	1	3	1	3	3	2	2	2	0	0	2	2	2	3	5	3	4
29	Hadayeq El-Zaitoun	4	1	2	0	1	1	0	1	1	1	3	3	3	2	0	1	3	2	1	4	1	3	3	2	2	3	1	2	0	3	2	3	5	4	5
30	Helmeyet El-Zaitoun	5	1	3	1	2	2	0	1	1	1	5	4	5	3	1	2	4	3	2	5	1	5	4	3	3	4	1	3	3	0	3	5	8	5	7
31	El-Matareyya	4	1	2	0	1	1	0	1	1	1	3	3	3	2	0	1	2	2	1	4	1	3	3	2	2	3	0	2	2	3	0	3	5	3	5
32	Ain Shams	6	1	3	1	2	2	0	1	1	1	6	4	5	3	1	2	4	3	2	6	1	6	5	3	3	4	1	3	3	5	3	0	9	6	8
33	Ezbet El-Nakhl	10	2	6	1	4	3	0	2	2	2	9	7	9	6	1	4	7	5	4	10	2	9	8	5	5	7	1	5	5	8	5	9	0	10	13
34	El-Marg	6	1	4	1	2	2	0	1	1	1	6	5	6	4	1	2	4	3	2	6	2	6	5	3	3	5	1	3	3	5	4	6	9	0	9
35	New El-Marg	9	2	5	1	3	3	0	2	2	2	9	7	8	5	1	4	6	5	3	9	2	9	7	4	5	7	1	5	5	7	5	8	13	9	0

Figure (3) "First Line Matrix" a part [35-35] of the whole [O-D] matrix which contains 9 parts of matrices.

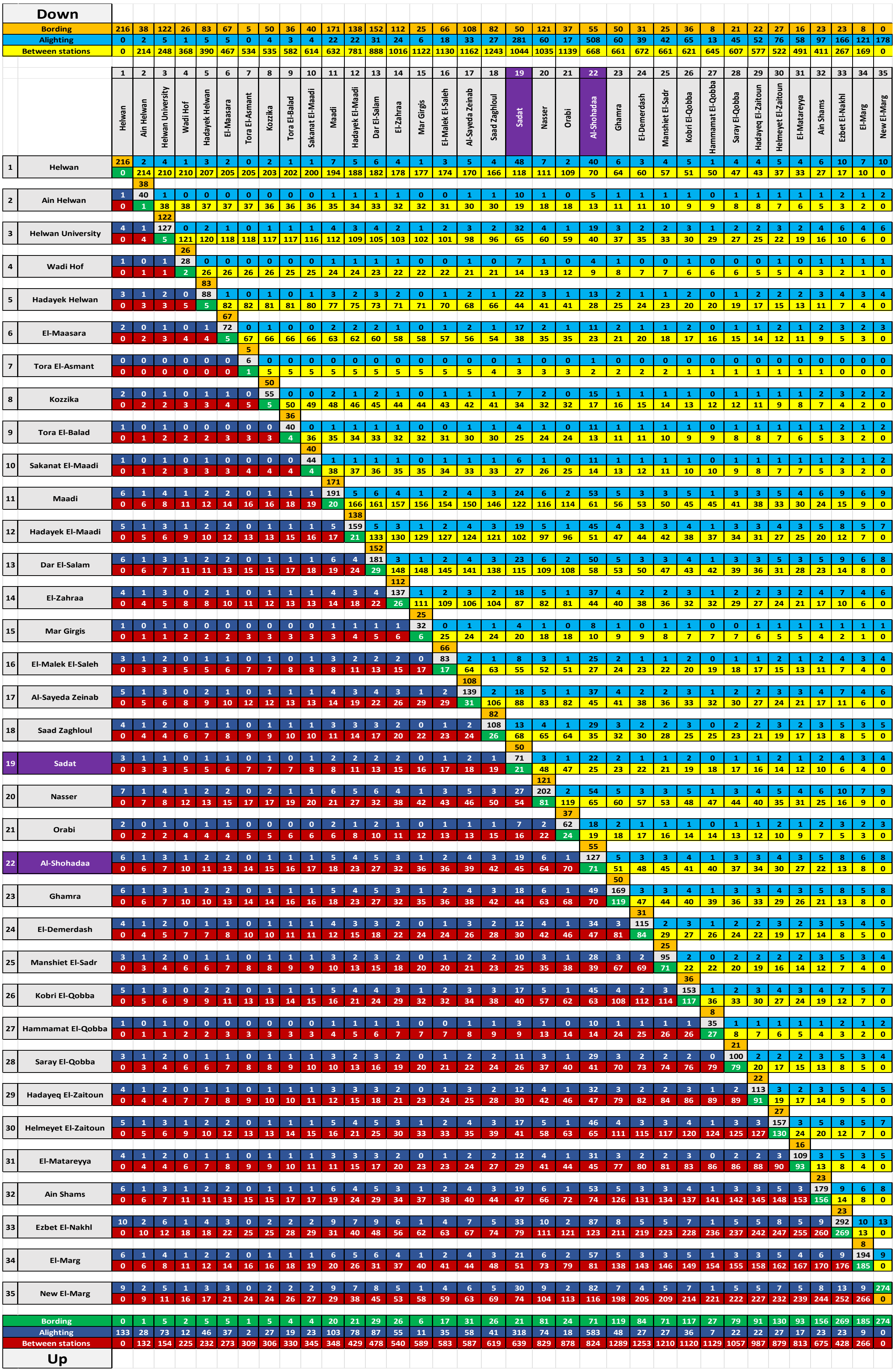
In this research, we conducted a study on the initial matrix in the first row from the left, representing passengers on the first line of the Greater Cairo Metro, and we will refer to it as the "First Line Matrix".

To study the First Line Matrix, we created a model using Microsoft Excel, naming it the "Modified Matrix." in this matrix we changed the diagonal to the entry numbers of passengers (P_{ti}). Then we created a new row in front of each station name, placed below the original row of the matrix .

In this configuration, each station name has two rows associated with it: the upper row, which represents the original matrix and indicates the numbers of passengers alighting in both down and up directions, and the lower row, which contains the numbers of passengers between two consecutive stations who are still inside the train cars in both down and up directions, (it can be obtained by subtracting the entry numbers of passengers from the upper row).

Furthermore, we added a new cell above each element of the top row of the matrix, coloring it orange. This configuration makes the diagonal contains three cells or elements stacked on top of each other.

The middle element, colored gray, represents the total number of passengers entering the station, while the lower element, colored green, signifies the number of passengers boarding in the up direction. The upper element represents the number of passengers boarding in the down direction.



Down																																				
Bording		216	38	122	26	83	67	5	50	36	40	171	138	152	112	25	66	108	82	50	121	37	55	50	31	25	36	8	21	22	27	16	23	23	8	0
Alighting		0	2	5	1	5	5	0	4	3	4	22	22	31	24	6	18	33	27	281	60	17	508	60	39	42	65	13	45	52	76	58	97	166	121	178
Between stations		0	214	248	368	390	467	534	535	582	614	632	781	888	1016	1122	1130	1162	1243	1044	1035	1139	668	661	672	661	621	645	607	577	522	491	411	267	169	0
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
		Helwan	Ain Helwan	Helwan University	Wadi Hof	Hadayek Helwan	El-Maasara	Tora El-Asmant	Kozzika	Tora El-Balad	Sakanat El-Maadi	Maadi	Hadayek El-Maadi	Dar El-Salam	El-Zahraa	Mar Girgis	El-Malek El-Saleh	Al-Sayeda Zeinab	Saad Zaghloul	Sadat	Nasser	Orabi	Al-Shohadaa	Ghamra	El-Demerdash	Manshiet El-Sadr	Kobri El-Qobba	Hammamat El-Qobba	Saray El-Qobba	Hadayeq El-Zaitoun	Helmeyet El-Zaitoun	El-Matareyya	Ain Shams	Ezbet El-Nakhl	El-Marg	New El-Marg
1	Helwan	216	2	4	1	3	2	0	2	1	1	7	5	6	4	1	3	5	4	48	7	2	40	6	3	4	5	1	4	4	5	4	6	10	7	10
		0	214	210	210	207	205	205	203	202	200	194	188	182	178	177	174	170	166	118	111	109	70	64	60	57	51	50	47	43	37	33	27	17	10	0
			38																																	
2	Ain Helwan	1	40	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	10	1	0	5	1	1	1	1	0	1	1	1	1	1	2	1	2
		0	1	38	38	37	37	37	36	36	36	35	34	33	32	32	31	30	30	19	18	18	13	11	11	10	9	9	8	8	7	6	5	3	2	0
				122																																
3	Helwan University	4	1	127	0	2	1	0	1	1	1	4	3	4	2	1	2	3	2	32	4	1	19	3	2	2	3	1	2	2	3	2	4	6	4	6
		0	4	5	121	120	118	118	117	117	116	112	109	105	103	102	101	98	96	65	60	59	40	37	35	33	30	29	27	25	22	19	16	10	6	0
					26																															
4	Wadi Hof	1	0	1	28	0	0	0	0	0	0	1	1	1	1	0	0	1	0	7	1	0	4	1	0	0	1	0	0	0	1	0	1	1	1	1
		0	1	1	2	26	26	26	26	25	25	24	24	23	22	22	22	21	21	14	13	12	9	8	7	7	6	6	6	5	5	4	3	2	1	0
						83																														
5	Hadayek Helwan	3	1	2	0	88	1	0	1	0	1	3	2	3	2	0	1	2	1	22	3	1	13	2	1	1	2	0	1	2	2	2	3	4	3	4
		0	3	3	5	5	82	82	81	81	80	77	75	73	71	71	70	68	66	44	41	41	28	25	24	23	20	20	19	17	15	13	11	7	4	0
							67																													
6	El-Maasara	2	0	1	0	1	72	0	1	0	0	2	2	2	1	0	1	2	1	17	2	1	11	2	1	1	2	0	1	1	2	1	2	3	2	3
		0	2	3	4	4	5	67	66	66	66	63	62	60	58	58	57	56	54	38	35	35	23	21	20	18	17	16	15	14	12	11	9	5	3	0
								5																												
7	Tora El-Asmant	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	1	5	5	5	5	5	5	5	5	5	5	4	3	3	3	2	2	2	2	1	1	1	1	1	1	1	0	0	0
									50																											
8	Kozzika	2	0	1	0	1	1	0	55	0	0	2	1	2	1	0	1	1	1	7	2	0	15	1	1	1	1	0	1	1	1	1	2	3	2	2
		0	2	2	3	3	4	5	5	50	49	48	46	45	44	44	43	42	41	34	32	32	17	16	15	14	13	12	12	11	9	8	7	4	2	0
										36																										
9	Tora El-Balad	1	0	1	0	0	0	0	0	40	0	1	1	1	1	0	0	1	1	4	1	0	11	1	1	1	1	0	1	1	1	1	1	2	1	2
		0	1	2	2	2	3	3	3	4	36	35	34	33	32	32	31	30	30	25	24	24	13	11	11	10	9	9	8	8	7	6	5	3	2	0
											40																									
10	Sakanat El-Maadi	1	0	1	0	1	0	0	0	0	44	1	1	1	1	0	1	1	1	6	1	0	11	1	1	1	1	0	1	1	1	1	1	2	1	2
		0	1	2	3	3	3	4	4	4	4	38	37	36	35	35	34	33	33	27	26	25	14	13	12	11	10	10	9	8	7	7	5	3	2	0
												171																								
11	Maadi	6	1	4	1	2	2	0	1	1	1	191	5	6	4	1	2	4	3	24	6	2	53	5	3	3	5	1	3	3	5	4	6	9	6	9
		0	6	8	11	12	14	16	16	18	19	20	166	161	157	156	154	150	146	122	116	114	61	56	53	50	45	45	41	38	33	30	24	15	9	0
													138																							
12	Hadayek El-Maadi	5	1	3	1	2	2	0	1	1	1	5	159	5	3	1	2	4	3	19	5	1	45	4	3	3	4	1	3	3	4	3	5	8	5	7
		0	5	6	9	10	12	13	13	15	16	17	21	133	130	129	127	124	121	102	97	96	51	47	44	42	38	37	34	31	27	25	20	12	7	0
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13	Dar El-Salam	6	1	3	1	2	2	0	1	1	1	6	4	181	3	1	2	4	3	23	6	2	50	5	3	3	4	1	3	3	5	3	5	9	6	8
		0	6	7	11	11	13	15	15	17	18	19	24	29	148	148	145	141	138	115	109	108	58	53	50	47	43	42	39	36	31	28	23	14	8	0
															112																					
14	El-Zahraa	4	1	3	0	2	1	0	1	1	1	4	3	4	137	1	2	3	2	18	5	1	37	4	2	2	3	1	2	2	3	2	4	7	4	6
		0	4	5	8	8	10	11	12	13	13	14	18	22	26	111	109	106	104	87	82	81	44	40	38	36	32	32	29	27	24	21	17	10	6	0
																25																				
15	Mar Girgis	1	0	1	0	0	0	0	0	0	0	1	1	1	1	32	0	1	1	4	1	0	8	1	0	1	1	0	0	1	1	1	1	1	1	1
		0	1	1	2	2	2	3	3	3	3	3	4	5	6	6	25	24	24	20	18	18	10	9	9	8	7	7	7	6	5	5	4	2	1	0
																	66																			
16	El-Malek El-Saleh	3	1	2	0	1	1	0	1	0	1	3	2	2	2	0	83	2	1	8	3	1	25	2	1	1	2	0	1	1	2	1	2	4	3	4
		0	3	3	5	5	6	7	7	8	8	8	11	13	15	17	17	64	63	55	52	51	27	24	23	22	20	19	18	17	15	13	11	7	4	0
																		108																		
17	Al-Sayeda Zeinab	5	1	3	0	2	1	0	1	1	1	4	3	4	3	1	2	139	2	18	5	1	37	4	2	2	3	1	2	2	3	3	4	7	4	6
		0	5	6	8	9	10	12	12	13	13	14	19	22	26	29	29	31	106	88	83	82	45	41	38	36	33	32	30	27	24	21	17	11	6	0
																			82																	
18	Saad Zaghloul	4	1	2	0	1	1	0	1	1	1	3	3	3	2	0	1	2	108	13	4	1	29	3	2	2	3	0	2	2	3	2	3	5	3	5
		0	4	4	6	7	8	9	9	10	10	11	14	17	20	22	23	24	26	68	65	64	35	32	30	28	25	25	23	21	19	17	13	8	5	0
																				50																
19	Sadat	3	1	1	0	1	1	0	1	0	1	2	2	2	2	0	1	2	1	71	3	1	22	2	1	1	2	0	1	1	2	1	2	4	3	4
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																					121															
20	Nasser	7	1	4	1	2	2	0	2	1	1	6	5	6	4	1	3	5	3	27	202	2	54	5	3	3	5	1	3	4	5	4	6	10	7	9
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																						37														
21	Orabi	2	0	1	0	1	1	0	0	0	0	2	1	2	1	0	1	1	1	7	2	62	18	2	1	1	1	0	1	1	2	1	2	3	2	3
		0	2	2	4	4	4	5	5	6	6	6	8	10	11	12	13	13	15	16	22	24	19	18	17	16	14	14	13	12	10	9	7	5	3	0
																							55													
22	Al-Shohadaa	6	1	3	1	2	2	0	1	1	1	5	4	5	3	1	2	4	3	19	6	1	127	5	3	3	4	1	3	3	4	3	5	8	6	8
		0	6	7	10	11	13	14	15	16	17	18	23	27	32	36	36	39	42	45	64	70	71	51	48	45	41	40	37	34	30	27	22	13	8	0
																								50												
23	Ghamra	6	1	3	1	2	2	0	1	1	1	5	4	5	3	1	2	4	3	18	6	1	49	169	3	3	4	1	3	3	4	3	5	8	5	8
		0	6	7	10	10	13	14	14	16	16	18	23	27	32	35	36	38	42	44	63	68	70	119	47	44	40	39	36	33	29	26	21	13	8	0
																									31											
24	El-Demerdash	4	1	2	0	1	1	0	1	1	1	4	3	3	2	0	1	3	2	12	4	1	34	3	115	2	3	1	2	2	3	2	3	5	4	5
		0	4	5	7	7	8	10	10	11	11	12	15	18	22	24	24	26	28	30	42	46	47	81	84	29	27	26	24	22	19	17	14	8	5	0
																										25										
25	Manshiet El-Sadr	3	1	2	0	1	1	0	1	1	1	3	2	3	2	0	1	2	2	10	3	1	28	3	2	95	2	0	2	2	2	2	3	5	3	4
		0	3	4	6	6	7	8	8	9	9	10	13	15	18	20	20	21	23	25	35	38	39	67	69	71	22	22	20	19	16	14	12	7	4	0
																											36									
26	Kobri El-Qobba	5	1	3	0	2	2	0	1	1	1	5	4	4	3	1	2	3	3	17	5	1	45	4	2	3	153	1	2	3	4	3	4	7	5	7
		0	5	6	9	9	11	13	13	14	15	16	21	24	29	32	32	34	38	40	57	62	63	108	112	114	117	36	33	30	27	24	19	12	7	0
																												8								
27	Hammamat El-Qobba	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	3	1	0	10	1	1	1	1	35	1	1	1	1	1	2	1	2
		0	1	1	2	2	3	3	3	3	3	4	5	6	7	7	7	8	9	9	13	14	14	24	25	26	26	27	8	7	6	5	4	3	2	0
																													21							
28	Saray El-Qobba	3	1	2	0	1	1	0	1	1	1	3	2	3	2	0	1	2	2	11	3	1	29	3	2	2	2	0	100	2	2	2	3	5	3	4
		0	3	4	6	6	7	8	8	9	10	10	13	16	19	20	21	22	24	26	37	40	41	70	73	74	76	79	79	20	17	15	13	8	5	0
																														22						
29	Hadayeq El-Zaitoun	4	1	2	0	1	1	0	1	1	1	3	3	3	2	0	1	3	2	12	4	1	32	3	2	2	3	1	2	113	3	2	3	5	4	5
		0	4	4	7	7	8	9	10	10	11	12	15	18	21	23	24	25	28	30	42	46	47	79	82	84	86	89	89	91	19	17	14	9	5	0
																															27					
30	Helmeyet El-Zaitoun	5	1	3	1	2	2	0	1	1	1	5	4	5	3	1	2	4	3	17	5	1	46	4	3	3	4	1	3	3	157	3	5	8	5	7
		0	5	6	9	10	12	13	13	14	15	16	21	25	30	33	33	35	39	41	58	63	65	111	115	117	120	124	125	127	130	24	20	12	7	0
																																16				
31	El-Matareyya	4	1	2	0	1	1	0	1	1	1	3	3	3	2	0	1	2	2	12	4	1	31	3	2	2	3	0	2	2	3	109	3	5	3	5
		0	4	4	6	7	8	9	9	10	11	11	15	17	20	23	23	24	27	29	41	44	45	77	80	81	83	86	86	88	90	93	13	8	4	0
																																	23			
32	Ain Shams	6	1	3	1	2	2	0	1	1	1	6	4	5	3	1	2	4	3	19	6	1	53	5	3	3	4	1	3	3	5	3	179	9	6	8
		0	6	7	11	11	13	15	15	17	17	19	24	29	34	37	38	40	44	47	66	72	74	126	131	134	137	141	142	145	148	153	156	14	8	0
																																		23		
33	Ezbet El-Nakhl	10	2	6	1	4	3	0	2	2	2	9	7	9	6	1	4	7	5	33	10	2	87	8	5	5	7	1	5	5	8	5	9	292	10	13
		0	10	12	18	18	22	25	25	28	29	31	40	48	56	62	63	67	74	79	111	121	123	211	219	223	228	236	237	242	247	255	260	269	13	0
																																			8	
34	El-Marg	6	1	4	1	2	2	0	1	1	1	6	5	6	4	1	2	4	3	21	6	2	57	5	3	3	5	1	3	3	5	4	6	9	194	9
		0	6	8	11	12	14	16	16	18	19	20	26	31	37	40	41	44	48	51	73	79	81	138	143	146	149	154	155	158	162	167	170	176	185	0
35	New El-Marg	9	2	5	1	3	3	0	2	2	2	9	7	8	5	1	4	6	5	30	9	2	82	7	4	5	7	1	5	5	7	5	8	13	9	274
		0	9	11	16	17	21	24	24	26	27	29	38	45	53	58	59	63	69	74	104	113	116	198	205	209	214	221	222	227	232	239	244	252	266	0
Bording		0	1	5	2	5	5	1	5	4	4	20	21	29	26	6	17	31	26	21	81	24	71	119	84	71	117	27	79	91	130	93	156	269	185	274
Alighting		133	28	73	12	46	37	2	27	19	23	103	78	87	55	11	35	58	41	318	74	18	583	48	27	27	36	7	22	22	27	17	23	23	9	0
Between stations		0	132	154	225	232	273	309	306	330	345	348	429	478	540	589	583	587	619	639	829	878	824	1289	1253	1210	1120	1129	1057	987	879	813	675	428	266	0
Up																																				

Figure (4) shows the proposed modified matrix.

C - Analysis & results:

By analyzing the elements of the modified matrix model, we can determine the numbers of passengers in both up and down directions. We represented the passengers in the down direction with orange and those in the up direction with green. Similarly, we represented the alighting passengers in both down and up directions with dark blue, and boarding passengers with light blue. Passengers who still inside the train car between two consecutive stations represented with yellow for the down direction and red for the up direction. To calculate these numbers for each station, we performed the following steps:

1. From the diagonal of the matrix, we can determine the direction of passengers in the metro. If the upper triangle represents the down direction (Helwan - Marg), and the lower triangle represents the up direction (Marg - Helwan).

2. We conducted vertical summation for each station to reach the diagonal in both directions. This was done to obtain the total count for passengers, alighting passengers, and passengers who are still inside the train car between two consecutive stations.
Through the results obtained from the vertical aggregation, we can determine the passenger density in the following scenarios: on the platform, at the doors, and inside the metro train cars. Consequently, we can ensure the fulfillment of the following conditions:

-Interaction between Passenger and Platform: Passenger density on the platform ≤ 2 passenger/$m2$.

$$Platform\ density\ = \frac{Number\ of\ passengers\ boarding}{(L*2.5)}\ (p/m2)\ldots(7)$$

-Interaction between passenger and metro doors, stopping time and train frequency (Headway): the Stopping time(t) ≤30(sec.).

$$(t) = \frac{(P_{tj}+P_{ti})*0.5}{4\ doors\ per\ car*(n)} + 3(opening\&closing\ door)(\text{sec.})\ldots(8)$$

Where: n= 9 cars for 1st line, and 8 for 2nd and 3rd lines.

-Interaction between Passenger and Train: Passenger density inside metro train cars < 7 passenger/$m2$ and ≤ 3 passenger/$m2$.

$$P_{in} = \frac{(1+optimum\ peak\ hour\ factor)\ Ptb - (48*9)}{(6*33.93+3*34.7)}\ (p/m2)\ldots(9)$$

When compensating in equations (7, 8, and 9), we multiplied by a correction factor of (3.5). This is because the data obtained from the Metro Authority represents only passengers using smart cards, which account for approximately one million passengers out of a total of 3.5 million passengers served daily through the Greater Cairo Metro network. The reason for this difference is attributed to the use of subscription cards, as mentioned in the official article [17] and also in the Cairo Metro website [18] . Additionally, when calculating passenger density on the platform, we multiplied by a safety factor of 2.5, and for stopping time, we multiplied by a safety factor of 2, due to the irregular distribution of passengers observed through field monitoring of metro stations, and it also raised in the previous researches mentioned in the literature review.

After obtaining the results from the previous equations, we were able to calculate the headway time by assuming that the headway time is inversely proportional to passenger density, which is logical because as the number of passengers increases, more trains are needed, thus reducing the required headway time:

1. In the case of passenger density on the platform ≤ 2 passenger$/m2$. During the peak hours, we can use the following relationship to obtain the headway time:

$$\text{Required Headway} = Hi * \frac{\text{Standard Rate of Platform Passenger Density}}{\text{Actual Platform Passenger Density}} \dots.(10)$$

Where: Hi = Actual Headway Time (according to the official schedule).

2. In the case of passenger density at the doors, where the standard rate of the stopping time(t) $\leq$30(sec.), we can use the following relationship to obtain the headway time:

$$\text{Required Headway} = Hi * \frac{\text{Standard Rate of Stopping Time}}{\text{Actual Stopping Time}} \quad ....(11)$$

3. In the case of passenger density inside metro train cars < 7 passenger$/m2$ during the peak hours, we can use the following relationship to obtain the headway time:

$$\text{Required Headway} = Hi * \frac{\text{Standard Rate of Passenger Density inside Metro Cars}}{\text{Actual Passenger Density inside Metro Cars}} \quad .\dots(12)$$

Thus, we obtained three values for the headway time, and we took the minimum value since we are working under peak conditions.

Table (7) shows the results & conclusions.

		Up					Down				
	station	a	b	c	h	Recommendation	a	b	c	h	Recommendation
1	Helwan	-	7	-	7/2=3.5	stopping a train of two ones	4	5	-	4	The irregularity factor of passenger density is taken 1.5 instead of 2.5
2	Ain Helwan	366	21	309	21/5=4	stopping a train of five ones	12	17	28	12/3= 4	stopping a train of three ones
3	Helwan University	94	11	82	11/2=5.5	stopping a train of two ones	4	8	20	4	Basic assumptions
4	Wadi Hof	297	28	25	25/5=5	stopping a train of five ones	18	21	10	10/2=5	stopping a train of two ones
5	Hadayek Helwan	87	15	23	15/3=5	stopping a train of three ones	6	10	4	4	The irregularity factor of passenger density is taken 2 instead of 1
6	El-Maasara	89	17	17	17/4=4.25	stopping a train of four ones	7	12	7	7/2=3.5	stopping a train of two ones
7	Tora El-Asmant	932	37	14	14/3=5	stopping a train of three ones	85	34	6	6/2=3	stopping a train of two ones
8	Kozzika	103	20	14	14/3=5	stopping a train of three ones	9	14	6	6/2=3	stopping a train of two ones
9	Tora El-Balad	131	23	12	12/3=4	stopping a train of three ones	13	18	5	5	Basic assumptions
10	Sakanat El-Maadi	112	21	11	11/2=5.5	stopping a train of two ones	12	17	5	5	Basic assumptions
11	Maadi	23	8	11	11/2=5.5	stopping a train of two ones	3	6	5	3	Basic assumptions
12	Hadayek El-Maadi	22	9	8	8/2=4	stopping a train of two ones	3	6	4	3	Basic assumptions
13	Dar El-Salam	16	8	7	7/2=3.5	stopping a train of two ones	3	6	3	3	Basic assumptions
14	El-Zahraa	18	11	6	6/2=3	stopping a train of two ones	4	7	3	3	Basic assumptions
15	Mar Girgis	73	25	5	5	Basic assumptions	18	20	3	3	Basic assumptions
16	El-Malek El-Saleh	27	15	5	5	Basic assumptions	7	11	3	3	Basic assumptions
17	Al-Sayeda Zeinab	15	10	5	5	Basic assumptions	4	7	3	3	The effect of subscribtion factor is taken 3 instead of 3.5
18	Saad Zaghloul	18	13	5	5	Basic assumptions	6	9	3	3	The effect of subscribtion factor is taken 3 instead of 3.5
19	Sadat	23	4	5	4	Basic assumptions	9	4	3	3	Basic assumptions
20	Nasser	6	7	4	4	Basic assumptions	4	6	3	3	Basic assumptions
21	Orabi	19	17	3	3	Basic assumptions	13	15	3	3	The effect of subscribtion factor is taken 3 instead of 3.5
22	Al-Shohadaa	7	3	4	3	Basic assumptions	8	4	5	4	Basic assumptions
23	Ghamra	4	6	3	3	The effect of subscribtion factor is taken 3 instead of 3.5	9	9	5	5	Basic assumptions
24	El-Demerdash	6	9	3	3	The effect of subscribtion factor is taken 3 instead of 3.5	15	12	5	5	Basic assumptions
25	Manshiet El-Sadr	7	10	3	3	The effect of subscribtion factor is taken 3 instead of 3.5	19	13	5	5	Basic assumptions
26	Kobri El-Qobba	4	7	3	3	Basic assumptions	13	9	5	5	Basic assumptions
27	Hammamat El-Qobba	17	19	3	3	Basic assumptions	60	24	5	5	Basic assumptions
28	Saray El-Qobba	6	9	3	3	Basic assumptions	22	13	5	5	Basic assumptions
29	Hadayeq El-Zaitoun	5	9	3	3	Basic assumptions	21	12	6	6/2=3	stopping a train of two ones
30	Helmeyet El-Zaitoun	4	7	3	3	Basic assumptions	17	9	6	6/2=3	stopping a train of two ones
31	El-Matareyya	5	9	4	4	Basic assumptions	29	12	7	7/2=3.5	stopping a train of two ones
32	Ain Shams	3	6	5	3	Basic assumptions	21	8	9	9/2=4.5	stopping a train of two ones
33	Ezbet El-Nakhl	3	4	8	3	The irregularity factor of passenger density is taken 1.5 instead of 2.5	21	6	18	6/2=3	stopping a train of two ones
34	El-Marg	3	5	6	3	Basic assumptions	55	8	12	8/2=4	stopping a train of two ones
35	New El-Marg	3	4	-	3	The irregularity factor of passenger density is taken 1.5 instead of 2.5	-	6	-	6/2=3	stopping a train of two ones

Note:
Basic assumptions are : The effect of subscription factor = 3.5 , the irregularity factor of passenger density on platform = 2.5 , the irregularity factor of passenger density at doors = 2 , the irregularity factor of passenger density inside metro cars = 1.

Conclusions:

This research has revealed significant discrepancies between the current Greater Cairo Metro operation and the dynamic needs of its ridership. The official timetable's rigidity fails to adapt to passenger fluctuations, leading to overcrowding and inefficiencies. Uneven passenger distribution across platforms and trains further exacerbates the issue, highlighting the need for improved flow management strategies within stations. Additionally, the lack of dedicated boarding and alighting doors, coupled with illegal passenger behavior, contributes to increased stopping times and operational disruptions.

To address these challenges, this research proposes an innovative methodology for optimizing metro operations. By developing dynamic headway models that cater to varying passenger volumes and circumstances, this approach ensures efficient service provision while minimizing passenger wait times. Furthermore, optimizing station design through strategic modifications to the six key components can significantly improve passenger flow and reduce congestion. Additionally, analyzing the impact of potential ticket price adjustments and new infrastructure on ridership patterns can provide valuable insights for informed decision-making.

By implementing the proposed methodology, the Greater Cairo Metro can achieve optimal operation, characterized by efficient service provision, improved passenger experience, and enhanced safety. This will not only contribute to a more sustainable and efficient transportation system but also foster a positive impact on the city's overall economic and social well-being. The future of the Greater Cairo Metro lies in embracing dynamic solutions that adapt to the ever-evolving needs of its passengers, and this research serves as a crucial step towards achieving that goal.

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