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PEDESTRIAN SIMULATION OF METRO RAIL TRANSIT (MRT) LINE 7 STATION 1-NORTH AVENUE STATION, QUEZON CITY, PHILIPPINES

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ABSTRACT: Simulation of pedestrian flow represents an advanced approach in modeling and evaluating train stations. In this study, pedestrian simulation was done using the simulation software Simio to assess the passenger capacity of MRT 7 Station 1-North Avenue Station through level of service (LOS), queuing system, and train facility utilization. This paper presents the actual situation inside the train station while predicting the behavior of queuing pedestrians and provides an accurate estimate of the volume-to-capacity ratio of passengers entering the station. The study's approach debugged the conventional assignments of pedestrians currently used in the field. The constructed three-dimensional building of the North Avenue Station served as framework for the simulation. Sources, sinks, servers, and paths of the software were the main elements of the simulation. Each library was defined by their time usage based on data gathered. Time usages of 1.21 sec. and 240 sec. for sources and sinks, respectively, were used in the simulation. Servers were defined by the train facilities utilized in the simulation, namely, automatic ticketing machines (TVM) with time usage of 43 seconds, ticketing toll gates with 1.4 seconds, and manual ticketing windows (BOM) with 20 seconds. In addition to the libraries, paths that provided the flow, direction, and distribution of pedestrians were calibrated using 10% for TVM users, 35% for BOM users, and 55% for others (regular tickets, beep cards, promo trips) based on data obtained. Simulation results showed that the new proposed plan has a higher passenger capacity than the original plan.

Keywords: Pedestrian simulation, Rail transit system, Simio, Level of service

1. INTRODUCTION

The railway system is one of the easiest and most convenient ways of travelling from one place to another. For this reason, many people prefer trains as their mode of transportation. Since trains provide comfort, uninterrupted movement, and high speed while generating low pollution and low energy consumption, which are essential attributes of sustainable transport, a high rail-based travel demand is expected [1].

This attraction to rail transport causes heavy pedestrian traffic and severe congestion in train stations, which has become an object of growing public concern. Since the increasing number of commuters is unavoidable, the only solution is to improve train station infrastructures and facilities. One proposed approach is to adopt a pedestrian simulation technique in order to systematically assess and estimate the actual movements and activities of commuters inside train stations. This approach is based on the conventional way of subjectively estimating the volume of commuters in a certain area and assuming the sufficient number of facilities that can support the estimated demand.

Representing another milestone in the field of transportation engineering in the Philippines, pedestrian simulation will be conducted as part of the preliminary study for the design and construction of Metro Rail Transit (MRT) Station. This approach in pedestrian analysis is expected to exceed basic operational assessments because of the technique's ability to demonstrate people's movements and frequently traveled paths, and separately, levels of service (LOS) [2]. Solutions to this problem depended on the proposed plans for train stations, which were solely based on site characteristics where the building will be constructed. Planning of facilities was also carried out based on the allotted space in the building, without regard to the number of people that will be using the facilities. Insufficient consideration given to passenger characteristics and behavior opens the door to the search for more accurate and systematic methods of developing and designing the interior properties of train stations.

The study will be essential in debugging the conventional subjective assignments of pedestrians over train stations with more sophisticated planned paths. An overview of the actual situation inside the station provided a dynamic illustration for prospective recommendations. It helped increase the capacity of the building and assign better arrangements of machine and manual ticket vending facilities. The analysis of this simulation was presented in a dynamic and illustrative way, which can prove to be a vital tool for the engineering industry [3].

The Metro Rail Transit Line 7 is a transportation infrastructure development project proposed in 2008 and greenlighted for construction in April 2016. The P69.30-billion upcoming train line will be serving approximately 850,000 passengers per day when equipped with completed upgrades. Hyundai Rotem, the supplier of LRT 1 and MRT 3 train cars, will cover the communication, signaling and power supply while EEI Corporation will provide the elevated trackway in the construction of the train system [4]. The 23.17-kilometer rail composed of 14 stations will connect San Jose Del Monte in Bulacan to MRT 3 and LRT 1 [5]. Expected to be completed and operational by April 2020, the MRT 7 will initially accommodate 350,000 passengers and will shorten travel time by approximately 2.5 hours [6]. Despite the outstanding progress not only in the field of railway transportation but also in transportation in general, pedestrians were not highlighted as a major factor in the design of MRT stations [7].

In line with the current thrust to resolve pedestrian-related problems, pedestrian simulation in train stations was recently introduced in the Philippines. It offered an advanced approach toward a more realistic and effective model of pedestrian flow in train stations. Pedestrian simulation has broad applications, including modeling of various scenarios, simulating different models, and studying behavioral patterns of people. Two of the most common scenarios that can be modelled are planning for security aspects and temporary events where a high density of people is expected. Simulation of different models runs from non-living objects to people with various unique characteristics, while behavioral patterns of people are studied in populated areas like train stations, airports, and large public buildings [8]. Most researches on these applications have been conducted in Japan, owing to the country's advanced innovation and continuing progress in the field of railway engineering.

One of the studies that focused on the application of microscopic pedestrian simulation model was conducted by Kardi Teknomo of the Institute of Lowland Technology in Saga University, Japan. The simulation was used to predict the effects of new policies for train stations before their implementation [9]. As a futuristic approach, Teknomo incorporated the sense of time and direction of passengers to increase the accuracy of their movement relative to real life scenarios.

In contrast to Teknomo's study, policies to be implemented here are subjective because their impacts cannot cover the entire population under consideration. The high population of the elderly in Japan affects the space allocated to maintain level of service transfer of passengers. The suggested travel space of a person would therefore become a limitation in conducting a similar study in the Philippines.

A study on pedestrian accessibility was conducted in China to evaluate the capacity of urban rail transit systems. Using Kishi's Logit Price Sensitivity Meter (KLP) Model, space and time thresholds were determined and were used to evaluate the layout of the station. Due to limited data, however, the study recommended that further research should be conducted [10].

Aside from modeling pedestrian traffic to identify the capacity of a station, level of service or LOS is also used to evaluate train stations. A study conducted in Bangkok, Thailand that formulates pedestrian LOS for Thai people used LOS for evaluating occupancy of sidewalks in roads and local train stations. Based on the same study, the formulated LOS has lower space but higher flowrate compared to Western studies [11]. Since Thai people, or noticeably Asians including Filipinos, were smaller compared to their Western counterparts, the square meter space for pedestrian is lower than 0.82 meters per pedestrian for LOS.

Simulation of train passengers was also correlated to the increasing trend of railway technology in the country, which follows the paths of Japan and other countries. Using Simio in running the pedestrian simulation for train stations, Dalian Jiaotong University in China created a model of the Dalian Railway Station to obtain the maximum passenger capacity and the passenger arrival pattern in redesigning the station. The research also aimed to forecast the train station's capability to accommodate the passengers arriving, assess the level of service of passenger routes, and report performance of ticketing facilities and their utilization [12]. Although the present paper has similar objectives, pedestrian simulation of Dalian Railway Station was further improved because of its recommendation on redesigning the facility and simulating pedestrian emergency plan.

The general objective of this study is to assess the pedestrian capacity of MRT 7 Station 1 North Avenue Station. Specifically, it aims to model pedestrian traffic inside the MRT station on a normal day peak hour basis; forecast delay and capacity of accumulation of passengers at the concourse area; and evaluate the level of passenger service transfer and determine train station facility utilization.

2. MATERIALS AND METHODS

From June to July 2016, preliminary procedures in creating a model from site visits in North Avenue and trial simulations were conducted at the office of STRIDE Consulting, Inc. Succeeding phases of the study were carried out at the College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños from August 2016 to May 2017, with several consultations at STRIDE Consulting, Inc.

2.1 Source of Data and Software

Data regarding the population entering the vicinity of North Avenue were provided by STRIDE Consulting, Inc. and were gathered from the official website of the Department of Transportation (DOTr). Data reliability could be attributed to the company as the source of secondary data. The software used for the simulation, SIMIO, was also provided by the company and was licensed under the University of the Philippines Diliman.

2.2 Three-dimensional Model

Using the 3D modeling software Sketch Up, the AutoCAD version of the proposed plan for the North Avenue Station was reconstructed into a 3D model. The actual dimensions of the plan were adapted in rebuilding the model. The design of the plan was obtained from Philkoei International, Inc., in coordination with the design teams of EEI Corporation and San Miguel Corporation. AutoCAD files of the plan were disclosed from STRIDE Consulting, Inc. and was updated depending on the design team of the MRT 7 Rail Transit System.

2.3 Pedestrian Simulation

The constructed 3D model of the station served as the foundation of the simulation. Major procedures prior to the simulation include source mapping, assessment of the servers, delivering the exits, and path analysis.

2.3.1 Sources

In source mapping, critical points in the station for pedestrian entry were determined. These include, but are not limited to, entrance stairs and escalators, merging concourse area for two stations, and elevators. These were also composed of pedestrian walkways from the street level calibrated to the number of people entering the train station

2.3.2 Servers

The assessment of servers, machines and manual ticketing systems was worked out depending on the assumptions and standards set by the rules on rail transit systems in the Philippines. These machines and manual ticketing systems were also part of the preliminary plan for the interior design of the station. These include the position of the automatic ticketing machines, windows, and rooms for manual ticketing machines and toll gates that regulate the flow of passengers entering the platform area. However, servers simplified the simulation and comfort rooms and other operations were not accounted as delays. Moreover, emergency events and fluctuations in the volume of passengers during holidays were excluded as factors for the adjustments of the servers.

2.3.3 Sinks

The sinks in the software were the exits installed as pedestrians leave the station boarding the train. It controlled the use of the train based on its headway, frequency of trips, and capacity of the train. The properties of the train were the key factors in the adjustment of the sink object in the software.

2.3.4 Paths

Path analysis served as the framework of the simulation because it connected the source, servers, and sinks of the model. The connections were the paths of pedestrians as they move throughout the concourse and platform areas of the train station. Adjustments in travel time, processing time, delays, and transfer times are the major contributions of this procedure and it influenced the overall outcome of the simulation. After setting up all the necessary paths, the simulation was run and the results for each facility, its utilization status, and time-related factors in the system about pedestrian were determined. Using the software, results were tabulated and sorted based on the needs of the machine to be utilized. Current number of users in the system and capacity of the system were also determined from the results produced by the software. Finally, the simulation provided footages of the behavior of queuing in the station and the count for the maximum passenger capacity of the station.

3. RESULTS AND DISCUSSION

3.1 Presentation of Data

A substantial amount of data is needed to enable simulation of real-life scenarios inside a train station. These data were divided into three core data, namely, proposed plan of the station, historical data and site survey reports. Each datum contributed to run the replica of the rail transit system.

3.1.1 Proposed plans

The first essential data in the simulation were those obtained from the proposed plan of the North

Avenue station. The plan served as the floor of simulation as well as an aesthetic element in the simulation. The plan was then converted to a three-dimensional building to deliver a close-to-reality image of the station.

There are two common stations for MRT 7 North Avenue Station, as MRT 3 North Edsa Station has been connected to the extended LRT 1 Roosevelt Station on the same level of elevated platform train station. These original and new proposed plans for the common station will be located in front of SM North Edsa. The top view of the proposed plans is shown in Fig. 1.

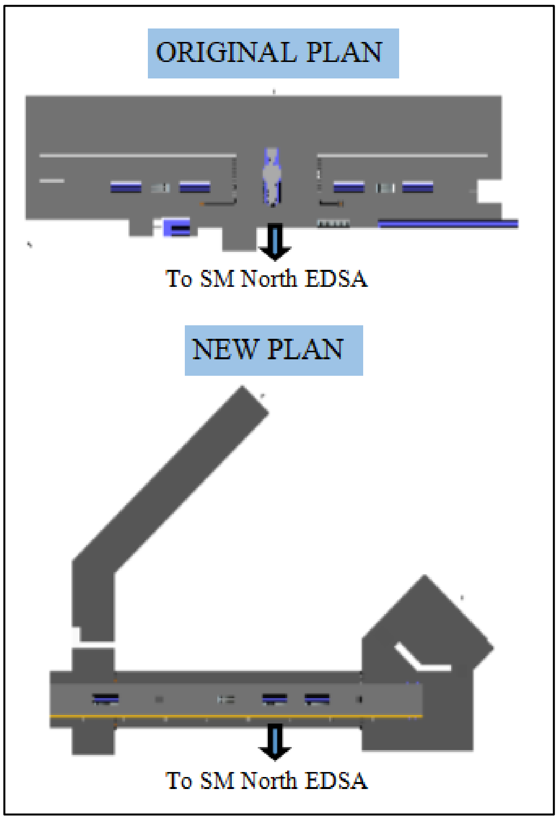

Fig. 1 Top view of common stations

Several assumptions were considered in the simulation in terms of the three-dimensional model. To simplify the station, various facilities of the train station such as the communication room, maintenance room, and electricity room, among others, were omitted and represented only by interior boundary walls in the concourse area. Simplifications also included openings, wherein no windows and doors were visible in the model. Lastly, exterior walls were also not drawn because these hinder the users' view, as well as to minimize the use of three-dimensional objects that slow down the loading time.

3.1.2 Historical data

After constructing the model's framework, historical data are the next essential data for the simulation. Data on the population, which are the traffic per hour per station and number of monthly passenger traffic for 2014, were based on those data obtained from the official website of the DOTr. These were the latest data available to public and can be easily accessed and downloaded from DOTr's website. The arrival of passengers at North Edsa station with respect to the operating time of the station was the main source for the population used in the simulation [12].

From the available data, the peak number of passengers is 6,818, recorded at a time interval of 8AM to 9AM. The count was from the MRT 3 North Edsa Station, which was assumed to be the source of passengers boarding the incoming MRT 7 North Avenue Station. The peak count for passengers were directly used in the simulation through the source library, with 6,818 passengers for the original plan and 8,237 passengers for the new plan. The growth rate used was 3.2% based on the Metro Manila Urban Transportation Integration Study (MMUTIS) conducted in 1999.

3.1.3 Pedestrian speed

In addition to the historical data, pedestrian speed as well as time interval in using the stairs were incorporated in the simulation through the time paths. Summarized in Table 1 are the speeds of a normal male passenger and the speed of escalators and stairs. These speeds were converted to time intervals because time paths in Simio requires time intervals instead of speeds. With the length of the stairs and escalators available, time intervals were obtained.

Table 1 Summary of speeds for passengers and vertical components

STATION COMPONENTS	SPEED(m/s)
Passengers (Tregenza, 1976)	1.70
Escalator (Schindler, 2007)	0.60
Stairs (Fruin, 1971)	0.57
Elevator (Schindler, 2007)	0.60

Note: escalator and elevator speeds were based on 27° inclination.

3.1.4 Delays and time usage

The last core data used in the simulation were the delays and time usages, which were subdivided into four major stages. These are entrance and security check, ticket issuance, gate passage, and waiting time for train departure. Security guards check the arriving passengers, thereafter passengers have two options: to go directly to the ticket gates or fall in line at the manual and automatic ticket windows. Passengers with tickets will then go to the gate to enter the paid concourse area [13].

An inter-arrival rate of 1.21 seconds was adopted in the study [13]. During the second part of the simulation, upon entering and undergoing security check, passengers will use the manual Booking Office Machine (BOM) or automatic Token Vending Machine (TVM).

Based on the report obtained from the MRT 7 design team and Hyundai Rotem, the duration of issuance of one ticket for TVM was 43 seconds and 20 seconds for BOM. The same report indicated that the time processing in using the gate passage to enter the paid concourse is 1.4 seconds. These three major calibrations represented by servers in the simulation were adopted to virtually present the scenario wherein the passenger gets a ticket and enters the gates. In addition, the same report showed passenger distribution within the train facilities. In the path of the simulation, 10% of the passengers were designated to use TVM while 35% was assigned to BOM. The remaining 55% of passengers were assumed to have availed of promos and reloading beep cards, wherein passengers directly proceed to gate passages [14].

Meanwhile, the headway used in the simulation was based on the official operations page of the DOTC-MRT 3 website. The headway was intended for the AM peak operation of MRT 3 North Edsa Station. Summarized in Table 2 are the time usages used in the calibration of sources, servers, paths and sinks.

Table 2 Summary of time usage in simulation

BOARDING PHASES	TIME USAGE(s)
Inter-arrival Time	1.21
TVM Usage	43
BOM Usage	20
Gate Passing Time	1.4
Waiting Time	240

3.2 Simulation Analysis

Based on the simulation results panel of Simio, the results produced included the capacity, service time, level of service (LOS), and utilization of facilities. Illustrated in Fig. 2 and Fig. 3 are the results for the capacity of each station and the total service time from entering to exiting through the trains. The maximum passenger capacity obtained was 2,507 passengers for the new station, compared to the 2,031 passengers for the original station. It was observed that both stations reached a constant capacity at some point after running the simulation for more than an hour. For the original station, the constant capacity was recorded at the 75-minute mark. The passenger count at this point was constant until the end of the simulation. On the other hand, the constant capacity was recorded at the 90-minute mark for the new plan.

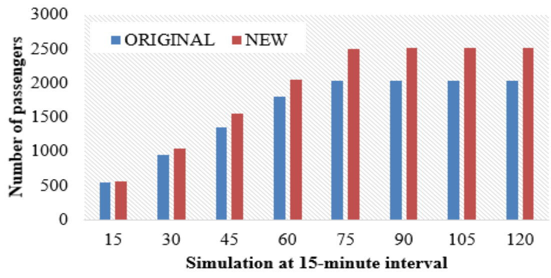

Fig. 2 Maximum number of passengers

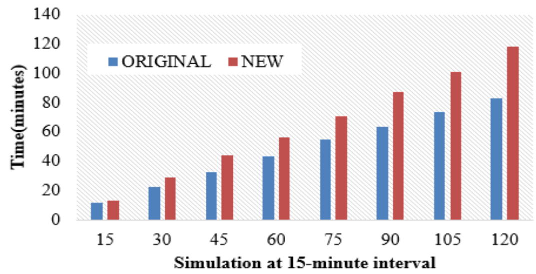

Fig. 3 Maximum time in the system

The capacity for each plan was reached at different times, which means that one station was better than the other in terms of accommodating passengers. As a station reaches its capacity, passengers will be more congested inside as time progresses, decreasing the travel time, reducing passenger convenience, and resulting in lower level of service. Since the original plan reached its capacity first, it was the first one to experience severe congestion and lower level of service.

In terms of service time, a consistent result was obtained, indicating that the new plan has a longer time in the system than the original plan. Both plans recorded at the 120-minute mark, with the new plan registering 117.942 minutes of passenger stay while the original plan registering 83.01 minutes. It was expected that the longest stay would be recorded at the end time mark since more passengers have already accumulated inside the train station. The 35-minute difference was long enough to decrease rail transportation convenience and reduce passenger satisfaction.

Accounting also for queuing in the station, it was identified that at the 7:30AM mark, 167 passengers were already in line for the BOM based on the original plan. In contrast, only 80 passengers have queued for the BOM at the same time mark based on the new plan. The 7:30AM mark was used as the first simulation, since starting 7:00AM, the first 15 minutes were used as warm-up period. It is assumed that before the peak hour, the station was already occupied by passengers. Illustrated in Fig. 4 are the scenarios at the two stations. These were snapshots from the actual simulation for both stations.

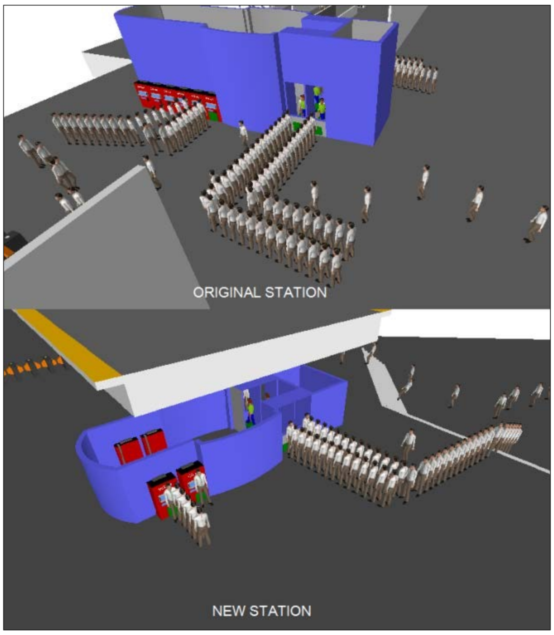

Fig. 4 Queuing at 7:30AM for both stations

The second illustration for queuing was captured at the 8:30AM mark. At this point, peak hour was achieved and both stations were expected to form extensive passenger lines. It was recorded that the maximum number of passengers waiting in the queue was 394 passengers for the original plan, which is higher compared to 209 passengers forthe new plan. Queuing scenarios are illustrated in Fig. 5. The severe queuing observed was corroborated by the level of service, which is expected to be at a low level.

The LOS was categorized based on the pedestrian level of service formulated by Kardi Teknomo in 2002, as shown in Table 3. The LOS was computed using the average volume of passengers at each time interval divided by the capacity (volume-to-capacity ratio), which are summarized in Table 4.

The volume-to-capacity ratio (V/C ratio) for the original station at 8:30AM was 0.6061, resulting in LOS categorized as E. On the other hand, the LOS for the new plan was categorized as D for the same time mark with a V/C ratio of 0.5844. The V/C ratio was computed by taking the average number of passengers as the current volume in each 15-minute time interval and dividing it by the capacity also in each interval. It is evident that the results support the claim that new plan has a higher capacity, since it only reached a lower LOS of E at 8:45AM in contrast to an earlier time of 8:30AM for the original plan.

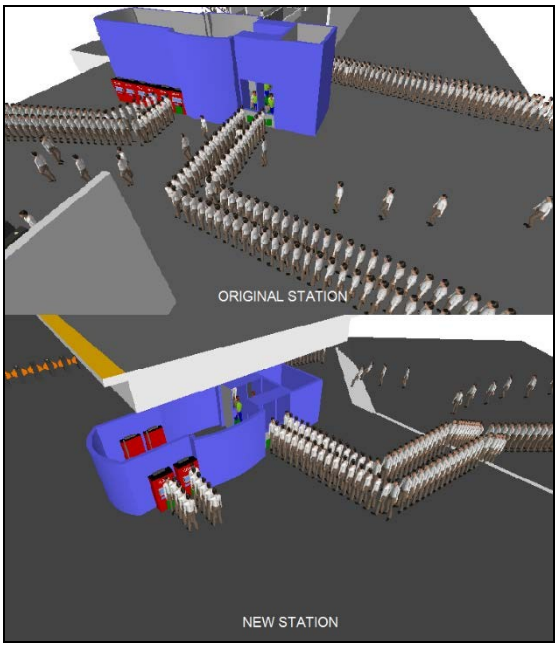

Fig. 5 Queuing at 8:30AM for both stations

Table 3 Pedestrian level of service in walkway

LOS	V/C Ratio
A	≤0.08
B	≤0.28
C	≤0.40
D	≤0.60
E	≤1.00
F	Variable

Note: average condition for 15 minutes.

Table 4 Level of service

TIME	V/C RATIO(LOS)	
	Original	New
7:00AM	0.5922(D)	0.6084(E)
7:15AM	0.5637(D)	0.5454(D)
7:30AM	0.5491(D)	0.5236(D)
7:45AM	0.5259(D)	0.5173(D)
8:00AM	0.5611(D)	0.5228(D)
8:30AM	0.6061(E)	0.5844(D)
8:45AM	0.6197(E)	0.6152(E)
9:00AM	0.6137(E)	0.6271(E)

For the utilization of train facilities, only TVM and BOM were analyzed. This resulted in an average of 99.38% utilization of BOM for the original plan while an average of 99.04% utilization for the new plan. High utilization of the BOMs is essential since the increase or decrease in quantity of this facility depends on its utilization. Moreover, BOMs are more difficult to install since these occupy more space and are considered structures that are part of the building. In addition, TVM utilization is higher in the original station with a peak of 99.04% compared to 90.70% for the new station.

4. SUMMARY AND CONCLUSIONS

Employing the combination of data and simulation, the capacity, service time, LOS, and utilization of train facilities for MRT 7 were obtained based on the original and new plans. Comparing the two stations, the new plan allowed for a higher capacity of 2,507 passengers compared to the 2,031-passenger capacity of the original plan. The service time for the original plan is shorter, however, at 83.01 minutes relative to 117.94 minutes for the new plan. At the 8:30AM mark, the LOS in the new plan was rated D, which is better than the E rating of the original plan.

Finally, train facilities were more optimized in the original station, with an average of 99.38% utilization compared to 99.04% for the new plan. However, in the context of maximum passenger capacity, which is the focus of this study, the lead of the original plan in terms of facility utilization can be considered insignificant. Based on the foregoing results, it is evident that the new plan proposed for the MRT 7 Station 1-North Avenue Station is better than the original plan.

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