Research on Medium Capacity Rail System: Case on Pham Van Dong Route in Ho Chi Minh City, Vietnam

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***Abstract*—This paper delves into the study and proposition of a Medium Capacity Rail System (MCS) model to tackle urban traffic issues, both in the immediate future and, more specifically, the public transportation challenges along the Pham Van Dong (PVD) route. Drawing from statistical surveys and an in-depth analysis of motorcycle traffic patterns at intersections during near-peak and peak hours in the morning and afternoon along PVD's main artery in the northeastern part of Ho Chi Minh City (HCMC), Vietnam. Moreover, this research explores the relatively new concept of MCS, which have gained traction in recent years due to their distinct advantages over existing systems. The findings in this article underscore the practicality of the proposal and provide a blueprint for sustainable, integrated urban transport development, improve traffic flow, reduce congestion, reduce environmental pollution and enhance a complete and modern urban railway network for Ho Chi Minh City or other similar global scenarios.**

***Index Terms*—urban railway, light rail transit, bus rapid transit, medium capacity rail system, mass rapid transit**

I. INTRODUCTION

Urban transport is a serious problem that needs to be solved for all major cities in the world. Due to the raise in vehicle, the road is incapable of handling the traffic...The planning and construction of roads in large urban areas with large corridors aims to provide sufficient traffic capacity. However, the population growth rate and high population density in large cities have been too rapid in recent decades. Therefore, these avenues are quickly overloaded on the route and create local traffic jams at the intersections. There are many ways to solve the problem of traffic congestion and peak hour overload, such as traffic diversion [1], intelligent traffic monitoring, arranging signal installation [2], controlling, monitoring and managing traffic congestion [3–7], construction of steel solutions or even dividing office work time according to each group of subjects to divide the number of private vehicles participating on the roads [8–10]. However, this is not an effective solution to the problem of urban traffic and environmental pollution caused by private vehicles, especially in Hanoi and HCMC, Vietnam [11–14]. To solve this problem, there needs to be an effective solution that addresses the nature of the problem, which is to evaluate the traffic and limitations of personal vehicles. This means replacing it with a means of public transport with large transport capacity, efficiency, environmental friendliness, and sustainability, promoting more comprehensive urban development [12]. In the urban transport system, many types of services can meet the large transport capacity with high service frequency. The choice of type must be considered by many factors of the general development of urban transport, topography (routing), and characteristics of its superstructure and infrastructure [13–15]. However, properly assessing the situation and traffic needs is an important first step that needs to be clarified.

Urban rail transit supports the development of megacities, while changes in urban spatial structure affect the structure of urban rail transit networks and the carbon emissions of vehicles [16]. The interactions between urban rail transit and urban space in megacities form a complex spatial networking system. It has become important to guide cities toward low-carbon, energy-saving, and sustainable development through rail transit planning recently [17–19]. Experience of leading countries and regio countries with relatively close conditions shows that these have all developed and are planning to build a multi-purpose urban transportation system with types such as free bicycle loans, buses, bus rapid transit, and urban railways such as trolleybus, tramway, light rail transit (LRT), mass rapid transit (MRT) and commuter rail, in addition to developing walking corridors [20–22].

In addition, in recent years, the Medium Capacity Rail System (MCS) system has been introduced with outstanding advantages that can meet the traffic capacity range that bus rapid transit - BRT (from 5,400 passengers per hour per direction - p/h/d to 10,800 (p/h/d) or LRT (from 18,000 p/h/d to 24,000 p/h/d) cannot meet the requirement or MRT (from 18,000 p/h/d to larger) with too expensive construction costs [23–26]. In this study, MCS is the proposed solution in the case study on the

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PVD route with a surveyed traffic flow of 29,595 motorcycles during peak hours in direction [8–10, 13].

II. MEDIEUM—CAPACITY RAIL SYSTEM

A. Introducing MCS

A MCS is a rail transport system with a capacity greater than light rail, but less than typical MRT. The definition of a MCS varies due to its non-standardization. Inconsistencies in international definitions are even reflected within individual countries. The exclusive right-of-way is usually provided similar to LRT class A and elevated segment subways. However, the biggest difference of MCS is that it can be built along roads without much impact on the current status.

MCS has a carrying capacity from 15,000 p/h/d to 32,000 p/h/d or even greater, depending on train structure and service headways. Typical trains of this type have from 2 cars to 8 cars per train, with a passenger capacity depending on the structure and size of a train, the smallest can be 200 passengers/train to 1,200 passengers/train, and service headways can be from 3 minutes/train/direction up to 1.5 minutes/train/direction with Communications-Based Train Control (CBTC) or even designed up to 72 seconds/train/direction for GoA4 standard – (unattended train operation (UTO)) [27–36].

The main reason for building MCS instead of regular subways is cost savings, mainly because the carriages are shorter and the stations are shorter in this system. The MCS has the potential to operate faster than MRT systems due to shorter dwell times in stations and faster acceleration and deceleration of light trains.

The disadvantage is similar to other types, the route capacity is designed to be limited, meanwhile, the number of passengers is likely to increase in the future.

However, this limitation can be easily overcome through adequate forecasting for potential growth over the life of the MCS line when constructing station platform length, as well as forecasting capacity consumption.

B. Signal and Train Control

According defined in the IEEE 1474 standard, A CBTC system is a "continuous, automatic train control (ATC) system utilizing high-resolution train location determination, independent from track circuits; continuous, high-capacity, bidirectional train–to–wayside data communications; and train borne and wayside processors capable of implementing Automatic Train Protection (ATP) functions, as well as optional Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) functions," as defined in the IEEE 1474 standard.

Thus, to accommodate high carrying capacity in a streamlined system structure, MCS uses a CBTC system. CBTC is a railway signaling system that uses telecommunications between the train and track equipment for traffic management and infrastructure control. CBTC allows a train's position to be known more accurately than with traditional signaling systems. This makes MCS traffic management safer and more efficient. MCSs can reduce headways while maintaining or even improving safety [37, 38].

Modern CBTC systems allow different levels of automation or Grades of Automation (GoA), which shall consist of three major components: ATS, ATO, and ATP. This is the core technology that supports the purpose of operating MCS, as defined and classified in the IEC 62290–1.

The grades of automation available applicable for MCS range from a manual protected operation, GoA 1 (only applied as a fallback operation mode in this MCS) to the fully automated operation, GoA4 [39].

C. Automatic Fare Collection System (AFC)

AFC is an indispensable requirement for MCS at PVD route. The AFC system consists of the central control server, integrated with automatic gates and ticket vending machines being installed at every station. In this option, a stable and integrated platform must ensure smooth passenger high flow during peak hours; At the same time, all data will be collected and transmitted to the center. The central control server has functions for adjusting fares, managing contactless IC cards, calculating sales revenue, and submitting a Consolidated Report.

D. Power Supply

Similar to MRT, the MCS system is supplied with power from the power stations, with voltage levels from 22 kV to 35 kV from 110 kV or 220 kV Grid Sub–Stations [35, 36]. The 22 kV AC power is converted to 750 V DC at the substations and supplied to the power lines along the guideway tracks for train operation. Simultaneously, the 22 kV AC power is also stepped down to 400 V AC three-phase and distributed via an uninterruptible power supply (UPS) for the signaling, communication, and other equipment [25]. Regenerative Energy Storage Systems are provided at each station and connected to the traction power circuits. When an arriving train approaches a station and decelerates by using regenerative braking, the energy fed back to the traction power supply system will be stored in the batteries [40–50].

III. TRAFFIC SITUATION AND SOLUTIONS FOR THE PVD ROUTE

A. Traffic Situation on the PVD Route

In many ASEAN countries, motorcycles are a popular vehicle, especially in Vietnam, where the proportion of two-wheeled vehicles is very high, accounting for 74% in HCMC, cars account for 1%, and buses account for 4% [8, 15]. In [13–15], HCMC aims that by 2020, the market of public passenger transport throughout the city will assume 15% to 20% of the needs of the people moving. By 2025, it will reach 20.5% to 26.6%, and by 2030, this ratio will increase to 29.3% to 36.8%. However, until now, public passenger transport in HCMC has only met about 9% of the travel needs of the people-the distance is quite far from the goal. In recent years, HCMC has focused a lot of investment in buses from infrastructure to policies to support new car loan interest and waiting stations. However, over the years, the number of bus passengers tends to reduce. Compared to the end of 2017, the bus network in HCMC is currently down seven routes (five subsidy routes including 37, 40, 60, 95, and 149, and two non-subsidized routes including 12 and 49).

Based on an analysis of the current state of urban traffic in major cities in Viet Nam such as Hanoi and HCMC. The research results show that the capacity values of urban roads of 2, 3, and 4 lanes per direction are 13,358; 21,725, and 24,335 respectively (motorcycles per hours) [13]. Similarly, the results of research and survey on the PVD with 2 lanes to 4 lanes each way for motorcycles are the largest at the largest at the Giga Mall shopping center are 29,595 and 27,603 motorcycles/hour/direction at after midnight and past-morning (AM and PM), in Table I.

TABLE I: SURVEY RESULTS OF MOTORCYCLE TRAFFIC CAPACITY ON THE PVD ROUTE

Point station	Motorcycles/hour/direction			
	AM (hours)		PM (hours)	
	7–8	8–9	5–6	6–7
Linh Xuan (LX)	7,834	10,425	8,212	9,865
An Binh (AB)	8,418	11,860	8,867	12,564
Linh Tay (LT)	9,625	13,089	9,548	13,806
To N. Van (TNV)	10,368	14,590	11,854	15,648
Linh Dong (LD)	12,887	18,556	13,687	19,275
Hiep Binh (HB)	15,014	24,529	18,935	24,709
Giga Mall	17,174	29,595	19,635	27,603
Binh Trieu (BT)	14,270	24,193	17,452	25,564

The results of motorcycle traffic on the PVD route were surveyed statistically from February 2023 to July 2023, summarized in Table I. In this table, the largest value is shown in two rush hours (at AM and PM), this is the time frame with the heaviest traffic on the route during the day. In the morning, traffic flows from the suburbs to the center in the direction of Linh Xuan (LX) intersection to Binh Trieu (BT) intersection and vice versa in the evening. Survey results show that motorcycle traffic through Giga Mall station is the largest at 29,595 motorcycles/hour/direction (m/h/d) and 27,603 m/h/d during peak morning and afternoon hours.

On the route, in Fig. 1, the flow of passenger traffic tends to gradually increase from the LX node to the Giga Mall node during morning peak hours (towards the center) and gradually decrease from the Giga Mall node to the LX node in the afternoon exit direction. In the inbound direction, passenger traffic increased significantly at Linh Dong intersection is 18,556 motorcycles/hour (8:00 AM. to 9:00 AM), due to the traffic flow from To Ngoc Van intersection. At the same time, also at Linh Dong intersection is the merger of three traffic flows on PVD, Kha Van Can, and Linh Dong streets, this traffic flow will increase at Hiep Binh (HB) intersection, and traffic result is 24,529 motorcycles/hour, see Table I and Fig. 2. At the Giga Mall node, traffic increased due to a large number of traffic flowing in from HB street to PVD and flowing to the Giga Mall node, and the traffic value is 29,595 motorcycles/hour, see Table I and Fig. 3. On the contrary, in the afternoon exit direction, the flow at the Giga Mall node is due to the number of vehicles coming from the direction of Tan Son Nhat (TSN) Airport and Highway 13 from Mien Dong Bus Station, these are two large flows that cause traffic increase traffic flow at this node, and the largest traffic volume is 27,603 motorcycles/hour at 6:00 PM to 7:00 PM, see also Table I and Fig. 4.

Fig. 1. PVD route map.

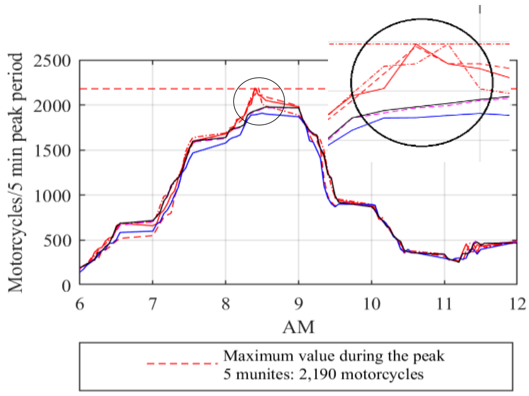

Fig. 2. Traffic flow on weekdays at the PVD—HB intersection at AM.

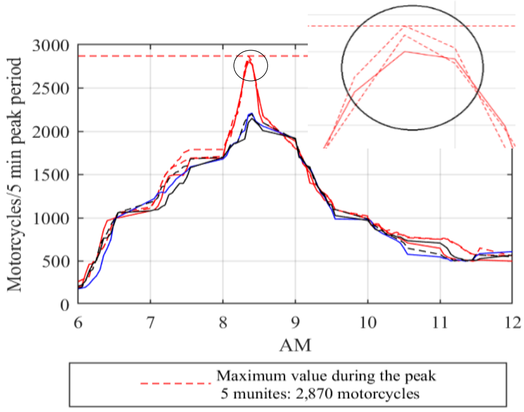

Fig. 3. Traffic flow on weekdays at the PVD—Giga Mall intersection at AM.

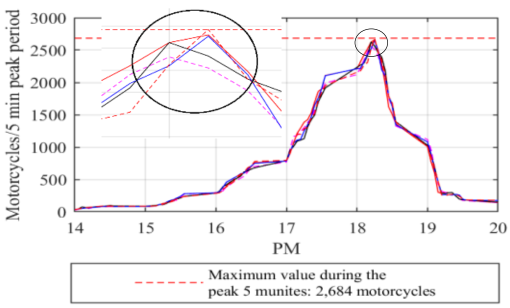

Fig. 4. Traffic flow on weekdays at the PVD—Giga Mall intersection at PM.

In addition, the largest motorcycle traffic during peak hours on weekdays from Monday to Friday is mainly on Monday mornings, traffic flow at the PVD-Giga Mall intersection on Mondays can increase by up to 2,870 motorcycles in a 5-minute peak period. On the remaining days, motorcycle traffic does not change significantly between weekdays during peak hours in the direction from LX to BT as shown in Fig. 2 and Fig. 3. On the contrary, during evening peak hours, motorcycle traffic has almost no change between weekdays from Monday to Friday, the largest traffic is up to 2,748 motorcycles in a 5-minute peak period and gradually decreases from HB node is 2,684 motorcycles in a 5-minute peak period, as depicted in Fig. 4 and Fig. 5.

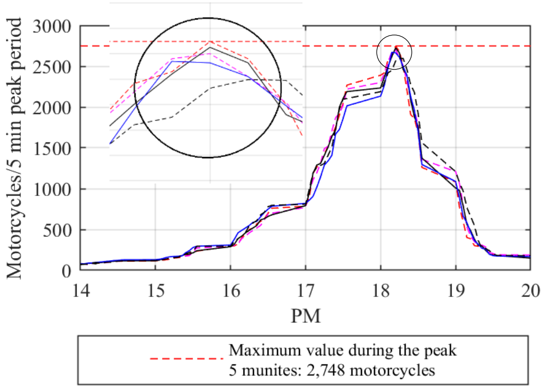

Fig. 5. Traffic flow on weekdays at the PVD—HB intersection at PM.

Survey results and description of the traffic situation on the PVD route show that this is a route with very high traffic density. Currently, with the existing number of lanes, traffic density on the route is relatively dense, with some local traffic jams at railway intersections during morning and evening rush hours such as at PVD and To Ngoc Van intersection due to railway traffic barriers. Furthermore, shortly, urban development will increase traffic capacity on the route. Therefore, solving traffic problems on the route needs to be researched soon and appropriate solutions will be found.

Capacity increases with the number of urban lanes, but the sustainable urban transport development plan cannot develop the number of lanes to keep up with the growth of motorcycles. There has been a recommended solution for HCMC urban traffic is to plan for an extensive public transportation system, which would include MRT and bus rapid transit corridors [38]. However, the above survey and analysis show that it is necessary to consider a MCS for the PVD route instead of comparing the bus rapid transit and MRT.

B. Line Planning

Based on “Approval of Adjustment of Ho Chi Minh City Transport Development Planning to 2020 and Vision after 2020” and analysis of the current status of actual needs on the PVD route. The author proposes that it is necessary to plan an urban railway line to meet this need in the nearest possible future, Fig. 6 and Fig. 7. The construction of the MCS line also completes the missing transport network of HCMC.

Fig. 6. Planning network HCMC metro

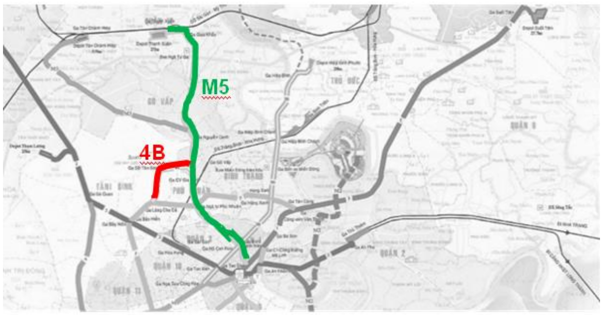

Fig. 7. Metro Line M5 and 4B planning.

Currently, the proposal for phase 1 of the route will have a route from LX intersection as the first station (ST.B) to BT intersection as the last station (ST.E). The final station will be an integrated station with line M3 at BT station. In the next phase, it will expand in both directions: from ST.B station to Di An City (Binh Duong Province) and from ST.E station to Gia Dinh Park. Also in this proposal, the ST.E station will be expanded to go through Gia Dinh station (integrated) of the M4 line, extending to TSN Airport and ending at Lang Cha Ca station (integrated) of line M5. The proposed MCS system for the HCMC urban railway network map will be more complete with the route from Di An passing through TSN Airport ending at Lang Cha Ca station mostly along the PVD line. Thus, the extension route 4B (Gia Dinh Park - TSN Airport - Lang Cha Ca) currently in the planning is not necessary and will be eliminated and replaced with the newly proposed plan, see Fig. 8.

Fig. 8. Proposed medium-capacity rail line PVD.

The planning of stations along the route will prioritize convenient locations near intersections or junctions. If the above conditions are not met, the minimum distance is 500 meters/station and the furthest is 1,200 meters/station.

IV. Operation Plan

A. Design of Service Capacity

The problem of the carrying capacity of the line on the planned schedule to meet the needs of passengers to use the subway is based on many mutually binding factors such as the capacity of the train, service frequency, and signal control system. From the service frequency point of view, the headway can be neither equal to every hour nor varying throughout the day, depending on the demand and capacity provided. This depends on the needs of train riders at each time frame of the day and the transport capacity of the largest possible capacity line. In terms of providing transportation services and operating most efficiently, the design must anticipate the maximum number of passengers using the train service when planning, which considers the need for future capacity development with the initial build system constraints.

The calculations for planning service provision on the route with the highest capacity for a system life cycle based on the control signal system are given below [51–55], and all variables of simulation calculations are defined as in Table II.

TABLE II. VARIABLE DEFINITION

Variable	Definition	Value/Unit
V_f	maximum traffic flow value	motorcycle/hours/direct
A_f	traffic actual flow	motorcycle/hours/direct (m/h/d)
PHF	peak hour factor	-
P5	peak 5-minute train passenger load	motorcycle/5 minute/direct
j	the times	-
n	integer	-
$D_{\text{e-max}}$	maximum traffic demand in each phase	person/ hour/direct (p/h/d)
PDF	traffic growth coefficient	-
k_c	demand coefficient	0.9 to 1.1
$C_{\text{L-max}}$	person capacity	person/ hour/direct (p/h/d)
$T_{\text{c-max}}$	line capacity	train/ hour/direct (t/h/d)
$C_{\text{t-max}}$	maximum person per train on schedule	person/train
n_c	number of the car	4–8 cars
L_c	car interior length	20–25 meters
$L_{\text{t-max}}$	longest train length	120–200 meters
L_{st}	longest station length	meters
p_t	person per meter of train length	4.0 to 13 persons/ meters length
$H_{\text{s-min}}$	station headway	second
$T_{\text{s-min}}$	train separation	second
d_{eb}	distance from the front of the stopped train to the start of the station exit block	meter
v_a	station approach speed	meters/second
v_{max}	maximum line speed	meters/second
k_{br}	braking safety factor	worst-case service braking is $k_{\text{br\%}}$ of specified normal rate – typically 75%
B	separation safety factor	equivalent to the number of braking distances (a surrogate for blocks) that separate trains (2.4 three-aspect, 1.2 cab signal, and 1.0 moving block)
t_{os}	time for overspeed governor to operate	second
t_{jl}	time lost to braking jerk limitation	typically 0.5 seconds
t_{br}	brake system reaction time	second
t_d	dwell time	second
t_{om}	operating margin	second
a_s	initial service acceleration rate	m/s^2
d_s	service deceleration rate	m/s^2
a_g	acceleration due to gravity	m/s^2
G_i	grade into station	%
G_o	grade outstation	%
l_v	line voltage as percentage of specification	90%
P_e	positioning error – moving block	meter
S_{mb}	block safety distance – moving block	meter

The maximum load and service capacity is determined by:

$$V_f = A_f \times \text{PDF} \text{ with } \text{PHF} = \frac{1}{n}\sum_{j=1}^{n}\frac{A_{f,j}}{12P_{5j}} \tag{1}$$

$$D_{\text{e-max}} = V_f \times \text{PDF} \times k_c \tag{2}$$

$$C_{\text{L-max}} = T_{\text{c-max}} \times C_{\text{t-max}}, \text{ for } C_{\text{L-max}} \geq D_{\text{e-max}} \tag{3}$$

$$C_{\text{t-max}} = L_{\text{t-max}}\, p_t \text{ for } \begin{cases} L_{\text{t-max}} = nL_c \\ L_{\text{t-max}} \leq L_{st} \\ 4 < p_t \leq 11.5 \end{cases} \tag{4}$$

$$T_{\text{c-max}} = \frac{3600}{H_{\text{s-min}}} \tag{5}$$

In Eq. (5), $H_{\text{s-min}}$ (station headways) is the minimum train separation determined with three types of train control systems.

Eqs. (6) and (7) determine the minimum station headway (H_s) and the minimum train separation (T_{cs}) in seconds with three-aspect fixed-block signaling system, with (8) and (9) for cab signaling, (10) and (11) for moving block (MVB) with fixed stopping distance, and (12) and (13) for MVB with variable stopping distance:

$$H_{\text{s-min.op}(i)} = \sqrt{\frac{2(L_t + d_{\text{eb}})}{a_s}} + \frac{L_t}{v_a} + \left(\frac{100}{k_{\text{br}}} + B\right)\left(\frac{v_a}{2d_s}\right) + \frac{a_s t_{\text{os}}^2}{2v_a}\left(1 - \frac{v_a}{v_{\max}}\right) + t_{\text{os}} + \sum t \tag{6}$$

$$t_{\text{co.os}(i)} = \sqrt{\frac{2(L_t + d_{\text{eb}})}{a_s}} + \frac{L_t}{v_a} + \left(\frac{100}{k_{\text{br}}} + B\right)\left(\frac{v_a}{2d_s}\right) + \frac{a_s t_{\text{os}}^2}{2v_a}\left(1 - \frac{v_a}{v_{\max}}\right) + t_{\text{os}} + t_{\text{jl}} + t_{\text{br}} \tag{7}$$

$$H_{\text{s-}i\,\text{min.op}(ii)} = \frac{L_t + S_{\text{mb}}}{v_a} + \frac{100}{k_{\text{br}}}\left(\frac{v_a}{2d_s}\right) + \sum t \tag{8}$$

$$t_{\text{cs.op(ii)}} = \frac{L_t + S_{\text{mb}}}{v_a} + \frac{100}{k_{\text{br}}}\left(\frac{v_a}{2d_s}\right) + t_{\text{jl}} + t_{\text{br}} \tag{9}$$

$$H_{\text{s-imin.op}}=\frac{L_t+P_e}{v_a}+\left(\frac{100}{k_{\text{br}}}+B\right)\left(\frac{v_a}{2d_s}\right)+\frac{a_s\left(1-\left(\frac{a_g}{100}\right)G_i\right)l_v^2t_{\text{os}}^2}{20000v_a}\left(1-\frac{v_a}{v_{\max}}\right)+t_{\text{os}}+\sum t \tag{10}$$

$$t_{\text{cs.op(iii)}}=\frac{L_t+P_e}{v_a}+\left(\frac{100}{k_{\text{br}}}+B\right)\left(\frac{v_a}{2d_s}\right)+\frac{a_s\left(1-\left(\frac{a_g}{100}\right)G_i\right)l_v^2t_{\text{os}}^2}{20000v_a}\left(1-\frac{v_a}{v_{\max}}\right)+t_{\text{os}}+t_{\text{jl}}+t_{\text{br}} \tag{11}$$

$$H_{\text{s-imin.op(iv)}}=\frac{L_t+P_e}{v_a}+\left(\frac{100}{k_{\text{br}}}+B\right)\left(\frac{v_a}{2d_s(1+0.1G_i)}\right)+\left(\frac{a_s(1+0.1G_i)t_{\text{os}}^2}{2a_s}\right)\left(1-\frac{v_a}{v_{\max}}\right)+t_{\text{os}}+\sum t \tag{12}$$

$$t_{\text{cs.op(iv)}}=\frac{L_t+P_e}{v_a}+\left(\frac{100}{k_{\text{br}}}+B\right)\left(\frac{v_a}{2d_s(1+0.1G_i)}\right)+\left(\frac{a_s(1+0.1G_i)t_{\text{os}}^2}{2a_s}\right)\left(1-\frac{v_a}{v_{\max}}\right)+t_{\text{os}}+t_{\text{jl}}+t_{\text{br}} \tag{13}$$

$$\sum t=t_{\text{jl}}+t_{\text{br}}+t_d+t_{\text{om}} \tag{14}$$

According to [46–48], for HCMC, the demand coefficient for calculating traffic capacity is 1.0, and load parameters as Table III. The simulation calculation method using MATLAB R2017b/Script and results for the operating plan are summarized in Table IV.

TABLE III. DATA VALUES FOR SIMULATIONS

Term	value
Train length	120 m–200 m
V_f	29,595 m/h/d
PDF	100%; 150%; 200%
k_{br}	75%
B	2.4; 1.2; 1.0
Overspeed governor time	3 s
Jerk limitation time	0.5 s
Controlling dwell time	30 s–45 s
Operating margin time	15 s–20 s
Service acceleration rate	1.3 m/s^2
d_s	1.3 m/s^2
P_e	6.25 m
Moving-block safety distance	50 m
G_i	1.5%
$v_{\max}$	27.8 m/s
a_g	9.818 m/s^2

TABLE IV. SUMMARIZES THE RESULTS OF THE OPERATIONAL PLAN SIMULATION

Parameters	Value		
PHF	0.8		
$D_{\text{e-max-1}}$ (Phase.1 100%)	23,676 (p/h/d)		
$D_{\text{e-max-2}}$ (Phase.2 150%)	35,514 (p/h/d)		
$D_{\text{e-max-3}}$ (Phase.3 200%)	47,352 (p/h/d)		
$T_{\text{s-min}}$ (i)	60.2466 s		
$T_{\text{s-min}}$ (ii)	48.3310 s		
$T_{\text{s-min}}$ (*iii*)	35.0641 s		
$T_{\text{s-min}}$ (iv)	30.2846 s		
$H_{\text{s-min}}$ (i)	126.3713 s		
$H_{\text{s-min}}$ (ii)	113.3310 s		
$H_{\text{s-min}}$ (iii)	100.0641 s		
$H_{\text{s-min}}$ (iv)	93.7184 s		
$T_{\text{c-max}}$ (i)	28.4875 (t/h/d)		
$T_{\text{c-max}}$ (ii)	31.7654 (t/h/d)		
$T_{\text{c-max}}$ (iii)	35.9769 (t/h/d)		
$T_{\text{c-max}}$ (iv)	38.4129 (t/h/d)		
$C_{\text{L-max}}$	Phase. 1	Phase. 2	Phase. 3
	(p/h/d)	(p/h/d)	(p/h/d)
$C_{\text{L-max}}$ (i)	19,941	31,336	37,034
$C_{\text{L-max}}$ (ii)	22,236	34,942	41,295
$C_{\text{L-max}}$ (iii)	25,184	39,575	46,770
$C_{\text{L-max}}$ (iv)	26,889	42,254	49,937

Note: three-aspect fixed-block (i), cab signal (ii), MVB fixed stopping distance (iii) and moving-block variable safety distance (iv)

B. Result and Discussion

According to the survey, the average peak hour coefficient analysis result is 0.8 as depicted in Fig. 9.

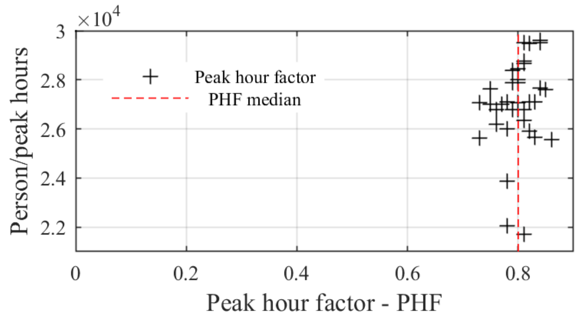

Fig. 9. Peak hour factor on line PVD.

In operation, to meet the expectation of a system with the largest carrying capacity of the same type in each phase. The characteristic of the MCS type is to operate with the highest service frequency. This study describes and compares the separation capabilities of the following types of rail transit train control systems: Three-aspect fixed-block (i), cab signal (ii), MVB fixed stopping distance (iii) and MVB variable safety distance (iv).

Based on the parameters of Table II, the necessary calculation results for the system to work with the highest capacity are described in Table III. Which, type (i) has the minimum station headway time and minimum train separation time are 126.3713 seconds and 60.2466 seconds respectively. Similarly, type (ii) is 113.3310 seconds and 48.3310 seconds; type (iii) is 100.0641 seconds and 35.0641 seconds, and finally, type (iv) is the smallest 93.7184 seconds and 30.2846 seconds with a variable safety distance MVB system and automatic train operation (ATO).

The results are also simulated, minimum train separation and station headway at the station for the PVD route according to capacity demand are compared with different types of signal control systems, as shown in Fig. 10 and Fig. 11.

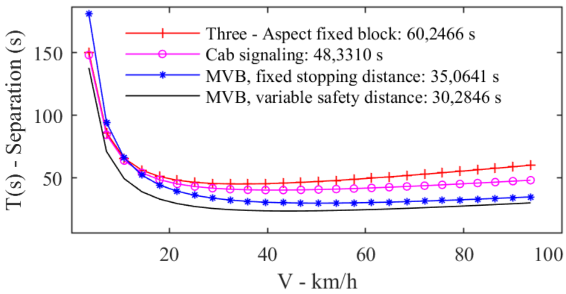

Fig. 10. Minimum train separation versus speed limited for PVD route.

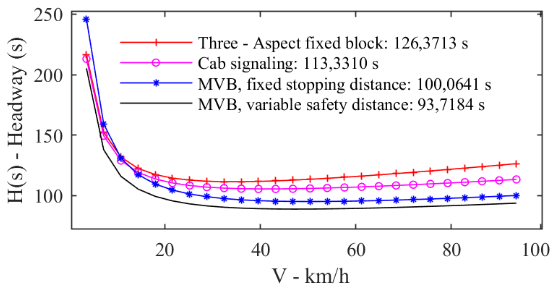

Fig. 11. Station headway for the PVD route.

The minimum total station travel time will correspond to the maximum service frequency or line capacity on the route according to each control signal type that can be provided. The results are: for the Three aspect fixed-block system it will provide 28.4875 trains/hour/direct; for the Cab signal system provide 31.7654 trains/hour/direct; for the MVB fixed stopping distance system provide 35.9769 trains/hour/direct and for the MVB variable safety distance provide 38.4129 trains/hour/direct, described in Table III. Note, the results T_c (i...iv) in Table III are raw data that are not rounding because the $H(s)$ (i...iv) have not been optimized.

The next step, the carrying capacity of the train is based on the number of cars in each train, the length of each car, and the number of passenger spaces per unit of car length. According to the agency's loading standard is based on peak-within-the-peak conditions, a peak hour factor must be used, a PHF of 0.80 was calculated above. This factor accounts for lower passenger demand during the other remaining time of the peak hour, which would result in unused transport capacity being accurately forecasted for capacity demand in the design.

The next one is that the line's capacity will be based on the train's carrying capacity and the frequency of service that each train signal control system provides to solve the greatest traffic demand in each phase, rated according to comfort and flexibility (persons per meter length). In this operational design, the specified maximum each train consists of 5 cars, each car is 25 m length. In this operational design, the specified maximum train of five cars is 125 m length. The load level of train cars will gradually increase from 4 to 13 passengers per linear meter of train length. Corresponding to the peak service frequency will result in the maximum carrying capacity of the route as follows.

- At the most comfortable level, from 4 to 7 passengers per meter of train length, the capacity provided on the route during peak hours depends on each type of train control signal, and the results are described in Table IV and Fig. 12. The results show that, with a peak traffic demand of 23,676 passengers per peak hour direction (p/h/d), which two types of MVB systems (iii) and (iv) are 25,184 p/h/d and 26,889 p/h/d respectively, larger than 23,676 p/h/d capable of providing in phase 1 operation with 100% of traffic demand. Meanwhile, which two systems (i) and (ii), respectively 19,941 p/h/d and 22,236 p/h/d, are smaller than the peak traffic demand of Phase 1.

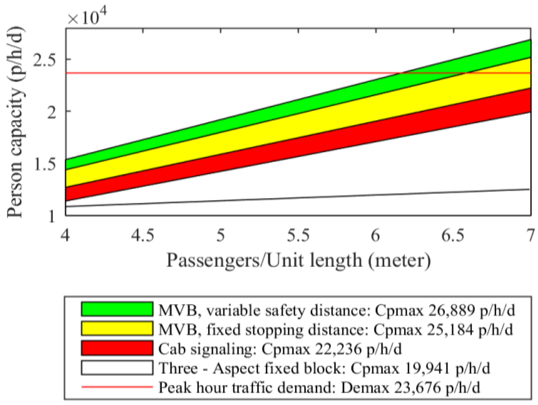

Fig. 12. Provide capacity corresponds to service frequency in Phase 1.

- The standard rush hour range of 8 to 11 passengers per meter of train length, may make passengers feel less comfortable than the smaller range of 8 passengers per meter of train length. With a service frequency of 38.4129 trains per hour per direct (t/h/d), the MVB variable safety distance system provides capacity is 42,254 p/h/d, and similarly, it is 39,575 p/h/d for the fixed stopping distance system with service frequency 35.9769 t/h/d, which is enough to satisfy requirement peak traffic demand in Phase 2 with 35,514 p/h/d, see Fig. 13.

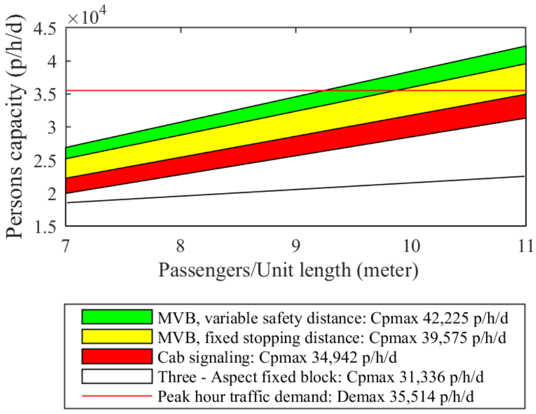

Fig. 13. Provide capacity corresponds to service frequency in Phase 2.

- At higher levels during peak hours, from 11 to 13 passengers per linear meter of train length, equivalent to Asian standards for both maximum and crush loads reach 7 or 8 standing passengers per square meter. The total number of passengers transported at peak hours that the system (iv) can provide is up to 49,937 p/h/d, which is greater than the expected demand growth of 200% in Phase 3. In Phase 3, only the MVB variable safety distance system satisfies the requirement demand with a service frequency of 38.4129 t/h/d and train capacity of 12.5 passengers per linear meter of train length, equivalent to 48,016 p/h/d, greater than the peak traffic demand 47,352 p/h/d, see Fig. 14. However, at a grade of 12.5 to 13 passengers per linear meter of train length, in peak-hour traffic services of rapid trains, the comfort satisfaction rating is still acceptable.

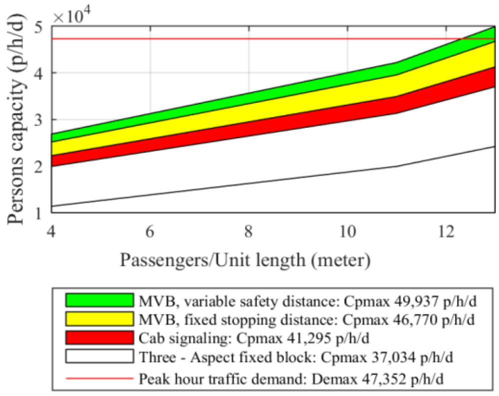

Fig. 14. Provide capacity corresponds to service frequency in phase 3.

V. Conclusion

This article presents the findings of a study on an innovative urban railway transport system. The research delves into various contrasting traffic capacity cases, ranging from a gradual rise in traffic demand to the maximum capacity required for each future period. Furthermore, it explores multiple train control system options to thoroughly assess the selection of the signaling system for high-capacity operations. Research results also show the limitations of the two control signal systems Three aspects fixed-block and cab signal, compared to the superiority of the MVB variable safety distance system used in MCS on the PVD route. Furthermore, the study of the new traffic model MCS applied on the PVD route, is a step forward in planning a complete and modern urban railway network for HCMC. From the perspective of providing transport capacity, the study also shows that MCS can solve the limitations that the BRT, LRT system cannot solve, and avoid wasting investment costs for the MRT system. Finally, this research can also be widely applied to the planning and design of routes with similar traffic demand around the world.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors contributed the work equally.

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References

[1] M. Q. Tran, T.D. Pham, L.H.H. Nguyen *et al*., "Effective traffic routing for urban transportation capacity and safety enhancement," *IATSS Research*, vol. 46, no. 4, pp. 574–585, Dec. 2022.

[2] O. Jafari, S. Kolosov, N. Vo *et al*., "Traffic light solution for green and sustainable smart city," in *Proc. of IEEE, 2023 12th Mediterranean Conference on Embedded Computing (MECO)*, pp. 1–5, June 2023. doi: 10.1109/MECO58584.2023.10154954

[3] A. A. Ouallan, A. Ait, A. Bakali *et al*., "Overview of road traffic management solutions based on IoT and AI," *Procedia Computer Science*, vol. 198, pp. 518–523, 2022.

[4] N. U. Ahmed and T. H. Yeap, "Optimum management of urban traffic flow based on a stochastic dynamic model," *IEEE Trans. on Intelligent Transportation Systems*, vol. 20. no. 12, pp. 4377–4389, Dec. 2019.

[5] W.-H. Lee and C.-Y. Chiu, "Design and implementation of a smart traffic signal control system for smart city applications," *Sensors*, vol. 20, no. 2, 2020. https://doi.org/10.3390/s20020508

[6] S. Javaid, A. Sufian, S. Pervaiz *et al*., "Smart traffic management system using Internet of Things," in *Proc. 2018 20th Int. Conf. on Advanced Communication Technology (ICACT)*, March 2018, pp. 393–398.

[7] V. Bali, S. Mathur, V. Sharma *et al*., "Smart traffic management system using IoT enabled technology," in *Proc. 2020 2nd Int. Conf. on Advances in Computing, Communication Control and Networking (ICACCCN)*, March 2021, pp. 565–568.

[8] L. Hee and S. Dunn, "Urban mobility: 10 cities leading the way in Asia Pacific," Centre for Liveable Cities, Singapore, and Urban Land Institute, Singapore, 2017.

[9] PADDI, "Building and ambitious public transport system in Ho Chi Minh City (Vietnam)," Urban Development Management Support Centre – PADDI, HCMC, 2015.

[10] H. C. Pham, "Report on the result of collection and complication of 10 SUTI index in Hanoi City," ESCAP, Hanoi, November 2017.

[11] H. D. Nguyen and N. V. Nguyen, "Analysis study of current transportation status in Vietnam's urban traffic and the transition to electric two-wheelers mobility," *Sustainability*, vol. 13, no. 10, May 2021. https://doi.org/10.3390/su13105577

[12] T. P. L. Le and T. A. Trinh, "Encouraging public transport use to reduce traffic congestion and air pollutant: A case study of Ho Chi Minh City, Vietnam," *Procedia Engineering*, vol. 142, pp. 236–243, 2016.

[13] Y. C. Nguyen and K. Sano, "Estimating capacity and motorcycle equivalent units on urban roads in Hanoi, Vietnam," *Journal of Transportation Engineering*, vol. 138, no. 6, pp.776–785, Jun. 2012

[14] T. P. L. Le and M. S. Ho, "Evaluating public bus transportation services in Ho Chi Minh City, Vietnam." *Can Tho University Journal of Science*, vol. 4, pp. 128–139, 2016. doi: 10.22144/ctu.jen.2016.052

[15] T. Kurniati and R. Fajriati, "The effect of motorcycle proportion on traffic flow parameters at the multi-lane urban road," in *Proc. ICAnCEE 2018, MATEC Web of Conf.*, vol. 276, Mar. 2019. https://doi.org/10.1051/matecconf /20192760 3016

[16] X. Liu and H. Xia, "Networking and sustainable development of urban spatial planning: Influence of rail transit," *Sustainable Cities and Society*, vol. 99, Dec. 2023. https://doi.org/10.1016/j.scs.2023.104865

[17] R. Hrelja, J. Khan, and F. Pettersson, "How to create efficient public transport systems? A systematic review of critical problems

and approaches for addressing the problems," *Transport Policy*, vol. 98, pp. 186–196, Nov. 2020.

[18] S. A. R. Shah, M. Shahzad, N. Ahmad *et al*., "Performance evaluation of bus rapid transit system: A comparative analysis of alternative approaches for energy efficient eco-friendly public transport system," *Energies*, vol. 13, no. 6, Mar. 2020. https://doi.org/10.3390/en13061377

[19] J. Wang, W. Cheng, Y. Lu *et al*., "Effect of rail transit on travel behavior: A systematic review and meta-analysis," *Transportation Research Part D: Transport and Environment*, vol. 122, Sep. 2023. https://doi.org/10.1016/j.trd.2023.103882

[20] M. Glotz-Richter and H. Koch, "Electrification of public transport in cities (Horizon 2020 ELIPTIC project)," *Transportation Research Procedia*, vol. 14, pp. 2614–2619, 2016.

[21] Ć. Małgorzata, W. Bartnik, and S. Jarzębowski, "Railway vehicle energy efficiency as a key factor in creating sustainable transportation systems," *Energies*, vol. 14, no. 16, Aug. 2021. https://doi.org/10.3390/en14165211

[22] D. J. Graham, "Productivity and efficiency in urban railways: Parametric and non-parametric estimates," *Transportation Research Part E: Logistics and Transportation Review*, vol. 44, no. 1, pp. 84–99, Jan. 2008.

[23] W. Liu, C. Zhang, F. Wang, J. Zhang, and L. Wang, "Study on the selection of middle urban mass rapid transit system and adaptability analysis," *Journal of Internet Technology*, vol. 22, no. 3, pp. 605–613, May. 2021.

[24] S. D. Srivastava and R. Agrawal, "Automated people movers: A futuristic approach to modern transportation planning," *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, vol. 11, no. 3, pp. 1–11, 2014.

[25] M. Novales, A. Orro, E. Conles, and J. Anta, "Medium-capacity transit systems: some reflections about making the right choice," *WIT Trans. on The Built Environment, Urban Transport XVIII*, vol. 128, pp. 269–280, 2012. doi:10.2495/UT120241

[26] Y. Ding and I. C. Steven, "Improving transit service quality and headway regularity with real-time control," *Transportation Research Record Journal of the Transportation Research Board*, vol. 1760, no. 1, Jan. 2001. doi:10.3141/1760-21

[27] D. S. Hoo, K. H. Chua, Y. S. Lim *et al*., "Comparison of regenerative braking energy recovery of a DC third rail system under various operating conditions," *International Journal of Electrical Power & Energy Systems*, vol. 155, Part B, Jan. 2024. https://doi.org/10.1016/j.ijepes.2023.109575

[28] D. D. Van, "A research on the load calculation method in designing the traction power supply for integrated subway–MCR," *Engineering, Technology & Applied Science Research*, vol. 13, no. 3, pp. 10882–10887, Jun. 2023.

[29] D. D. Van and T. Nguyen, "The design method of traction power supplies in integrated metro systems," *Engineering, Technology & Applied Science Research*, vol. 13, no. 3, pp. 10957–10962, Jun. 2023.

[30] H. Alnuman, D. Gladwin, and M. Foster, "Electrical modelling of a DC railway system with multiple trains," *Energies*, vol. 11, no. 11, Nov. 2018. doi:10.3390/en11113211

[31] Y. He, J. Lv, and T. Tang, "Communication-based train control with dynamic headway based on trajectory prediction," *Actuators*, vol. 11, no. 8, Jul. 2022. doi: https://doi.org/10.3390/act11080237

[32] J. Wang, J. Xiao, X-G. Hu *et al*., "A novel three-dimensional Train safe braking model based on train-to-train communication," in *Proc. Int. Conf. on Guidance, Navigation and Control*, Jan. 2023. https://doi.org/10.1007/978-981-19-6613-2_40

[33] X. Wang, L. Liu, T. Tang *et al*., "Enhancing communication-based train control systems through train-to-train communications," *IEEE Trans. on Intelligent Transportation Systems*, vol. 20, no. 4, pp. 1544–1561, Apr. 2019.

[34] Y. Li, L. Zhu, X. Wang *et al*., "Metro train scheduling optimization for virtual coupling based train control," in *Proc. IEEE, 2021 China Automation Congress (CAC)*, Mar. 2022. doi: 10.1109/CAC53003.2021.9728666

[35] C. Qiu, T. Chen, S. Lu *et al*., "A safety-oriented dynamic moving block train control system based on train-to-train communication," *IEEE Intelligent Transportation Systems Magazine*, vol. 14, no. 3, pp. 17–187, May–June 2022.

[36] M. D. Meyer, "Transportation planning Handbook," *Institute of Transportation Engineers, Fourth edition*, Transit Planning, pp. 485–576, 2016

[37] L. Yu, Y. Cong, and K. Chen, "Determination of the peak hour ridership of metro stations in Xi'an, China using geographically-weighted regression," *Sustainability*, vol. 12, no. 6, Mar. 2020. https://doi.org/10.3390/su12062255

[38] R. Chen and J. Guo, "Development of the new CBTC system simulation and performance analysis," *WIT Trans. on The Built Environment, Computers in Railways XII*, vol. 114, pp. 497–507, 2010. doi:10.2495/CR100461

[39] L. Schnieder, "Umbau, Test und Inbetriebnahme automatischer Zugbeeinflussungssysteme," *Communications-Based Train Control (CBTC)*, Springer Vieweg, Berlin, Heidelberg, 2022. https://doi.org/10.1007/978-3-662-65285-5_8

[40] M. A. Rios and G. A. Ramos, "Power system modelling for urban massive transportation systems," *Infrastructure Design, Signalling and Security in Railway, IN-TECH*, Chapter 7, pp. 179–202, Apr. 2012. doi:10.5772/35191

[41] H. Mishra, R. Gnanavignesh, and G. Narayanan, "Review of traction standards and simulation of traction power supply system," in *Proc. 2022 IEEE India Council International Subsections Conference (INDISCON)*, pp. 1–6, Aug. 2022. doi: 10.1109/INDISCON54605.2022.9862868.

[42] G. Du, D. Zhang, G. Li *et al*., "Maximum safety regenerative power tracking for DC traction power systems," *Energies*, vol. 10, no. 2, Feb. 2017. doi:10.3390/en10020244.

[43] F. Mao, Z. Mao, K. Yu *et al*., "The modeling and simulation of DC traction power supply network for urban rail transit based on simulink," *Journal of Physics: Conference Series*, vol. 1087, no. 4, 2018. doi: 10.1088/1742 6596/1087/4/042058.

[44] Z. Tian, N. Zhao, S. Hillmasen *et al*., "Traction power substation load analysis with various train operating styles and substation fault modes," *Energies*, vol. 13, no. 11, June 2020. doi:10.3390/en13112788.

[45] S. Razmjou and A. Younesi, "A comprehensive DC railway traction system simulator based on MATLAB: Tabriz line 2 Metro project case study," *Journal of Operation and Automation in Power Engineering*, vol. 9, no. 2, pp. 144–159, Aug. 2021. doi: 10.22098/joape.2021.8197.1569.

[46] Y. Chen, Z. Tian, S. Hillmansen *et al*., "DC traction power supply system reliability evaluation and robust design," in *Proc. IEEE 3rd International Electrical and Energy Conference (CIEEC)*, pp. 1153–1158, Apr. 2020. doi: 10.1109/CIEEC47146.2019.CIEEC-2019424

[47] Y. Chen, Z. Tian, C. Roberts *et al*., "Reliability and life evaluation of a DC traction power supply system considering load characteristics," *IEEE Trans. on Transportation Electrification*, vol. 7, no. 3, pp. 958–968, Sep. 2021. doi: 10.1109/TTE.2020.3047512.

[48] H. Cho, J. Kim, H. Jung, and H. Kim, "Simultaneous DC railway power system analysis method using model-based TPS," *Applied Sciences*, vol. 12, no. 14, Jun. 2022. https://doi.org/10.3390/app12146929

[49] B. Dixit, "Selection of traction system and energy conservation in metro system," presented Urban Mobility India Conference and Expo 8^{th}, India, 2015.

[50] T. Nguyen, "Research on the operating voltage on the contact lines of the subway system with the design of new conductor rails – ROCS," in *Proc. 2022 Scientific Conference*, Ho Chi Minh City University of Transport, pp.83–89, 2022.

[51] H. S. Jaafar, N. M. Rais, M. R. H. Samsudin *et al*., "Measuring railway track capacity and utilization for KERETAPI tanah melayu berhad (ktmb)," *Advances in Transportation and Logistics Research*, vol.3, pp. 908–916, 2020.

[52] G. Wang, H. Liu, and X. Zeng, "Study on train headway in a different turning-back mode of urban mass transit station," *Transportation Research Procedia*, vol. 25, pp. 451–460, 2017. https://doi.org/10.1016/j.trpro.2017.05.425

[53] C. Wu, Y. Pei, and J. Gao, "Model for estimation urban transportation supply-demand ratio". *Mathematical Problems in Engineering*, vol. 2015, Article ID 502739, Oct. 2015. http://dx.doi.org/10.1155/2015/502739

[54] T. Parkinson and I. Fisher, "TCRP report 13: Rail transit capacity," *Transportation Research Board (TRB). Transit Cooperative Research Program (TCRP)*, 1996.

[55] D. C. Gill and C. J. Goodman, "Computer-based optimization techniques for mass transit railway signal design," *IEE*

Proceedings-B, vol. 139, no. 3, pp. 261–275, May 1992.

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