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Application of a transport organisation model based on Transit-Oriented Development: A case study of urban railway line No. 1 in Ho Chi Minh city, Vietnam

Phu Quang Tran[1], Quoc An Bui[1*], Thai Hong Nguyen[2]

[1]Ho Chi Minh City University of Transport, 2 Vo Oanh Street, Thanh My Tay Ward, Ho Chi Minh City, Vietnam
[2]University of Transport and Communications, 3 Cau Giay Street, Lang Ward, Hanoi, Vietnam

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Abstract:

Metro line No. 1 is the first urban railway line in Ho Chi Minh city, traversing densely populated urban areas and major passenger attraction centres. While it offers the potential for modern transport connectivity, operational experience has revealed that the existing transport infrastructure in adjacent areas does not fully meet passenger travel demand and has not kept pace with the city's rapid urban development. This study focuses on assessing the scientific basis and current state of transport organisation, with the aim of applying the Transit-Oriented Development (TOD) model to Metro line No. 1. The research develops and compares two simulation scenarios: (i) the current situation scenario, reflecting existing conditions of transport connectivity, and (ii) the TOD scenario, applying TOD-based transport organisation solutions. Transport network performance indicators analysed from the simulation results include travel time, level of service, accessibility, and traffic volume. Based on the analysis of current conditions, the study proposes solutions and evaluates their effectiveness through simulation results to formulate a set of TOD-based transport organisation measures. These proposals are expected to enhance the operational efficiency of Metro line No. 1 while promoting the sustainable development of Ho Chi Minh city's urban areas.

Keywords: **Transit-Oriented Development, transport organisation, urban railway No. 1.**

Classification number: **2.3**

1. Introduction

Ho Chi Minh city (HCMC), the largest economic centre in Vietnam, is undergoing rapid urbanisation, which has led to a significant increase in travel demand. Despite considerable efforts to invest in the development of transport infrastructure-particularly the public transportation system-the proportion of trips made by public transport remains very low, accounting for less than 5% of total trips [1]. Therefore, the development of a high-capacity public transport system is essential to shift travel behaviour and reduce dependence on private vehicles.

One of the models successfully implemented in many major cities worldwide is Transit-Oriented Development (TOD) [2]. Beyond its operational role, integrating transport services at rail stations carries strategic importance for advancing sustainable urban development. A well-connected transport network facilitates the creation of vibrant transit hubs that act as catalysts for more intensive land use and compact urban growth in surrounding station areas. In turn, this supports the realisation of the TOD concept, which promotes high-density, mixed-use development anchored by high-quality public transport infrastructure [3].

The Ho Chi Minh city urban railway line No. 1 (Ben Thanh - Suoi Tien) is the city's first mass transit project, conceived to alleviate increasingly severe traffic congestion and meet growing travel demand in the context of rapid urbanisation. In 2007, the project was officially approved, with a total length of approximately 19.7 km comprising 14 stations (three underground and eleven elevated). The line begins at Ben Thanh station, traverses the central districts and the eastern corridor, connects with key urban areas, and terminates at the Long Binh depot. Serving as the backbone of the initial metro network, it is expected to relieve traffic pressure on major arterial roads such as Nguyen Huu Canh and Vo Nguyen Giap, while simultaneously stimulating socio-economic development and restructuring urban spaces towards sustainability in line with the TOD model (Fig. 1).

*Corresponding author: Email: an.bui@ut.edu.vn

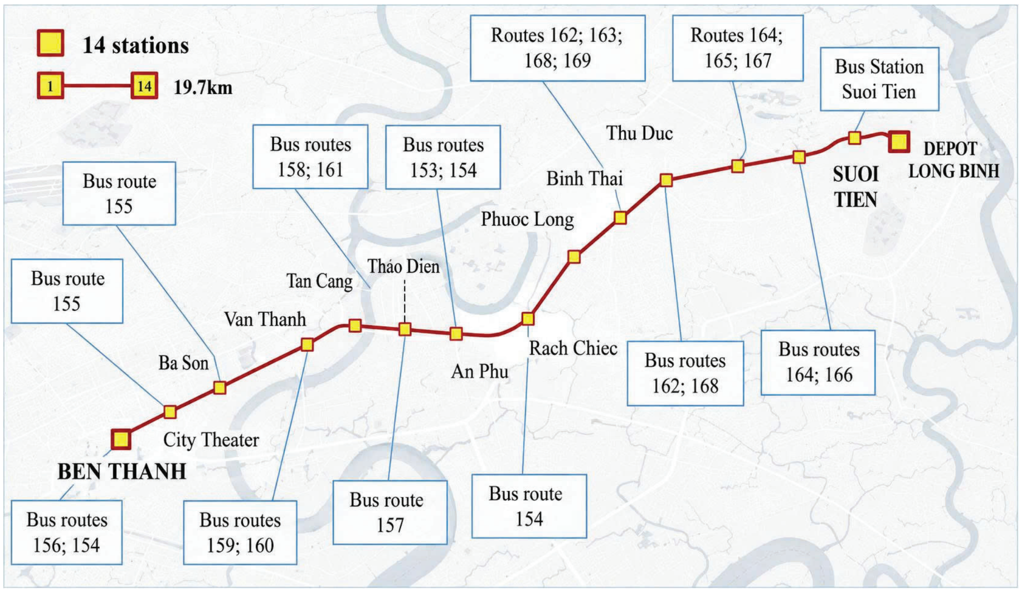

Fig. 1. Diagram of bus system connectivity with stations of urban railway line No. 1 [4].

Metro line No. 1 traverses densely populated urban areas and major passenger attractors, and it commenced operations in December 2024. However, operational experience to date has revealed that the existing transport infrastructure in these areas neither adequately meets passenger needs nor keeps pace with the rate of urban development, particularly with respect to effective multimodal connectivity to stations. Narrow roads, the absence of continuous and safe pavements, a lack of cycle-parking facilities, and limited bus access in the vicinity of stations constitute significant barriers, undermining both the operational efficiency of the metro line and the mobility of local residents.

The station network of metro line No. 1 plays a pivotal role, as it is located in areas with high urban development potential and significant travel demand. Reorganising the transport space and integrating different transport modes around stations following the TOD model will help increase public transport usage, encourage sustainable travel modes, and enhance the operational efficiency of metro line No. 1. Studying transport organisation based on the TOD model at stations along urban railway line No. 1 can provide valuable lessons and a scientific foundation for proposing optimal traffic management schemes that align with land-use planning and the city's sustainable development goals. The organisational model and technical solutions developed in this study can be replicated for other stations within Ho Chi Minh city's metro network and across Vietnam in the future.

2. Materials and methods

2.1. Theoretical foundations of transport organisation under the TOD model at urban rail stations

The organisation of multimodal transport at railway stations encompasses the planning, implementation, and management of transport operations to ensure seamless intermodal connectivity. Key objectives include optimising accessibility, maximising station utilisation, reducing travel time and costs, and ultimately enhancing the passenger experience [5].

The organisation of multimodal transport at urban rail stations is closely linked to the development of interchange hubs - critical nodes where multiple modes of transport converge, including rail, bus, taxi, private vehicles, and bicycles [6]. The primary objective of these transport hubs is to optimise passenger accessibility, enabling seamless and efficient transitions between different transport modes. The effective coordination of transport services at rail stations plays a central role in ensuring the overall integration and operational efficiency of the urban transport network [7]. When various transport modes are integrated at a single interchange, such as a railway station, passengers can switch between modes with greater ease, thereby enhancing the user experience and encouraging a modal shift from private vehicles to public transport [8]. The harmonious integration of rail with feeder services-such as buses, shared bicycles, or taxis-provides an optimal solution for improving accessibility while alleviating traffic congestion in the surrounding areas [9].

The above perspectives affirm that the organisation of multimodal transport at rail stations is not merely a technical matter but a critical component of urban and sustainable mobility planning. Interchange nodes and the operational integration of transport modes enhance the overall efficiency of the transport system while supporting economic and social development around station areas.

Transport organisation, in this context, refers to the planning, implementation, and management of mobility services to ensure effective connectivity between the rail network and other transport modes such as buses, taxis, private vehicles, bicycles, and pedestrian access. It is a vital aspect of both urban and regional transport planning, especially in the context of urban rail and high-speed rail stations [10].

2.2. Research methods for transport organisation under the TOD model for railway lines

At present, transport planning projects under the TOD model lack effective evaluation methodologies and tools for simulating travel behaviour. This study applies modelling approaches to simulate and analyse travel patterns, as well as to forecast transport demand, with the aim of optimising transport organisation in the vicinity of railway stations and enhancing the operation of the public transport system. This method is not only based on historical data but also integrates urban planning factors, transport organisation schemes, and relevant traffic policies [11].

The simulation allows researchers to predict project impacts on the transport system, thereby identifying transport-related effects and proposing suitable adjustment measures. It also enables the evaluation of the effectiveness of various transport improvement strategies, such as the implementation of dedicated bus lanes, intelligent traffic signal systems, and traffic management solutions.

A transport organisation assessment and simulation model is applied to estimate future traffic volumes on both road and public transport networks accessing the station in the target forecast year. The modelling process for transport organisation is carried out through the steps presented in Table 1 and Fig. 2.

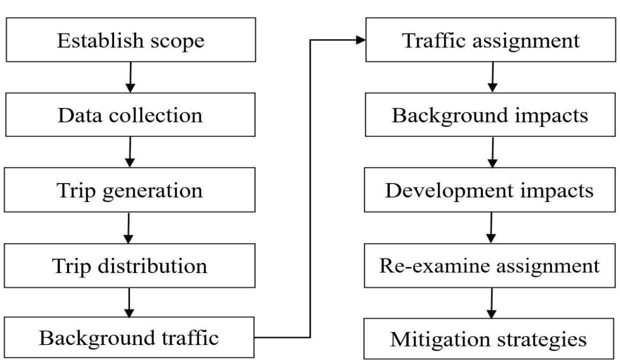

Fig. 2. Flowchart of the assessment and simulation process of transport organisation at railway stations [12].

Table 1. Sequential assessment and simulation framework for transport organisation in station areas [12].

Step 1: Establishing the scope of assessment and simulation
▪ Define an analysis time frame of 10-20 years. ▪ Delineate the surrounding road network within a radius of 1.0-1.5 km from the development site.
Step 2: Data collection
▪ Collect existing traffic data from the network surrounding the development site. ▪ Gather geometric data of the road network, corridors, and intersections.
Step 3: Trip generation estimation
▪ Define Traffic analysis zones (TAZs) and conduct zoning. ▪ Estimate the number of trips generated by the new development using the trip generation manual [13].
Step 4: Trip distribution
▪ Distribute generated trips from the development site to adjacent zones. ▪ Use standard trip distribution models within the four-step transport forecasting process. ▪ For small-scale developments, trips may be distributed proportionally based on existing origin-destination (O-D) patterns.
Step 5: Estimating background traffic for the target year
▪ Evaluate the future development without directly associating it with current traffic volumes, while account for local traffic growth over the 2-5 year analysis period (as defined in step 1). ▪ Apply the annual traffic growth rates provided by local transport authorities, typically ranging from 5-10% per year; ▪ Use the formula $F=P(1+i)^n$, where F = future traffic volume, P = current volume, i = annual growth rate, n = number of forecast years.
Step 6: Traffic assignment
▪ Assign trips to road links within the network around the development area. ▪ Apply shortest-time or shortest-distance principles (O-D), or more advanced algorithms depending on the scale of the development. ▪ The output includes estimated link volumes on all access roads and turning movements at all intersections in the study area (defined in step 1).
Step 7: Background traffic impacts
▪ Use methodologies from the Highway Capacity Manual (HCM) [14] to assess the Level of Service (LOS) at key locations within the surrounding road network; ▪ This will serve as a baseline for evaluating the impact of the proposed development.
Step 8: Development traffic impacts
▪ Calculate LOS at selected critical points in the target year, considering both background traffic and additional trips generated by the new development. ▪ Compare this with the background LOS (step 7) to determine the incremental impacts of the development.
Step 9: Re-examining traffic assignment
▪ Based on the outcome from Step 8, traffic assignment results from Step 6 may need to be re-evaluated or recalculated to avoid potential congestion or bottlenecks. ▪ If necessary, reassign traffic and re-estimate LOS at key points within the network.
Step 10: Mitigation strategies
▪ Depending on future year evaluations, propose mitigation strategies to ensure LOS is maintained even with the new development in place. ▪ Assess the LOS under proposed mitigation measures and ensure network capacity and operational conditions are acceptable. ▪ Provide alternative mitigation options considering both traffic performance and economic feasibility.

In cases where the assessment results indicate a decline in the Level of service (LOS), further studies will be conducted on traffic management solutions aimed at reducing delays and queue lengths to improve the operational efficiency of traffic flows. If such traffic organisation measures prove insufficient, alternative plans involving the upgrading, retrofitting, or expansion of the intersection will be considered.

3. Current situation of transport organisation on urban rail line No. 1, HCMC

3.1. Introduction to urban rail line No. 1

Ho Chi Minh city's road transport system is currently under considerable pressure due to the increasing number of private vehicles, leading to congestion and environmental pollution. To address these challenges, the development of an urban rail transit system (metro, monorail, light rail transit - LRT) is an inevitable step towards creating a sustainable, modern city and reducing dependence on private vehicles.

Metro line No. 1 (Ben Thanh - Suoi Tien) commenced construction in 2012 and was officially put into operation on 22 December 2024. The line has a total length of 19.7 km, including a 3.8 km underground section through the city centre, and comprises 14 passenger stations [15]. As the first metro line in HCMC's urban rail system, it is expected to lay the foundation for a modern public transport network, helping to connect the central area with the northeastern regions and alleviating pressure on the existing road network.

According to a report from the Ho Chi Minh city urban railway one member limited liability company - the management and operation unit of metro line No. 1-the line is expected to serve between 70,000 and 100,000 passengers daily [16]. The replacement of private vehicles with public transport modes such as the metro not only contributes to reducing road traffic volumes but also decreases greenhouse gas emissions, saves energy, and minimises air and noise pollution in the urban area. Furthermore, due to the use of electrified operation technology, the metro system does not emit harmful gases during operation, thereby contributing to sustainable development goals and the national commitment to reducing greenhouse gas emissions under the Paris Agreement on climate change.

In addition to its transport and environmental benefits, metro line No. 1 also delivers significant economic and social value. Reductions in travel costs resulting from a more efficient transport network help improve social welfare and enhance residents' quality of life. Moreover, the presence of metro stations plays a crucial role in promoting urban space development in line with the TOD model, increasing real estate values and driving the formation of commercial and service hubs around stations, thereby contributing to urban economic growth.

3.2. Current status of transport integration for metro line No. 1

The urban railway system in HCMC is expected to become a key public transport axis, helping to alleviate traffic congestion and improve mobility efficiency in the city. However, to maximise the effectiveness of the metro system, the organisation of connecting transport systems at stations plays a critical role. Currently, integration between the metro and other public and private transport modes remains limited, lacking seamless connectivity and convenience for passengers.

3.2.1. Integration with the bus system

The bus system in HCMC consists of 144 routes, of which 107 are subsidised. The average length of each route is 20.4 km, with an average operating time of 14 hours per day [17]. The city has implemented 17 subsidised bus routes aimed at enhancing multimodal connectivity with metro line No. 1, contributing to improved operation of the public transport network. This initiative represents a strategic efforts to address the "last mile" problem and optimise the transport network as metro line No. 1 becomes operational.

Seventeen bus routes connecting metro line No. 1 are operated by Phuong Trang passenger transport joint stock company. These routes are designed to link the 14 stations along the line with nearby residential areas, commercial centres, and industrial zones. The bus routes primarily serve District 1, Thu Duc, and Binh Thanh, with an average route length of 10-15 km. They operate at high frequency, with intervals of 10-15 minutes during peak hours. Fares are subsidised, ranging from 5,000 to 10,000 VND per ticket, aiming to encourage residents to shift from private vehicles to combined metro-bus usage [18].

However, the bus stop infrastructure serving these connecting routes has not been optimally designed to maximise passenger convenience. Many bus stops are located far from metro stations, lack convenient pedestrian access, and are often missing essential amenities such as shelters, seating, and clear signage providing route information and bus schedules. This situation reduces the attractiveness of buses as feeder services and consequently limits the operational efficiency of the metro system.

3.2.2. Connection with private vehicles

Private vehicles, including cars and motorbikes, remain the predominant mode of transportation for residents in HCMC. Therefore, the organisation of parking facilities at metro stations plays a crucial role in encouraging the public to shift towards public transport use. The motorbike parking system along metro line No. 1 has been designed to address demand for parking that facilitates transfers from private vehicles to public transport. Currently, there are 10 parking lots located beneath elevated stations and five dedicated motorbike parking areas at Van Thanh, Thao Dien, Rach Chiec, Phuoc Long, and Binh Thai stations [17].

In some areas, the absence of dedicated lanes for passenger drop-offs or short-term parking facilities leads to traffic congestion during peak hours. Passengers face difficulties accessing stations, particularly when using taxis, ride-hailing services, or private cars. These shortcomings cause many commuters to prefer using private vehicles for their entire journey rather than combining them with the metro system.

3.2.3. Connection with green transportation modes (bicycles, walking)

Green transportation modes, including bicycles and walking, are sustainable and suitable options for connecting with the metro system. However, in HCMC, pedestrian pathways leading to metro stations have not been adequately developed. Many sidewalks are narrow, unsafe, or unfriendly to pedestrians. The lack of adequate lighting, shelters, and clear directional signage also causes inconvenience for passengers, especially at night or during adverse weather conditions.

Regarding bicycles, although the city has developed a public bicycle system, supporting infrastructure such as dedicated bicycle lanes and parking facilities at metro stations has yet to be fully implemented. This limits the viability of bicycles as an effective feeder mode for commuters. The absence of fare integration policies, such as bike-sharing services or integrated ticketing between the metro and green transportation modes, also poses barriers to the development of this transport option.

3.3. Summary of SWOT analysis on TOD-based transport organisation for urban railway line No. 1

While public transport modes such as buses have contributed to easing traffic congestion, the robust and sustainable development of public transport systems-particularly urban railway (metro) lines-is considered a fundamental and long-term solution. A SWOT analysis focuses on the organisation of transport based on the TOD model along urban railway line No. 1 (Ben Thanh - Suoi Tien), in connection with integrated urban development surrounding the stations.

The SWOT analysis indicates that organising transportation based on the TOD model along HCMC's metro line No. 1 has significant potential but also faces challenges (Table 2). The line passes through densely populated areas and serves as a main axis in the transport network, making it favourable for implementing the TOD model and influencing residents' travel behaviour.

Table 2. SWOT analysis on TOD-based transport organisation for urban railway line No. 1.

Strengths (S)	Opportunities (O)
- Metro line No. 1 passes through densely populated residential areas, facilitating feeder transport organisation. - The metro serves as a central corridor, guiding the organisation of public transport under the TOD model. - Zoning plans and connectivity planning have been established for many stations. - High potential to promote a shift in travel behaviour from motorcycles to public transport.	- TOD is a development orientation prioritised by the city government. - Metro line No. 1 serves as a pilot project for expanding the TOD network citywide. - The application of technologies (e-ticketing, big data, operational software, etc.) supports efficient transport organisation. - There is an opportunity exist to mobilize international funding and public-private partnerships (PPP) for TOD-based transport development.
Weaknesses (W)	**Threats (T)**
- Lack of seamless integration between the metro and feeder modes (buses, bicycles). - Access infrastructure to stations is underdeveloped, lacking amenities for pedestrians and people with disabilities. - Absence of a coordinated mechanism for integrated public transport (metro - bus - taxi - bicycle). - Lack of unified data and planning tools to support TOD-based transport planning.	- The habit of using motorbikes remains widespread, making it difficult to attract passengers to the metro. - Urban development is often uncoordinated with public transport infrastructure around many stations. - The current bus network is weak, making it challenging to effectively serve as a feeder system. - High investment costs and risks in managing and operating an integrated network.

Many stations have established zoning and connectivity plans, providing a foundation for integrated development. However, the current model still lacks synchronised connections between the metro and feeder modes such as buses and public bicycles; station access infrastructure remains inadequate; and there is a lack of coordination mechanisms and data to support transport management. In the context of the city government prioritising TOD development, together with opportunities to apply technology and mobilise international funding, metro line No. 1 could become a model for development. Nevertheless, the greatest challenges remain the widespread use of motorbikes and uncoordinated urban development.

4. Solutions for transportation organisation based on the TOD model for metro line No. 1

To provide input data for forecasting and simulation in the evaluation of transport alternatives in areas developed under the TOD model, this study proposes transport organisation solutions based on the TOD approach for metro line No. 1.

4.1. Strengthening the legal framework and management mechanisms

In the context of modern urban development and the need to optimise public transport systems, the issuance and updating of a legal framework is a crucial first step in establishing a solid foundation for the TOD model. Specifically, it is necessary to develop and promulgate legal documents, regulations, and detailed guiding standards that clearly define indicators such as building density, optimal distances between public transport nodes, and design standards for pedestrian-friendly public spaces [19].

Alongside improving the legal framework, developing inter-agency coordination mechanisms is another important factor in ensuring close linkages among relevant management bodies. Coordination involving urban planning authorities, transportation agencies, and operating units creates a forum for information exchange, consensus building, and the formulation of common development orientations [20].

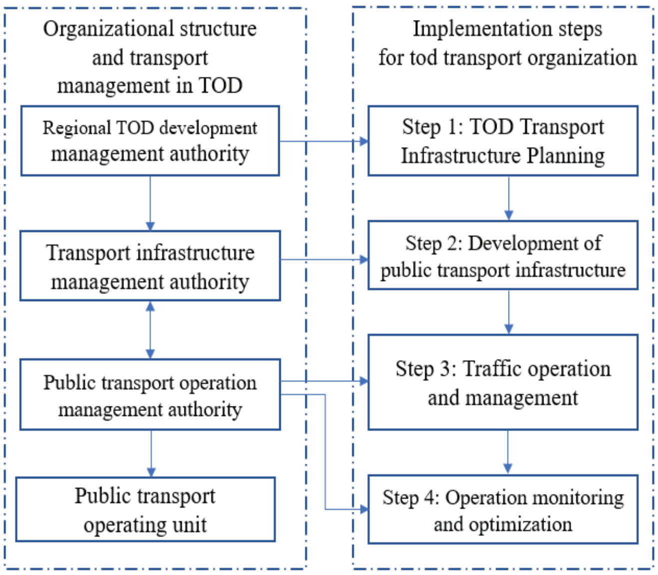

Fig. 3. Flowchart of the organisational structure and implementation of transportation management under the TOD model. Source: Authors' compilation.

Figure 3 illustrates the organisational structure and implementation framework for transportation management under the TOD model, clearly defining the responsibilities of each agency as well as the roadmap for effectively deploying transport organisation within the TOD framework. The organisational and management structure for transportation in TOD areas includes:

- The TOD development management agency, which plays a key role in urban planning and guiding urban development integrated with public transport systems.

- The infrastructure management agency, proposed to be the Ho Chi Minh city traffic infrastructure management centre, which is directly responsible for constructing and maintaining public transport system facilities such as metro stations, bus stops, parking areas, and transport corridors.

- The public transport operation management agency, proposed to be the public transport management centre, which is responsible for operating and supervising public transport services, including buses, metro, water buses, public bicycles, and other feeder services.

- Public transport operators, consisting of enterprises or organisations providing transportation services such as bus companies, metro operators, water bus services, and public bicycle providers.

Regarding feasibility, this solution is highly rated due to strong interest from both central and local governments. Relevant agencies recognise the importance of modernising transport infrastructure and developing sustainable urban areas in line with the TOD model, as stipulated in Resolution No. 98/2023/QH15 [21].

4.2. Improving connecting bus services

Transport routes should be designed with the objective of serving all user groups to the greatest possible extent, including pedestrians, cyclists, public transport users, and motorised vehicle users. Designing station access routes with priority given to pedestrians and non-motorised transport, combined with solutions such as traffic calming and shared space or shared street concepts, will help create a safe, convenient, and user-friendly travel environment for residents. This approach not contributes only to reducing traffic congestion but also enhances the quality of urban living spaces [22].

Synchronisation of the public transport network should focus on adjusting the routes and frequencies of public transport services, particularly buses, to align with metro schedules, thereby maximising convenience for passengers transferring between modes. An integrated ticketing system between the metro, buses, and other public transport modes should be developed to enable users to access multiple transport services without the need to purchase separate tickets for each mode. In addition, integrating a digital-based traffic information system will provide timely updates on schedules, routes, and waiting times, helping passengers plan their journeys more effectively.

Bus priority measures are necessary to enable buses to access stations without delays caused by general traffic. The types and precise locations of these measures will depend on forecasted bus volumes following the redesign of the bus network. Feeder buses terminating at stations must be provided with adequate space at bus stops to wait between trips, allowing for schedule recovery and efficient passenger boarding. The number and exact locations of bus stops required will also depend on the projected bus volumes after the network redesign.

To best accommodate passenger needs, the distance between two consecutive stops along a route should be arranged within a range of 200-300 m, with an average spacing of approximately 250 m. In practical station placement, consideration should be given to residential areas, workplaces, and infrastructure connections with other transport modes. The required number of stops on each route is determined using the following formula:

$$N_{td} = \left(\frac{L}{L_{tb}}\right) - 1 \quad (1)$$

where N_{td} is the number of required stops, L is the length of the route, and L_{tb} is the average distance between two stops.

Thus, the number of stops needed on each route at the typical station (Thao Dien station) is calculated as follows:

Route 1: Along Nguyen Van Huong - Thao Dien Streets with a total length of 5,600 m:

N_{td1}=(5600 /250)-1=21 (station)

Route 2: Along Tran Nao - West Belt - Tran Luu - Nguyen Quy Duc - Song Hanh - Tran Nao roads with a total length of 5,300 m:

N_{td2}=(5300/250)-1=20 (station)

Feeder services for metro line No. 1 are important for expanding the service coverage of the line. In addition to connecting the metro to existing bus services at terminals and passenger boarding points, where feasible, a "motorbike taxi" service can be arranged to transport passengers from residential - commercial areas to stations and vice versa.

It is proposed to develop integrated transfer centres directly at metro stations to facilitate convenient transfers between different transport modes, such as metro trains, buses, water buses, taxis, public bicycles, and private vehicles. Specifically, the design of pedestrian corridors, overpasses, and underground walkways that directly connect stops of various public transport modes will reduce transfer times and improve the user experience. At the same time, the provision of smart parking facilities, such as multi-storey and underground parking near stations, will encourage users to park private vehicles, thereby promoting greater use of public transport.

4.3. Other connecting transport services

4.3.1. Encouraging green and shared mobility

To contribute to reducing environmental pollution and creating a sustainable transport system, the use of green mobility options should be promoted. Specifically, implementing public bicycle parking areas and personal electric vehicle stations at transit stations will encourage the use of environmentally friendly vehicles. Developing shared mobility services such as car-sharing and bike-sharing with flexible parking locations will allow passengers to easily access vehicles after disembarking from trains. Additionally, promoting the use of electric buses and electric taxis will help reduce greenhouse gas emissions, thereby contributing to a green and sustainable transport network.

4.3.2. Applying technology in multimodal traffic coordination and operations

The application of advanced technologies helps to optimise the operational efficiency of the transport system. Implementing intelligent transport systems (ITS) can optimise routes, reduce waiting times, and prevent congestion around transit stations. The use of big data technologies enables simulation, forecasting, and analysis of passenger travel behaviour, providing timely and effective recommendations for improving transport connectivity. Furthermore, developing integrated mobile applications allows users to book tickets, track routes, and receive vehicle suggestions directly on smartphones, thereby enhancing the travel experience and facilitating seamless modal transfers.

4.3.3. Developing public transport associated with TOD urban development

In the context of modern urban development, public transport development linked to the TOD model aims to optimise land-use efficiency and improve transport quality. Proposed solutions include prioritising buses and urban rail transit on mixed-traffic networks through dedicated lanes and priority traffic signals at intersections. Public transport routes are designed with high frequency to ensure sufficient capacity and meet the increasing travel demand of residents. Strong connectivity between high-capacity transport modes, such as urban rail transit and metro systems, and other forms of public transport will create an integrated network, enabling quick and convenient transfers. Bus stops, stations, and surrounding areas should be designed to be user-friendly, ensuring convenient operation of vehicles and infrastructure, alongside the establishment of green transport hubs at main stations to foster a sustainable transport environment. Simultaneously, urban development along urban rail transit corridors will maximise the capacity of these transport modes, reduce dependence on private vehicles, and promote synchronised urban growth.

4.3.4. Supporting non-motorized transport to build a sustainable transport system

To reduce dependence on private motorised transport and optimise space usage, parking management plays a crucial role in the development strategy of multimodal transport systems. Specifically, in areas developed under the TOD model, the number of motor vehicle parking spaces will be limited and high parking fees applied to encourage people to shift to public transport and non-motorised modes. Within a 100-metre radius of transit stations, on-street parking will be restricted except for special cases such as delivery vehicles and short-term drop-off and pick-up services. Additionally, motor vehicle parking spaces will be designed for shared use to optimise space, while bicycle parking facilities will be enhanced and shared bicycle parking locations expanded [22]. To ensure order and efficient use, strict management measures, such as high fines for illegal parking, will be implemented. Consequently, the entire transport system and supporting infrastructure around stations will be scientifically adjusted, aiming for sustainable and user-friendly urban development.

Bicycle parking is provided at all stations. Bicycle parking areas may be located beneath stairways at elevated stations and near entrances at underground stations. Charging points for electric bicycles should also be installed. Bicycles can be accommodated within motorbike parking areas outside station boundaries, with the front rows nearest the station reserved for bicycles.

4.3.5. Adjusting policies and planning to support multimodal transport connectivity

This solution involves issuing policies that encourage the development of public transport infrastructure and restrict private vehicle use around transit stations. Measures such as implementing congestion charging zones, providing tax incentives for public transport users, and adjusting urban planning towards TOD principles will create favourable conditions for multimodal transport development. Concurrently, enhancing traffic management and control to limit illegal parking and the occupation of public spaces will improve traffic order and increase the operational efficiency of the transport system.

In the strategy to develop multimodal transport systems, organising transport services around stations as trip origin and destination points is essential. Stations are positioned as transit hubs, equipped with bicycle parking and green transport infrastructure to encourage environmentally friendly transport use. This not only reduces reliance on private motor vehicles but also facilitates convenient transfers between different transport modes, such as between buses and the metro, enabling quick and seamless connections. This optimised integration between transport modes contributes to improved travel efficiency and passenger experience.

4.3.6. Improving personal vehicle services

Motorcycles will serve as the third primary access mode to stations, following walking and bus transit. Metro passengers will arrive at stations as motorcycle riders, motorcycle passengers, or motorcycle taxi (xe ôm) users. Drop-off points should be located so as not to interfere with bus stops or bus traffic flows. Passengers requiring motorcycle access to stations will use commercial parking facilities near stations or motorcycle parking along pedestrian pathways outside station areas.

Facilities for taxi pick-up and drop-off are included at all stations near stairways and lifts providing access to the metro, serving all passengers, including those with disabilities. Taxi drop-off points are positioned to avoid interference with bus stops or bus traffic flows to and from these stops.

5. Simulation and evaluation of transport organisation in the area: The case of Thao Dien station

5.1. Simulation procedure and proposed scenarios

This study conducts simulations of the Thao Dien station area to assess travel flows, transport organisation, and impacts on the surrounding traffic system. Thao Dien station is part of metro line No. 1.

5.1.1. Macroscopic simulation of the regional transport system

The macroscopic simulation aims to forecast traffic volumes and evaluate the Level of service (LOS) of road links connecting railway stations, based on the development of both the existing-condition model and the planned urban transport network in Ho Chi Minh city. Information from investment reports of urban development projects around the stations-including location, construction area, gross floor area, and land-use functions-was collected to build a traffic flow simulation model using JICA STRADA (System for Traffic Demand Analysis) software developed by the Japan International Cooperation Agency (JICA). This model is employed to assess how the implementation of the TOD model affects transport demand. The analysis considers trends in transport development, urban growth, and the interrelationships between residential, employment, and recreational activities and travel demand, together with forecasts of population, employment, and public transport supply, to estimate future demand across various transport modes.

The total daily travel demand of Ho Chi Minh city residents, including home-based trips for education, work, other purposes, and return-home trips, is estimated based on data from the Ho Chi Minh city statistical yearbook, as well as population, student, and workforce statistics within the study area. By analysing economic trends, forecasts of future travel demand can be established.

Trip generation and attraction for the study area are calculated using regression functions with independent variables representing population, employment, and student enrolment. The equations for trip generation (G_i) and trip attraction (A_j) are linear regression models adopted from the " Ho Chi Minh city master plan for the period 2021-2030 with a vision to 2050" [23], using the three aforementioned variables. Specifically:

- Trip generation model:

$$G_i = (1.006536\times\text{population}) + (2.63507\times\text{workers}) + (1.76379\times\text{students}) \quad (2)$$

- Trip attraction model:

$$A_j = (0.966569\times\text{population}) + (2.73488\times\text{workers}) + (1.713429\times\text{students}) \quad (3)$$

The transport network surrounding railway stations will be modelled under different scenarios. The key input data required for this assessment include:

- The regional transport network and public transport routes within the project area, modelled according to different future scenarios.

- Land-use functions of sub-areas and zones, analysed to estimate trip generation and attraction to and from the project area.

- Application of the four-step travel demand model to estimate traffic volumes along key corridors within and around the study area for a target forecast year.

Transport system performance will be assessed using the Level of service (LOS) indicator. By analysing changes in the number of trips and transport routes, the study will evaluate how LOS may vary under future scenarios [24]. In cases of significant degradation in LOS, appropriate mitigation strategies will be developed and tested to determine their effectiveness in improving transport quality.

5.1.2. Microscopic simulation of regional transport organisation

The microscopic simulation is conducted to assess the traffic impacts of various scenarios. Traffic flows and transport modes accessing or departing from the stations of urban railway line No. 1 are modelled using the VISSIM software. VISSIM was selected due to its ability to be calibrated to Vietnamese traffic conditions, including the simulation of mixed traffic flows. Furthermore, the software is capable of modelling individual vehicle types, particularly motorcycles, which constitute the predominant mode of transport in Vietnam.

The simulation process for evaluating traffic impacts and organising transport is carried out according to the following sequence: (1) microscopic simulation of private traffic flows, public transport systems, and pedestrian movements; and (2) simulation of mixed traffic flows comprising cars, trucks, bicycles, buses, rail transit, and pedestrians [25].

The geometric parameters of the Thao Dien station area are input into the VISSIM model to analyse the urban rail transit system, bus operations, and road traffic. These include the shape and geometric dimensions of each intersection leg, number of lanes, lane widths, curb radii, locations of stop lines, pedestrian crossings, and traffic signals, all of which are modelled within the VISSIM simulation software [26].

5.1.3. Proposed simulation scenarios

Based on the quantitative data collected and the adopted traffic modelling methodology, two transport organisation scenarios are proposed for comparison:

- Scenario 1: Assessment of the 2025 traffic conditions under the current transport organisation, used to calibrate and validate the simulation model.

- Scenario 2: Application of a TOD-based transport organisation model, oriented towards high-density urban development, multimodal connectivity, and the prioritisation of public and non-motorised transport modes, including the following measures:

- Improving and reorganising the bus service network connected to the station, including two routes: Route 1 runs along Nguyen Van Huong - Thao Dien Streets, with a total length of 5,600 m; Route 2 runs along Tran Nao - Western Ring Road - Tran Luu - Nguyen Quy Duc - Song Hanh - Tran Nao Streets, with a total length of 5,300 m.

- Establishing covered pedestrian walkways and constructing pedestrian overpasses or underpasses dedicated to foot traffic, connecting the station to residential areas, shopping centres, and bus stops.

- Allocating space for bicycles and small personal vehicles to encourage sustainable mobility.

- Restructuring the bus routes serving the station to ensure direct access, and arranging convenient "kiss-and-ride" locations for pick-up and drop-off activities.

• Developing smart parking facilities following the "park-and-ride" model or providing public bicycle services to facilitate flexible mobility within the Thao Dien area.

• Expanding parking areas for private vehicles used by metro passengers.

• Constructing a connecting road between the station and Binh An station of the Bach Dang - Linh Dong river bus route to integrate river bus services with the metro station.

• Designating specific entrances and exits by zone to alleviate congestion.

• Creating open spaces with integrated amenities such as parks, playgrounds, and cafés within the station area to enhance the user experience.

Since the model incorporates motorised traffic flows, adjustments to the simulation model were also applied. The authors used calibration results from [27], including the parameters presented in table 3.

Table 3. Parameters for adjusting driving behaviour in the VISSIM model.

Characteristic	Value	Note
Lateral		
- Minimum lateral distance		
+ At 0 km/h	0.15 m	Observed at the field
+ At 50 km/h	0.8 m	Taken same as dynamic motorcycle lane
- Desired position at free flow	Free	
Lane change		
- General behaviour	Free lane section	
- Maximum deceleration (own)	$-2.28\ m/s^2$	
- Maximum deceleration (trailing)	$-1.72\ m/s^2$	
- $1 m/s^2$ per distance (own)	5 m	[27]
- $1 m/s^2$ per distance (trailing)	5 m	
- Accepted deceleration (own) (mean value)	$-1.15\ m/s^2$	
- Accepted deceleration (trailing) (mean value)	$-0.8\ m/s^2$	
- Maximum deceleration for cooperative braking	$-1.72\ m/s^2$	
Car following model (Wiedemann 74)		
- Looking ahead distance	20-30 m	Assumed
- Number of observed vehicles	3-4	Assigned
- Average standstill distance	0.25 m	Observed at the field
- Additive part of safety distance	0.5 m	Assumed
- Multiple part of safety distance	0.75 m	Assumed

To provide a basis for traffic forecasting in the model, traffic volume counts were conducted at locations within the study area, specifically on the following road links: Saigon Bridge, Vo Nguyen Giap, Tran Nao, Quoc Huong, and Thao Dien. The traffic count surveys on these road links were carried out during three daily peak periods (6-8h, 11-13h, and 17-19h) on 21 May 2025 (early week), 23 May 2025 (midweek), and 26 May 2025 (weekend), in order to collect traffic volume data and measure the geometric characteristics of the surveyed areas. The specific parameters required for input into the model include:

• Alignment and specifications of the urban railway system

• Alignment and specifications of the connecting bus network

• Geometric dimensions of the intersection and its branches

• Lane configuration; locations of stop lines, pedestrian crossings, traffic signal poles, and bus stops

• Traffic volume and composition of vehicle flows entering and exiting the intersection branches

• Pedestrian volumes from different directions at the intersection

• Traffic signal control programmes, including the number of signal phases, signal cycle length, green time, red time, yellow time, etc.

Fig. 4. Geometric simulation of the Thao Dien Station area. Source: Author's compilation.

Figure 4 illustrates the existing geometric layout of the Thao Dien station area along with the proposed traffic management solutions. The traffic streams depicted include automobiles, motorcycles, and buses travelling in multiple directions.

5.2. Evaluation results of service levels on roads connecting to Thao Dien station

The model is developed based on current survey data, spatial information, and urban development planning, including detailed information on construction projects around the station such as location, land area, total floor area, floor area ratio, and land-use functions (residential, commercial, office, and services). Based on different infrastructure and urban development scenarios, the traffic simulation model is used to evaluate the operational efficiency of the network. Future scenarios are developed as decision-support tools aimed at achieving the goal of sustainable transportation network development.

Scenarios 1 and 2 are simulated to assess traffic operation efficiency through technical indicators such as traffic volume, volume-to-capacity ratio (V/C), and roadway level of service (LOS).

In Scenario 1, no new solutions are introduced beyond the existing infrastructure and transport organisation. According to the simulation, the roads surrounding Thao Dien station under this scenario experience high traffic volumes (thousands of vehicles per hour), resulting in a volume-to-capacity (V/C) ratio of approximately 0.6-0.7 and primarily a level of service (LOS) at grade C. This indicates that the main roads are operating near their capacity threshold, with vehicle speeds reduced due to high traffic density. Without infrastructure upgrades or diversification of public transport modes, residents remain heavily dependent on private vehicles. In contrast, the TOD model emphasises the development of public transport to minimise private car use and foster sustainable urban environments. The lack of restructuring the transport system towards public transit will lead to deepening traffic congestion associated with urban sprawl, with cities expanding in a car-dependent manner and increasing travel distances and greenhouse gas emissions.

Scenario 2 proposes a transport organisation based on the TOD model for the Thao Dien station area and its surroundings, developed into a high-density, mixed-use urban district. Specifically, the core area (with a radius of approximately 400-500 metres around the station) comprises a mix of residential, commercial, office, and service functions aimed at increasing the local population and encouraging walking. The TOD urban design criteria seek to enhance land-use efficiency while limiting private vehicle use, thereby reducing congestion and pollution. The transport system is integrated across multiple modes, enabling passengers to easily transfer between the metro, bus, bicycle, walking, and other modes. The plan includes the construction of pedestrian bridges, walkways, and bicycle lanes directly connecting to stations and bicycle parking areas, along with the application of electronic ticketing and intelligent traffic management systems. As a result, scenario 2 synchronises the public transport network with residential areas, facilitating convenient transfers for passengers and reducing waiting times.

By analysing trends in transportation and urban development, as well as the interrelations between residential, occupational, recreational, and mobility needs, together with forecasts of population, employment, and public transport service expansion, future travel demand across various urban transport modes can be projected (Fig. 5).

Fig. 5. Diagram of forecasted transport demand. Unit: 100 PCU/h. Source: Authors' compilation.

Table 4. Evaluation results of roads connecting Thao Dien Station.

No.	Route	Direction	Scenario 1 Volume PCU (Passenger car unit)	V/C	LOS	Scenario 2 Volume PCU (Passenger car unit)	V/C	LOS
1	Sai Gon Bridge	Binh Thanh district → District 2	5,284	0.65	C	5,190	0.64	C
		District 2 → Binh Thanh district	5,217	0.64	C	5,124	0.63	C
2	Vo Nguyen Giap	Sai Gon bridge → Rach Chiec bridge	5,704	0.59	C	5,603	0.58	C
		Rach Chiec bridge → Sai Gon bridge	5,666	0.58	C	5,565	0.57	C
3	Vo Nguyen Giap Frontage Rd	Sai Gon bridge → Rach Chiec bridge	1,106	0.68	C	1,041	0.64	C
		Rach Chiec bridge → Sai Gon bridge	1,041	0.64	C	981	0.61	C
4	Tran Nao 1	Tran Nao → Vo Nguyen Giap	1,853	0.38	B	1,763	0.36	B
		Vo Nguyen Giap → Tran Nao	1,962	0.40	B	1,886	0.39	B
5	Tran Nao 2	Vo Nguyen Giap → Thao Dien	2,215	0.68	C	2,086	0.64	C
		Thao Dien → Vo Nguyen Giap	1,544	0.48	B	1,454	0.45	B
6	Tran Nao 3	Luong Đinh Cua → Vo Nguyen Giap	2,294	0.61	C	2,077	0.55	C
		Thao Dien → Luong Dinh Cua	2,318	0.61	C	2,090	0.55	C
7	Quoc Huong	Xuan Thuy → Vo Nguyen Giap	1,096	0.47	B	918	0.39	B
		Vo Nguyen Giap → Xuan Thuy	1,122	0.48	B	940	0.40	B
8	Vo Nguyen Giap Frontage Rd	Sai Gon bridge → Rach Chiec bridge	1,217	0.41	B	1,146	0.39	B
		Rach Chiec bridge - Sai Gon bridge	1,406	0.48	B	1,325	0.45	B
9	Thao Dien	Xuan Thuy → Vo Nguyen Giap	2,332	0.48	B	2,197	0.45	B
		Vo Nguyen Giap → Xuan Thuy	2,219	0.46	B	2,090	0.43	B
10	Tran Ngoc Dien	Tran Ngoc Dien → Thao Dien	388	0.27	A	365	0.25	A
		Thao Dien → Tran Ngoc Dien	369	0.26	A	348	0.24	A

According to the simulation results (Table 4), traffic volumes on the main corridors decrease under Scenario 2. The total main corridor volume dropping from approximately 5,300 vehicles per hour to about 5,200 vehicles per hour, corresponding to a reduction of 0.01-0.05 in the V/C ratio compared with Scenario 1. Most main roads maintain a Level of service (LOS) of C (signs of congestion but stable conditions) or B (higher speeds) under Scenario 2, while smaller branch roads (such as Tran Ngoc Dien street) achieve LOS A-B due to lower traffic volumes. A key distinction is the significantly improved efficiency of public transport usage: higher population density near the station and a convenient connection system attract more passengers to use metro and bus services instead of motorbikes.

5.2.1. Evaluation results of pedestrian generation/attraction at Thao Dien station

After the model was set up and executed, the simulation produced the following results. These outcomes provide an overview of the impact of pedestrian movements on traffic organisation at the Quoc Huong - Vo Nguyen Giap frontage road intersection. A comparative analysis was conducted on the simulation results at this intersection from two perspectives: the impact of pedestrians and the impact on traffic flow at the junction.

Table 5. Typical waiting time of pedestrian flows.

No.	Movement option	Waiting time (s) 100 people	200 people	300 people	500 people
1	Vo Nguyen Giap Frontage Road	71.68	97.99	127.43	226.29
2	Tran Nao Street (crossing Vo Nguyen Giap)	140.94	177.51	214.08	250.65

In the case where a pedestrian overpass is implemented, pedestrian flows and vehicle flows are almost completely separated, resulting in no significant mutual interference.

Fig. 6. Simulation of pedestrian flow at Thao Dien station. Source: Authors' compilation.

The results (Table 5 and Fig. 6) indicate that pedestrians experience longer waiting times as both vehicular volumes and pedestrian numbers increase. Additionally, the incorporation of traffic signals can help reduce pedestrian waiting times. However, under the observed trend, when pedestrian volumes are high, delays tend to affect pedestrians in a similar manner across different scenarios.

Although the Thao Dien station area has seen some improvements in traffic organisation, several challenges remain in enhancing transport efficiency. While the city has implemented feeder bus routes to connect with the metro system, the current bus network does not yet meet the flexible mobility needs of passengers. Road traffic along access routes, private vehicle parking, pick-up and drop-off zones, and streets for private vehicles remains suboptimal in design, leading to traffic conflicts among buses, private cars, and motorbikes.

The increasing number of vehicles, especially during peak hours, coupled with the slow development of transport infrastructure and poor network connectivity, limits alternative route options. Moreover, infrastructure for pedestrians and green transport modes, such as bicycles, is still underdeveloped, reducing the safety and convenience of accessing the station. Traffic behaviour also contributes to worsening congestion, with frequent violations of traffic rules, such as lane encroachment, driving against traffic, speeding, reckless overtaking, and disorderly lane usage.

Strategic directions to be considered include improving the public transport connection network, optimising traffic flows at intersections, expanding space for pedestrians and private vehicles, and implementing technological solutions for smart traffic management. These efforts will help enhance transport service quality, reduce congestion, and create more favourable conditions for metro use in the Thao Dien area.

5.3. Scenario comparison

When comparing the scenarios, scenario 2 performs better than scenario 1 across most evaluation criteria. From a transport engineering perspective, scenario 2 demonstrates a slight reduction in road traffic volume and improved traffic flow; the V/C ratios on major routes are lower or equivalent to those in scenario 1, enabling more stable system performance. The level of service (LOS) on main corridors in scenario 2 remains at levels C or B, comparable to or better than those in scenario 1.

Regarding public transportation, scenario 2 shows significantly higher efficiency: the metro and bus networks are more optimally utilised, attracting more passengers (convenient public transit routes help reduce the number of motorcycle trips). Thanks to multimodal integration and prioritisation policies, the share of passengers using public transport increases, thereby alleviating pressure on the road network.

In terms of sustainability, scenario 2 also yields better results: transit-oriented urban development reduces urban sprawl, which in turn lowers energy consumption and emissions. In contrast, Scenario 1 continues to shape the city around private vehicles, potentially leading to higher air pollution and costly infrastructure investments.

In summary, the comparison indicates that scenario 2 (transport organised according to the TOD model) is more optimal than scenario 1 in terms of both transport efficiency and system sustainability.

Table 6. Comparison of two scenarios.

Criteria	Scenario 1	Scenario 2
Level of intervention	None	Strong, comprehensive
Average V/C ratio	~0.58-0.68	~0.55-0.64
Level of service (LOS)	Mostly B and C	Mostly B, some A
Public transport efficiency	Low	High, due to integration and restructuring
Congestion risk	Medium to high	Significantly reduced
Sustainability	Low	High

The results (Table 6) show that although the public transport system has seen certain improvements-such as the introduction of new electric bus routes and the construction of pedestrian overpasses-it still faces issues related to waiting times and a lack of seamless connectivity. Several new bus routes have been adjusted; however, their itineraries remain suboptimal, resulting in unreasonable transfer distances and extended waiting times, especially in areas located far from stations. The lack of synchronisation in the electronic ticketing system and inadequate communication between transport modes also detract from the passenger experience during modal transitions between bus and metro services.

Table 7. Evaluation results of the transportation network around Thao Dien station.

No.	Criteria	Scenario 1 result	Scenario 2 result
1	Average travel speed [km/h]	20.88	21.93
2	Average delay time [s/vehicle]	19.05	18.14
3	Total travel distance [km]	20.125	20.327
4	Total travel time [hours]	964	927
5	Total delay time [hours]	184	177
6	Number of stops	3.152	3.061

The evaluation results (Table 7) indicate that scenario 2 delivers better operational performance of the transport network compared with scenario 1, as reflected by higher average speeds, reduced delays and stop frequencies, as well as lower total travel time and total delay. These improvements demonstrate that scenario 2 contributes to enhancing traffic flow, mitigating congestion, and optimising the operational efficiency of the transport network in the Thao Dien station area.

Thao Dien station is designed with multiple functional floors, including ticketing areas, commercial spaces, and technical zones, along with side platforms serving passengers. Based on the current conditions and proposed solutions, the study evaluates the effectiveness of the transport system, identifies congestion points, and proposes measures to optimise passenger and vehicle flows. The results from this modelling can be applied to enhance traffic organisation at other metro stations within the city's transit system.

6. Conclusions

In the context of HCMC accelerating the development of public transport and shaping a sustainable urban space, the TOD model is considered an appropriate approach to optimise transport organisation and improve urban connectivity. This study has clarified the theoretical foundations of the TOD model while also assessing its applicability in organising transport services at urban railway stations, specifically focusing on metro line No. 1-the city's first and strategically significant public transport corridor.

Through the analysis of the current status of metro line No. 1 and a representative station area - Thao Dien Station-the study reveals that the existing feeder transport system lacks coordination and has not yet fully optimised accessibility and passenger distribution. The SWOT analysis indicates that the TOD model holds strong potential for implementation, particularly in promoting public transport use, developing green mobility options, and integrating urban planning with transport infrastructure. However, several limitations persist, including an underdeveloped legal framework, weak intermodal coordination, and inadequate infrastructure for pedestrians and shared mobility services.

Based on these analyses and evaluations, the study proposes a set of TOD-based transport organisation solutions tailored to the specific context of HCMC. These include strengthening the legal and institutional framework for inter-agency coordination; improving the quality of bus feeder services; promoting green and shared modes of transport; adopting digital technologies for transport network management; and revising urban planning policies to support multimodal mobility. These recommendations aim not only to enhance the operational efficiency of metro line No. 1 but also to contribute to the development of a sustainable public transport ecosystem.

Simulation of various transport organisation scenarios at Thao Dien station clearly demonstrates the effectiveness of TOD implementation, with improvements in accessibility, reduced travel times, and increased sustainability of the transport system. This finding affirms that the TOD model holds practical potential beyond theory, provided that policy, planning, and operational efforts are well - aligned.

Planning and organising public transport connections (bus, cycling, walking, etc.) around urban rail stations in accordance with the TOD orientation will significantly increase metro ridership and improve travel quality in surrounding areas. High-density, mixed-use urban centres should be developed around metro stations, incorporating commerce, services, public amenities, and housing to stimulate sustainable growth. In this context, metro lines serve as the backbone of the urban transport network, enabling high-capacity passenger movement. To organise urban space effectively around stations, compact urban planning must be implemented, supported by a well-connected bus network and seamless integration with other transport modes, thereby optimising the commuter experience and encouraging a shift from private vehicles to public transport.

CRediT author statement

Phu Quang Tran: Methodology, Conceptualisation, Visualisation, Writing original draft, Writing - Reviewing and Editing; Quoc An Bui: Data curation, Formal analysis, Software, Methodology, Writing original draft, Writing - Reviewing and Editing; Thai Hong Nguyen: Conceptualisation, Visualisation, Writing - Reviewing and Editing.

COMPETING INTERESTS

The authors declare that there are no potential conflicts of interest related to this study and confirm that the manuscript has not been previously published.

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