Chapter 4

Design and Analysis of Feeder-Line Bus

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Chapter 4

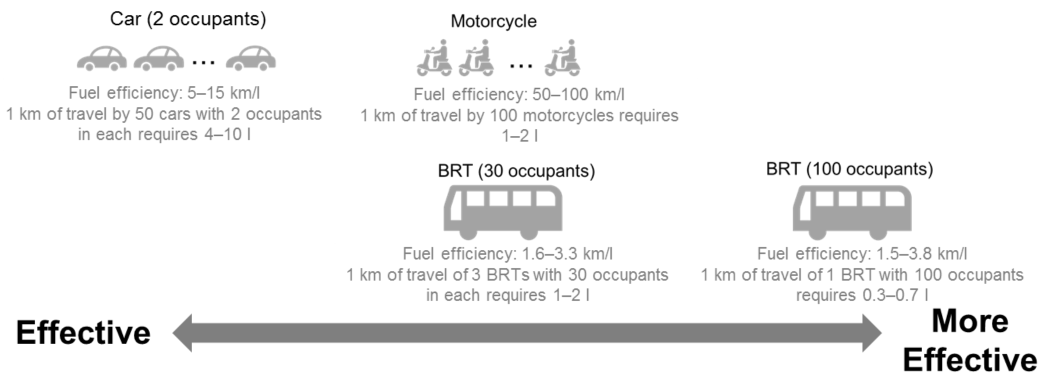
Design and Analysis of Feeder-Line Bus

1. Towards Promotion of Bus Rapid Transit System Use

As Da Nang City has been developing rapidly, like other Asian cities, transport demand is expected to grow significantly. The city is planning to expand and improve roads and public transport, and the introduction of a BRT system is one of the key features. In a BRT system, dedicated BRT lanes give the bus system priority over private transport, allowing the system to carry larger numbers of passengers faster. If used effectively, it could contribute to reducing energy consumption in the transport sector.

As a rough estimate of the energy consumption reduction effect by introducing the BRT system, suppose 100 people travel 1 kilometre (km) along the same road (Figure 4.1). If one person rides on one motorcycle, as is typical in Da Nang City, 100 motorcycles are needed to transport 100 people. When using the BRT, a reduction in fuel consumption of about 60 percent is expected as a bus can accommodate 100 people. Additionally, the BRT is expected to reduce fuel consumption by about 90 percent compared to cars. However, when the number of passengers per vehicle is reduced, the BRT needs as much fuel as motorcycles and the savings are reduced. Therefore, it is important to maximise the number of BRT passengers to improve energy efficiency. Figure 4.1 illustrates the fuel consumption of the different transport modes.

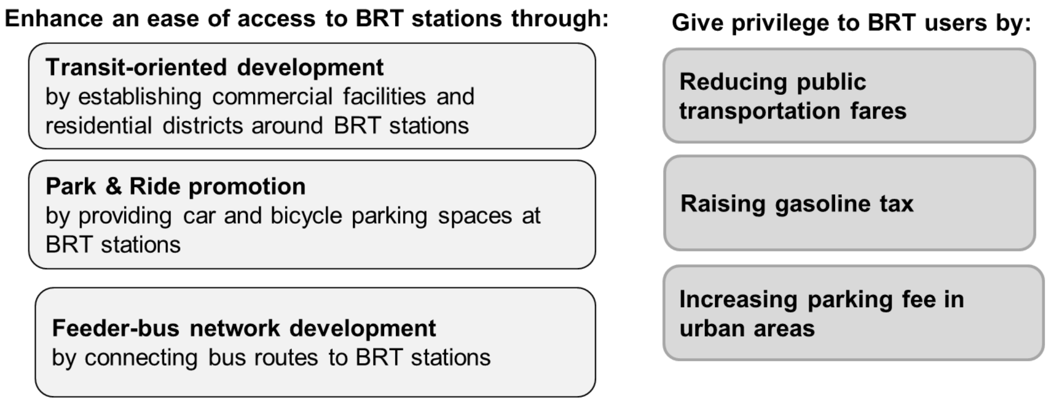
Figure 4.1: **Estimated Fuel Consumption by Transport Mode**



BRT = bus rapid transit, km = kilometre, l = litre.
Source: Study team.

How can we increase the number of passengers who prefer the BRT to motorcycles or cars as means of transport? Possible measures to enhance the attractiveness of BRT are summarised in Figure 4.2. One measure is to improve ease of access to BRT, for example by pursuing transit-oriented development, installing park-and-ride facilities, and establishing feeder bus services. These measures aim to increase the number of potential users that choose the BRT as their mode of transport. However, even if the BRT stations are convenient and close to users, the number of users will not increase if the cost is much higher than that of the private transport, such as motorcycles. Therefore, a second measure is to make BRT use more attractive by making the cost of using BRT lower than that of private transport such as motorcycles and cars. This can be achieved by providing privileges to BRT users by reducing fares, or by penalizing automobile and motorcycle users by raising gasoline tax or increasing parking fees.

Figure 4.2: **Measures to Enhance the Attractiveness of Bus Rapid Transit**



BRT = bus rapid transit.
Source: Study team.

Generally, greater impact can be achieved by implementing a well-balanced combination of measures rather than using any one of them individually. It is technically difficult to evaluate the future effects of all measures quantitatively, so the study chose to analyse the impact of a feeder-bus network that Da Nang City is interested in developing.

To conduct a quantitative evaluation on the feeder bus, specific feeder bus routes must be set for the study. Designing such routes requires specialised expertise and experience, therefore, feeder bus routes were decided using the technique developed by authors in a 2015 study.[65] Using this technique, the best bus route and travel frequency can be determined for the given conditions of traffic demand in the city, roads, and the BRT network. When applied actual cities, the technique has some problems such as the difference between the assumed model and reality. Section 2 reviews these issues and refine the technique, and Section 3 evaluates the

[65] Kutani, T., Y. Sudo and Y. Li (2015), 'Preliminary Design and Analysis of Feeder Line Bus, in Energy Efficiency Improvement in the Transport Sector through Transport Improvement and Smart Community. ERIA Research Project Report 2014-31, Jakarta: ERIA, pp. 65–82. Available at: http://www.eria.org/RPR_FY2014_No.31_Chapter_4.pdf

introduction of a feeder bus system by calculating the optimised feeder bus routes using the planned BRT network in Da Nang City as given conditions.

2. Feeder Bus Route Design and Evaluation Method

The technique to design feeder bus routes was developed to obtain the best bus route and calculate the optimal travel frequency under the given conditions. Since the feeder bus facilitates access (or egress[66]) to the main public transport (the BRT in Da Nang City), its coverage must be expanded by setting up routes that connect as many residential areas as possible to BRT stations. Too much expansion, however, could cause unnecessarily expense, which means installing feeder buses is a kind of balance problem.

The technique developed in 2015 uses mathematical programing to deal with the problem. It applies the problem to a mathematical model that minimises sum of all travel times as the objective functions within given constraints in the feeder bus network design. The technique can obtain the feeder bus route that can minimizes the travel time and, as a result, increase the number of passengers who can travel faster by using the public transport. In addition, it sets the upper limit on the total travel distance of the feeder bus as a constraint to preferentially select the most effective route. Limits can also be set on the number of passengers carried per vehicle for buses and the BRT as one of the constraints to determine how many buses are needed to carry all the passengers.

However, this mathematical model differs from reality in the following ways:

- It places constraints on the total travel distance of the feeder bus but it does not do so for cost, even though cost effectiveness is an important consideration. It was therefore decided to find a method to design bus routes using budget constraint instead of travel distance constraint. This is described in section 2.1
- The total travel time is used as the objective function, assuming that passengers choose the transport mode that enables the shortest total travel time. The model is therefore unrealistic because it assumes that time is the only consideration when deciding transport means. In reality, people consider other factors, such as cost, in addition to travel time. Furthermore, the choice of a deterministic model is also unrealistic. In the deterministic model, a person always favours the lower-cost option however minimal the difference is (e.g. the travel time of one option could be one second less than another). In reality, people will choose either transport means if the cost is almost same. However, it is technically difficult to use the probabilistic model that accommodates this kind of decision making in the mathematical programming framework. Therefore, we improved the calculation process, as described in section 2.2.

[66] When using multiple means of transport, transport to the main transport, such as a BRT station, is called access, and a transport to the destination from the main transport is called egress.

2.1 Constraints on Operating Cost of Feeder Bus

In order to represent the budget constraint on the feeder bus by cost rather than by travel distance, the cost is needed for each expense item must be determined. Items to be considered include fuel cost, vehicle purchase cost, and personnel cost. To avoid excessive detail, a uniform cost per unit distance was used. In this way, the cost conversion is easy, and the unit cost per travel distance can be obtained relatively easy by examining past records. According to a Da Nang City official, the cost is VND15,000–16,000/km for a standard 40-passenger bus. This value is used as a rough estimate in this study, although targets are not necessarily limited to 40-passenger buses in the feeder bus design.

2.2 Transport Mode Choice Model

As mentioned earlier, it is difficult to use the probabilistic transport mode choice model in the optimisation calculation. Therefore, we decided to improve the calculation process (Figure 4.3). At first, we use the method built in 2015 to design the feeder bus with the deterministic model considering only the travel time. Then, we evaluated the feeder bus network area obtained using the traffic flow simulator with a probabilistic model considering both cost and time effect. Using the more sophisticated transport mode choice model helps to ensure the appropriateness of the model.

The model built for the Japan International Cooperation Agency Study on Integrated Development Strategy for Da Nang City and Its Neighboring Area Project (DaCRISS) was a candidate for a more sophisticated transport mode choice model for Da Nang City.[67] The model used in the DaCRISS project was built after individual homes were interviewed about transport means used as of 2008. It is therefore considered realistic, even though data are a little old. However, when the model is applied to 2025, when the BRT and the route bus are expected to be well developed, the number of public transport users becomes extremely low (Figure 4.4).

The survey results at the time show that motorcycle and car users accounted for nearly 99 percent and public transport users made up only 0.2 percent (Figure 4.5). The public transport share was low because the bus service was not developed enough to provide sufficient bus routes, and there was no BRT. It is not possible to build an accurate model of public transport mode choice based on this information because there were too few samples to estimate the number of public transport users.

Therefore, section 3 uses a newly built transport mode choice model. As this model is based on the stated preference survey assuming the introduction of the BRT system, it is suitable to evaluate a BRT system that does not yet exist in Da Nang City.

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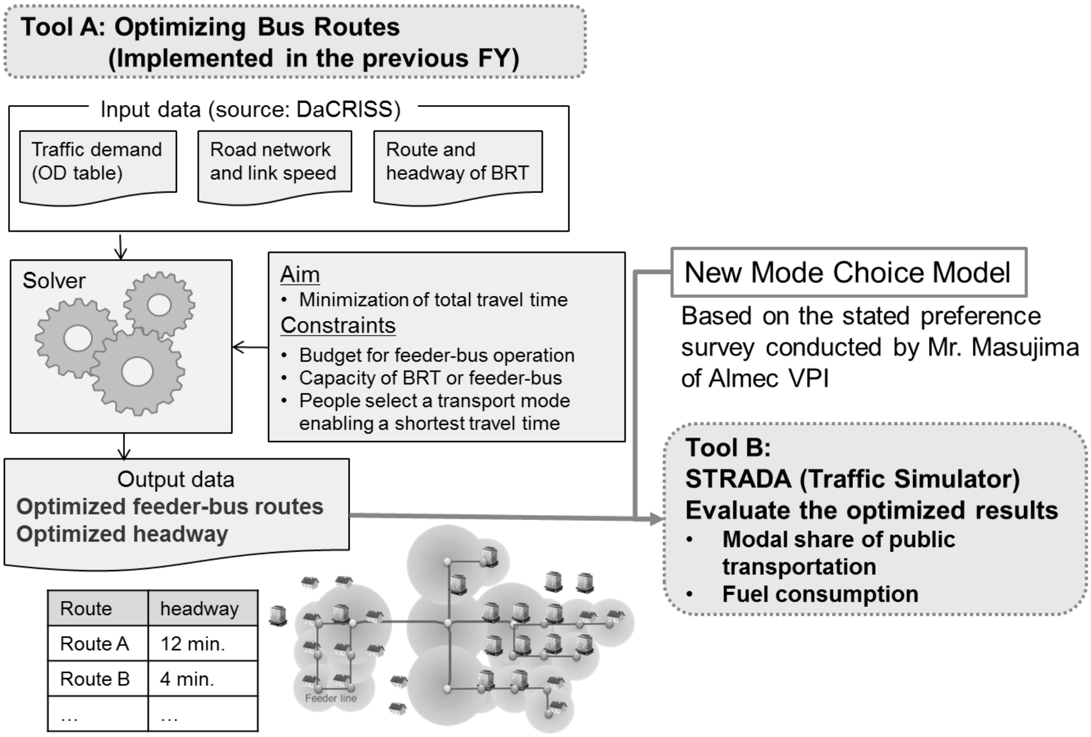
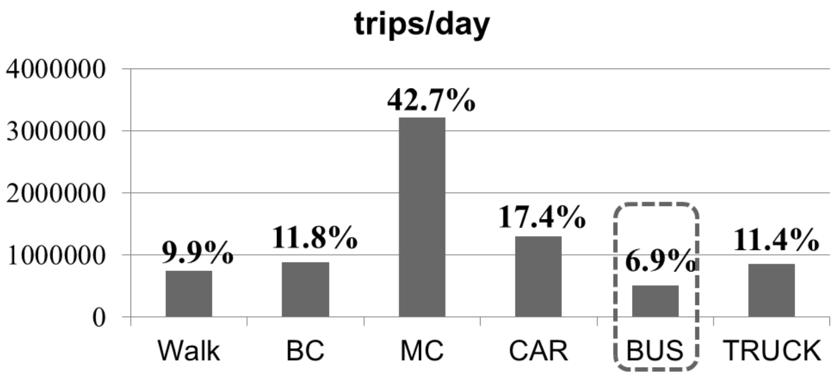
[67] Japan International Cooperation Agency (2010), '*Study on Integrated Development Strategy for Da Nang City and Its Neighboring Area in the Socialist Republic of Vietnam*.' Tokyo.

Figure 4.3: Feeder Bus Simulation Analysis Method



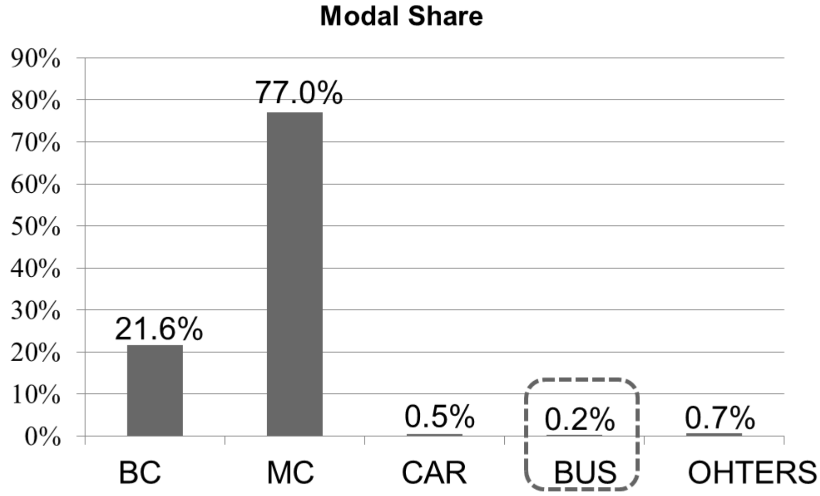
BRT = bus rapid transit, DaCRISS = Study on Integrated Development Strategy for Da Nang City and Its Neighbouring Area Project, FY = fiscal year, min = minutes, OD = origin–destination.
Source: Study team.

Figure 4.4: **Modal Split Using DaCRISS Model, Assuming 2025, Excluding Feeder Bus**



BC = bicycle, DaCRISS = Study on Integrated Development Strategy for Da Nang City and Its Neighboring Area Project, MC = motorcycle.
Source: Study team.

Figure 4.5: **Modal Split, Excluding Walking, as of Individual Home Interview in 2008**



BC = bicycle, MC = motorcycle.
Source: Study team.

3. Optimised Feeder Bus Routes and Simulation Evaluation

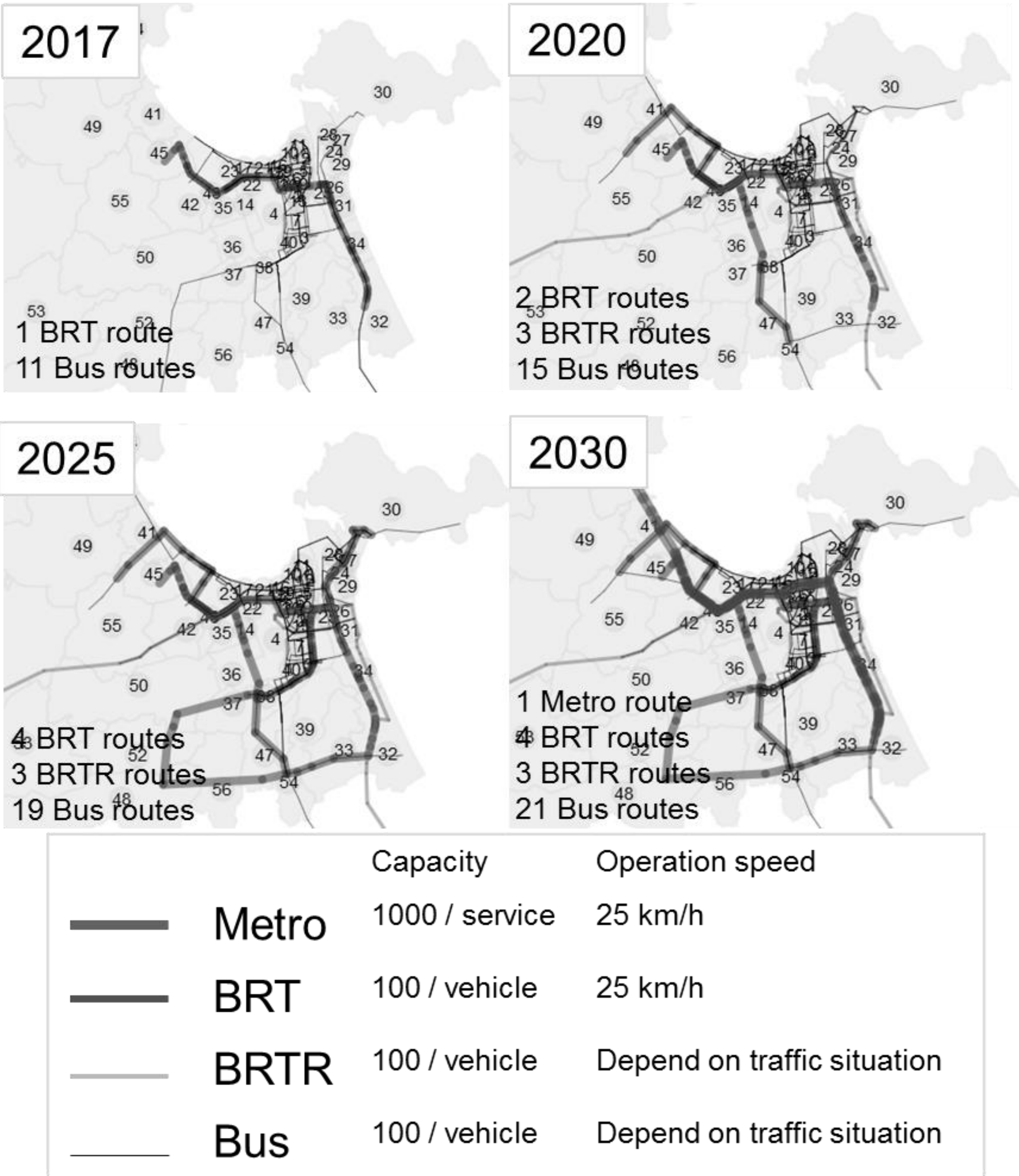
3.1 Preconditions for Analysis

Preconditions for the study to carry out the feeder bus analysis are as follows. According to the transport plan of Da Nang City, the first BRT line will be introduced in 2017, and four more will be implemented in 2025. In addition, metro is scheduled to be introduced in 2030. Metro is a track vehicle that is expected to have 10 times the capacity of the BRT. The target years of the analysis are 2017, 2020, 2025, and 2030.

The analysis uses data on roads and the public transport network sourced from the Da Nang City transport plan. As shown in Figure 4.6, four types of transport are scheduled: BRT, BRT standard bus (BRTR),[68] metro, and bus. Since the metro, BRT, and BRTR are considered to play the role as the main public transport modes, the current plan is used as preconditions. 'Bus' is excluded from preconditions and instead, the feeder bus routes are newly redesigned. To model the future transport demand, the numbers in the DaCRISS Scenario 3 of 2025 multiplied by the rate of population change are used (Figure 4.7).[69] The traffic volume in the entire city (trips between zones) is estimated at about 2 million trips per day, and the figure is expected to almost double to about 3.8 million trips per day in 2030. Figure 4.6, from the city's transport plan, shows how the city intends to cope with the expected sharp increase in traffic volume.

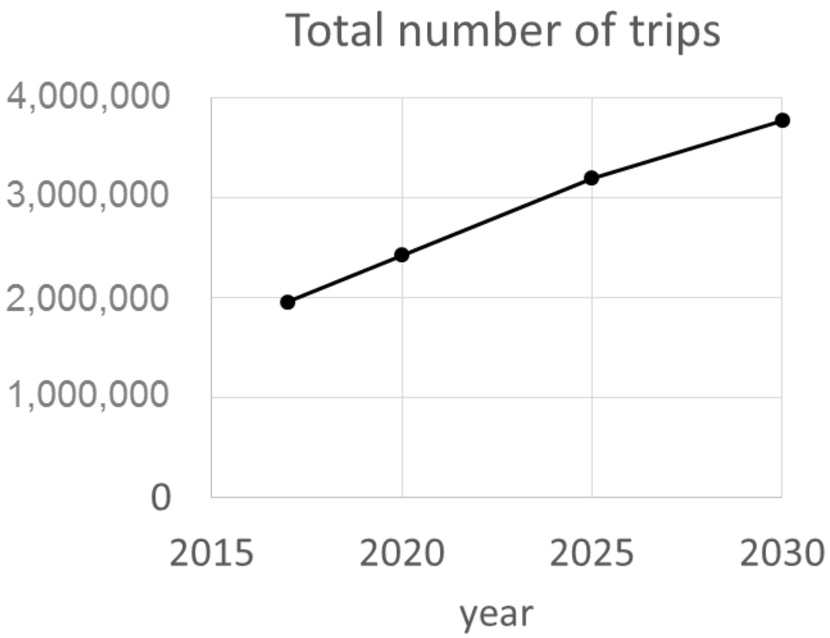
[68] BRTR is a type of bus that is specific to Da Nang City. Although it is positioned as special kind of bus, it is little different from a normal bus given that it does not have dedicated lanes. It is treated here as the main public transport (not the target of optimization) considering its special positioning.
[69] Scenario 3 is one of the urban development visions defined by Da Nang City. The city adopted this scenario that will most accelerate the growth. A population of 2.5 million–3.0 million is assumed in 2030 as the future urban development target.

Figure 4.6: **Da Nang City Transport Plan**



BRT = bus rapid transit, BRTR = BRT standard bus, km/h = kilometres per hour.
Source: Da Nang City transport plan.

Figure 4.7: **Change in Traffic Volume Assumed in DaCRISS**



DaCRISS = Study on Integrated Development Strategy for Da Nang City and Its Neighboring Area Project.
Source: DaCRISS.

3.2. Optimised Feeder Bus Routes

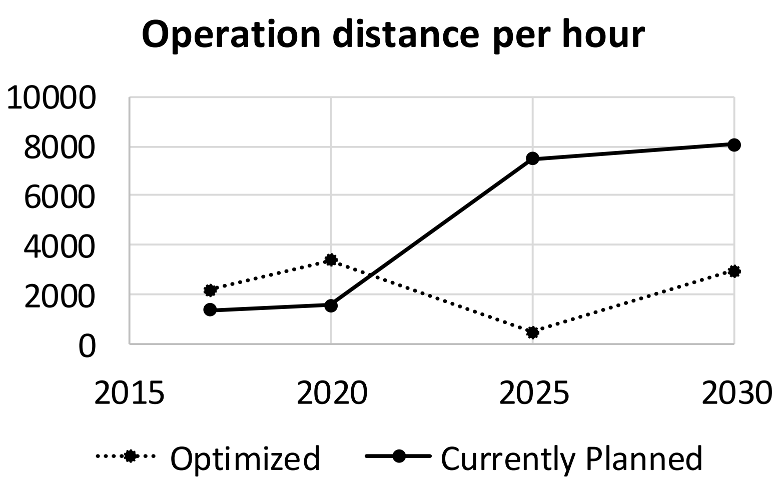
This section describes the calculation of optimised bus routes using certain preconditions Feeder bus routes are designed with large enough (effectively limitless) operating cost constraints. Figure 4.8 shows the calculated operation distance of feeder bus per hour and Figure 4.9 shows the feeder bus routes selected. The operation distance is about 2,000–3,000 km/hour, except in 2025, when it is about 500 km/hour.

The optimised result is compared to the travel distance of the currently planned route bus to evaluate its appropriateness. The total travel distance is about 1,000 km/hour for both. Hence, the optimised route is designed with a similar travel distance to that of the general bus operation plan. As for 2017 and 2020, the travel distance of the plan is about 2,000 km/hour, which is slightly shorter than the optimised result. Under the plan for 2025 and 2030, the travel distance is scheduled to be increased to about 8,000 km/hour. Such a tendency is not shown in the optimised result, which is curious considering the surge in the traffic demand. What could cause of this difference?

The first possibility is the limits of the main public transport capacity. Since the capacity of the BRT is small – about one-tenth that of the metro – it is likely that the BRT reaches its capacity just by carrying residents along its routes. Even if the feeder bus brings more passengers, the BRT might not have extra capacity to carry them. The optimised calculation is designed to add no new feeder bus route if the BRT does not have extra transport capacity, as it considers adding new feeder bus routes a waste of money. Therefore, it is assumed that the feeder bus operation distance cannot be increased due to the BRT transport capacity limit for 2025 and 2030. The same reason seems to apply to why the feeder bus travel distance is extremely small in 2025 in the optimised result. This point needs to be closely considered in the evaluation using the STRADA (traffic flow simulator) later.

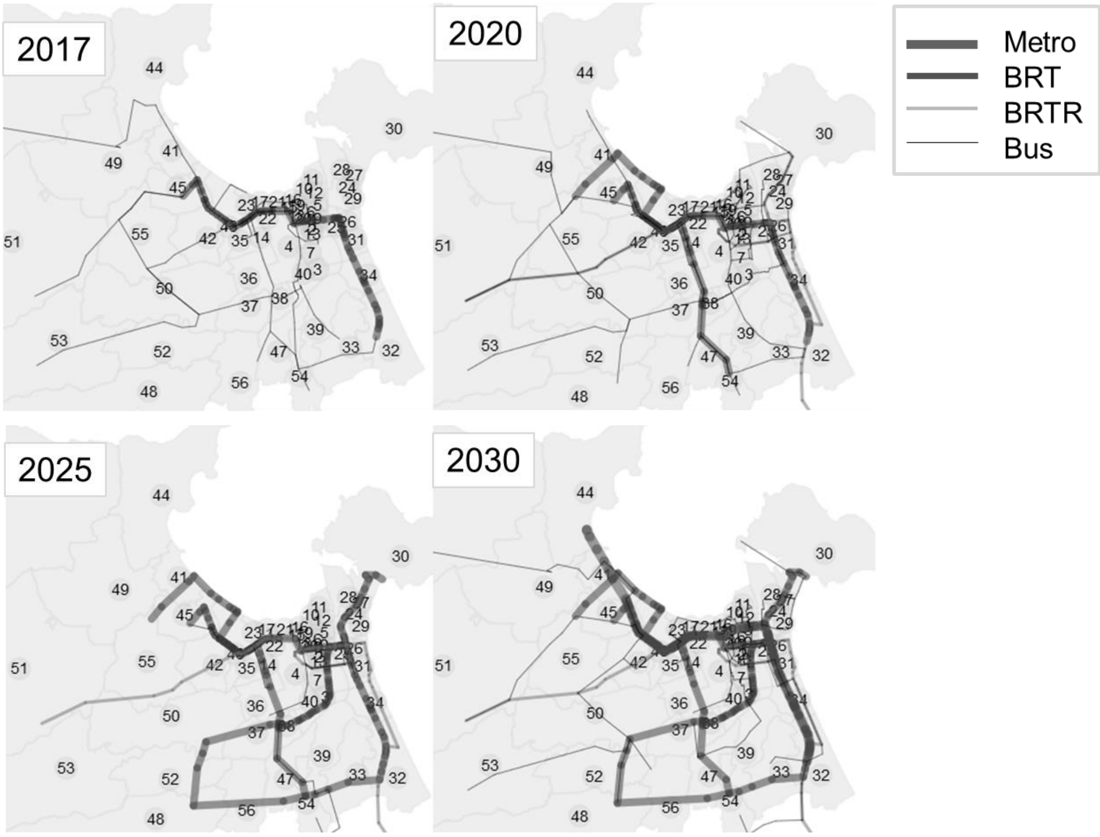
Another reason why the city's plan and the optimised result are different is the trips data used for the calculation.. When comparing the optimised result (Figure 4.9) to the plan (Figure 4.6), the density of the routes in the centre of Da Nang City is largely different. In the plan, there is a high density of routes in the centre of the city, but in the optimised result the density is lower. This is because our calculation used only origin–destination data as a trip demand (i.e., trips from a zone to another zone) because detailed trip data of from a zone to the same zone does not exist. The city's plan, on the other hand, is supposed to have been made based on the experience on the route decision and knowledge of the locality. However, if there is a need to design detailed bus routes, it is necessary to conduct a further research and collect movement data. In any case, the knowledge based on the experience is not included in the data available this time, these issues are not discussed but to be explored in the future.

Figure 4.8: **Optimised Feeder Bus Travel Distance** (kilometres/hour)



Source: Study team.

Figure 4.9: **Optimised Feeder Bus Routes**



Source: Study team.

3.3. Evaluation of Optimised Result Using Traffic Flow Simulation

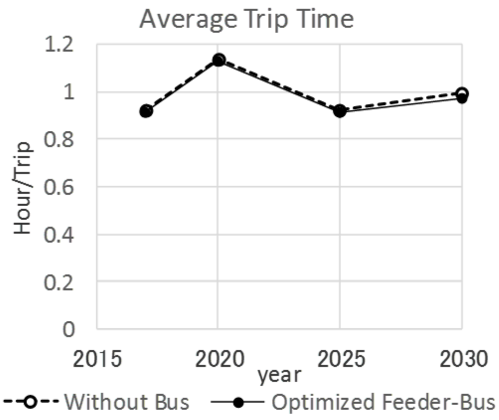
The result of evaluating the obtained feeder bus routes using STRADA is shown below.

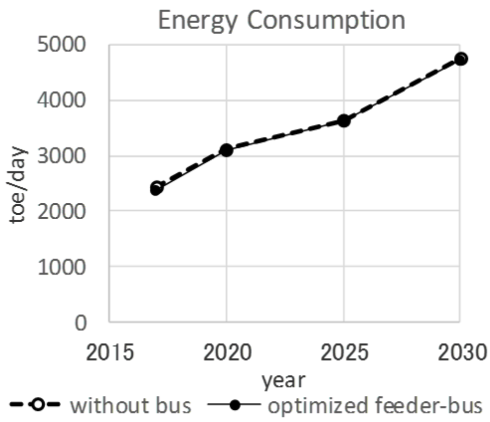
First, the average trip time is shown in Figure 4.10 (left). There is almost no difference between when there is no feeder bus (broken line) and when the feeder bus is introduced (solid line). Figure 4.10 (right) shows the effect on energy consumption. Again, there is no difference between the with and without feeder bus route scenarios. These results suggest that adding new feeder bus routes has no effect, but is it really the case?

To answer to this question, the modal split is shown in Figure 4.11. When the feeder bus is introduced, the share of the motorcycle use decreases by several percentage points compared to the case when there is no feeder bus, and the share of the public transport increases accordingly. Therefore, although the introduction of the feeder bus may not immediately reduce fuel consumption, it is likely to change transport means choice behaviour.

The importance of motorcycles as a mode of transport in Da Nang City is significant. Though it is not considered in this calculation, it is highly likely that overall income levels in Da Nang City will increase and the transport mode will change from motorcycles to cars accordingly. If such a modal shift occurs, it will lead to higher fuel consumption than calculated in Figure 4.10 because the fuel consumption of cars is larger than that of motorcycles. The introduction of feeder buses is significant for fuel consumption as it encourages a shift to public transport by reducing the shift from motorcycles to cars.

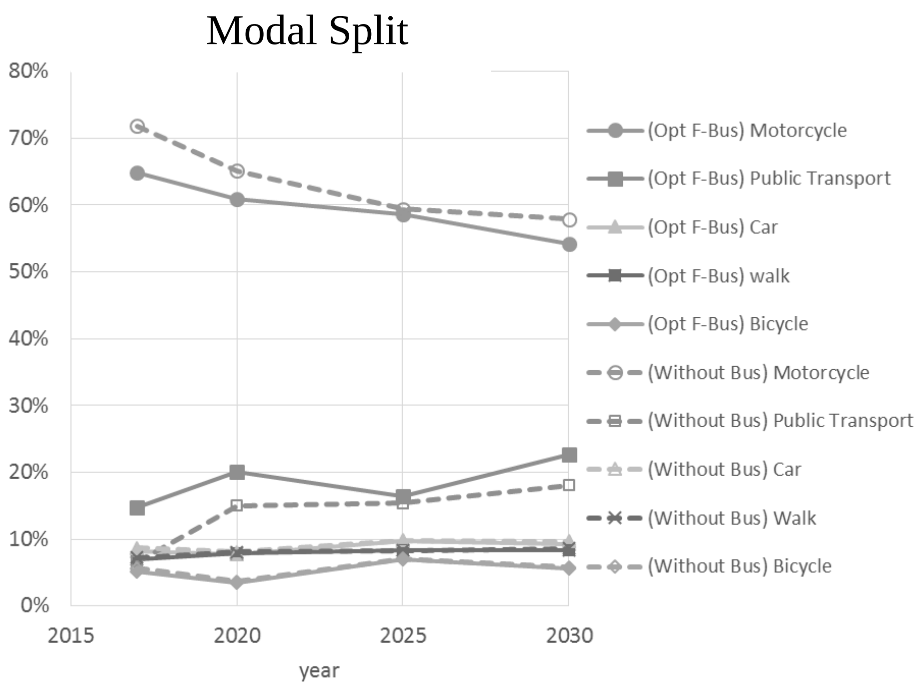
Figure 4.10: **Change in Trip Time and Energy Consumption with and without Feeder Buses**





Source: Study team.

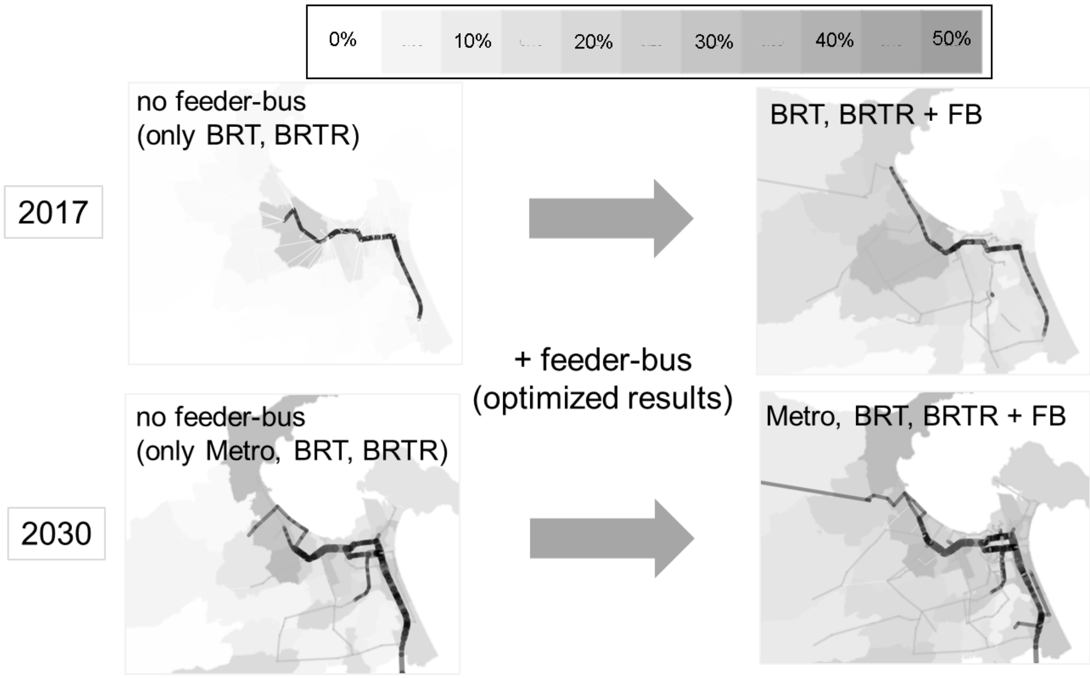
Figure 4.11: Modal Split



Opt = option.
Source: Study team.

Next, to examine the findings in more detail, we illustrate how the introduction of feeder buses affects the modal split of public transport by zone (Figure 4.12). If there is no feeder bus, the public transport share is high only in the areas along public transport routes such as the BRT (10–30 percent). On the other hand, if feeder buses are introduced, the high-share areas are expanded. Without feeder buses, the use of the BRT service will be limited to the residents along the routes, whereas the introduction of feeder buses makes it easier to access the BRT, and the BRT service will be used in wider areas.

Figure 4.12: **Modal Split of Public Transport by Zone**



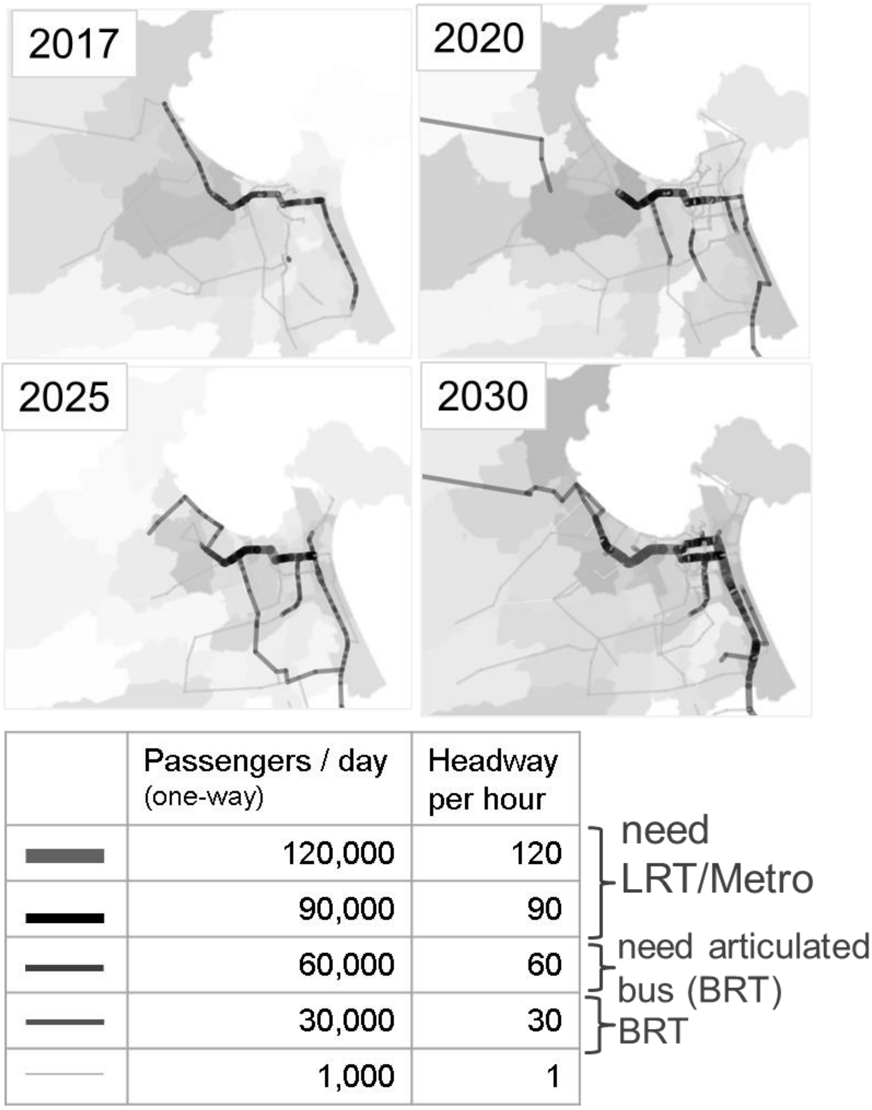
BRT = bus rapid transit, BRTR = BRT standard bus, FB = feeder bus.
Source: Study team.

Figure 4.13 shows the number of passengers boarding public transport on each section of the main transport network. In 2017, immediately after the introduction of the BRT, large numbers of passengers are expected in sections in the centre of Da Nang City. The result indicates the introduction of the articulated bus is necessary to carry such large number of passengers. The number of passengers will further increase after 2020. The number is expected to exceed far beyond the transport capacity in some sections, especially along BRT Line 1. The metro is scheduled to be introduced in 2030, but the simulation result indicates that its timing should be moved forward. If the number of passengers that attempt to use the BRT exceeds its capacity, the attractiveness of the BRT will decrease because of the congestion or the wait time, and the share of public transport will peak. To avoid such a situation, the transport capacity of the BRT should be increased early on.

It is also necessary to consider technical problems of the traffic flow simulator. Because the STRADA simulation computes people's choice of transport mode without considering transport capacity limits and the subsequent congestion, public transport use is overestimated when the demand exceeds supply.

The results enable the following conclusion to be drawn. The transport capacity of the BRT needs to be improved early on. Then, introducing feeder bus services can play an important role to increase the number of BRT users.. In addition, in the evaluation of traffic flow simulation, evaluation techniques that can take the transport capacity into consideration are needed.

Figure 4.13: **Number of Passengers Boarding Main Public Transport Modes, by Section**



BRT = bus rapid transit, LRT = light rail transit.
Source: Study team.

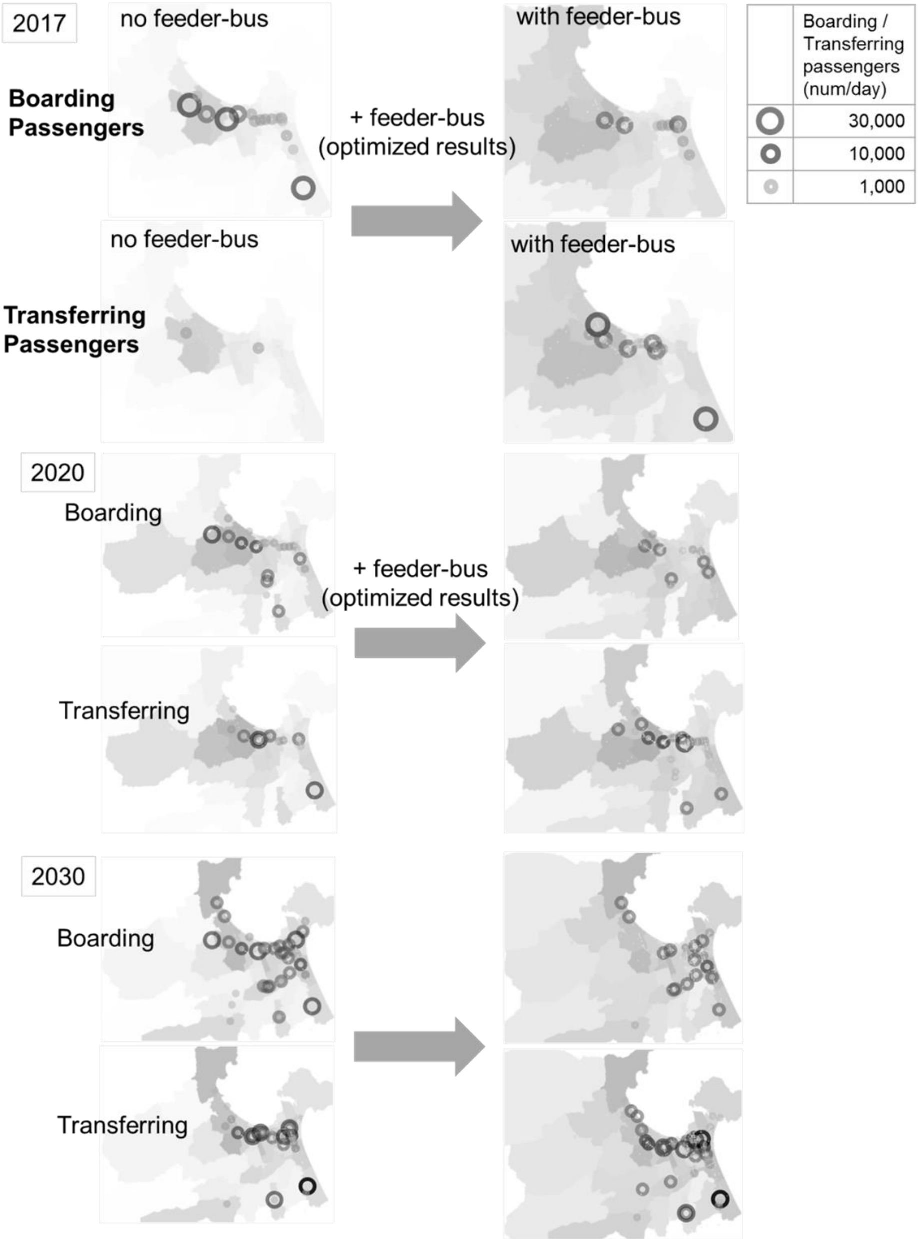
Finally, Figure 4.14 shows the simulation result of how the metro and BRT stations are used. Circles in this figure show the boarding or transferring passengers at each stations. The results for 2017 show that the introduction of the feeder buses tends to reduce the number of boarding passengers at each station and increase the number of transferring passengers. In 2020 and 2030, the introduction of four BRT lines sharply increases the number of passengers who transfer at each station. These findings suggest that the facilities required at stations will change with the introduction of feeder buses and the expansion of the BRT network. Initially, it is important to prepare parking space for motorcycles and cars in front of the station, as most of the passengers are boarding and disembarking from the station. As the public transport network expands, however, the importance of facilities to support smooth transfer increases. The stations with larger number of transferring passengers are hubs for the public transport network. Securing smooth transfer at these main stations could greatly influence the attractiveness of the BRT.

4. Discussion of the Simulation Result

Section 3 discussed the result in the case where there is no constraint on the feeder bus operating cost. What if the constraints are added to the feeder bus operation cost? Figure 4.15 shows the result of optimizing the feeder bus routes by changing the budget in phases and evaluating them using STRADA.

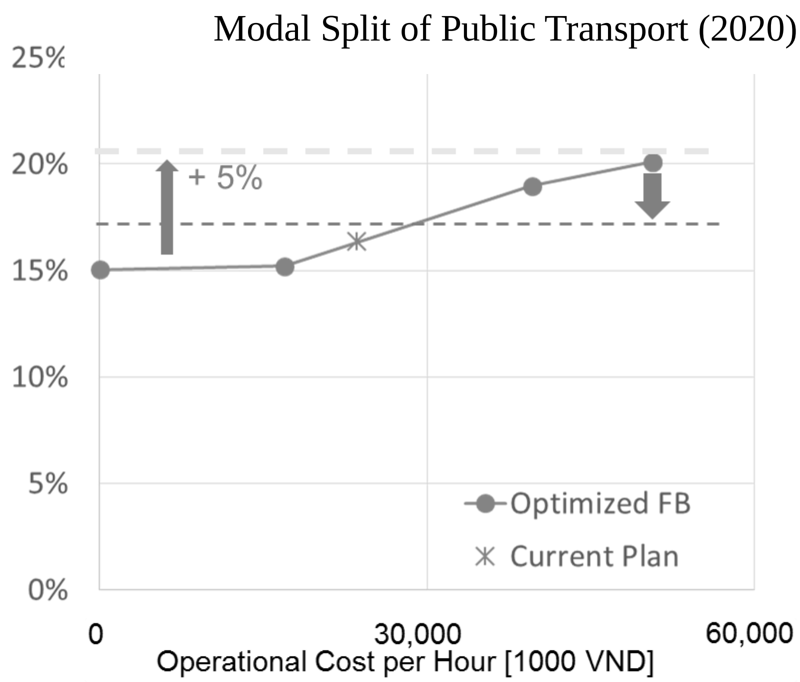
As the feeder bus budget constraint is relaxed and the travel distance increases, the share of public transport increases accordingly. The result shows that in 2020, a 5 percent increase in the share of public transport is expected. However, in reality, as mentioned in Section 3, there is a limit to BRT transport capacity, which is not considered in the STRADA calculation. Thus, the 5 percent increase in the share of public transport is overestimated. To maximise the feeder bus effect, feeder buses need to be used in combination with larger-capacity BRT (BRT using articulated vehicles), light rail transit, or metro.

Figure 4.14: **Number of Passengers by Metro and Bus Rapid Transit Station**



Source: Study team.

Figure 4.15: **Modal Split of Public Transport by Changing Feeder Bus Budget, 2020**



BRT = bus rapid transit, FB = feeder bus, km = kilometre, VND = Viet Nam dong.
Source: Study team.

5. Conclusion

In this chapter, feeder bus routes in Da Nang City were optimised for 2017, 2020, 2025 and 2030, and the results evaluated based on the new stated preference model assuming the BRT introduction. The results indicate that the introduction of the BRT increases public transport use, but the number of people who want to use the BRT far exceeds the planned BRT transport capacity. The following conclusions are drawn:

First, the transport capacity of the BRT should be enhanced at an early stage. The introduction of the articulated vehicle is a possible solution. However, as it is not sufficient, a shift to light rail transit or metro is required (Figure 4.16, left and middle). At present, metro is scheduled to be introduced in 2030, but its introduction should be brought forward.

Second, a feeder bus system is needed to promote the modal shift from motorcycles to public transport. The introduction of feeder buses can transform the BRT from a service that is only available to residents along the routes to one that is available in wider areas, contributing to an increase in the share of public transport. The introduction of the feeder bus system will promote the shift from motorcycles to public transport. But in the future, a rapid shift from motorcycles to cars is also expected along with an increase in income levels. If appropriate measures are not taken, the fuel consumption will increase together with the heavy traffic congestion. Increasing public transport users as much as possible before such a situation arises is a valuable choice for the future of Da Nang City.

Third, if the public transport network becomes well developed by introducing a feeder bus system and expanding BRT routes, the number of transferring passengers at the key stations is expected to increase sharply. Therefore, the transfer of passengers between different routes and different public transport means needs to be made smoother to enhance the attractiveness of the public transport. Measures such as the introduction of transfer systems, shown in Figure 4.16 (right), should be introduced at an early stage.

This study assumed a BRT system that uses non-articulated buses. Further research should evaluate the utility of introducing a BRT system with a higher transport capacity.

Figure 4.16: **Example of Measures to Improve Bus Rapid Transit Capacity.**

LRT = light rail transit.
Source: Study team.