Chapter 4

Preliminary Design and Analysis of Feeder Line Bus

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CHAPTER 4

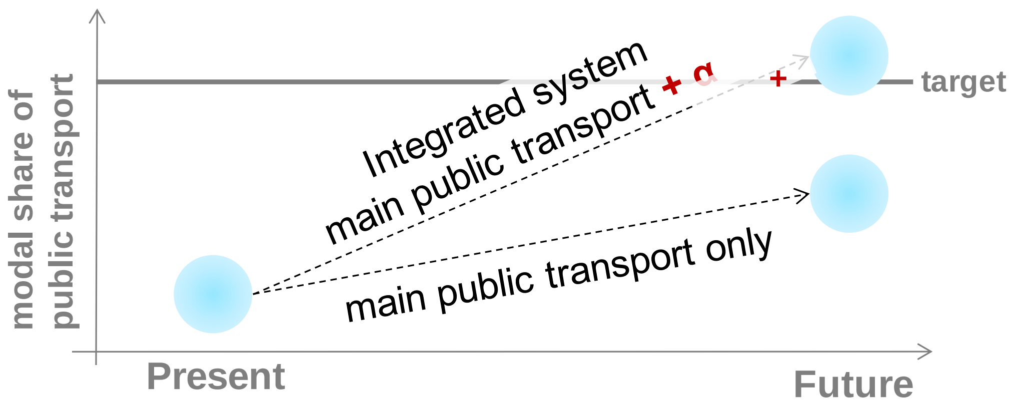
PRELIMINARY DESIGN AND ANALYSIS OF FEEDER LINE BUS

1. Background

1.1 Raising the Attractiveness of Public Transport

How to drive commuters to use public transport is a common goal of Asian countries. Their cities' transport master plans may include detailed goals such as the ideal modal share of public transport, and stipulate measures to achieve the goals. How the public transport system is planned starts with, in most cases, making sure that the main public transport is the centre of the plan. Then, as the master plan requires other components, considerations are then made to additional measures (e.g. feeder networks, traffic demand management) in accordance with the main public transport used. Here, plans for the main public transport are integrated with additional measures that can enhance the former's attractiveness (Figure 4.1).

Figure 4.1: Importance of Additional Measures that Enhance the Attractiveness of Main Public Transport



Source: Author.

For instance, in the case of Da Nang City, one may need to ask, 'How much can the main public transport alone satisfy the requirements of the goal?' The city targets a modal share for public transport of 35 percent by 2030. The number of trips coverable by the main public transport alone was calculated based on the traffic data assumed for the year 2030 (Table 4.1). By defining the trips coverable by the main public transport as trips whose origin and destination are within walking distance (i.e. within 400 m) from bus rapid transit (BRT) stations, it calculated the number of such trips as only about 14 percent of all trips. This result indicates that BRT alone is not capable of achieving the target number. Additionally, the simulation assumes the maximum possibility of BRT being selected by the people; in actual situations, the public's selection will split into public transport and private transport (e.g. cars, bikes). Considering the extremely high rate of bikes currently selected by the people of Da Nang, it can be said that achieving the goal by BRT alone is extremely difficult. In other words, *it is essential to take additional measures to achieve the goal.*

Table 4.1: Trips Covered by Bus Rapid Transit (2030)

a.	**Number of all trips**	7,799,362 trips/day
b.	**Trips within 400 m from BRT stations**	1,099,740 trips/day
c.	**BRT coverage (b/a)**	14%

Source: Calculated by applying the population growth rate in 2025 and 2030 to the Origin–Destination table based on the 2025 Scenario 3 of DaCRISS[5].

1.2 Measures that Enhance the Attractiveness of Main Public Transport

Now, what can be the potentially effective additional measures? Two types of measures are worth considering (Table 4.2).

[5] Scenario 3 is one of the urban development visions stipulated by the city of Da Nang, which is adopted by the city as the scenario with the highest population growth rate. Specifically, it assumes the population of approximately 2.5 million to 3 million people in 2030 as the future urban development target

Table 4.2: Examples of Additional Measures that Enhance the Attractiveness of Main Public Transport

Measures that increase the number of trips covered by public transport	• **Enhancement of feeder network** • **Park & Ride** • **Transit-Oriented Development**
Measures that improve the relative attractiveness and selection rate of public transport	• **Appropriate public transport fares** • **Appropriate gasoline tax** • **Appropriate parking fees** • **Priority lanes and traffic lights for public transport**

Source: Author.

One type of measure is that which increases the number of potential users for the main public transport. For instance, in the case of Da Nang City, the number of trips covered by the bus rapid transit (BRT) was approximately 14 percent of all trips. To increase this number, the strategy will include:

- measures to enhance the accessibility to the stations of main public transport such as enhancement of peripheral public transport (e.g. feeder network) and park & ride facilities; and
- transit-oriented development[6] measures (e.g., allocation of commercial facilities and residential areas near the target stations)

Another type of measures includes methods that enhance the relative attractiveness of public transport compared to private transport. For instance, in the case of Da Nang where 14 percent of all current trips are covered by BRT, this type of measure is intended to increase the rate of the people selecting public transport over bikes or cars. Such can be achieved by lowering the monetary cost and temporal cost of public transport compared to private transport, including

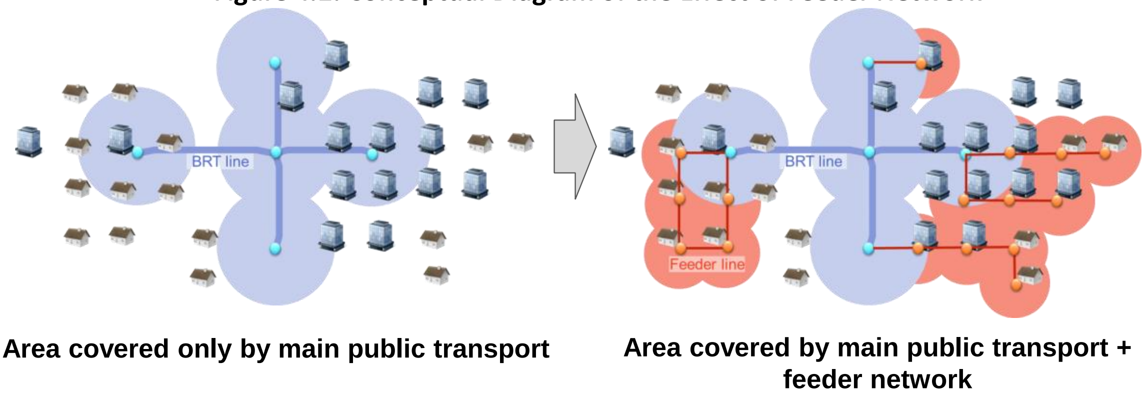
[6] Urban development that aims at achieving a society whose main transportation mode is public transport without relying on cars. Use of public transport is promoted, for instance, by selectively allocating commercial facilities near the public transport stations at city centres and by systematically building residential areas near the public transport stations in suburban areas at the same time.

- raising the cost effectiveness of public transport over other transportation modes (e.g. reducing public transport fare, adding to gasoline cost, charging parking fees, road pricing); and
- shortening the transit time of public transport (e.g. establishing priority lanes and priority traffic lights).

1.3. Scope of Considerations

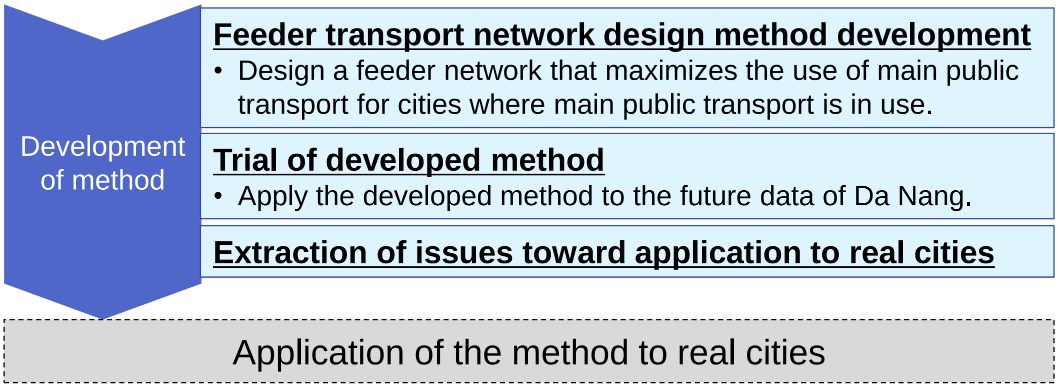
In increasing the number of trips covered by public transport, considerations are given specifically on the feeder network (Figure 4.2). In the case of Da Nang, the considerations were given to fixed route buses, but not to the feeder buses. It is thus worth it to look at the feeder-bus option as an integral part of the main public transport system. Also, in general, past considerations given to the feeder network in the stage of traffic planning by a foreign aid often lingered at the conceptual level, whereas there are actual demands from cities for specific and concrete plans. For this reason, this study found it necessary to develop a generic tool that enables considerations and evaluation of feeder networks for other Asian cities as well. This chapter therefore focuses on the development method for a feeder network design. A trial application of the developed method will cover Da Nang's data up to the year 2016 (details are described in below), where the goal is to extract the potential issues and tasks. The tool's 'live' rollout to other cities is still to be scheduled (Figure 4.3).

Figure 4.2: Conceptual Diagram of the Effect of Feeder Network



Source: Author.

Figure 4.3: Objective of this Chapter



Source: Author.

2. Method for Feeder Network Design

2.1 Aim of Feeder Network Design

Since the area covered by the main public transport is limited, the role of a feeder network is to expand the covered area and thereby increase the number of potential users of the public transport system. Introducing a short-headway feeder network to as large an area as possible is ideal. However, in reality, the budget is limited, and it is not practical to run buses to all the areas with an adequate headway. For that reason, route selection and headway setting that achieve the maximum effect within the given budget are the requisites for the feeder network design. Feeder network routes are to be selected from potential routes identified in advance.

Once the design is established, it will then be possible to investigate the costs and benefits of the design, including the use rate of public transport vis-a-vis the allocated budget, which will then be utilised as information for making a decision on the budget.

2.2. Outline of Design Method

The design method of the feeder network consists of the following procedures:

a) Create input data

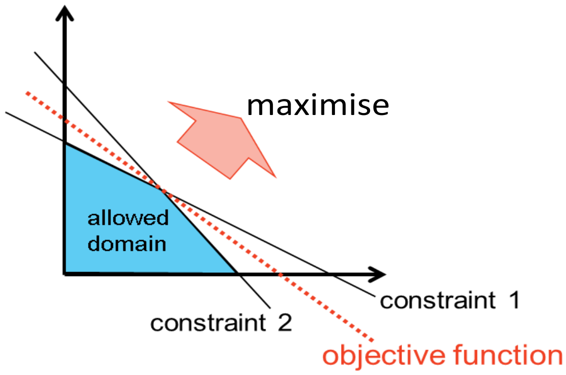
- At this stage, candidate routes of the feeder network are also created. Candidate routes are assumed to be manually (not automatically with computers) using existing or planned bus network as reference.

b) Calculate the 'optimal' route and headway under budgetary restrictions

- The 'optimal' route among the candidate routes created by Procedure 1 and its headway are determined.
-

For Procedure 2 above, mathematical programming is employed. This method is used to find a solution that minimises (or maximises) the objective function under the given constraints (Figure 4.4). A mathematical model for the feeder network design is also created.

Figure 4.4: Conceptual Diagram of Mathematical Programming



Source: Author.

2.3. Modelling

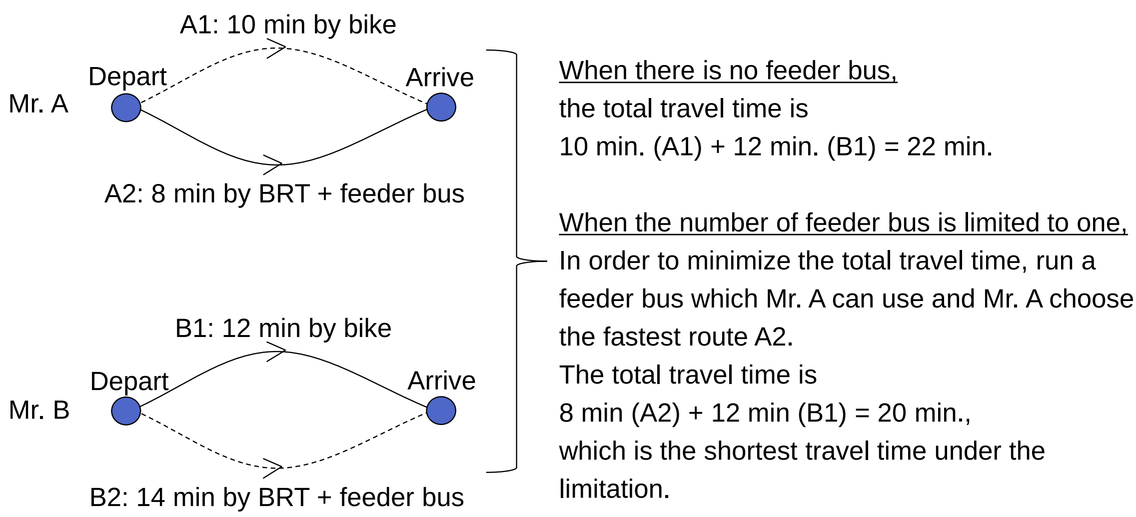
Before determining the objective function and constraints in the model, the mathematical representation of the transportation network needs to be defined. In a transportation system on a time-space network, the variables are the feeder network routes and their timetables (headway).

To determine the route and headway for the feeder network, it is necessary to select from the spatial direction (route) and from the time direction (headway). A feeder network is designed in relation to time (i.e. a timetable is obtained); thus, the traffic demands also need to be factored in, in relation to time. However, traffic demands (OD table) generally lack information on the time direction. For this reason, a specific timeframe (e.g. one hour of traffic congestion) is assumed here, and demands are randomly generated for the given timeframe. The calculation will produce a timetable for each feeder route. However, in principle only the total amount has a meaning as the demand, and a meaning will also be given only to the headway for the feeder network.

Other variables shall be sought in advance. For instance, traffic information such as congestion shall be calculated in advance using a traffic flow simulator, etc. So with the speed of BRT and feeder network.

Users are assumed to travel by either private transport (car or bike) or public transport (BRT or feeder bus), or their combination. Thus, the sum of the travel time of all trips (hereinafter referred to as 'total travel time') is specified as the objective function, and the feeder network design shall aim to lessen the total travel time (Figure 4.5). To minimise total travel time, a feeder network should be designed in such a way that the transit time becomes shorter than that of private transport.

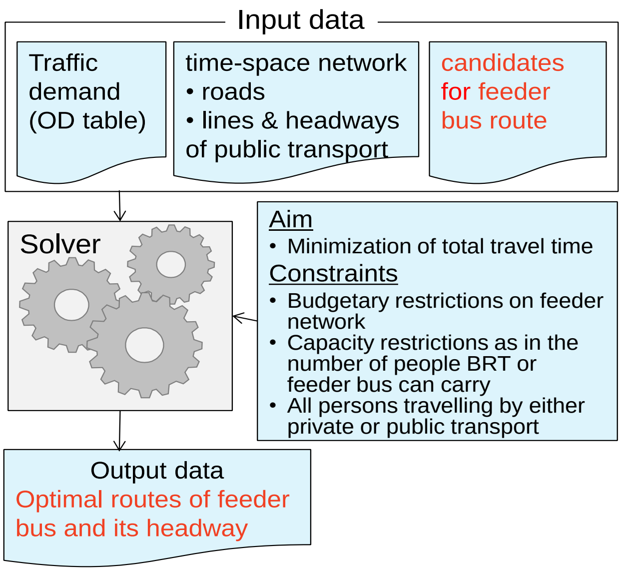
Figure 4.5: Model of Feeder Network Route Selection and Transportation Modal Choice



Source: Author.

Constraints in the feeder network design are summarised as follows (Figure 4.6):

Figure 4.6: Flow of Feeder Network Designing



Source: Author.

- Aim: To minimise the total travel time
- Constraints:
  - ➢ All commuters select either public transport or private transport
  - ➢ There is an upper limit in the budget that can be used for running the feeder network.
    - ✧ In this study, assuming that the cost of feeder network is proportional to the total operational route length, an upper limit is specified for the total operational route length for simplicity.
  - ➢ There is a capacity limit in the number of people a bus or BRT can accommodate.

Meanwhile, the design uses the following assumptions:

- The total travel time specified as the objective function
  - o In general, the BRT fare, gasoline cost, etc., in addition to the travel time, are taken into account when selecting a movement mode. Therefore, the model may become more practical when the generalised cost is used as the objective function, instead of the total travel time.
- Upper budgetary limit for the feeder network
  - o Since there is no information yet on the actual budget in running the feeder network, the model assigns restrictions to the total operational route length as the index of cost. However, in reality, other factors need to be taken into account, such as the purchasing cost of buses that run on the feeder network and personnel costs.

Future tasks may include investigating the actual situation and modifying the model. However, the basic framework described above is applicable as it is to the modified model.

3. Result of Preliminary Analysis

3.1 Data Used

The preliminary analysis used data on Da Nang City calculated for the year 2016. It was considered easy to examine the appropriateness of the obtained solution and issues by using data that are close to the present (year 2015). Details are as follows:

- Traffic demand data (or Origin–Destination [OD] data)
  - DaCRISS created the OD data for the year 2025, and the 2016 data were created by referencing it. Using Scenario 3[7] of DaCRISS, the ratio of Da Nang City's population in 2016 to that in 2025 was calculated, and the 2016 data was created by applying this ratio to the 2025 data.
  - The obtainable OD data was for one day and too broad to calculate the bus headways. Assuming peak hours, the OD data was used after reducing to 1/10.
  - For the OD data, one representative point was placed to each zone, and the representative points were treated as an origin point or destination point. For that reason, route calculation could not be made for travel within a zone; thus, intra-zone transit data were not counted among the users of public transport.
- Road traffic network
  - The currently existing road network (year 2015) was used.
  - Traffic speed (degree of congestion) of each road section was calculated by traffic flow simulation.
- Public transport network (Figure 4.7)
  - BRT routes
    - The analysis assumed the case where only BRT Line 1 exists, as planned in the Feasibility Study for the Da Nang Sustainable City Development Project by Sinclair Knight Merz Pty. Ltd.
    - BRT Line 1 is to be opened in 2016 as the first route in the plan.
    - Since the location of BRT Line 1 stations is unknown, stations were placed near every intersection and zone representative point.
    - The travelling speed of BRT was specified to be 25 km/h. This speed

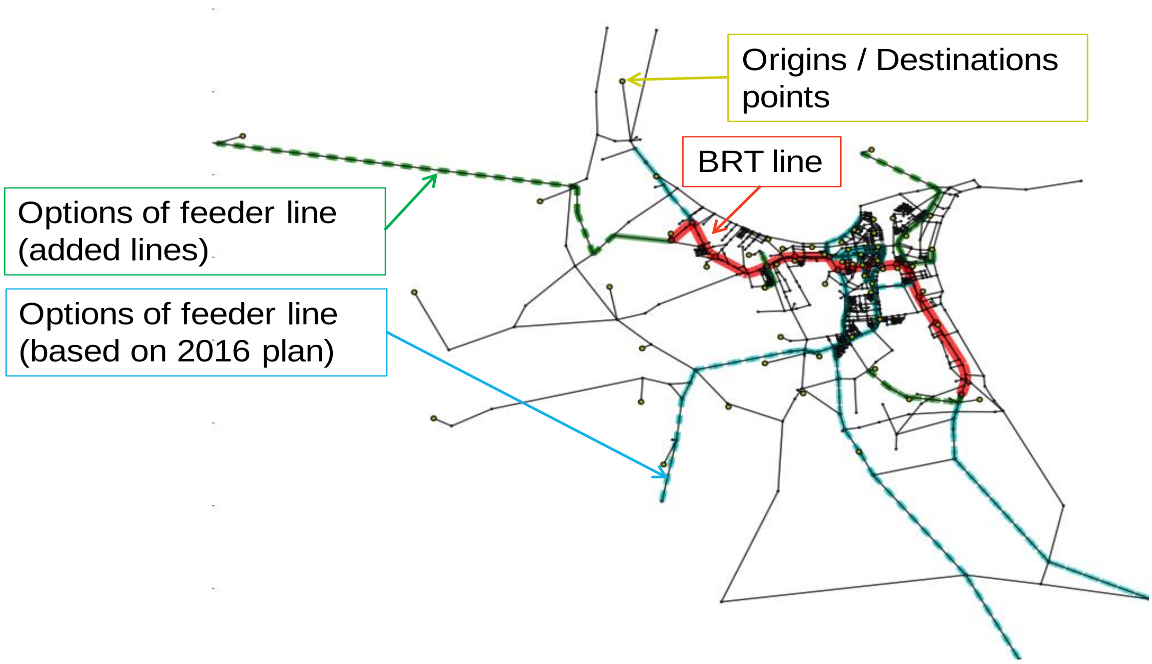
[7] One of the urban development visions adopted by the city of Da Nang as the scenario with the highest population growth rate. Specifically, it assumes the population of about 2.5 million to 3.0 million people in 2030 as the urban development target.

is faster than that of private transport affected by traffic congestion, and assumes that priority roads are used.

- Feeder network route candidates (11 lines)
  - Candidate routes were created through partial amendment of and addition to the fixed route bus lines that exist in 2015. There were 11 candidate lines.
  - Majority of fixed route bus lines shares routes with BRT, and sections of shared routes were omitted. For that, lines split into multiple sections were regarded as different lines. As a result, seven lines remain as candidates.
  - For areas (e.g. suburban areas) where no fixed route bus is currently running and development of transportation network is considered insufficient, four route candidates were added.

The travelling speed of feeder buses was assumed to be the same as that of private transport. No special lanes were developed for feeder buses, and the buses were assumed to travel along with private vehicles.

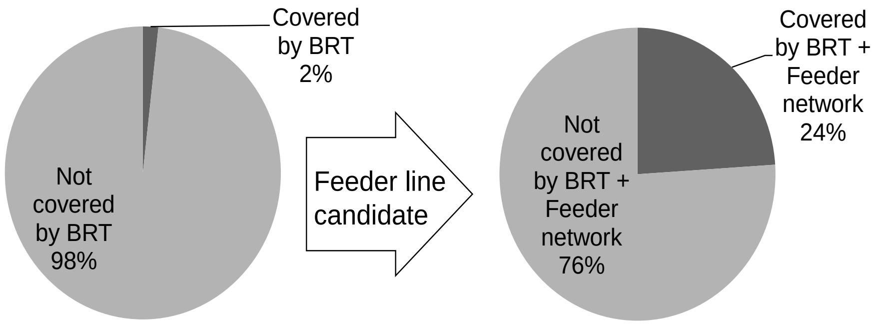
Figure 4.7: Traffic Network Assumed to Exist in 2016



Source: Author.

For these input data, fundamental considerations were made first. Since the role of a feeder network is to expand the coverage of the main public transport (which is BRT Line 1 in this case), the coverage by BRT alone and the coverage for when the feeder network route candidates were added (in reality, some of which may not be selected) were investigated (Figure 4.8). Results show that the coverage of trips where a public transport existing within walking distance (400 m) of both O and D by BRT alone was 2 percent. However, the coverage of trips when feeder network candidates were added rose to 24 percent—a significant increase in coverage. For trips where the travel time becomes shorter by using public transport than by using private vehicles, the use of public transport will be selected.

Figure 4.8: Coverage by BRT and Feeder Line Candidates (potential trips by public transport)



BRT = bus rapid transit.
Source: Author.

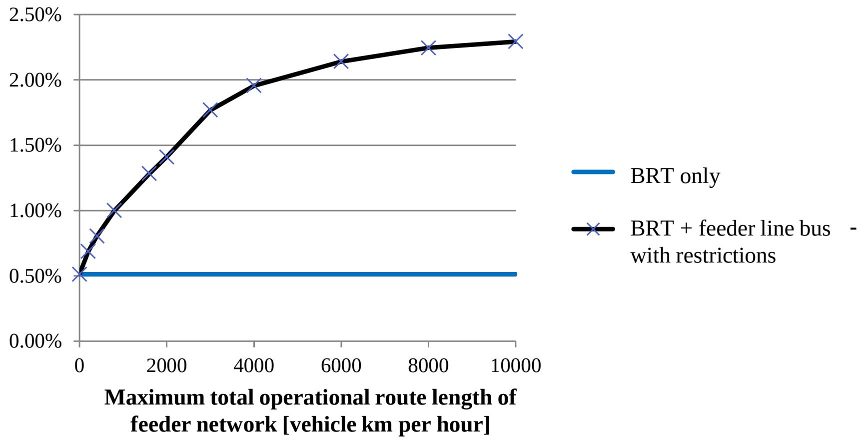
3.2 Calculation Results

The modal share of public transport[8] in relation to the upper limit of total operational route length per hour (i.e. the upper cost limit for operating the feeder network) is shown in Figure 4.9. The modal share of public transport increases as the total operational route length (cost) of the feeder network increases. However, the increase rate of the modal share of public transport starts to significantly decrease at around a constraint

[8] Modal share of public transport was calculated as the percentage of trips where public transport (BRT or feeder network) is used among all the trip types, including intra-zone traffics, inter-zone traffic, walking, and bicycles.

of 4,000 km per hour, reaching a plateau of around 2.3 percent eventually. This result indicates that further investment will not return much benefit. Since the modal share of public transport by BRT alone is around 0.5 percent, it can be said that *investment into the development of feeder networks increases the modal share of public transport by a maximum of 4.6 fold (= 2.3% / 0.5%).*

Figure 4.9: Modal Share of Public Transport



Source: Author.

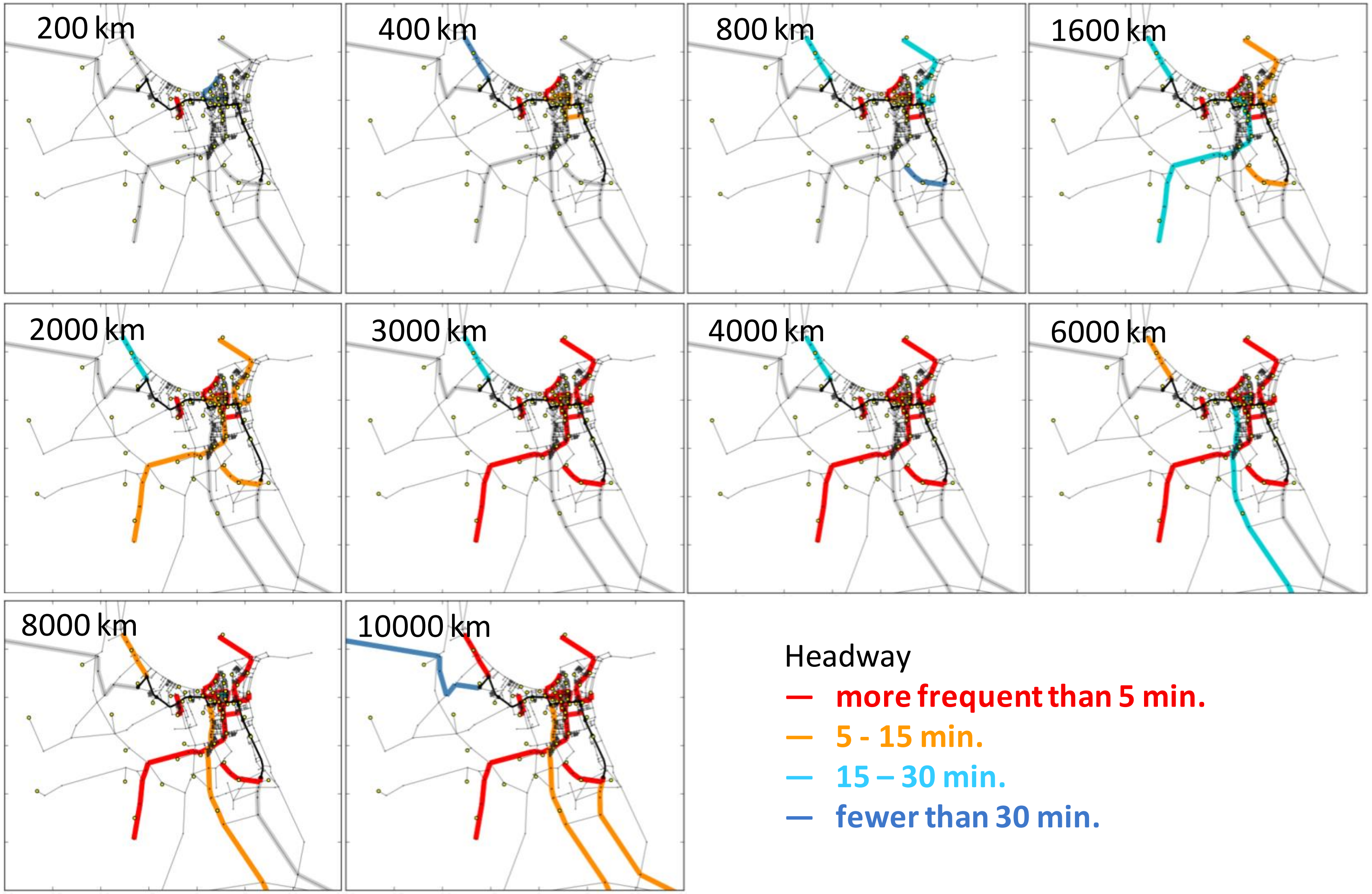
An examination of the feeder network routes in Figure 4.10 identifies the routes at the central section of Da Nang city as preferentially selected, especially when the cost for the feeder network is small (for instance, for cases where the constraint of total operational route length per hour is 200 km, 400 km, or 800 km). As shown in Figure 4.9, the modal share of public transport significantly rises when the total operational route length is increased slightly. Meanwhile, when the cost for the feeder network is large (for instance, in cases where the constraint of total operational route length per hour is 6,000 km, 8,000 km, or 10,000 km), the increase in the modal share of public transport is small. Taking into account these results and the fact that origin points and destination points of many trips concentrate in the central part of Da Nang, one can conclude that investments in lines near the city centre are more effective in increasing the number of people that use public transport. From such findings, the following were derived:

- Preferential coverage for the areas with large traffic demands—specifically, concentrating the operational area of BRT and feeder network into the city centre and its vicinity—increases cost effectiveness.

- On the contrary, building of points that readily become origin points or destination points (e.g. residential areas, commercial facilities) near the stations of BRTs or feeder network would create demand for public transport. To that end, it may be required to re-consider the land use plan after the traffic plan has been reviewed by the land use planning organisation.

Figure 4.10: Feeder Network Route Selected

(the distance shown in each map indicates the total operational route length of feeder bus per hour)



Source: Author.

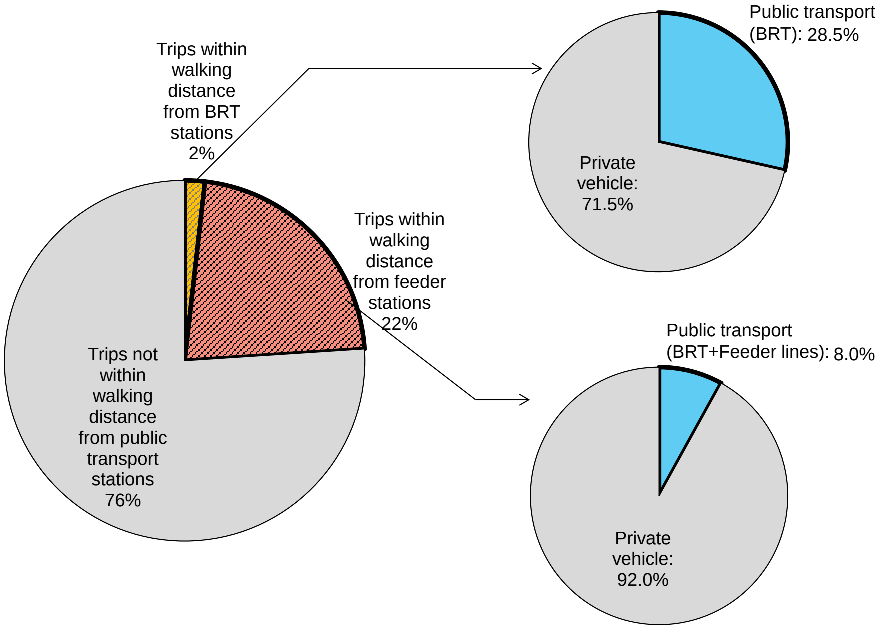
Although most of the discussion here focused on the selection method on feeder networks with high economic effectiveness, it is also necessary to consider the method to raise the plateau value of the modal share of public transport (2.3 percent) shown in Figure 4.9. Thus, details of the transport modal choice were reviewed as well.

Details of the transport modal choice for the scenario where the total operational route length of feeder network is set at 10,000 km per hour (practically limitless) are shown in Figure 4.11. The pie chart on the left indicates that the number of trips within walking distance from BRT stations is only 2 percent of all trips. Although the rate of public transport selection is relatively large at 28.5 percent for these trips (pie chart on the right, top), the population is only 2 percent of all trips—i.e. the number of people using public transport is small. Meanwhile, the number of trips within walking distance from feeder network stations is 22 percent of all the trips (pie chart on the left), indicating a relatively large area being covered. However, the rate of public transport selection is 8 percent (pie chart on the right, bottom), which is significantly smaller than the selection rate for trips within walking distance from BRT stations.

The reasons behind the low public transport selection rate could be: (1) there are no temporal benefits for the feeder network itself compared to private transport since the travelling speed of the feeder network is the same as that of private transport; and (2) buses often have a longer travelling distance compared to private transport. From these, the following are the conclusions:

- When the BRT Line Network expands in the future, the volume of trips coverable by BRT alone increases. Since the public transport selection rate is relatively high for such trips, the expansion may significantly add to the overall public transport selection rate. The city may consider establishing a feeder network that synchronises with the BRT extension plan.
- The public transport selection rate is low for trips covered by the feeder network. It may be required to consider the possibility of increasing the speed (temporal) advantage by using priority lanes and priority traffic lights.
- When public transport cannot maintain its superiority over private transport in terms of speed alone, it must consider other measures such as reduction of public transport fares, application of gasoline tax, and parking regulations.

Figure 4.11: Public Transport Selection Rate When the Total Operational Route Length of Feeder Network is Set Practically Limitless (10,000 km per hour)



Source: Author.

3.3. Summary of Results

Along with the development of the design method, some insights on the optimal route for the feeder network and its headways can be gleaned from the exercise. Among the findings are:

- An additional feeder network increases the public transport use rate. While higher investment into a feeder network increases the public transport use rate, the rate reaches a plateau after a certain investment level (Figure 4.9).
- Based on the study on feeder network optimisation, one can conclude that routes with many O/Ds are preferentially selected (Figure 4.10).
- The public transport selection rate of trips near the BRT stations is higher than that near the stations of feeder networks. (In this study, the former was 28.5 percent; the latter, 8.0 percent) (Figure 4.11).

Meanwhile, some findings were off-course from reality due to insufficient modelling:

- Whereas this study identified the total travel time as the objective function (taking into account the fact that cost is one of the factors in the selection of preferred transportation mode), the generalised cost as the objective function would have been closer to reality.

- While the initial methodology used the total operational route length (km) per unit time as the cost of the feeder network, all other costs, including the number of buses and personnel costs, need to be considered in actual cases. The constraints may have to be adjusted in accordance with the actual cost situation.
- After completing the initial development of the method, the next step is to modify or tweak the model to match the local situations as the researcher sees fit.

4. Identifying Issues from Da Nang's Case

Based on the results of the preliminary analysis, the transport sector issues that needed to be addressed if one were to achieve energy efficiency are summarised below:

a) Some tweaking of the model, including the following two points, is required to match the local situation:

  - ➢ Use generalised cost as the objective function
  - ➢ Match the cost of feeder networks to reality

b) Since the feeder network design method itself is unable to calculate the fuel consumption, fuel consumption needs to be evaluated using traffic flow simulation.

c) The feeder network design method does not incorporate models that reflect the social structure. To make sure results reflect reality as much as possible, it is necessary to carry out traffic flow simulation using the transport modal choice model for each traffic scenario built by DaCRISS, etc. and verify the appropriateness.

d) Since it is difficult for feeder networks to have temporal advantage over private transport, it can compensate in terms of preferential measures in cost (e.g. lower public transport fare, application of gasoline tax) and imposition of private-vehicle regulations on driving in the city centre.

e) At Da Nang City, a BRT will be introduced in the future. In designing the feeder network, it is necessary to ascertain that its plan considers the expansion plan for the BRT lines as well.

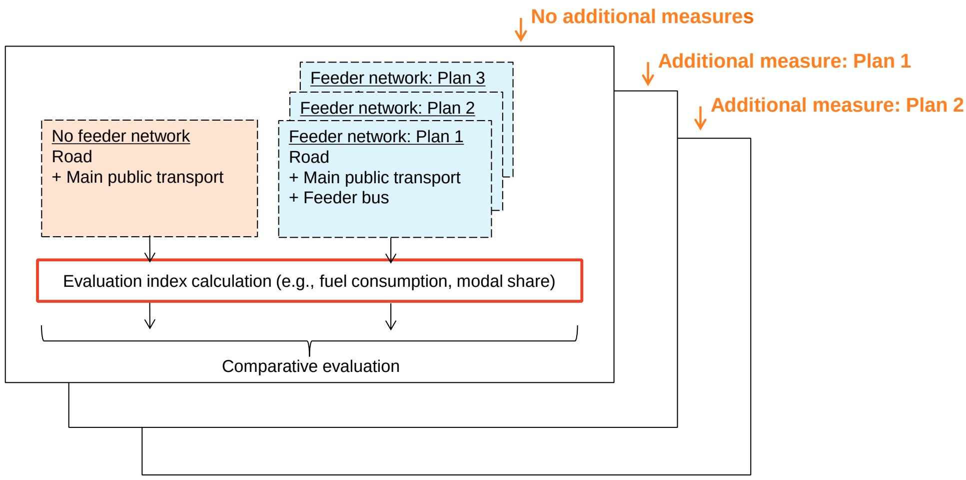
f) To promote the use of public transport, the findings need to be fed back to land use planning so that the planned transport network can be utilised effectively.

Regarding Item 1 above, a modification in the method may be needed after investigating the actual situation of the city to which the method is to be applied.

Items 2, 3, and 4 can be addressed by combining the method developed in this study with the traffic flow simulation. To evaluate fuel-saving effects, fuel consumption should be used as an evaluation index, in addition to the modal share of public transport. Evaluation indices, comparative assessment of scenarios under varying feeder network cost restrictions, and analyses of the effects of other measures that aim to enhance the attractiveness of the main public transport (e.g. preferential measures involving costs) can make the investigation more comprehensive.

For Item 5, devising simulation scenarios may enable proper analysis; this requires further investigation. Finally, whereas Item 6 is an important point, it may exceed the scope of the method developed in this study.

Figure 4.12: Simulation Evaluation Scenario



Source: Author.