REDUCING TRAVEL TIME IN BUS RAPID TRANSIT THROUGH LIMITED STOP SERVICES

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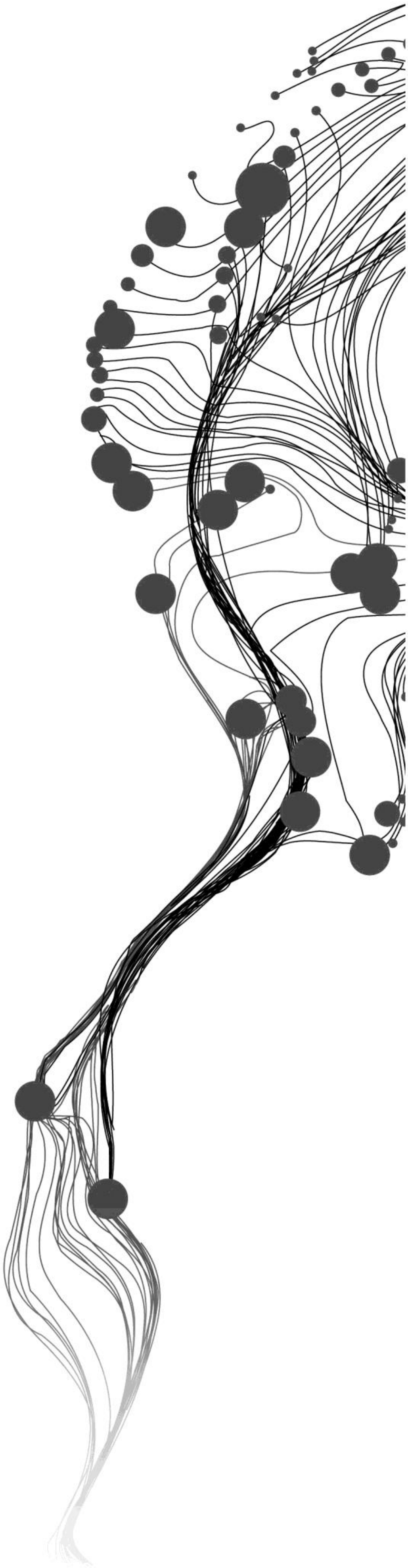

REDUCING TRAVEL TIME IN BUS RAPID TRANSIT THROUGH LIMITED STOP SERVICES

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Enschede, The Netherlands, March, 2015

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban Planning and Management

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ABSTRACT

Bus Rapid Transit system is a bus based mass transit with higher flexibility in comparison with rail based mass transit systems. It is implemented to reduce travel time through utilizing exclusive lanes, and improved facilities. However in some cities, such as Jakarta it still faces a lot of problem like long travel time, and consequently it has low modal share.

The main objective of this study is to develop a method to reduce travel time by implementation of limited stop services. The focus of this research is on defining itinerary of these services. Limited stop services are services which stop in a few stops along the way with high demand, and skip other stops in the corridor. Therefor it is expected that these services reduce travel time, due to lower dwell time, and expected increase in speed of the buses.

Two approaches have been taken to design the itinerary of limited stop services, and analysing the demand of each bus stop. In the First approach, the bus stops demand is analysed based on its location, and in the second approach, the demand of the bus stops is analysed based on travel pattern.

To assess these approaches, three scenarios for limited stop services are defined and evaluated based on travel time savings, and potential passenger percentage. The fourth scenario is defined based on the previous scenarios, and appropriate stop spacing.

Evaluation of the scenarios reveals travel time saving in the most of the corridors for the passengers of limited stop services.

Keywords

Bus Rapid Transit, Travel Time, Limited Stop Services, Itinerary, Bus Stop, Jakarta

ACKNOWLEDGEMENTS

I would like to express my thanks to my supervisors Ir. M.J.G. Brussel and Ing F.H.M van den Bosch for their helpful ideas, valuable comments and support.
I would like to thank my mother, the most special person for me.
I am thankful to my kind father, and brother for their support.
In addition a thank you to my Enschede friends, who made it easier to live far from home.

Gelareh Ghaderi
Enschede 2015

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1. INTRODUCTION

1.1. Background

As cities grow, demand for a sustainable transportation system is increasing. Public transportation as a sustainable approach has got wider attention recently, especially in developed and developing countries (Nkurunziza, 2008). Among different modes of public transportation, Bus Rapid Transit called as BRT is one of the most efficient solutions for providing transit services on in urban areas (Dimitriou & Gakenheimer, 2011). If a BRT system is implemented successfully, it can be chosen as a favourite public transport mode, and potentially attract many private vehicle users.

According to Janić (2014) BRT system is an advance public transportation system in comparison with regular buses because of its advanced operational system . A BRT system is defined as "rapid modes of transportation that combines the quality of rail transits and flexibility of the buses"(Thomas, 2001). The BRT systems are considered as a flexible "rubber-tired rapid transit mode that combines stations, vehicles, services, running ways, and ITS (Intelligent Transport System) into an integrated system with a strong positive image and identity" (H. Levinson et al., 2003).

First BRT system was implemented in Curritiba as a part of master plan of the city (H. Levinson et al., 2003). Later the operation of TransMilenio, BRT system in Bogota, is started. These two BRT systems became the successful examples of public transportation systems around the world, and inspired other cities in South America, Asia, USA, and Europe, such as Santiago, Jakarta, Beijing, Boston and Eindhoven (Rogat, Hinostroza, & Ernest, 2009). As it is reported, by operation of BRT significant travel time saving is observed, for instance travel time in Bogota is reduced by 50 percent, and an average 50 minutes travel time saving is reported after implementation of Metrobüs (BRT) in Istanbul.

Besides these successful examples of public transportation system many cities still face a lot of problems. The modal share of public transportation in many major Asian cities is still low, and people are not willing to use public transportation. ASEAN (Association of Southeast Asian Nations) countries face a lot of problems in their public transportation sector. Improvement in the transport infrastructure and reliability of the services is necessary to increase the satisfaction of the passengers (Sreedharan, 2013).

There are various factors that impact travel time, and performance of BRT systems, according to Janić (2014) travel time depends on the distance of the passenger from the origin to the destination using an specific route, speed of the vehicle, and the number and duration of the stops that are along the way.

In one study, Widadi (2004) evaluates bus stop attractiveness based on potential demand estimation using land use data, and population information. Then a bus stop distribution model is developed based on the attractiveness values and optimum bus spacing. The proposed model contributes to have a 20 percent increase in potential users and 56 minutes decrease in the travel time for bus system of Jakarta, Indonesia.

In another study, Tirachini (2013) estimated travel time, and compared the benefits of upgrading the fare payment technology on travel time with providing dedicated busways using regression models. The result shows that the number of the passengers is a crucial factor in determining the importance of upgrading fare payment system or providing dedicated busways lane in reducing the travel time. This indicates that the fare payment technology can be as important as dedicated bus lane that influence travel time. The result also indirectly indicates that increasing demand can make the duration of stops longer.

Many transit agencies use different services strategies, and network routes to improve performance of the system, and reduce travel time. (Wirasinghe & Vandebona, 2011) classify bus routes as following:

- "Local (stops at all bus stops),
- express (stops only at selected passenger generators),
- feeder (local, with a stop or terminus at a railway station or express bus stop),
- commuter (local in a given suburb, with subsequent express or non-stop service)" (Wirasinghe & Vandebona, 2011)

In this research, the "limited stop service" term is used instead of the "express service" term to be clear, and avoid confusion. Since the term "express service" in some previous studies has different definitions. Limited stop services can be defined as bus services that stop on some specific bus stops along their route. Although this type of services have been used in more than 140 cities around the world, little attention has been paid to design them carefully (Larrain, 2013). This study aims to improve performance and efficiency of BRT systems; especially the travel time for the passengers and Jakarta is selected as the case study.

1.2. Justification

One of the ASEAN cities that face a lot of problems in the transportation system is Jakarta.
In 2004, bus rapid transit (BRT) line called as TransJakarta began its operation in Jakarta, Indonesia (Ernst, 2005). Although Bus rapid transit system in Jakarta, encouraged many people to move from private cars to public transportation, still it has not been preferred to cars by the citizens (ERIA Study team, 2010).

Many factors affect people choice for mode of travel. Khan, Ferreira, Bunker, and Parajuli (2007) states that the vehicle travel time is the most influencing factor for a car user to shift in the Brisbane CBD corridor. Furthermore Nkurunziza, Zuidgeest, Brussel, and Van den Bosch (2012) claims that in Dar es Salam comfortableness is the most important factor on modal share of BRT system. However, the result of the preference survey that has been done in Jakarta represents travel time as the most important factor.

A case study has been done in Jakarta to confirm whether BRT service improvement could contribute to increase modal share of the BRT system. They conducted a stated preference survey in the corridor 3 of Transjakarta. Different scenarios have been offered as possible improvements to the respondents (table 1.1). The respondents were both BRT users and non BRT users. The new scenarios have 3 independent variables as following, reduced travel time, minimized number of transfer, and minimized transfer time (ERIA, 2013).
The interventions that are offered are:

1) Direct route from O to D, providing non-stop services (express buses) between origin and destination
2) Improved Procedure (SOP)/ Information systems to reduce transfer time, at the moment the transfer time is 15 minutes, with an improved SOP the transfer time will decrease by 10 minutes
3) Improved infrastructure, currently, travel time cannot reach its maximum speed, because many cars obstruct the BRT line, and the traffic jam interferes with the operation of the BRT

system. For improving travel time, 3 different kinds of infrastructural interventions have been offered

A) Sterile dedicated lane, sterilization of bus line, makes the Transjakarta operation faster
B) Providing passing place, it can make possible that express bus passes the regular bus, so the travel time of the express bus would be faster.
C) Bus priority signal, using intelligent Transport system can improve the infrastructure, Transjakarta bus sends a signal to the detector, the detector will automatically make the green time for the traffic light, so the bus will not stop at the intersection

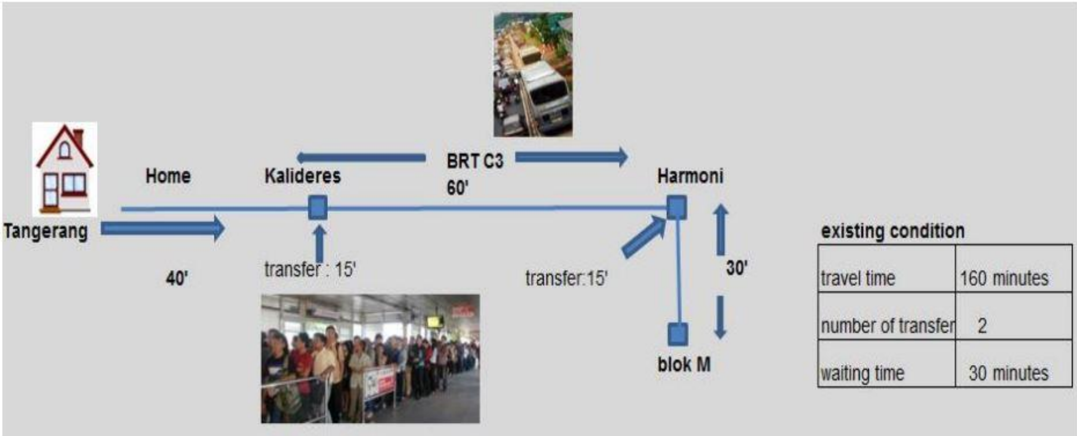


Figure 1-1: Itinerary of trip between Kalideres and Block M using TransJakarta (ERIA, 2013)

At the moment on corridor 3, it will take the passengers 40 minutes to reach the first BRT station, and to reach the destination passenger will have two transfers with an average waiting time of 15 minutes. This is either because of the ticketing line, or the passenger has to wait for the bus to come (figure 1.1).

Table 1-1: 8 choice set have been offered to the respondents of the survey (ERIA, 2013)

	Intervention and choice sets	Cumulative Time Travel Reduction	Number of Transfer	Transfer Time	Reduced Travel Time
1	1 Transfer, no improve SOP transfer, existing infra	(15+0+0)	1	15	15
2	1 Transfer, min improve SOP transfer, existing infra	(15+5+0)	1	10	20
3	1 Transfer, max improve SOP transfer, existing infra	(15+10+0)	1	5	25
4	No Transfer, existing infra	(30+0+0)	0	0	30
5	1 Transfer, no improve SOP transfer, improved infra	(15+0+35)	1	15	50
6	1 Transfer, min improve SOP transfer, improved infra	(15+5+35)	1	10	55
7	1 Transfer, max improve SOP transfer, improved infra	(15+10+35)	1	5	60
8	No Transfer, improved infra	(30+0+35)	0	0	65

The result of the model that used utility function to calculate shows that by reducing travel time by 65 minutes, if we do not consider people who were doubtful to move from car to BRT after improvement, the modal share of BRT will increase by 76 percent.

As the preference survey concluded, travel time was selected as the most effective factor on the choice of people in Jakarta. To encourage people to use BRT, and increase the modal share of BRT, it is needed to improve BRT system, and reduce travel time. Therefor it is necessary to provide express services, and improve infrastructure system.

1.3. Research problem

Transjakarta faces a lot of problems in infrastructural, technical, operational performances. Lack of an improved infrastructure systems, such as:

- Sterilized bus lane,
- Procedure (SOP)/Information Systems,
- Improved ticketing system,
- Many long transfers,
- Many bus stops make the trips so long for the passengers,

Further research is needed to evaluate the current situation of TransJakarta, and analyse how performances of the BRT system in Jakarta affect travel time.

Based on the problems that are stated, there are many possibilities that can be suggested to improve the system, and more importantly decrease the travel time for the passengers ranging from providing and enhancing ticketing system to upgrading segregated bus lanes. As it is mentioned in the stated preference survey that has been done recently, the first priority for both of the BRT and non-BRT users were bus and schedule improvement. As the case study concluded, many people responded positively to provision of some kind of limited stop services. This kind of service requires some infrastructural upgrades. The case study claims that buses will be full even if the bus doesn't stop along the path; however the impacts of this service on Transjakarta are unknown. Is it going to contribute to solve the Transjakarta problems? How a limited stop service can be implemented in Transjakarta? What will be its influence on the travel time? How can a minimum infrastructure intervention contribute to the limited stop service provision? These are the question that should be evaluated to improve the situation.

1.4. Objectives

1.4.1. General Objective

- To develop a method to improve travel time of a BRT by means of limited stop with focus on Jakarta BRT system.

1.4.2. Sub- objectives

1) To develop a method to design an alternative solution to decrease travel time by providing limited stop services
2) To analyze the impacts of implementing a limited stop service in the BRT system

1.5. Research questions

Sub-objective 1:

A) How to select nominate bus stops in a bus line to support limited stop services?

B) What will be the travel time for each trip of limited stop services?

Sub-objective 2:

A) What is the required infrastructural intervention to implement limited stop services for Transjakarta?

B) What are the impacts of the limited stop services on the travel time?

1.6. Research Design

1.6.1. Hypotheses and anticipated results

It is expected that the analysis of the current BRT system in Jakarta gives us an overview of the problems, and the reasons that make the trips so long. It is anticipated based on the introductory literature review, provision of limited stop services shorten the long trips for people using the system in some scale, since the similar systems have been implemented successfully in other cities such as Bogota. However a different urban context might influence the project.

Table 1-2: Research Objectives

	Objective	Anticipated result
General objective	- To develop a method to improve BRT system in Jakarta to reduce the travel time for the passengers	Less travel time for the passengers
Sub-objective 1	- To develop a method to design an alternative solution to decrease travel time by providing limited stop services	Nominated bus stops in the line, The anticipated travel time for each trip
Sub-objective 2	To analyse the impacts of implementing a limited stop service in the BRT system	Infrastructural requirements The predicted travel time (decrease or increase)

1.6.2. Research methods

First stage in this research is literature study, in this stage the research problem is formulated, required data, and case study is determined. Furthermore, this stage also helps to determine the design methodology for limited stop services. Afterwards, required data is determined, and extracted from the available data.

Next stage is designing limited stop services. In This research it is focused on designing the itinerary of the services. The itinerary of limited stop services is designed based on two approaches, travel pattern, and location characteristic of bus stops. First the travel pattern of work trips is analyzed using statistical tools.

Second, in order to analyze location characteristics, some factors must be determined. The list of these factors will be compiled based on the literature review, and analysis of the land use maps. Some initial spatial factors such as proximity of bus stops to the residential areas, shopping centers, employment centers are supposed to affect our choice. Besides spatial factors, there are also some non-spatial factors such as connectivity to the transfers which are assumed to influence the bus stop choice.

In the next stage, some scenarios are defined, based on the travel pattern and spatial analysis. These scenarios are compared and evaluated, by travel time saving and potential passenger percentage. Finally the results are discussed and analyzed. Figure 1.2 presents the conceptual framework and the stages in this research.

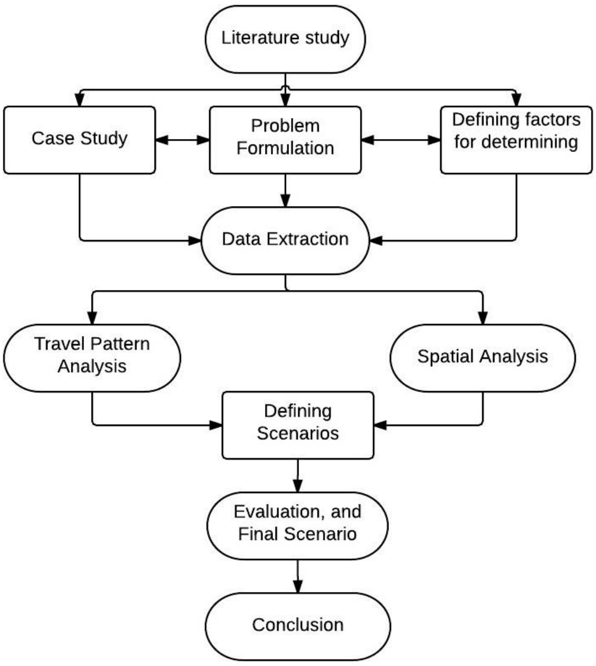


Figure 1-2: Conceptual Framework

1.6.3. Evaluation for implementation of the limited stop services

Through the literature review the infrastructural requirements of a limited stop service (such as the passing the lane, the minimum width of the lanes, or the capacity of the stations) for the BRT system can be identified.

Travel time can be calculated using the model that is proposed in the previous step, and the travel times, and the velocity that has been recorded during the on bus survey. This will not be an intensive work, however some assumptions must be done during the calculation for the speed of the vehicle, since the proposed service will skip some stops, and the velocity of the bus would be higher. During this step, literature review will help to estimate the travel time for the proposed service.

1.7. Thesis structure

The provisional titles of the thesis chapters will be as follows.

Chapter 1, introduction

It presents research background, research justification, problem formulation, research objectives and questions, and research design.

Chapter 2, overview on limited stop services

It defines BRT and explains its components. It describes limited stop services as a strategy to develop BRT system, and introduces design methods for these services.

Chapter 3, overview on case study

It explains more about Jakarta, its socio economic profile, and problems. Jakarta transportation system, more specifically Transjakarta, and travel behaviour in Jakarta is described. In addition it gives some explanation about the dataset that is used in this research.

Chapter 4, methodology

It describes the methodology that is used to design limited stop services. Different approaches for implementation of limited stops services described.

Chapter 5, results and discussion

It discusses the results of analysis of the previous chapter; furthermore some scenarios for implementation of limited stop services are defined and evaluated based on travel time saving.

Chapter 6, conclusions and recommendations

Conclusion and recommendations that answer research objectives is provided in this chapter.

2. OVERVIEW ON LIMITED STOP SERVICES

2.1. Bus Rapid Transit concept

Federal Transit Administration definition of BRT as "a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses" is the most common definition. The concept of bus rapid transit was initiated in late 1950s, when transit agencies were looking for a low cost transit service with a high quality. In 1963, the "Bus Rapid Transit concept" for the first time was presented by John Crain, as a competitor for automobiles, with their high quality door to door trips, but still an economical solution for the cities. Crain states that "BRT combine(s) the best features of rail rapid transit and conventional bus operations by retaining the flexibility of one while obtaining some of the speed and capacity of the other" (Waukesha, 1957). He adds how using exclusive lane for buses helps with the control of traffic. Signal priority, rapid fare collection methods, and enhanced method for boarding, and alighting of the passengers were another characteristics of BRT mentioned by Crain (Miller & Buckley, 2000). The first BRT system started its operation in Curitiba in 1974, however until 1990 it was considered as a public transportation system for small cities, with maximum capacity of 12000 passengers per hour. Introducing TransMilenio in Bogota with the capacity of 45000 pphpd opened up a new perspective of BRT systems, and was initiative to implement BRT in many big cities (Pen˜a, Jime´nez, & Mateos, 2013).

2.2. Main components of BRT system

A BRT system has seven main characteristics, including exclusive bus lane, enhanced ticketing system, stations, intelligent transportation system, vehicles, operation plans, and branding elements (Pen˜a et al., 2013). Exclusive bus lane is the most important, visible, and expensive component of the system, which has influence on people perception of the system. Stations also have the highest impact on people image, and they should have higher capacity in comparison with the regular stations, and protect the passengers from climate conditions. Boarding platforms should be as high as buses to ease boarding and alighting. Vehicles are the component in which passengers spend most of the time of their trip, and it has a high impact on comfort, speed and the capacity of the system. Fare collection has the direct impact on the capacity of the system, and should be collected off the board, and should be integrated with other routes, therefor the passenger should not have the need to buy a ticket for changing the bus. Intelligent transportation system is a component which improves overall performance of the system, and it consists of different technologies to collect information of the system's performance, including location of buses by using GPS, count of passengers, buses departure times, and traffic conditions. Operation plan also have direct impact on people perception, a good plan should reduce the number of transfers, and waiting time for the passengers. The BRT system must represent a brand, and with a good marketing strategy can attract more passengers (Pen˜a et al., 2013).

2.3. Bus Rapid Transit Enhancement

According to Satiennam, Fukuda, and OShima (2006), there are many strategies to enhance BRT systems, such as provision of headways of less than 5 minutes during peak hour, and around 10 minutes during off-peak hours, and less than 15-30 minutes for feeder services. In addition, providing exclusive busway is required. The majority of successful BRT systems have provided exclusive roads for the buses, for instance in Nagoya, an exclusive bus way, elevated above the CBD has been constructed to avoid interfering with traffic congestion. Other conditions to improve BRT suggested by Satiennam et al. (2006) includes, good route planning, providing network feeder, avoiding having competitive local service, ITS application and marketing strategies. Transit users expect to have a reliable service with predicted arrival time, and a minimum in-vehicle time (Murray & Wu, 2003).

In addition, there are various strategies, such as implementation of zonal express services, restricted zonal services, semi restricted zonal services, and limited stop services, for high demand bus corridors (Furth and Day, 1985). This research as it is discussed earlier deals with implementation of limited stop services for a BRT system as an additional service.

2.4. Limited stop service design models for bus corridors

Furth and Day (1985) suggested three different strategies for implementation of such service in heavy demand bus corridors as following:

a) Short turn, this strategy involves two types of services. In this strategy, some buses make shorter cycles to service areas with high demand. This strategy is implemented when there is less demand in one or both ends of the corridor (Furth & Day, 1985). Primary advantage for operators is reduced operation cost, due to less running time. Maintaining the amount of resources results in decrease in headway, which could be beneficial for the passengers. The one disadvantage is increase in waiting time of the passengers at the skipped stop on the end with less demand (Schwarcz, 1998).

b) Dead heading, empty vehicles along a low demand direction returns to the start point of the route to begin another cycle sooner. This service starts at the station when all the passengers alighted, one disadvantage of this services is increase in the waiting time of the passengers of skipped stops, and the advantage is decrease in the waiting time of the passengers at the stops with the higher demand (Eberlein, Wilson, Barnhart, & Bernstein, 1998).

c) Limited stop services, services that stop in selected stops, usually stops with the higher demand (Furth & Day, 1985). The primary advantage of this service is decrease in travel time for the passengers using limited stop services, and the disadvantage is increase in waiting and access cost of passengers using the regular service. This service is used to increase efficiency, by reducing travel time (Schwarcz, 1998).

Implementation of one strategy in a BRT corridor depends on the context, and travel pattern in the BRT system. Various literatures are focusing on the first two approaches such as (Furth, 1987) on the first strategy, and (Furth & Day, 1985) on the second strategy, however limited research has been done about the third strategy, limited stop services.

2.5. What is Limited stop bus service?

Limited stop services are defined as services that stop only in subset of stops (H. Levinson et al., 2003). This kind of service uses wider space between the stops in comparison with the local bus services, about 800 to 1600m (Tétreault & El-Geneidy, 2010). Spaces between stops in local services range between 140m to 400m (Furth & Rahbee, 2000). Limited stop services are designed to serve stops only at major zones, and along corridors with high demand (Schwarcz, 1998).

Limited stop services are attractive quality for high demand bus networks and can result in increased ridership. Limited bus services have proven its benefits for both the users and operators in systems such as Transmilenio (Bogota, Colombia) and Transantiago (Santiago, Chile). Due to reduced number of stops, limited stop bus service's speed is higher, consequently running time, travel time, and the number of peak vehicles needed are reduced (El-Geneidy & Surprenant-Legault, 2010). This primary advantage can result in benefits for both the passenger and the operator. According to Vuchic (2005), it is expected that decrease in running time, will increase ridership. One disadvantage of this type of service is increasing waiting time and access time for some of the passengers. As a result it is recommended to implement this service parallel to routes with high frequency (routes with headways shorter than 8 minutes) and high ridership (El-Geneidy & Surprenant-Legault, 2010).

2.6. Limited stop services in the literature

The previous academic research about limited stop services is limited.

Ercolano (1984) considers Limited bus services with the capacity between regional express services and local services. Following the case study that has been done in New York, it studies that how limited stop services, in comparison with local services have faster operating speed, lower travel time, and higher attraction levels for ridership. The paper adds that operating costs and the number of peak vehicles are also much lower, due to higher operating speed.

The paper distinguishes between limited stop services and modified limited services. Modified limited services in some parts of the routes stop in local stops, however in the other parts act as limited stop services. Data including passenger counts, delay durations, frequencies, and causes of stopped times collected through conducting survey in Manhattan from 15 bus routes. The study compares the relationship between route distance and travel time for local, limited stop, and modified limited services. The on bus survey analysis shows that limited stop services speed under light traffic conditions is 50 to 100 percent faster than regular services; however this figure is about 20 to 30 percent in moderate traffic conditions, this is an indication of significant influence of traffic conditions on the operation speed of limited stop services.

The relationship between operation speed changes for current service and modified limited stop services and route distance was analyzed using regression analysis. It concludes that increasing in route distance, will results in increase in travel time saving, after reaching 14.4 km; a diminishing return may be observed, although the actual travel time saving is much higher for longer distances.

Economic analysis has been done to compare and estimate total capital and operating costs for local and modified limited services. The study shows that regardless of the fact that labour costs are a big share of operating costs, total annual costs saving results from decrease in required peak time vehicles to keep the schedule for the limited stop services.

The study also compares passenger uses and preferences between limited stop services, and local services. The results indicates a higher passenger boarding volume for limited stop services, however no definitive conclusion can be made due to small proportion of the conducted survey. The results from the questionnaire that registered ridership preferences at high volumes, shows that "50 to 60 percent of peak riders prefer using limited buses where they are available" (Ercolano, 1984). However "only 12 percent of the responding limited bus riders walk beyond their nearest bus stop"(Ercolano, 1984). Observations results show that 42 to 74 percent of people choose to board on buses with limited stop services, when the two services are available at the time.

Paper's recommendations are as follows:

- Travel time reduction should be analysed beforehand. Travel time reduction of more than 5 minutes is necessary to be considered and justify limited services.
- Analysis should be done to evaluate the possibilities of increasing average operating speeds a minimum of 1.6 kmph.

- The possibility of limited stop services should be studied, based on OD trips during peak hours
- The strategies for selection of bus stops should be identified to increase coverage and ridership (Ercolano, 1984)

2.7. Modelling limited stop service

El-Geneidy and Surprenant-Legault (2010) evaluated the implementation of limited stop services to make transit service attractive in a heavily used bus route in the Island of Montreal. This research was helpful in designing limited stop services and defining scenarios for selection of stops in this research.
The writer asserts that limited bus services provide riders with shorter in vehicle travel time. The average running time for regular services increased about 0.8 minutes, which could be also caused by a new smart card service, which was introduced at the same time. The paper introduces different scenarios to select service stops. Scenarios were defined in a way to select one stop for new services replacing 4, or 5 stops of local services.
In the first scenario, only transfer stops have been selected. In the second scenario, stops are chosen from the first quartile of passenger activities recorded by Automatic Passenger Counter (APC). In the third scenario, Montreal Origin Destination survey has been used to select the top quartile of stops. In the fourth scenario all the factors that have been mentioned are utilized. Then the saving times for the different scenarios have been estimated using APC and AVL technology. The collected Data includes bus arrival and departure for each stop of the service before and after the implementation limited stop services and measuring the accuracy of the running time estimates that has been done by El-Geneidy and Surprenant-Legault (2010).

The paper also examines the passenger's perception of time savings after the implementation using an online survey. The results show that users feel a significant saving time, both in-vehicle and waiting time. Some users experience a minor increase in waiting time. In addition, the running time saving is overestimated by passengers, for example 1.5 of actual saving was perceived to be between 5.4 to 10.4 minutes.

2.8. Bus Rapid Transit Planning, and land use integration

Planning BRT requires a realistic assessment of demand, cost and benefits, in order achieve the objectives, which is providing a reliable service with higher capacity for future demand with lower costs, and attracting private car users (Miller & Buckley, 2000). One key factor in planning BRT is land use. As it is known, changes in a transportation system, not only affect the overall transportation systems, but also the surrounding land uses (Miller & Buckley, 2000). Therefor BRT planning should be integrated with land use planning of stations' surrounding area. Experiences from cities like, Curitiba, Adelaide, Brisbane, Ottawa, and Pittsburgh, have shown that implementation of BRT, can have beneficial impacts on land use, similar to rail transit services (H. Levinson et al., 2003). Despite all these examples, a study conducted by the World Bank observed, "The impacts of busways on land use and city structure have been little researched" (Fox, 2000). Bocarejo, Portilla, & Pérez (2013) confirmed the relationship between land value, and BRT network, in Bogota, Columbia. The result of the research also indicates that zones in the vicinity of BRT Network in Bogota, faces a significant changes in the density in comparison with other areas.

2.9. Bus Rapid Transit Evaluation

In general, the performance of a BRT system can be assessed, through ridership gain, and operation speed. Increase in bus riders indicates expanded service, improved facility, decreased travel time, and increased population. Operation speed, demonstrated the type of bus lane, stop spacing, and service pattern. Increase in the spaces between stops will result in improved operation speed (H. S. Levinson, Zimmerman, Clinger, & Gast, 2007). The same strategy can be utilized to evaluate limited stop services. In the previously mentioned study by El-Geneidy and Surprenant-Legault (2010), the limited stop service scenarios are evaluated by estimation of running time savings, and passenger activity using AVL, and APC data. Improved running time savings, and increased passenger activity indicates that the recommended service is attractive for the passengers.

2.10. Travel Time

In this research the BRT part of trips made by the passengers are analysed, therefore travel time refers to the time the passenger spends on the bus, which consists of bus running time, and dwell time. Running time refers to the time the bus spends to cover the distance between two points on the route (Tétreault & El-Geneidy, 2010), and dwell time refers to the time that the bus is stopped ("Madison Area Transportation Planning Board - City of Madison, Wisconsin," n.d.). Feng (2014) investigated impacts of different factors on the variability travel time. As Feng (2014) refers to travel distance as one of the most significant factors, however as the study discusses the estimated coefficient varies in the literature which might be due to different characteristics of the cases studies, including bus network, and traffic conditions. Traffic congestion is another variable which have impacts on travel time, however in the literature, "time of the day" or "travel direction" variable used to investigate traffic congestion impacts. Furthermore type of the buses, bus route, stops spacing, signalized intersection, Fare collection method, passengers boarding, and alighting activities as factors which affect travel time, and dwell time. Traffic signal delay will vary considerably, for characteristics such as cycle time, phasing and signal progression will influence the probability that a bus arrives at a signal during the red phase of the cycle. Factors, such as acceleration and deceleration rate, the number of doors available for boarding and alighting, which affect running time, and dwell time are classified as the bus type factor ("Madison Area Transportation Planning Board - City of Madison, Wisconsin," n.d.).

2.11. Experiences in cities with limited stop services

In this section, some examples of cities that utilize Bus Rapid Transit system and limited stop services are discussed. Curitiba is selected as an example of integrated land use and BRT development. Bogota as one of the most successful examples of a Bus Rapid Transit system increased its ridership and capacity by using express services.

2.11.1. Curitiba Bus Rapid Transit

Curitiba's bus system was developed as a part of the master plan of the city. The master plan of the city included radial expansion along "structural axes", maintaining the historical city centre, and integrated approach of land use and transportation development. This system is considered as a model of BRT and it is famous because of its innovative features, such as terminals, which allow free transfers between feeder system and BRT corridors, tube stations, and direct express services. Regardless of high ownership of private cars by Curitiba residents, 70 percent of commuters use the BRT system.

Simultaneously and integrated development of BRT service, and land use, allowed to have a balance between travel demand, and capacity of the bus service. The land surrounding of the busway was allocated to commercial use, and residential land uses are located beyond this distance. The Curitiba bus system acted as a driving factor for development of the city along "structural corridors". The busways are located along structural axes, 5 corridors and has overall length of 58 km. the space between stations, tube stops, are about 450 to 500 m. The tube platforms, which are equipped with climate protection, are as high as buses platform to ease boarding and alighting. Curitiba's bus rapid transit system consists of express and direct services operating on trunk lines. On the contrary with express, direct buses, feeder buses, operated on trunk lines are not separated from traffic. Express buses are operated on separated lanes, and stop at all the stops along the way; on the other hand called direct buses in this system, referred as limited stop service in this research serve a limited number of stops. The operation speed of the system is about 20 kph for regular services, and 30 kph for direct services. Average travel time saving of direct services is about 15 minutes per trip (Levinson et al., 2003).

2.11.2. New York City Transit

Characteristics of limited stop services, critical issues and passenger's responses in relation with this type of services are discussed by Silverman (1998). In this city, limited stop services are operated in routes with high demand.

Schwarcz (1998) distinguishes between limited stop services, and BRT services. Both services are implemented to decrease travel time, the latter requires components such as dedicated lanes, signal priorities, which are not necessary in a limited stop service.

Distance between stops in limited stop services are 1.2 miles, much higher than regular services with 500-750 feet stop spacing. In these services, bus usually stops in the main intersections or stops with high demand. Limited stop service was implemented for the first time, about 30 years ago in New York City, in order to help with traffic and road congestion. Today, besides 200 local bus routes, 35 limited stop services are existed, however 23 of these services operate only during rush hours.

As Silverman discusses, Limited stop services require following characteristics in order to be efficient:

- Wide roadways
- Roadways with progressive signal timing
- One half mile spacing between the stops
- Origin, destination data should indicate a large distance trip

Passengers responded positively to implementation of limited stop services in New York City. However some passengers complain about the longer distance they have to pass to reach the station, still even people who board at local stops are in favour of limited stop services. By Implementation of limited stop services, these corridors experience higher passenger attraction in comparison with the whole corridor. Researches show the perceived time saving is much higher than the actual time saving.

2.11.3. Bogota BRT system (TransMilenio)

Bogota is a pioneer in implementation of a successful BRT system, and is the first bus system that can compete with a rail system. It started its operation by carrying 790000 passengers per day. TransMilenio uses the basic principle of a bus rapid transit system, such as dedicated bus lane, and buses with high capacity. Nowadays, by using combination of regular and express services, it reached capacity of more than 1.5 million passengers per day. Express services in Transmilenio have the same meaning as limited stop services, services which stop at sub set of stops. It is predicted By the time the planned TransMilenio constructed fully, this rate will reach 5 million passengers per day (Dimitriou & Gakenheimer, 2011). If the system utilizes only regular services, they could not manage to carry more than 20000 passengers per hour in the directions with high demand. This was designed through analysing travel pattern and using transportation tools such as origin destination matrix, and algorithms to reach an optimized combination of express, and regular services (Pineda, 2011)

Due to congestion in major corridors of Bogota, average speed of TransMilenio regular services which stop at all the stations, is 21 kph, and average speed of express services, which only stop at few stops is 32 kph. Overall, by implementation of TransMilenio, average speed of public transportation increased from 15 kph to 26.7 kph (Federal Transit Administration, 2006). Overall time saving of the system is 136,750 hours per day and an average of 16 minutes per trip for each individual. Average travel time saving for people from low income group is 18 minutes, higher than people from high income group which is 10 minutes (Hidalgo & Graftiaux, 2006), this is due to the fact, that people from low income group live in margin of the city, therefor they have longer trips to the centre of the city in comparison with people with higher income, consequently they have higher travel time saving (Federal Transit Administration, 2006).

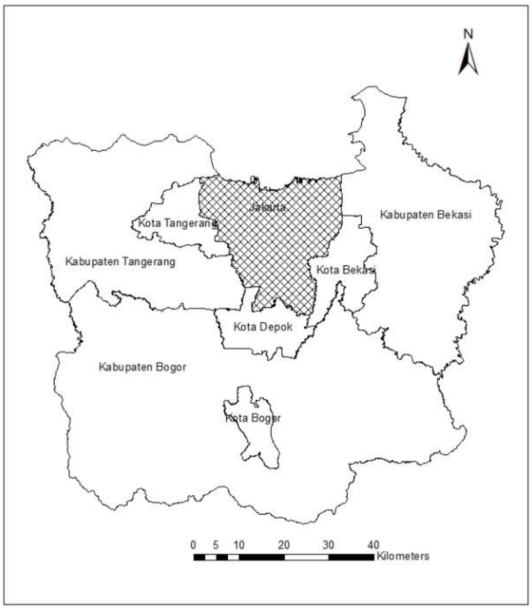
2.12. Summary

One strategy for enhancement of Bus Rapid Transit system is implementation of limited stop services in the corridors with high demand. Nowadays, many BRT systems such as TransMilenio utilizes this service to increase the supply capacity, decrease travel time, and consequently increase ridership. Regardless of its usage in different cities, there is a limited research conducted regarding limited stop service design. Designing a limited stop service includes determining its itinerary, frequency, and vehicle size (Leiva, Muñoz, Giesen, & Larrain, 2010). In this research the focus is on the former one. As it is discussed in the first chapter, Jakarta is selected as the case study because of long travel time of trips in the TransJakarta corridors. Limited stop service is investigated as a strategy to improve the situation. Since some stops are skipped in a limited stop service, and the distance between stops becomes higher, the operation speed increases. One important factor in designing the itinerary is the distance between the stops (El-Geneidy & Surprenant-Legault, 2010; Silverman, 1998). According to Silverman (1998), Schwarcz (1998), and El-Geneidy and Surprenant-Legault (2010), one strategy to deign limited stop services' itinerary is evaluating OD travel pattern, and passenger counts. In this research, designing itinerary based on the stops location in the city, surrounding land use pattern and the BRT system is investigated, and evaluated by comparing it to travel pattern itinerary. A limited number of studies focus on the relationship between land use and transportation systems especially Bus Rapid Transit.

3. OVERVIEW ON THE CASE STUDY, JAKARTA

The case study of this research is Jakarta; capital of Indonesia. This chapter presents this city, its transportation system, and more specifically Jakarta BRT system, called as TransJakarta. In the final section, database that is used in this research is explained.

Jakarta, capital city of Indonesia, is the largest city in South East Asia, and the second largest city in the world. The Mega city is called Greater Jakarta or "Jabodetabek ", made up of first parts of the names of the administrative units of Jakarta, Bogor, Depok, Tangerang and Bekasi (figure 3.1). Greater Jakarta's area is about 5,897 square kilometres, and consists of three provincial governments, Jakarta Special Capital Region, West Java, and Banten. Greater Jakarta's urban development is controlled by the central government (Firman, 2008). The overall population of Megacity of Jakarta has grown from 150,000 to about 28 million in the last century. Jakarta is the centre of economic, social, administrative, cultural, etc. activities.



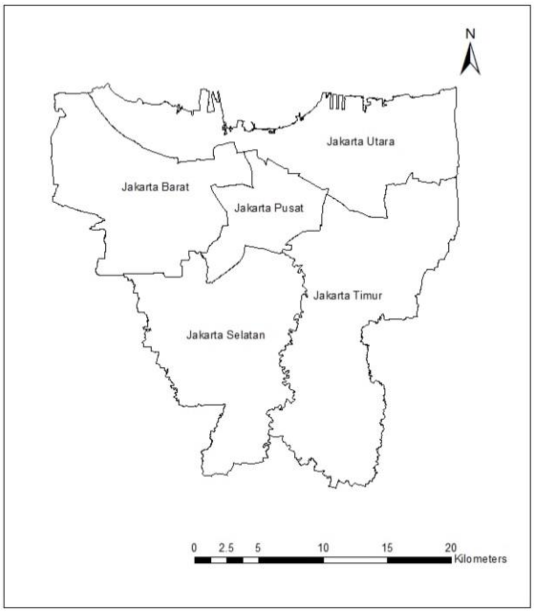


Figure 3-1: Jakarta Metropolitan Area

Figure 3-2: Greater Jakarta Area

3.1. Socio economic profile of Jakarta

The central Jakarta or Jakarta Metropolitan Area (JMA) is made up of five cities (figure 3.2) including, Jakarta Utara (North Jakarta), Jakarta Selatan (South Jakarta), Jakarta Barat (West Jakarta), Jakarta Timur (East Jakarta), Jakarta Pusat (Central Jakarta), and has a population of 9.7 million as of December 2012 with an area of 664 square Kilometres, and density of 14440 person per square Kilometre. In the recent decades Jakarta is developed rapidly in economical and physical sectors. Jakarta is considered as "global cities" beside cities such as Tokyo, Seoul, Taipei, Hong Kong, Manila, Bangkok, Kuala Lumpur, and Singapore in Asia. As figure 3.3 presents, population growth rate in Jakarta from 3.5% per year in 1970s decreased to 0.2% in 1990s, and increased to 1.3% per year (Wismadi, Soemadjito, & Sutomo, 2013).

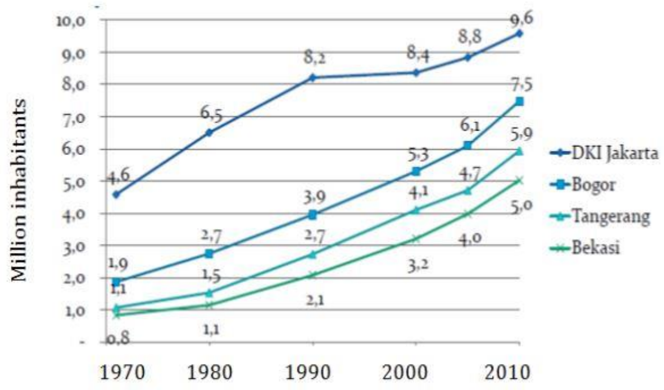


Figure 3-3: Greater Jakarta population growth(*Statistics Indonesia*, 2010)

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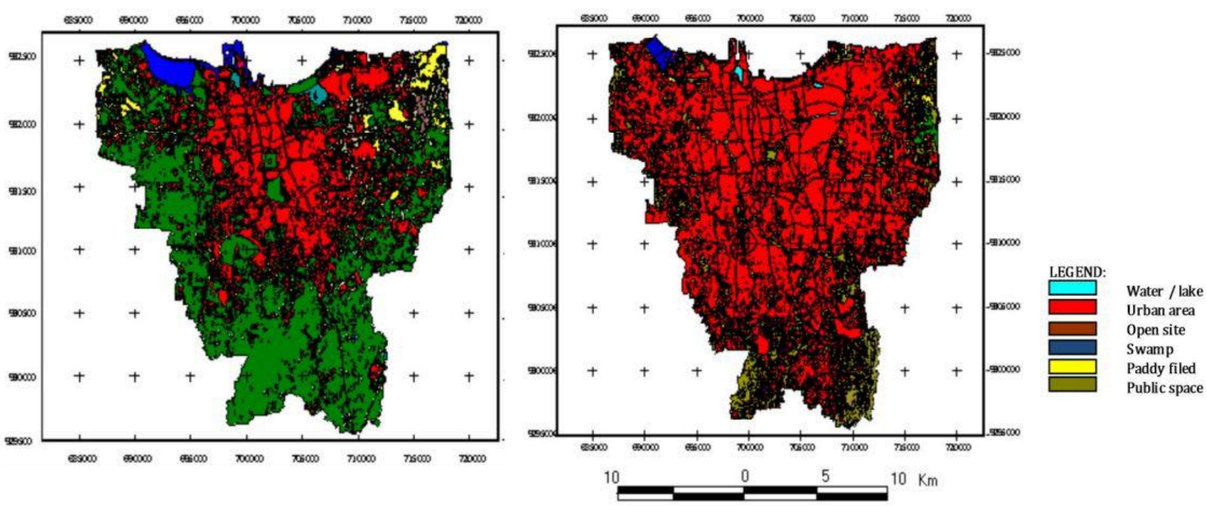


Figure 3-4: Jakarta sprawl development between 1982, and 2002 (Wismadi et al., 2013)

3.2. Problems in Jakarta

Due to significant growth of Jakarta in the last decades, the city struggles with traffic, and floods. Figure 3.4 depicts rapid urbanization in Jakarta, this rapid growth caused a lot of problems for Jakarta. Regardless of all the efforts that have been done, the situation is not improved. Every year flood kills many people, and makes thousands of people evacuate their houses. Traffic congestion in Jakarta, is another consequence of rapid growth and people preference to use private vehicles, which is discussed in the next section.

3.2.1. Traffic congestion in Jakarta

Jakarta suffers from traffic congestion, due to people preference to use private cars, and motorcycles. Along with, population, and economic growth (Susilo, Santosa, Joewono, & Parikesit, 2007), vehicle car ownership is also increasing by 9 to 11 percent per year in Jakarta ("Indonesia's urban studies: The Megacity of Jakarta: Problems, Challenges and Planning Efforts," n.d.). The number of motorized vehicles in Indonesia, in 1990 was about 9 million, and consists of 70 percent motorcycles, and 15 percent private cars (Susantono, 1998). The growth rate of vehicle ownership, as depicted in figure 3.5, during the Asian economic crisis period the number of registered vehicles dropped, due to the fact that people were unable to pay for their registration (Susilo et al., 2007). Private vehicle ownership in Jakarta has changed significantly. Number of registered cars has increased 2 times, while number of registered motorcycles has increased 4.6 times. This is due to the fact that motorcycle is affordable, and so more preferred by users, since it is still usable in traffic (Yagi, Nobel, & Kawaguchi, 2014).

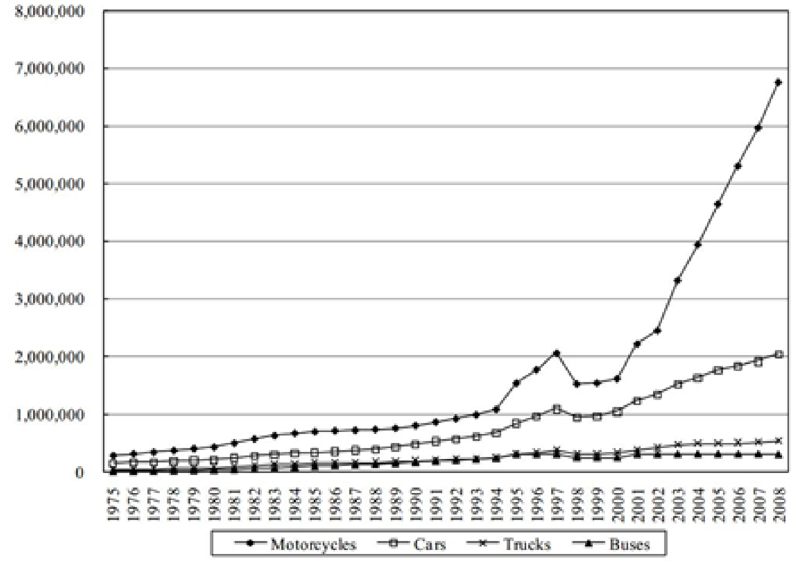


Figure 3-5: Number of registered vehicles in DKI Jakarta(*Statistics Indonesia*, 2010)

Modal split changes in the last decade show that the number of bus users decreased drastically, as figure 3.6 presents, modal share of bus was about 40 percent in 2002, and it is decreased to about 20 percent in 2010. Decrease in modal share of buses implies the need for improvement of bus services. As Yagi et al. (2014) discusses this major shift from buses to motorcycles indicates, commuters who are used to use private vehicle (motorcycle) tend to shift to cars, if their income increase. The consequences of such a shift is sever traffic congestion in Jakarta (Yagi et al., 2014).

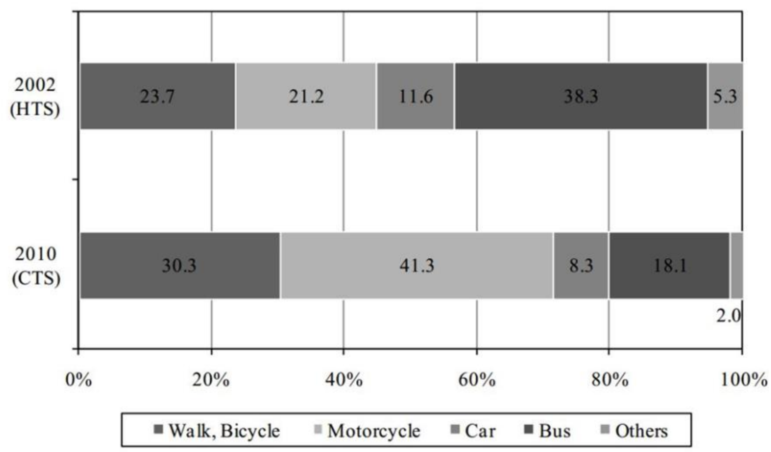


Figure 3-6: Changes in modal split of commuting trips in 2002, and 2010 (Yagi et al., 2014)

3.3. Public Transportation in Jakarta

Providing a decent public transportation system in order to alleviate traffic congestion, and rapid growth of private car users, should be considered as a priority for the government. In most of the cases, economic and political issues are major problems to have a user friendly transportation policy in Jakarta. Many strategies have been utilized to suppress the urbanization impacts on transportation in Jakarta from traffic restraint policy to one-way traffic policy, but none of them were successful, since development of public transportation has always been overlooked by the government (Susilo et al., 2007). Current public transportation systems in Jakarta are classified into bus services, rail services, and taxis as following:

(1) Bus services :
    - TransJakarta Network: a bus rapid transit service which started its operation in 2004, and currently is operated along 12 corridors with exclusive lanes for buses.
    - Kopaja Network: Kopaja, the Jakarta Transport Cooperative (*Koperasi Angkutan Jakarta*), operates minibuses with capacity of up to 30 seats within Jakarta on the designed network
    - MetroMini network: a similar service to Kapaja, however it is not organized under cooperative, and it has more than 50 routes around the city. Both Kopaja, and Metromini buses are old and being operated in poor condition, and maintenance (ITDP, 2013).
    - Mikrolet and Angkutan Kota (Angkot): Vans with capacity of 10 people are run on more than 20 routes in the city
(2) Rail services: These services including Argo and commuter services are run by national railway company and connect cities in Jabodetabek.
(3) Taxis are run by taxi companies and include Ojek, (motorcycle taxi), chartered buses, and limousines services (Yunita, 2008)
(4) In addition to these services the government has taken the first steps for provision of a developed transportation system, called as Mass Rapid Transit, which is expected to start operation of the first corridor by 2020 (Susilo et al., 2007).

3.4. TransJakarta

Operation of the first corridor of the Bus Rapid Transit (BRT) system in Jakarta, also called as TransJakarta was initiated on 1, February of 2004, since then, TransJakarta has been developing rapidly. The line has the most characteristics of BRT systems. Implementation of the first corridor reduced travel time by 59 minutes (Ernst, 2005). During the first year, TransJakarta with 12.9 km length, was used by 15 million passengers, in 2009 75 million used the system (Joewono, Santoso, & Ningtyas, 2012). Currently TransJakarta is operated along corridors with overall length of 200 km, much higher than BRT systems such as TransMilenio in Bogota, and BRT in Curitiba, but its ridership is lower than much smaller systems. TransJakarta carries about 450,000 passengers per day, much lower than TransMilenio with 84 km length, which carries 1.4 million passengers daily. TransJakarta because of its facilities such as air conditioning systems, and cheap fares is considered as a good public transportation alternative. However in order to increase its ridership, some efforts need to be taken ("Public Transport in Jakarta - (Indonesia)," n.d.). BRT systems of Europe, North America, and Latin America are studied by H. Levinson et al. (2003). Curitiba, Bogota, and Quito are the only BRT systems that have all of the characteristics. In table 3.1 existence of main characteristics of BRT systems mentioned by H. Levinson et al. (2003) and Wright (2002) is evaluated in TransJakarta BRT system.

Table 3-1: Characteristics of TransJakarta BRT system (Ernst, 2005)

(H. Levinson et al., 2003)	(Wright, 2002)	Jakarta BRT
Dedicated running ways	Segregated busways	Yes
Distinctive easy to board vehicles	Rapid and boarding and alighting	Yes
Attractive station and bus stops	Clean, secure and comfortable stations	Yes
Off vehicle fare collection	Efficient pre-board fare collections	Yes
Use of ITS technology	Signage and real time information displays	Yes
Frequent all-day service	Excellence in customer service	Yes
	Effective licensing ad regulatory regimes	No
	Modal integration at stations and terminals	No
	Clean bus technologies	No

Currently TransJakarta is operated along 12 corridors, and runs 889 buses, ("Transjakarta Under New and Improved Management - Institute for Transportation and Development Policy," n.d.). TransJakarta map for the year 2010 is displayed in the figure 3.7.

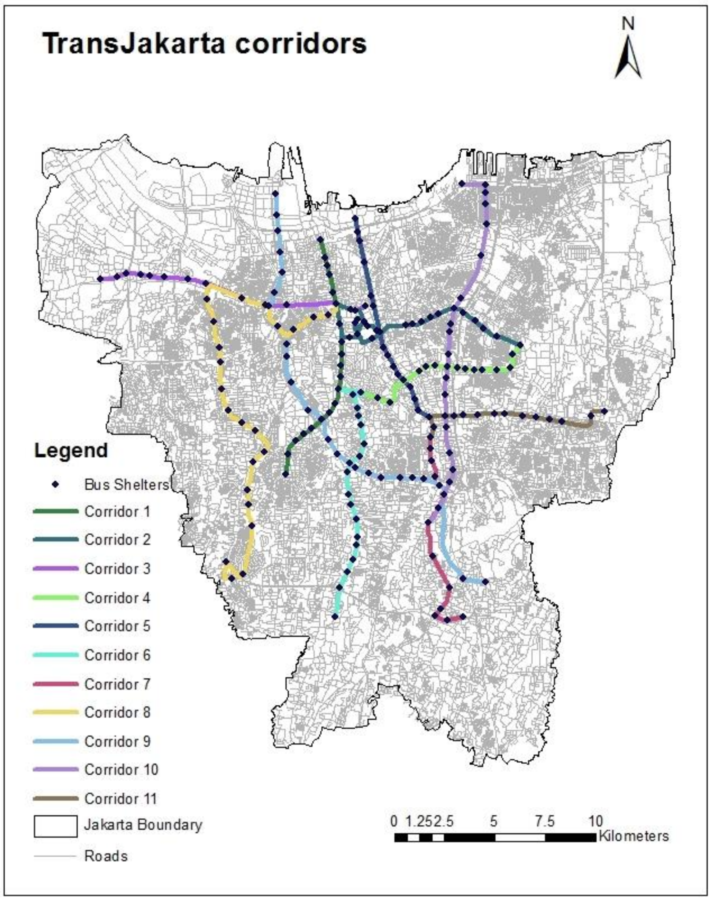


Figure 3-7: TransJakarta corridors in 2010

3.5. Introduction to the dataset

Two datasets are available for this research.

a) Jabodetabek Urban Transport Policy Integration Project (JUTPIP)
b) Geographic Information System (GIS) dataset

JUTPIP is a household commuter survey that has been conducted in 2010. JUTPIP is the result of cooperation of coordinating ministry of Economic affairs of the Republic of Indonesia, and Japan International Cooperation Agency (JICA). GIS database is provided for the project "Study on Integrated Transportation Master Plan for the Jabodetabek", also called as "SITRAMP" in 2004. These two datasets are complementary; JUPIP is joined to the GIS dataset for visualization. However the spatial resolution of JUTPIP is smaller than GIS dataset (Wachyar, 2014). In this research JUTPIP is used to analyse travel pattern of BRT users, and GIS dataset mainly is used to analyze land use pattern in the vicinity of BRT corridors.

3.5.1. JUTPIP dataset

It is a household based survey, and it includes three types of datasets.

1) Household socio economic characteristics, includes information about household income, and expenses, structure of the household (age, members), structure of the house (ownership status, infrastructure, type), and vehicle ownership.
2) Household modal choice provides information about household opinion toward their mode of travel, the reasons that they choose a specific mode of travel. They are also asked about the possibility of buying, or upgrading to private vehicle, if their income increases. Finally, their opinion about transportation management of four modes of travel: bus, busway, rail, and private car
3) Individual household members trip record, which demonstrates travel behaviour of the members. It includes information about passenger (age, gender, and driving licence), origin and destination locations, transport mode, and travel cost.

   Home to work trips also include information regarding (1) education level of the worker, and (2) Job status (type of job, number of employer at a work place, office location).

   For private cars information about travel time, number of passenger, and person who is the driver, and for public transportation, information about waiting time, modal change, travel time, and fare is collected (Wachyar, 2014).

The survey includes 178953 household sample (commuters dataset), 657165 household members, and 186819 samples of home-to-work trips (Wachyar, 2014). Household survey gives detailed information about the characteristics of each household. In this research the most important information derived from the household survey is the main mode of travel that is used by the whole household. Household members' survey gives information about the members of each household, and individual household member's trip record gives information about the work trip of each of the members, unfortunately some information is missing from this survey, such as mode of travel for each part of the trip. The individual household member trips include trip record of 0-2 member of each household (figure 3.8).

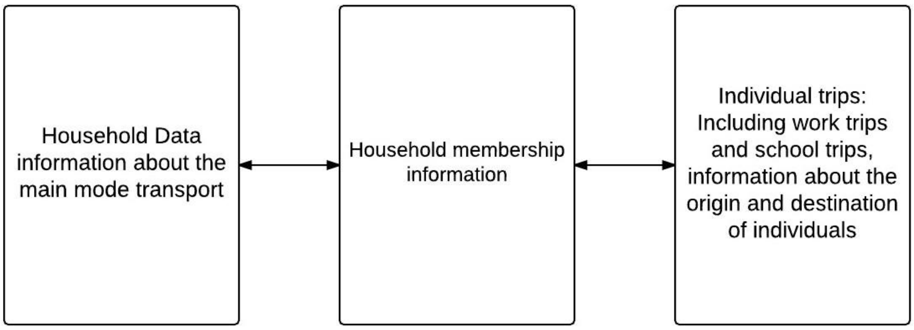


Figure 3-8: Relational diagram among surveys in JUTPIP

BRT work and school trips records are of interest in this research. As it is mentioned before, attribute of mean of travel is missing in work trip and school trip records. To distinguish the trips which are done by BRT, some steps including joining the surveys are done in ArcGIS (figure 3.9). The key attribute in the Data set that helped with this process is main mean of travel in use by the whole household. Individual trip records table first is joined with household member table based on the member ID, and then it is joined with household survey, based on house hold ID. The final table will be trip records including the main mean of travel attribute. The records with mentioned BRT as main mean of travel are chosen for further analysis, which comprises 6407 records. The following diagram highlights the conducted operations.

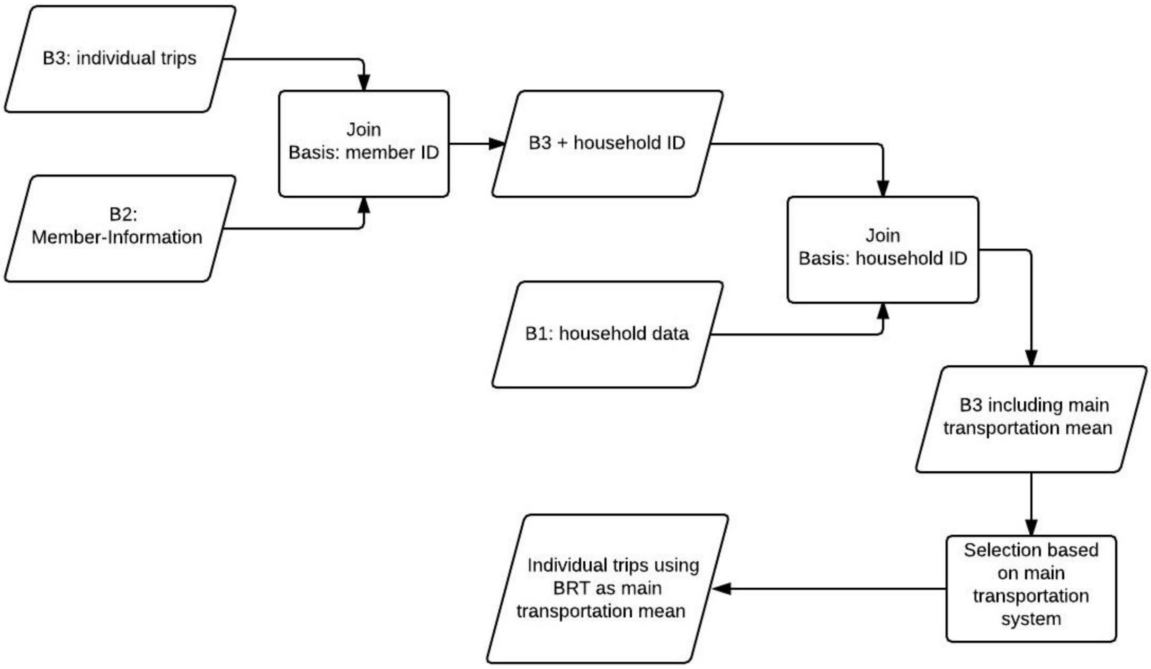


Figure 3-9: Stages in deriving data from JUTPIP survey

3.5.2. GIS Database

GIS database is a comprehensive data and it consists of infrastructure, land use, geographic, demographic and remote sensing data. In addition a GIS layer has been prepared with zoning system of JUTPIP survey (Wachyar, 2014). In this research GIS data is used to analyze the land use pattern in vicinity of each BRT stop. In GIS database, following datasets are used,
(1) Infrastructure data, including Bus rapid Transit Network, the available BRT layer was imprecise, and out of date, TransJakarta map in 2010 is used to update this layer.
(2) Administrative boundary,
(3) JUTPIP survey delineation zone,
(4) Land use data,

3.6. Zoning delination of the study area

3.6.1. Common zoning systems

In this study, two spatial units are considered for the study area.

- Administrative boundary is a geographic classification of area based on bureaucratic arrangement. The administrative hierarchy in Indonesia is as following:
    - Province level
    - Municipality/city level
    - District level
    - Sub district level
- Practical boundary is a geographic classification of the area based on a specific purpose. Common classification of practical boundary are as following:
    - Postal coverage
    - Purposive data collection which divides areas into zones, JUTPIP zone classification is an example of a practical boundary with purposive data collection.

3.6.2. TAZ delineation

For transport studies, spatial unit of analysis is based on Traffic Analysis Zone (TAZ). Homogeneity of trip production density and equity of number of trips inside of each zone are two of important criteria for delineation of TAZ (Ding, 1994). It is important that the TAZ area provide detailed information for transportation analysis. However in many studies a practical approach is taken to define the TAZ area, such as data availability. TAZ area is based on a more practical approach, such as using postal code.

In this study the practical approach has been taken to define the TAZ area. The following points should be considered to define the TAZ area.

- No document regarding TAZ classification in Jakarta is available.
- Joining JUTPIP, and GIS data set to the TAZ areas should be feasible (Wachyar, 2014).

The most detailed spatial zone available for this study is the JUTPIP survey zone level. For travel pattern analysis, JUTPIP survey zone level is chosen as TAZ due to practical matters, and availability of dataset. Administrative boundary at district level is also used for spatial analysis. As it is presented in figure 3.10, JUTPIP zone level is smaller than post code level.

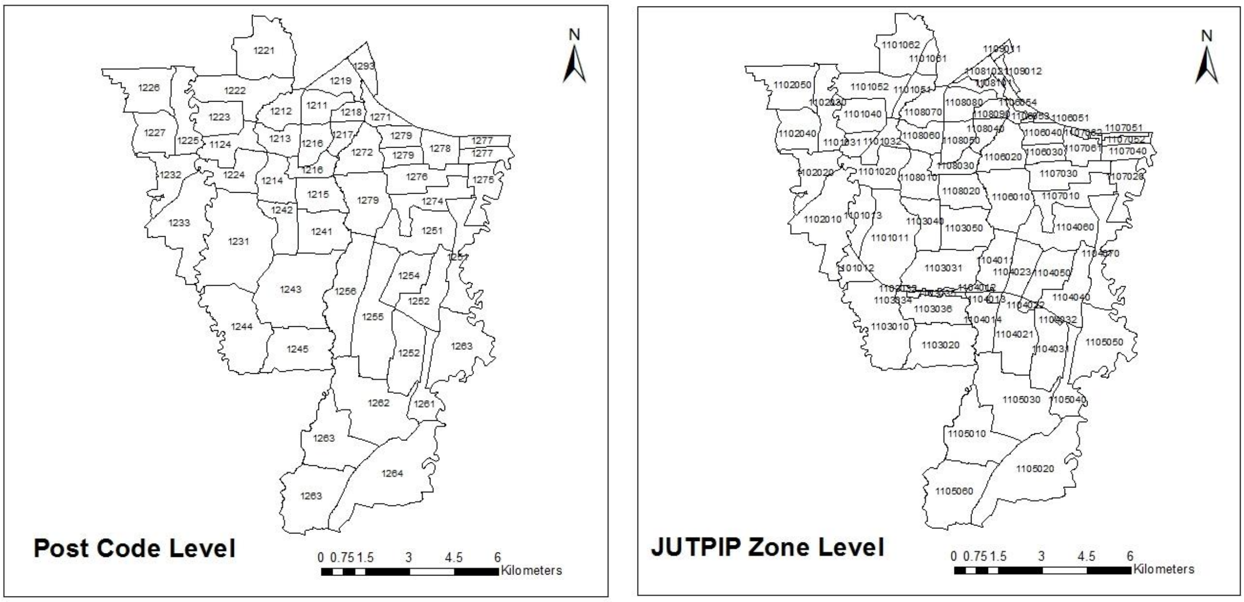


Figure 3-10: Practical Boundary of parts of Jakarta

4. METHODOLOGY

This chapter explains the methodology that is used to reach the objectives of this research. Literature review, spatial and network analysis are used to design limited stop services.

The focus of designing limited stop services in this research is on the itinerary of bus services, BRT stops that bus has to stop or skip along the corridor. Most of the methods for designing limited stop service are based on travel pattern, or passengers' counts. In this research, two different approaches have been taken in to account to define the itinerary.

In the first approach, a stop is nominated for the limited stop services based on its location characteristics, such as land use surrounding of the stop, or whether the stop is a transfer or not. This is due to the fact, that mostly special types of land uses, or also a transfer stop, are trip attraction areas. No literature confirming the relationship between TransJakarta, and the land use pattern in its surrounding area is found, however the surrounding area of the bus corridors in Curitiba was allocated to commercial use, and residential land uses are located beyond this distance. In the second approach, travel patterns of passengers are used to determine stops with higher demand.

4.1. Defining factors to nominate bus stops based on location characteristics

The First step to define itinerary of limited stop services based on the first approach (location of stops) is to identify factors which determine the importance of a bus stop.

Each study locates a bus stop based on some factors.

According to Delmelle et al. (2012), Space between the stops, distance to the nearest intersection, and adjacent land use are among factors which influence the attractiveness of a bus stop. Delmelle et al. (2012) use a number of factors to specify the attractiveness of each of the stops, and evaluate redundancy/efficiency of bus stops in a route. Their case study was route 9 of the bus system in Charlotte, North Carolina. Connectivity at each bus stop is computed by specifying the probability to reach all other stops, either with no transfer or one transfer. The study also assessed the walking accessibility of each stop using GIS. Furthermore demand is modelled using population information from the census; in the United States. The research takes a disaggregated approach using parcel data with descriptive information on land use (offices, government institutions, commercial, and residential areas). Another study O'Sullivan and Morrall (1996) consider the number of routes a stop serves as a strategy for planning.

Based on the literature review and available data, a number of spatial and non-spatial factors have been identified to assess attractiveness of each stop, to be selected for limited stop services. The selected factors are presented in table 4.1.

Table 4-1: Factors for single criteria analysis

Spatial Factors	- Proximity to job centers - Proximity to commercial centers - Proximity to educational centers - Proximity to recreational centers - Proximity to governmental centers - Proximity to CBD
Non- spatial Factors	- Connectivity to main destinations

4.2. Spatial analysis

Based on the define factors, spatial analysis has been done to evaluate attractiveness of each bus stop using ArcGIS. The detailed explanation is presented in this section.

The GIS layer of the BRT system was out dated and inaccurate. TransJakarta map of 2010 is georeferenced. Then on screen digitizing of bus stops and the bus routes is performed to update the BRT GIS layer, and prepare it for further analysis. Since the JUTPIP commuter survey is conducted in 2010, the TransJakarta map of 2010 was selected, which includes 11 corridors.

4.2.1. Buffer Analysis

Factors such as proximity of different types of land uses to the bus stops need to be analysed to determine the attractiveness of each bus stop in the BRT corridor. First step for this analysis is to define the buffer area for each bus stop in a way that BRT passengers with origin or destination within the buffer area of each bus stop, most likely use that stop, and are willing to reach that bus stop by walking or other means of travel. Researches show people are willing to walk to bus stops that are within 400 meter of their origin area (Lam & Morrall, n.d.) and ("Human Transit: basics: walking distance to transit," n.d.). However depending on the context of the transit system, this figure might change, for instance in Detroit, passengers are willing to walk 1.3 km in return trip to the transit stop (Hoback, Anderson, & Dutta, 2008). In this research, the moderate walking distance to a BRT transit stop is 500 m. In addition, people are willing to use "Ojek", a motorcycle taxi which is available almost everywhere in Jakarta, for maximum distances of 1 km to reach their nearest bus stop.

In ArcMap, buffers around bus stops with distances of 500 and 1000 meters are defined; intersection and Thiessen polygons tools are operated to divide overlapping areas. The result of these operations is identified as "vicinity zones" of each bus stop (figure 4.1).

As it is mentioned in the table 4.1 and based on the available land use data, proximity analysis of commercial, and transportation facilities, educational, governmental, recreational, is conducted. The area of each type of mentioned land uses within the vicinity zone of each bus stop was selected and labelled as the bus stop label, and then the areas are summarized based on the bus stop label to calculate total area of each type of land use in the vicinity zone of each stop (figure 4.2).

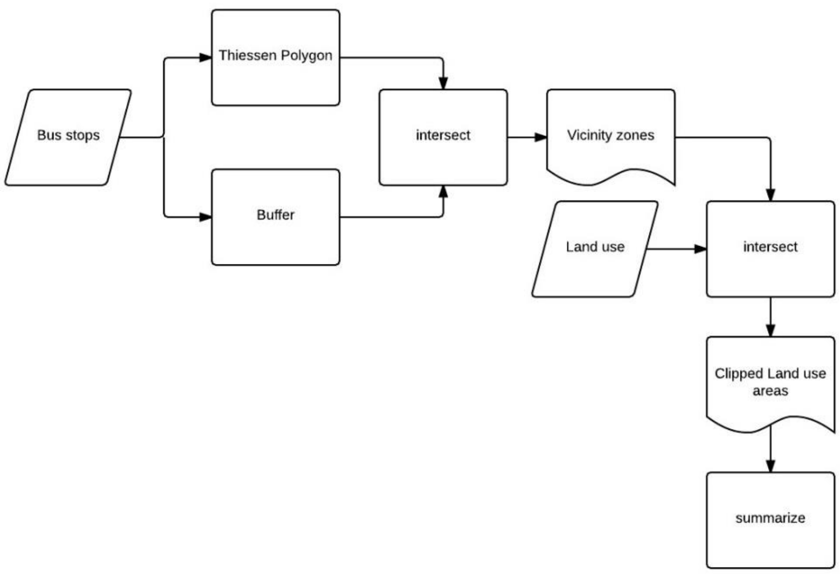


Figure 4-1: The process to define vicinity zones, and selecting specific land uses

Figure 4-2: Vicinity Zone, and commercial area within the zone

In addition, the job density of each vicinity zone is calculated. As it is presented in figure 4.3, the spatial resolution of the vicinity zone is different from the job density layer resolution which is the administrative boundary. First, vicinity zones' layer is intersected with job density zones'. As it is presented in figure 4.3, each vicinity zone contains areas with different job density. In order to calculate job density of each vicinity zone, equation 4.1 is used.

$$J_{stopi} = (\sum_{ai} J_{ai} * A_{ai}) / \sum_{ai} A_{ai} \quad (4.1)$$

i= number of the stop, ai sector with the same job density, A= Area, J= Job density

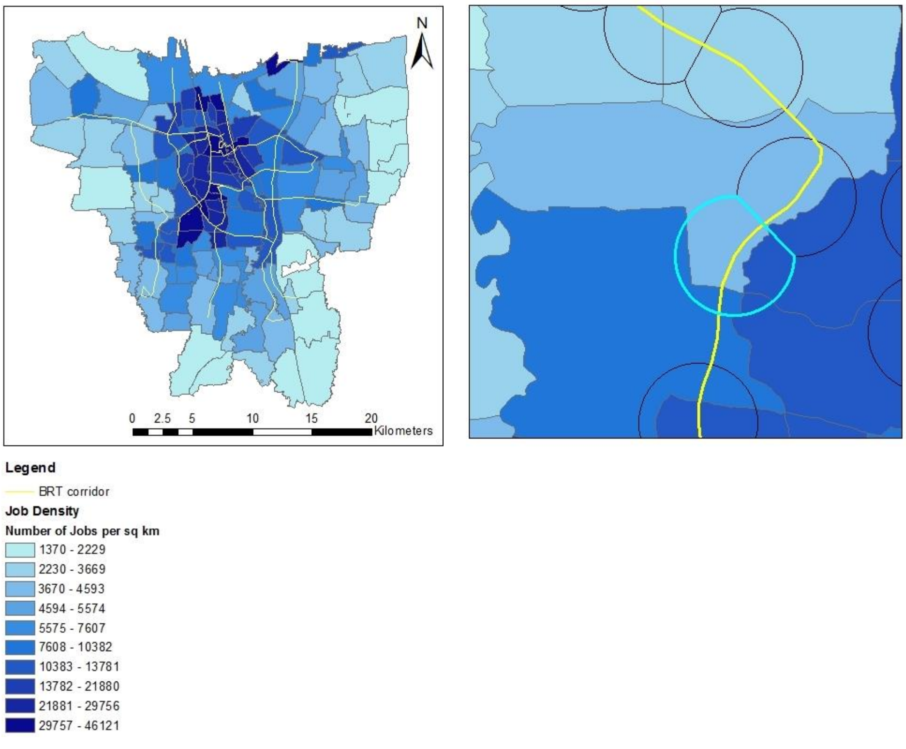


Figure 4-3: Job Density in Jakarta

4.2.2. Single criteria Analysis

A measure is defined, called as "attractiveness" of the bus stop to determine which stops are centrally located. A bus stop with higher attractiveness is centrally located and serves higher potential demand. As it is discussed before, attractiveness of a bus stop depends on proximity of commercial, governmental, educational, recreational, and transportation facilities. Other factors that affect attractiveness of a bus stop are job density, and connectivity to the main destinations.

Proximity of each type of land use for each bus stop is measured by calculating the area of that type of land use which is within the vicinity zone of the bus stop. Therefore higher calculated area of a specific land use for a bus stop means that bus stop has higher potential demand, and that bus stop is more accessible to shopping centres. Although area is not a comprehensive measure to compare accessibility of potential users and it has some limitations, for instance it does not consider the height or importance of each building.

Connectivity is measured by the number of routes each bus stop serves, so transfers have higher connectivity measures in comparison with other bus stops.
The next steps are standardization, and weighting. 0-1 scaling is selected as the standardization method. The measure of each factor for each bus stop is equal to the ratio of calculated quantity to the maximum quantity of that factor. Based on literature review, the importance of each factor is quantified by weighting. Final step to calculate attractiveness of each bus stop is to sum up all the measures for each bus stop. The bus stops are presented in figure 4.4 based on their attractiveness measure. Equation 4.2 is used in order to calculate attractiveness.

$$I = \omega_1 \sum_i \frac{A_i}{Max\ A_i} + \omega_2 \sum_i \frac{B_i}{Max\ B_i} + \omega_3 \frac{(n-1)}{3} + \omega_4 D_{CBD} + \omega_5 \frac{J_{stopi}}{Max\ J_{stop}} \qquad (4.2)$$

A = Area of land use i for buffers with 500m radius, B_C= Area of land use i for buffers with 1000m radius, i = Land use type, n= number of routes a BRT serve, and J= Job density,
ω_1 = 2, ω_2=1, ω_3=2, ω_4=1, ω_5=4

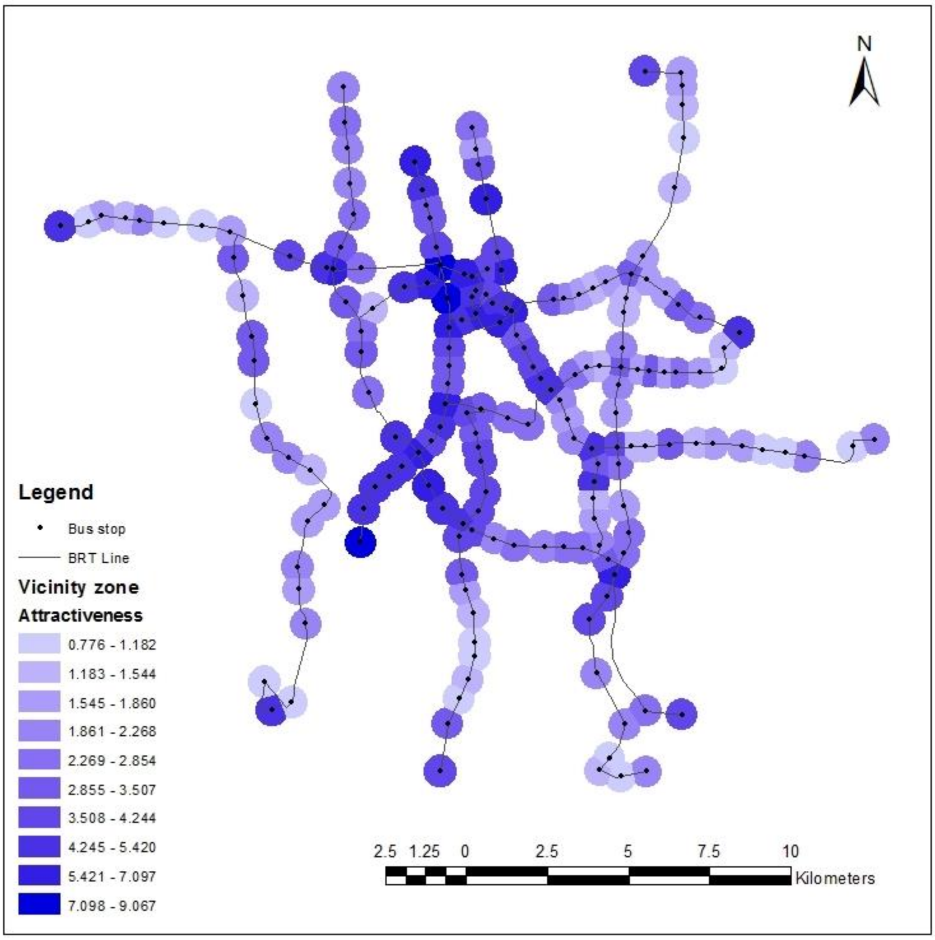


Figure 4-4: TransJakarta bus stops are visualized based on attractiveness measure

4.3. Nominate bus stops based on travel pattern

In this research understanding the travel pattern of work trips that are made by passengers using BRT is of great importance and helps with the design process of limited stop services. The main input data that is used in this research includes the origin and destination zones of trips, which refers to the residential, and work place address.

4.3.1. BRT Network Dataset

To analyse travel pattern it was essential to model TransJakarta BRT network, including 11 corridors, and transfer stops. ArcGIS was used to create a Network based on real world rules.

The base GIS layers of BRT routes, stops, and transfers were prepared beforehand. A BRT network with 11 corridors is modelled, similar to a Multimodal Network with 11 modes of travel in ArcGIS; therefore 11 connectivity groups are defined. Each corridor is connected through a junction with transfer cost to the other corridor. Transfers can be skipped for the trips without a transfer through the fake bridges that are added to the network. Figure 4.5 presents it more clearly.

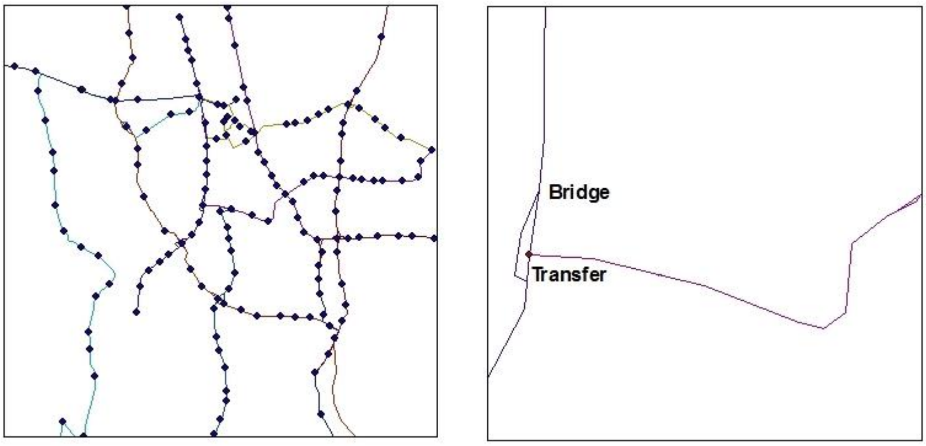


Figure 4-5: TransJakarta BRT network

4.3.2. Specifying Origin and Destination Stops

In addition to the mode of travel information, origin and destination zones of each trip are derived from JUTPIP survey. Origin, destination and transfer stops are not included in the survey. Therefore it is necessary to identify origin and destination stops of trip records.

JUTPIP commuter survey can be spatially joined to GIS data base based on JUTPIP zone code. To specify origin and destination stops, it is assumed that all passengers within each zone code will use the nearest bus stop to the centroid. Based on this assumption, origin, and destination stops of each record are determined. Origin and Destination stops of trip records with the same origin and destination zones cannot be specified. Therefore trip records with the same origin and destination zones are removed, leaving only 2702 records. Origin and destination zones of the trips are presented in figure 4.6.

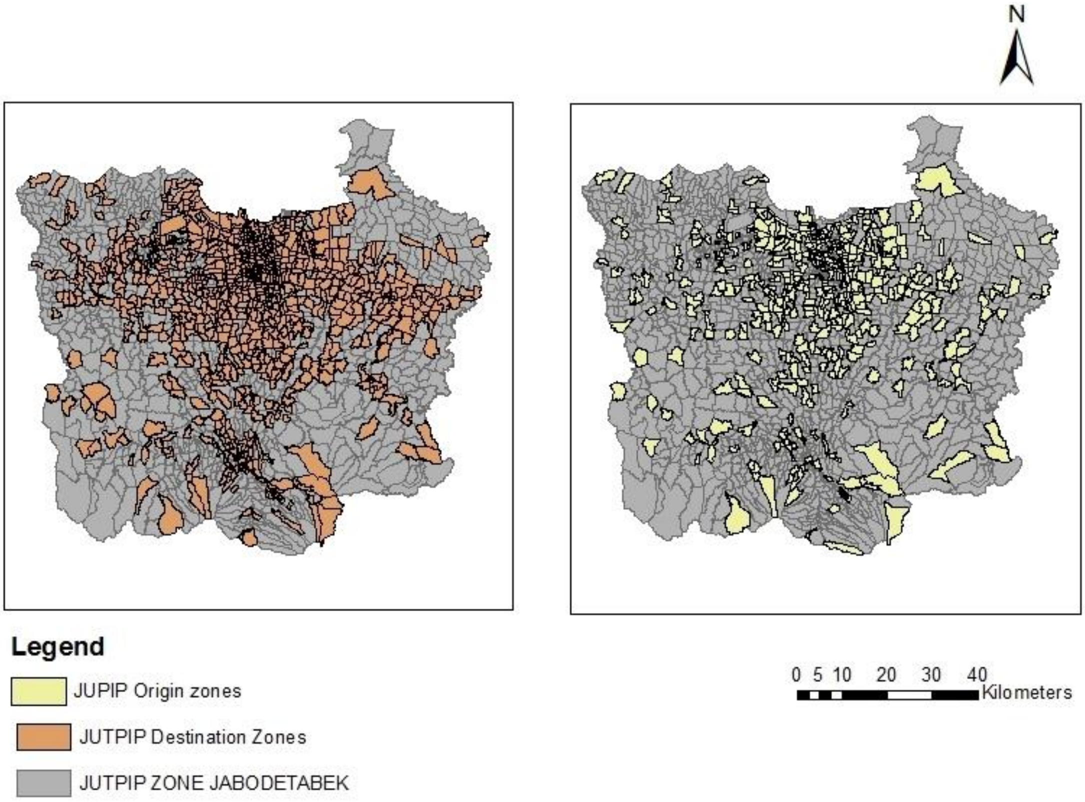


Figure 4-6: Origin and Destination zones in JABODETABEK based on JUTPIP survey

4.3.3. Specifying Transfer Stops

As it is discussed, for analysing travel pattern, detailed travel data is required including transfer stops. Network analyst in ArcGIS is used in order to identify transfer stops. It is possible to find the transfer of one trip by the shortest route operation, but it is cumbersome in a large dataset. Therefore another approach was taken to specify transfer stops.

- OD cost matrix is defined between origin and destination stops to measure cost for each trip record
- Transfer cost for transfer T_i is elevated in the built network data set.
- OD cost matrix is created once again.
- Records with increased travel cost are the ones passing through transfer i
- Repeat all the steps for each transfer one by one

After completing all the steps, the detailed trips records including origin, destination and transfer stops are created. Figure 4.7 represents the steps in the process.

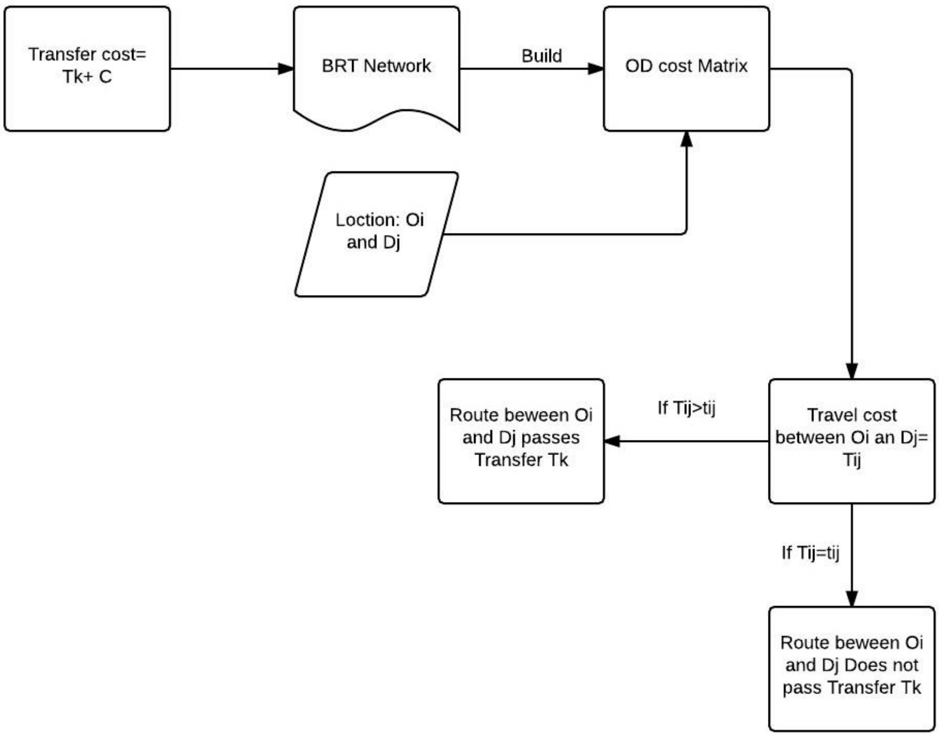


Figure 4-7: The process to locate transfers

T_k= transfer cost for transfer K, C>0 is constant, t_{ij}= travel time between stop i and j.

4.3.4. Travel pattern analysis

The final step is the statistical analysis of travel pattern. Frequency and crosstab tools in SPSS are used in order to analyse travel pattern. Frequency of each trip, number of trips that pass a specific transfer station, frequency of trips between each two corridors are calculated. Correlation analysis is also have been conducted to see if there is a relation between the attractiveness measure calculated by spatial analysis, or stop activity calculated by network analysis.

5. CHAPTER 5, LIMITED STOP SERVICES

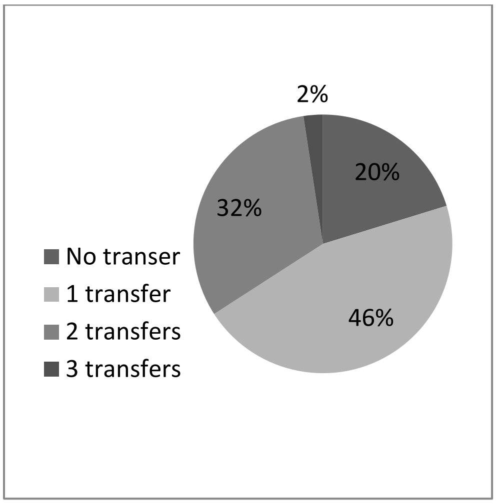
In this chapter the result of analysis is presented. Based on the results of spatial, and travel pattern analysis, limited stop services' scenarios are defined. The scenarios are evaluated according to its travel time saving, and coverage.

5.1. Travel pattern findings

This section presents result of statistical analysis, and travel pattern findings of JUTPIP survey.

5.1.1. Transfer stops

According to ERIA (2013), travel time from origin to destination, number of transfers, and comfort during transfers have significant effect on people's travel modal choice. Due to transfer costs, and long travel time many people choose not to use TransJakarta. The transfer cost is estimated to be about 15 minutes due to overcrowding in the stations (Yunita, 2008), and delays of the buses (ERIA, 2013).



The result of network analysis shows only 17 percent of the recorded trips (547 trips from 2702 trips) do not pass any transfer stop (figure 5.1)

Figure 5.2 shows the number of trips that pass each transfer. Harmoni Central station (T3812) is the busiest transfer station.

Figure 5-1: Proportion of transfer numbers in each trip based on JUTPIP survey

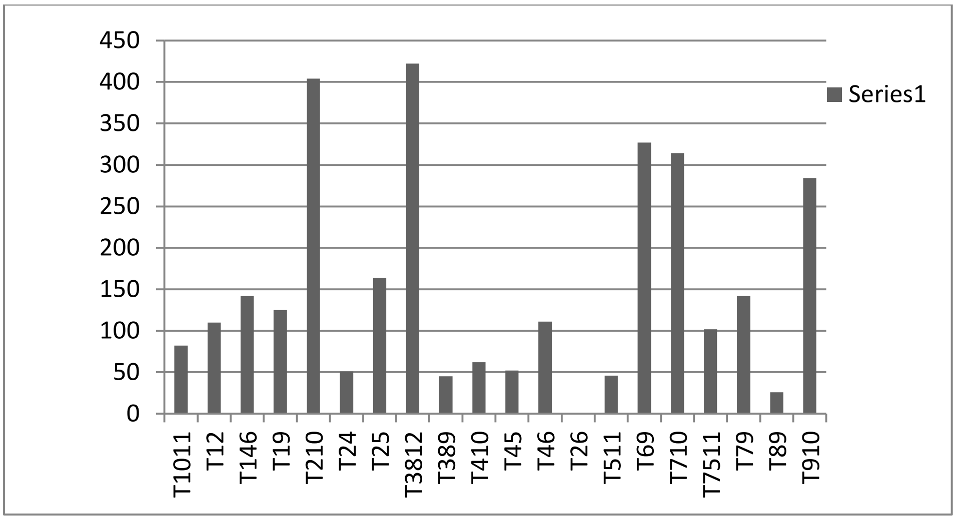


Figure 5-2: Number of trips passing each Transfer based on JUTPIP survey

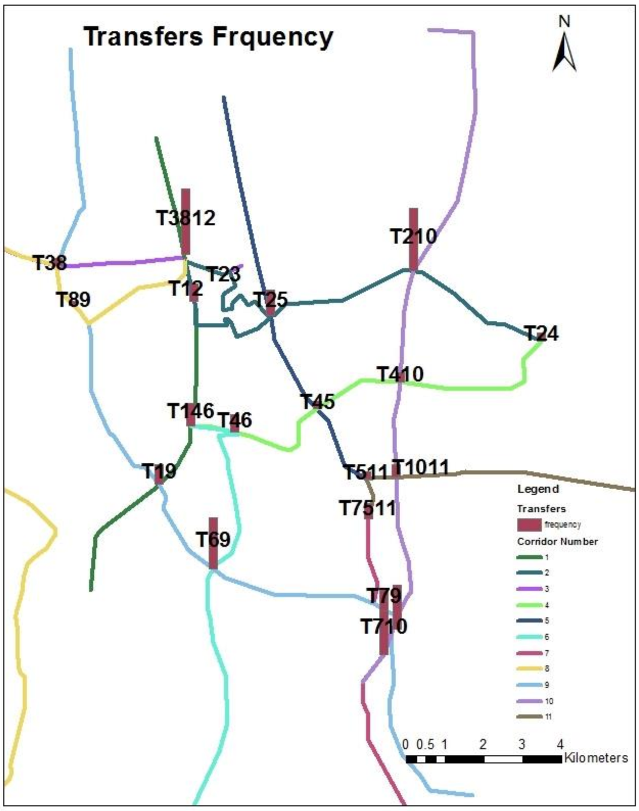


Figure 5-3: Frequency of trips that pass each transfer

Figure 5.3 presents frequency of trips that pass each transfer station in TransJakarta. T3812 refers to the transfer station, which connects corridor 3, 8, 1, and 2.

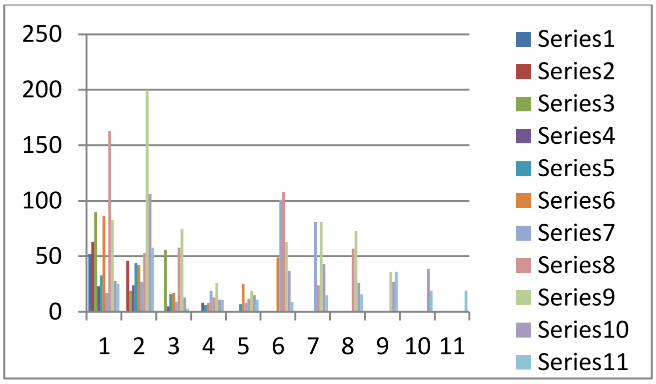


Figure 5-4: Frequency of Trips between each two corridors

The diagram demonstrates the frequency of trips between each two corridors, as it is shown in figure 5.4, highest number of trips records of JUTPIP survey are between corridors 2 and 9, following by corridors 1 and 8.

In other to further analyse travel pattern, each BRT corridor is divided into segments by the transfers, and then the segments are labelled (figure 5.5). Crosstab analysis has been done in order to find the frequency of trips between each two segments. Therefore distribution pattern of trips is specified in more details in comparison with the bar chart.

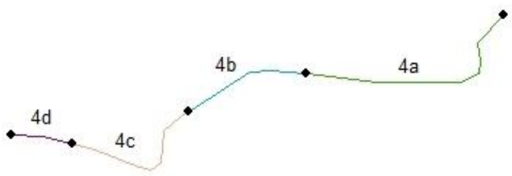


Figure 5-5: TransJakarta corridor 4, divided to segments by the transfers

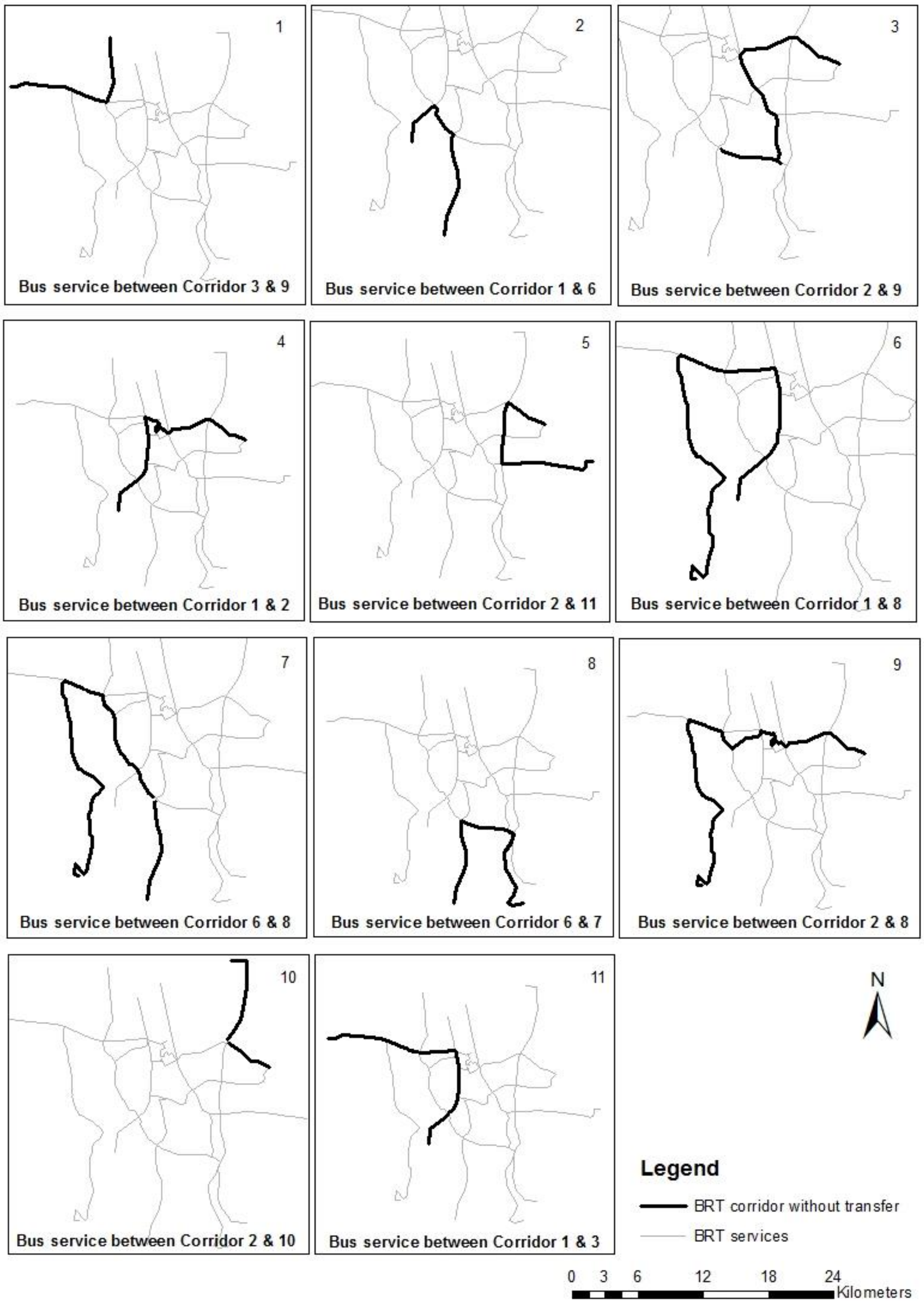


Figure 5-6: Bus Services based on the travel pattern analysis

The trip itineraries are defined between the two segments with frequency of higher than 50. Figure 5.6 presents these direct service's itineraries (without transfer). Transfer in a trip is both time consuming and inconvenient for users (Arias et al., 2007). According to ERIA (2013), the transfer time is about 15 minutes at Harmoni central station. If the transfer time is supposed to be 15 minutes for all of the transfer stops, then each of these bus services reduce travel time about 15, or 30 minutes. Passengers in some of these routes, including 6th, 7th, and 8th routes, face a significant detour (figure 5.6). These results indicate that some people of Jakarta use BRT to travel along these routes, however it is not efficient for the passengers to take this significant detour. This might be due to some errors in filtering the BRT trips from the commuter survey, or some errors during data collection. It is clear that, some work trips are made between these origins and destinations. Implementation of direct services along these routes is not an efficient solution and adding another corridor in the south of Jakarta is required to connect corridors 1, 6, and 8. As the current map of TransJakarta (Appendix A) presents, 13th and 15th corridors are planned to start their operation to connect corridors 1, 6 and 8.

Minimizing transfers is introduced as a concept called as direct services for improvement of TransJakarta. In the proposed plan, the transfer time will be omitted; consequently travel time will be decreased. These services serve passengers from the first mile of their origin to their destination. These services will use TransJakarta corridors in some part of their trip. A survey which is conducted by ITDP (Institute for Transportation and development policy) in 2011 shows 75 percent of passengers take medium or micro buses in spite of their poor condition to use TransJakarta. Replacement of these micro buses by direct services' buses seems logical, since each of these micro buses carries a significant number of passengers (ITDP, 2013).

5.2. Correlation Analysis

Correlation analysis has been done to see if there is a relation between bus stop attractiveness measure (calculated using GIS dataset), and passenger activity of bus stops (calculated using JUTPIP survey). Passenger activity of each bus stop is considered as the number of JUTPIP trips which start or end in that specific bus stop. In the JUTPIP survey, work places are considered as destinations and respondents' home as origins of trips. Attractiveness of each bus stop depends on adjacent land uses such as commercial, governmental, recreational, educational, and job centres, which mostly serve as destination of trips, on the other hand for correlation analysis, passenger activity is also calculated based on the destination of trips. The table below shows the result of the correlation analysis. As the result shows, R-value for corridors 1, 3, 4, 7, 8, 10, and 11 is higher than 0.5 which indicates a correlation between the two measures.

Table 5-1: Correlation Analysis

Corridor No	Pearson Correlation	Sig. (2-tailed)	No. of stop
1	0.722*	0.000	20
2	0.399	0.126	24
3	0.750*	0.002	16
4	0.734*	0.001	17
5	0.485**	0.041	18
6	0.405	0.134	19
7	0.635**	0.015	14
8	0.752*	0.000	24
9	0.477**	0.021	25
10	0.569*	0.006	22
11	0.845*	0.000	15

* Correlation is significant at the 0.01 level

** Correlation is significant at the 0.05 level (2-tailed)

5.3. Alternative Scenarios

In this section the scenarios that are used to select stops for limited stop services are defined. The scenarios were created, and developed based on the research which has been conducted by Tétreault and El-Geneidy (2010), however the methodology and the data that is used are different.

The first scenario, only keeps transfers stops without considering their passenger activity. Based on the travel pattern analysis, some of the transfer stops are not among the stops with high passenger activity. Figure 5.7 highlights the selected stops in this scenario.

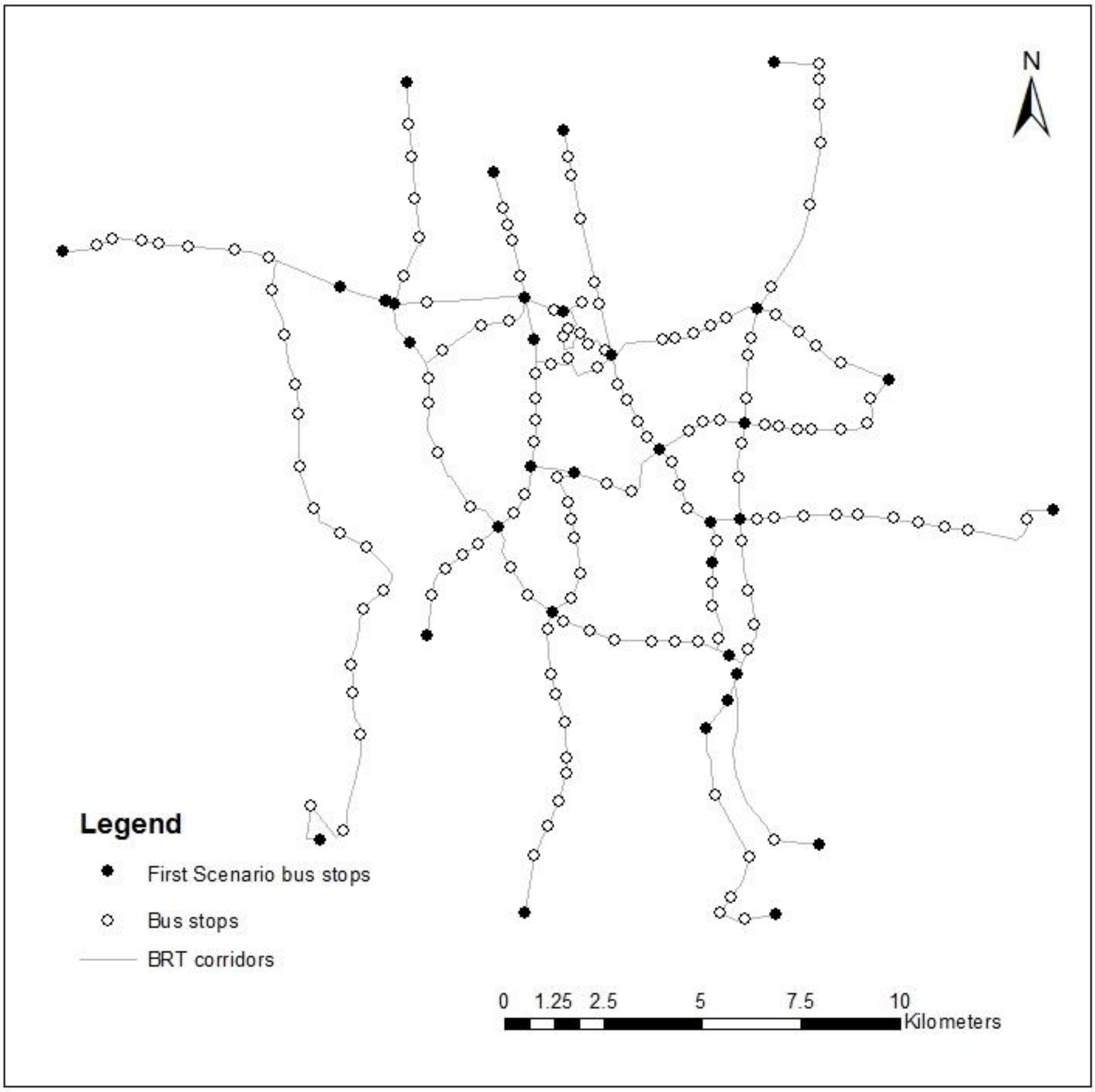


Figure 5-7: Limited stop service bus stops in the first scenario

The second scenario keeps the stops with the highest attractiveness measure (spatial analysis). Attractiveness of bus stops on each corridor is compared on the corridor separately. recommended average space between the stops for limited stop services is 800 to 1600 (Tétreault & El-Geneidy, 2010), higher than the averages space between the stops for regular services, which is about 500 meters in TransJakarta. Based on this guideline, about one out of 3 regular stops have been selected for limited stop services in the second and third scenarios (figure 5.8. & figure 5.9).

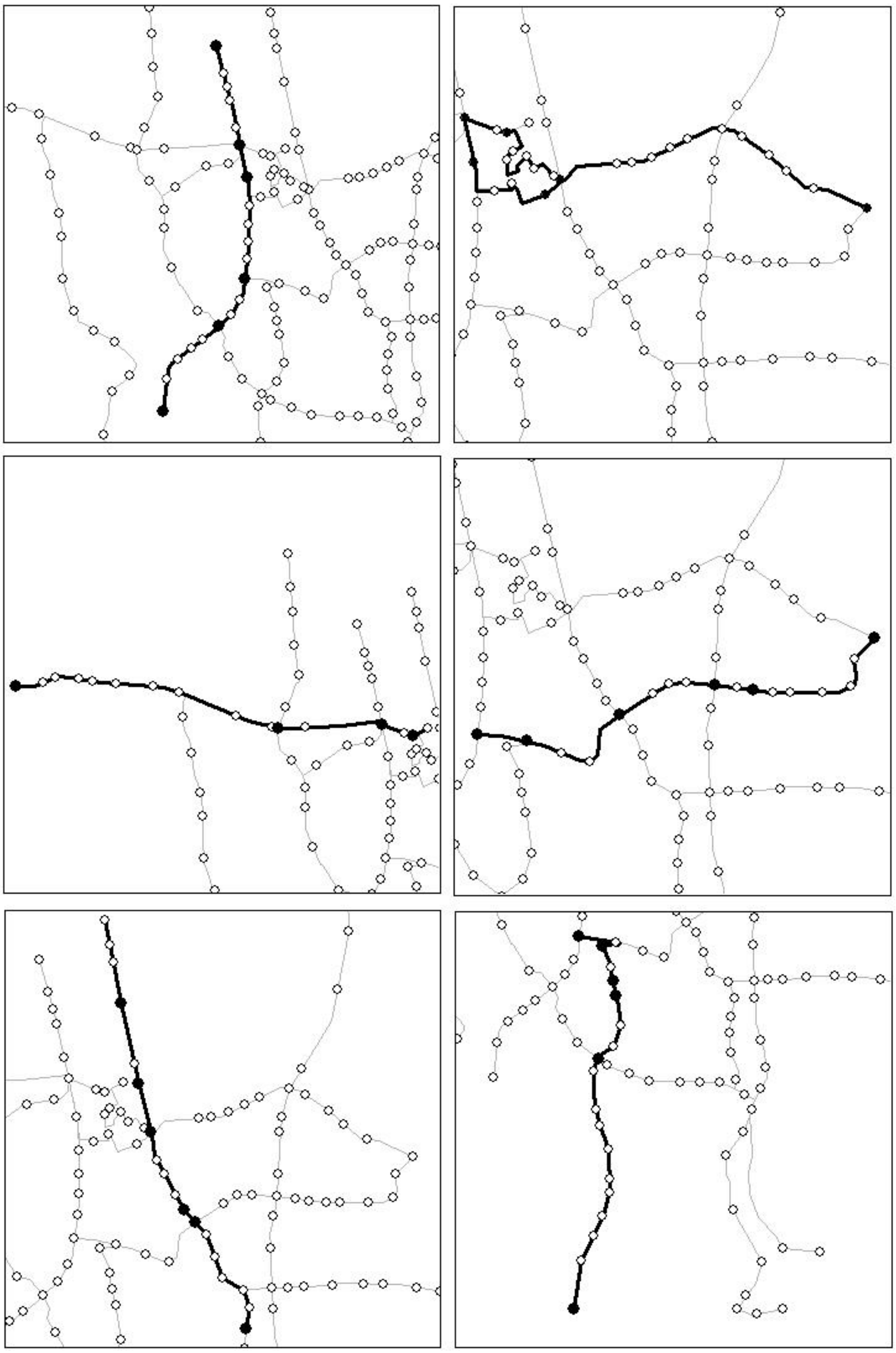


Figure 5-8: Limited stop services bus stops in the second scenario

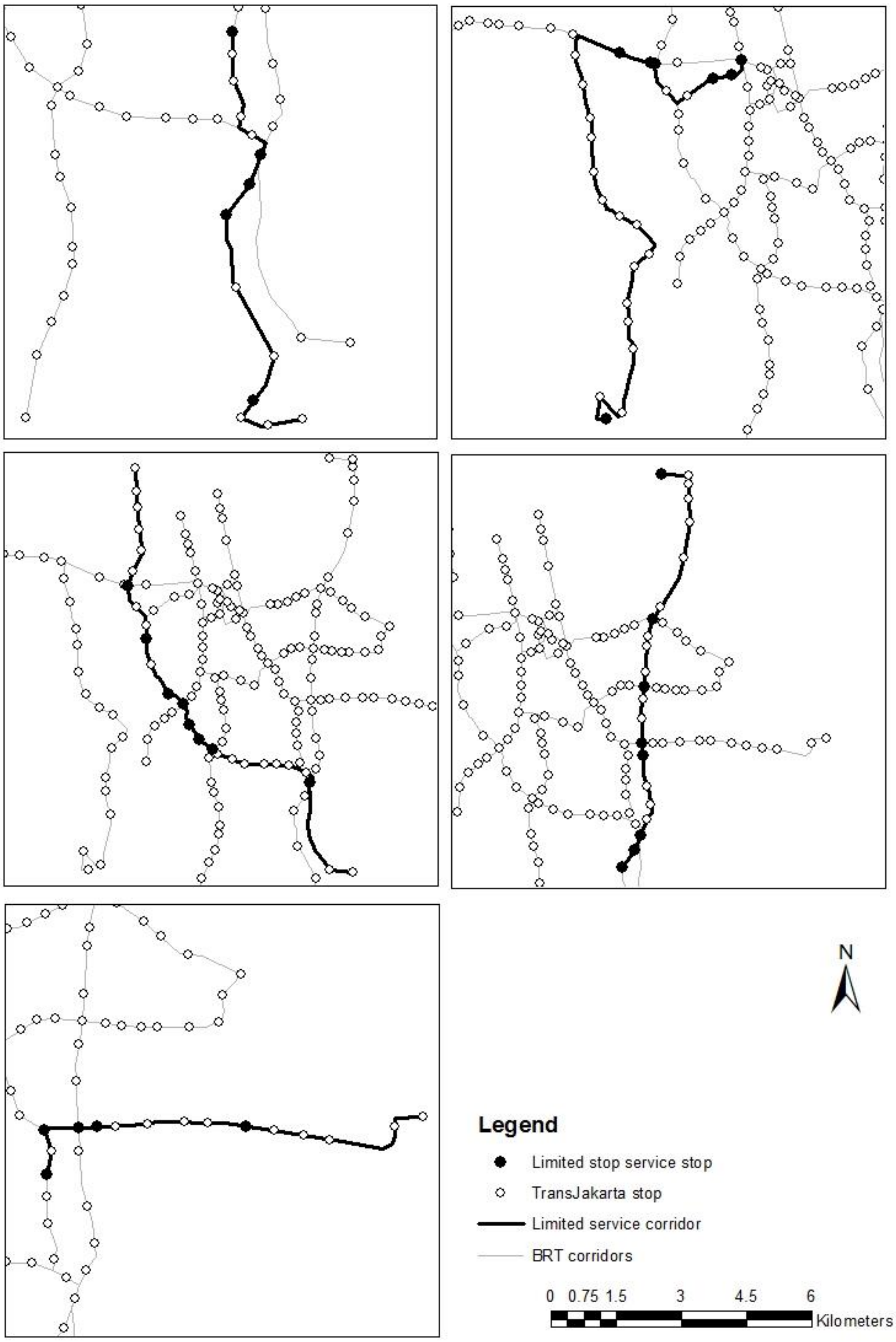


Figure 5-9: Limited stop services bus stops in the second scenario

Most of the transfer stops have been selected in this scenario; this is due to the fact that to calculate attractiveness measure, connectivity of the bus stop to other stops is also considered. In addition, most of the transfers are centrally located.

The third scenario keeps the stops with the highest passenger activity in each corridor. Passenger activity of each bus stop is calculated based on the travel pattern analysis, and equals the number of trips which either start or finish in the bus stop (figure 5.10 & figure 5.11).

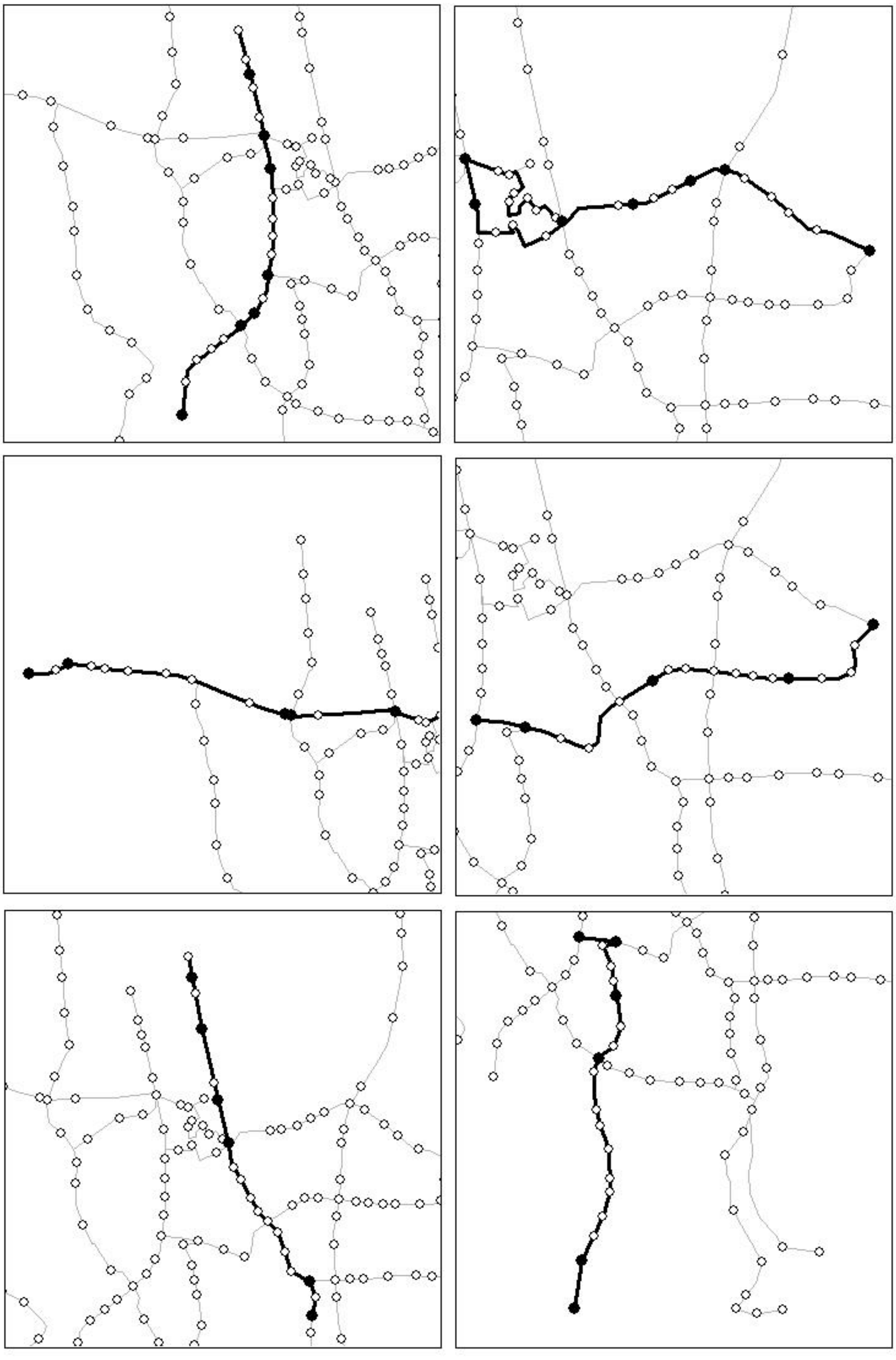


Figure 5-10: Limited stop services bus stops in the third scenario

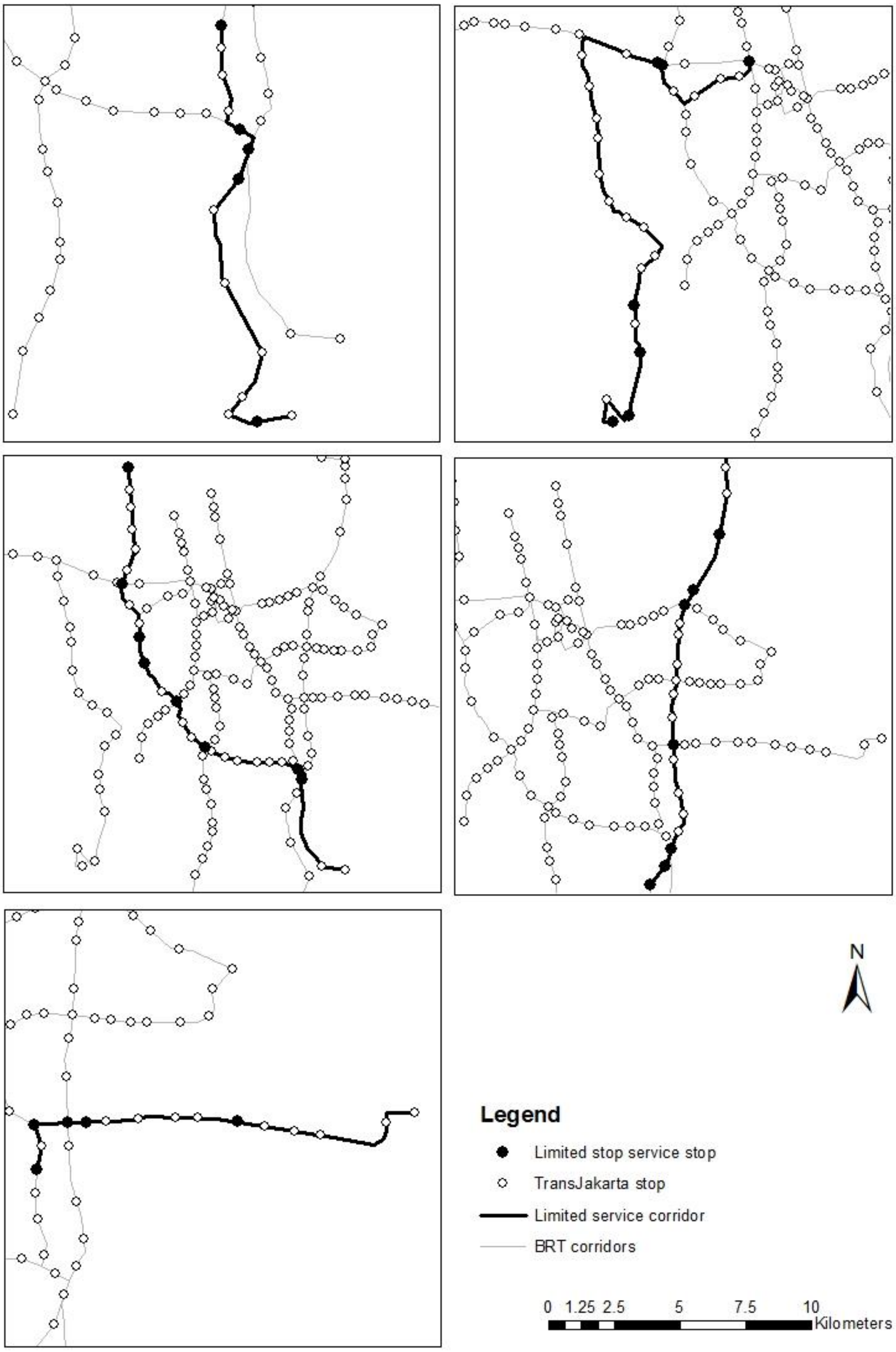


Figure 5-11: Limited stop services bus stops in the third scenario

Initial interpretation of comparison of defined scenarios:

Table 5-2 : Possible conditions of selection of bus stops

	Scenario one (transfers)	Scenario two (Location)	Scenario three (travel pattern)
A	x	x	x
B		x	x
C			x
D	x		
E	x	x	

A) The mutual selected stops of three scenarios indicate those transfer stops that are located near demand generators, which also serve a higher number of passengers based on the JUTPIP survey.
B) If a stop is mutual between the second and the third scenario, but not the first scenario, that stop is a non-transfer stop which is centrally located and serves a high number of passengers.
C) If a bus stop is selected in the third scenario but not in the first and second scenarios, means that bus stop serves a high number of passengers, regardless of the fact that the bus stop is neither located near travel demand generator land uses, nor is a BRT transfer stop. This bus stop might be an intermodal transfer stop, where serve passengers whom change their mode of travel.
D) If a bus stop is only selected in the first scenario, but not in the second and the third scenario, implies that this transfer stop might not be centrally well located, since it does not serve many passengers based on the travel pattern, and it has low attractiveness measure indicating that bus stop is not near demand generator land uses. This is one of the disadvantages of the first scenario for defining limited stop services, since it selects all the bus stop, regardless of their spatial characteristics and passenger activities.
E) If a bus stop is selected in both the first and the second scenario but not the third scenario, indicates a transfer stop, which is located near travel demand generators, but does not serve many passenger based on the JUTPIP survey. That bus stop might be located near travel demand generator land uses except work places, since the JUTPIP survey includes only work trips.

Each of these scenarios has some disadvantages. The first scenario keeps all the transfers, without considering potential demand of each corridor. Therefor a bus stop with low attractiveness measure, and low passenger activity might be selected (D). The second scenario does not consider passenger activities and it only takes location characteristic of a bus stop to account. As a result it might not select a bus stop with high demand, which has low attractiveness measure (C). The third scenario weighs the stops based on the work trips, and ignores the trips with other purposes (E). In addition, none of these scenarios consider space between the stops, which might results in less coverage. This will be discussed in the following sections.
Accordingly, in order to have a more comprehensive method for designing limited stop services; it is recommended to utilize all of the scenarios.

5.4. Evaluation

As H. S. Levinson et al. (2007) states, the performance of a BRT system is evaluated based on operation speed, and ridership increase. In this section, limited stop services for each defined scenario are compared and evaluated based on travel time savings, and estimated percentage of potential passengers.

5.4.1. Travel time

BRT travel time refers to the duration that bus leaves the first stop, and arrives at the final stop, which comprises in-motion bus time and bus dwell time. In-motion bus time is a function of acceleration and deceleration rates, the average operation speed, and distance between two stops. Acceleration and deceleration rates, which depend on vehicle type, are between 3.2, and 4 Kmphps.

The estimated travel time is not based on person perspective and it only considers the bus trip, it doesn't take waiting and transfer time into account.

- The time that the bus is moving, both in the congested and uncongested line (In-motion bus times)
- Time when the bus is stopped at a bus station, called as "dwell time"
- Time when the bus is stopped at the traffic signal ("Madison BRT transit corridor study, proposed BRT travel time estimation approach," n.d.)

In this research, since detailed information regarding travel time was not accessible, highest speed of 30 kmph, dwell time of 1.5 minutes (Sihombing, 2009), and acceleration, and deceleration rate of 3.8 kmphps ("Madison BRT transit corridor study, proposed BRT travel time estimation approach," n.d.) are used to estimate the travel time for each corridor in each scenario.

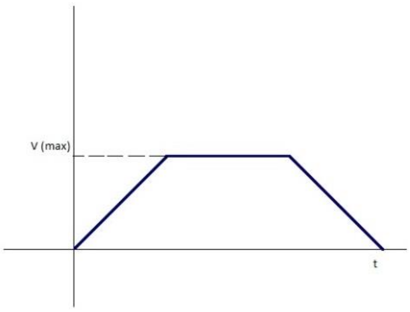


Figure 5-12:Speed-Time diagram

The travel time estimates are generated based on the simple function between distance, maximum speed, acceleration rate, and distance between each two stops using MATLAB codes. The figure represents the relation between speed and time, on each corridor. The overall travel time in one corridor is sum of the dwell time of all the stops, and time takes a bus to move between each two stops. Table 5.3 presents estimated travel time saving for each scenario.

Table 5-3: Estimated travel time savings for each scenario

corridor	Scenario 1 time savings (min.)	Scenario 2 time savings (min.)	Scenario 3 time savings (min.)
1	24.63	24.90	25.66
2	25.96	29.31	33.16
3	9.30	13.49	13.96
4	20.76	19.03	20.76
5	17.78	15.48	19.14
6	26.06	22.62	22.64
7	13.87	19.49	17.16
8	31.22	29.47	29.62
9	31.15	54.09	43.02
10	19.19	24.62	26.41
11	17.32	21.03	27.63

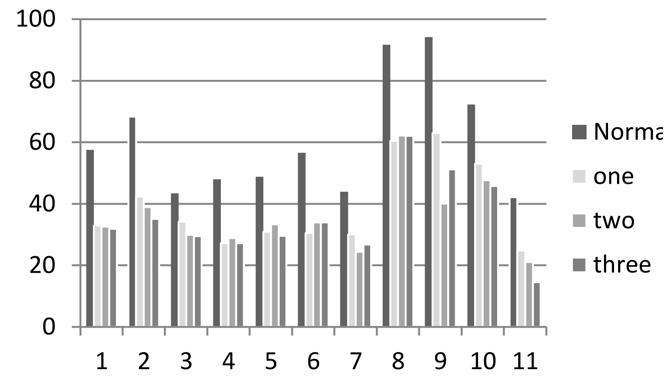


Figure 5-14: Estimation of travel time

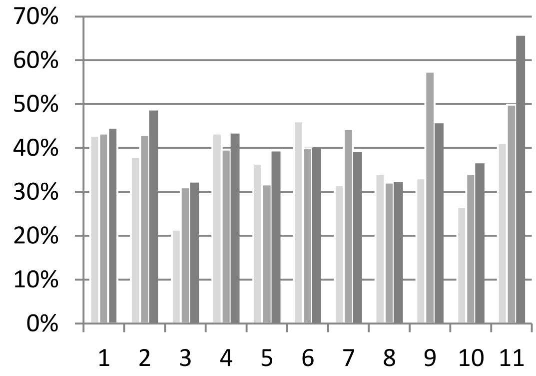


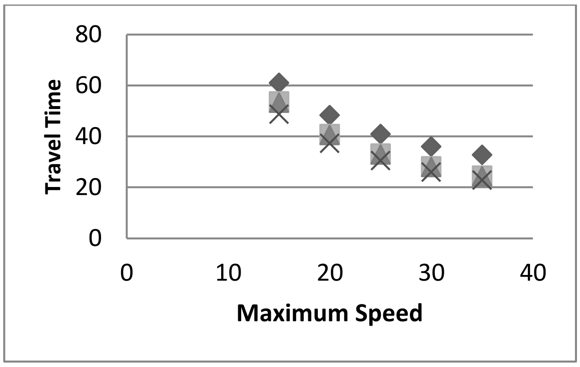
Figure 5-13: estimation of percentage of travel time saving

Ercolano (1984) recommends travel time saving on each corridor for limited stop services should be at least 5 minutes to be perceived by the users. Estimated travel time savings in these scenarios are much higher. Figure 5.14 shows estimated travel time for each corridor for regular services, and figure 5.13 presents estimation of percentage of travel time saving for each scenario.

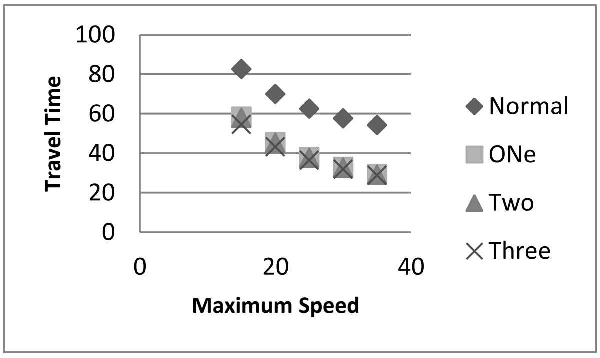
The first scenario, regardless of the fact that it has less number of stops along the corridor, it still has less travel time savings in the most of the corridors in comparison with the other scenarios (figure 5.13).

5.4.1.1. Sensitivity Analysis

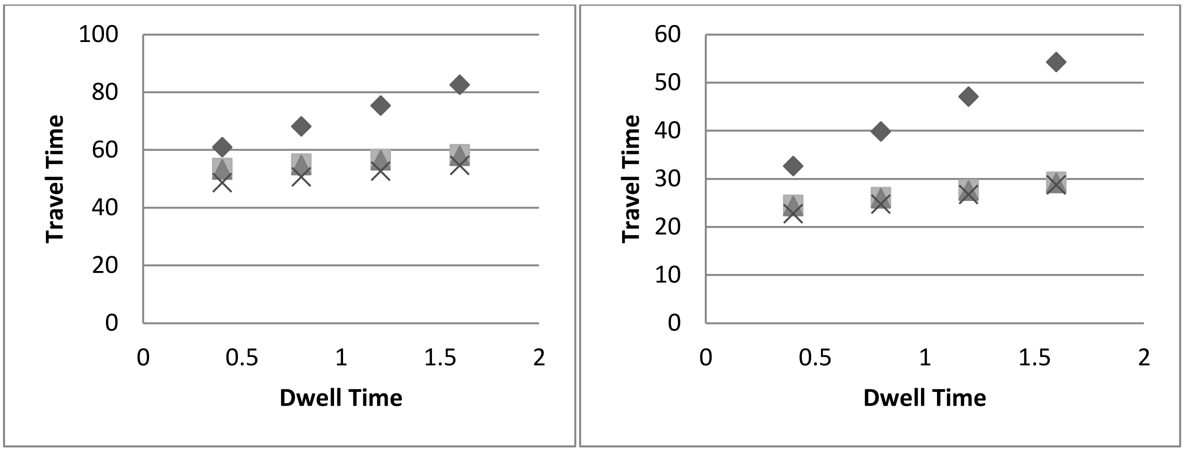
Sensitivity analysis has been conducted to see the effect of maximum speed, dwell time on the estimated saving time for each of the scenarios. As the speed increases, travel time decreases, however the changes' impacts on travel time saving is not significant. As dwell time increases, travel time and travel time saving increases, while the changes impacts on travel time saving is higher, when the maximum speed of bus is higher. Therefore if the speed of BRT system increases by improving infrastructure of components, implementation of limited stop services, will be more efficient. The Charts depicts the relationship between the parameters.



Dwell time = 0.4 min



Dwell time= 1.6 minute



Max speed= 15 km/h   Max speed= 35 km/h

Figure 5-15: Sensitivity analysis of estimated travel time of first corridor in different scenarios

5.4.2. Passengers at percentage of people are able to use the proposed services.

Percentage of TransJakarta users, who are able to use the proposed limited stop services for part of their trip, is calculated using the JUTPIP survey. The origin, and either destination or transfer stop of these passengers are included in the limited stop services' scenarios.

Table 5.4 presents the figures. Based on JUTPIP survey, 660 of passengers use the first corridor of TransJakarta for part of their trip. Based on the analysis, 68 percent of these passengers are able to use the third scenario of limited stop service for the first corridor. On the other hand, 32 percent of passengers, who use corridor one for part of their trip, are not able to use the defined limited stop services of the first scenario, unless they change their origin, or destination stop of their trip.

This does not necessarily indicate that exactly this percentage of people will opt for limited stop services. Certainly many variables, like frequency of these services, waiting time, and comfortableness will influence their choice. In addition some people might change their origin or destination stop, regardless of higher access time, to use these services.

Table 5-4: Potential number of passengers for each scenario and corridor based on JUTPIP survey

Corridor No.	Regular service	Scenario 1 (transfer)		Scenario 2 (land use)		Scenario 3 (travel pattern)	
1	660	263	40%	263	40%	447	68%
2	392	224	57%	192	49%	328	84%
3	299	160	54%	159	53%	127	42%
4	262	88	34%	88	34%	145	55%
5	205	24	12%	88	42%	81	40%
6	375	190	50%	194	51%	267	71%
7	596	171	29%	19	3%	278	47%
8	404	151	37%	148	37%	237	59%
9	581	341	59%	61	10%	342	59%
10	645	439	68%	453	70%	434	67%
11	215	32	15%	97	45%	97	45%

According to the evaluation results (table 5.3) travel time decreases for passengers who choose to use limited stop services. On the other hand by implementation of limited stop services, travel time of passengers of regular bus services might increase. Implementing limted stop services, will increase the headway of regular buses, cosequently waiting time of the passengers of regular services increases. Therefor it is recommended to implement limited stop services in corridors with high demand, and headway of less than 5 minutes in rush hours according to Satiennam et al. (2006) and 8 minutes according to El-Geneidy and Surprenant-Legault (2010). According to TransJakarta schedule, headway of TransJakarta corridors are less than 4 minutes.
Table 5.4 presents percentages of passengers whom take advantages of these service. if we assume travel pattern does not change after implementation of these services, then remaining percentage of people will face increase in their waiting time. So, in order to implement limited stop services efficiently, BRT schedule should be optimized in order to minimize wait cost, in-vehicle cost, and operator costs (Leiva et al., 2010).

5.5. Discussion

Evaluation of the third scenario, which is based on travel pattern, indicates higher travel time saving, and potential demand in most of the corridors of this scenario. On the other hand, evaluation of the first and second scenario also presents considerable travel time saving and passenger coverage.
In the reviewed researches, limited stop services are designed based on only the travel pattern analysis; these results indicate limited stop services can also be designed based on the stops' location when the travel pattern analysis is not available.

In the defined three scenarios, only stops are selected which are expected to have high demand either according to travel pattern, or its location. However as it is presented, some of these stops are located consecutively. Therefore less coverage is predicted for these services. The coverage of these services might be increased by enlarging the space between these consecutive stops, and decrease the space between the other stops (figure 5.15). As it is displayed in figure 5.15, by increasing the space between stop A and B on limited stop service, some BRT users (D3) will be able to use the services, on the other hand some of users who were boarding on stop B, considering the short distance between stop A and B and their trip length, might be willing to use stop A instead.

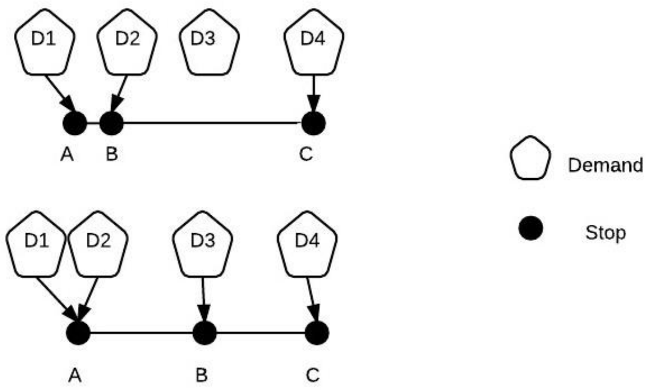


Figure 5-16: Bus stop distribution effect on demand

As it is discussed in section 5.3, in order to have a more comprehensive method for designing limited stop services, it is better to combine all the scenarios. In this section the fourth scenario for corridors 1 and 3 is created.

The itinerary for corridor 1 and 3 in the fourth scenario is defined based on the evaluation of previous scenarios, and considering appropriate space between the stops (figure 5.16). The route for the first and third corridors is defined considering the analysis in section 5.1.1. , and figure 5.6, a direct route which connects Block M and Kalideres stops, eliminating Harmoni transfer. The subset of stops in the route is selected based on the evaluation of the scenarios in section 5.4.

First, stops attractiveness measures, and network analysis measure, are standardized, then weighted based on the table 5.3, and summed. In order to avoid selecting consecutive stops, from each three continuous stops, at least one stop with higher calculated measure is selected. As it is previously explained and depicted in figure 5.15, it is expected that this scenario have higher potential demand in comparison with previous itineraries. Then travel time saving is estimated to be about 45 minutes (15 minutes transfer time saving).

Estimated travel times in this route before and after implementation of the limited stop service, are about 97 and 52 minutes. According to ERIA (2013), travel time between Kalideres and Block M stops is 105 minutes (figure 1.1).

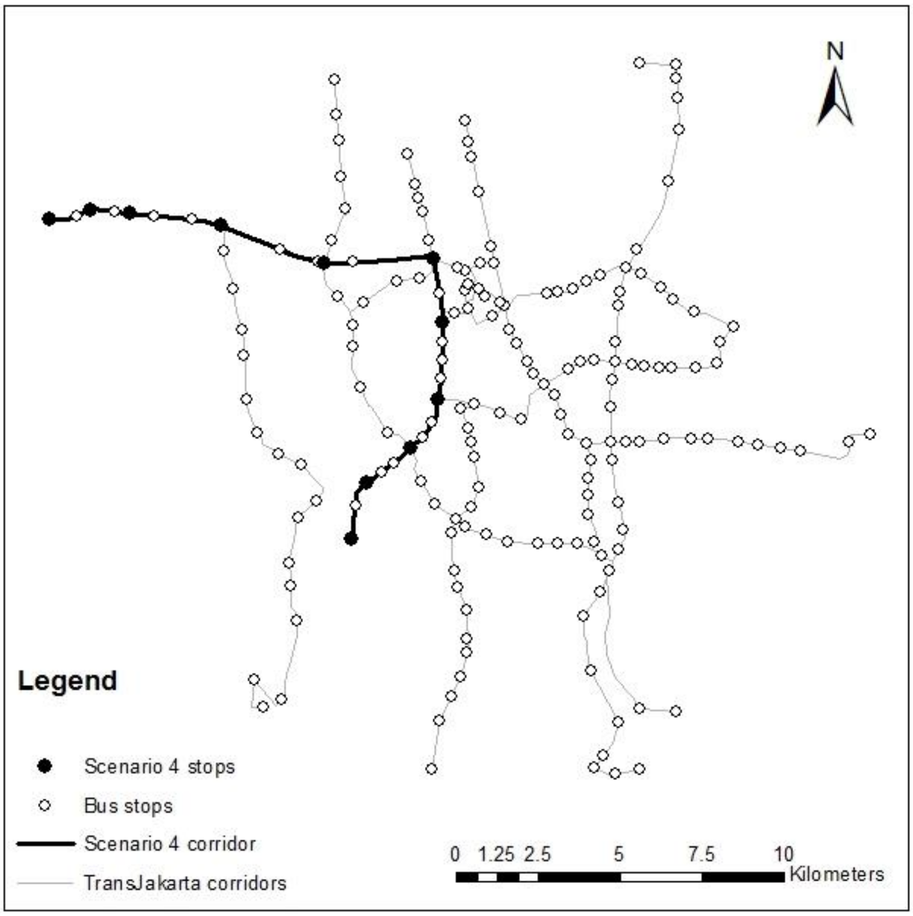


Figure 5-17: Scenario 4 for corridors 1 and n

5.6. Infrastructure requirements for implementation of limited stop service

In this research it is assumed, TransJakarta is being operated ideally and as it is planned. Currently TransJakarta faces many infrastructural shortfalls, for instance cars occupy BRT exclusive lane which is allocated to the buses. On the other hand some buses arrive with delay; consequently long queues in the stations are made. Clearly, in order to have efficient limited stop services, improvement of the level of service is required. The following upgrades are needed for implementation of these services (Hook, 2008):

- Provision of passing lane at the bus stops,
  This is necessary for implementation of limited stop services, which enables limited stop services' buses to skip stops and passes regular services on that specific stop.
- Adding sub stops (stop areas) to the limited stop service bus stops,
- Free transfer between the limited stop services and regular services,
- Adding bus doors,
  According to (Hook, 2008) TransJakarta buses have one door; while Transmilenio buses have 4 bus doors (size and number of doors are more important factors in comparison with bus size).

6. CONCLUSIONS AND RECOMMENDATION

6.1. Conclusions

The objective of this research was developing a method to reduce travel time. Implementation of limited stop services was developed and evaluated as a method to reduce travel time. Implementation of such services increases speed operation of BRT which have benefits for both the passenger, and operator. For passengers it reduces travel time (run time) due to lower number of stops, and higher speed between the stops. On the other hand, increased waiting time for the BRT users who are not using limited stop services is expected. Therefor a bus schedule should be designed in order to minimize waiting, bus run time, and operation costs. Besides designing limited stop services, elimination of transfers in some trips between corridors is evaluated. The results are elaborated in the previous section, and concluded in this section.

6.1.1. General conclusion

Generally, this research has proposed a method to improve travel time in Jakarta. BRT system can be improved by implementation of limited stop services, as an additional service to regular services. The focus of this research is developing a method to define itinerary of these services. Provision of direct services (no transfer) between two corridors is also evaluated according to the demand. In the design of limited stop service two main approaches have been considered. First approach, weighs the bus stops based on their location in both TransJakarta, and Jakarta, and the second approach weighs the bus stops with higher passenger activities based on the JUTPIP survey. Finally through defining scenarios, these approaches are evaluated and compared.

The limited stop services are developed based on the basis of TransJakarta situation in the end of 2010, when it was being operated along 11 corridors. Attractiveness measures, and passenger activity of each bus stop is assessed in comparison with the other stops in the same corridor.

Travel time in each proposed service is modelled using bus run time model with variables like acceleration, and deceleration rate, maximum speed, and dwell time. However a detailed run time records would give us a more accurate estimation. In addition based on the JUTPIP commuter survey, percentage of passengers who are able to use each of the suggested services is estimated.

In most of the studies, limited stop services are designed based on travel pattern. In this research, limited stop services of the first and second scenarios are designed based on the location, without considering travel pattern. Evaluation of the first scenario, and second scenario presents, that in the most of corridors travel time saving, and coverage is as high as the third scenario. With a more detailed land use data, the accuracy of the design of limited stop services based on the location of a stop will be even higher.

In the first scenario only transfer stops have been selected, but as the evaluation results show, its coverage in the most of the corridors is as high as the third scenario. This indicates that most of the work trips, based on the JUTPIP survey are long trips with one or two transfers. Therefor it evidences the effectiveness of implementation of limited stop services, and also direct services (elimination of transfers) in TransJakarta, since travel time saving of limited stop services is higher in longer distances as discussed.

In addition comparison of scenarios will give us more information about the importance of each stop, and its characteristics, and the reasons that one specific bus stop should be included in the limited stop services.

6.1.2. Answering Research Questions

The methodology is more focused on the design of limited stop service in TransJakarta. The research is conducted to answer the research questions.

The current problems of TransJakarta, and its impacts on the travel time are mostly reviewed in the literature.

Selecting the nominate bus stop has been reviewed in the methodology section. The focus on this research is on defining itinerary of limited stop services. Two approaches have been taken in order to clarify the itinerary, based on spatial analysis, and network analysis. Some assumptions have been made for this analysis.

- It is assumed that users use their nearest bus stop (Euclidean distance).
- For spatial analysis two buffers with radius of 500, and 1000m have been defined. It is supposed passengers are willing to reach the bus stop within 500, or 1000 m of their origin by walking or using Ojek.

The impact of implementation of limited stop services on travel time has been evaluated in the 5^{th} chapter, through defining scenarios. Based on spatial and network analysis, three scenarios have been proposed, and travel time saving for each of scenarios is estimated. The figures which are used for estimation of TransJakarta, like maximum speed, or dwell time are based on the reported figures for TransJakarta, or similar BRT services. In addition, the percentage of users who are able to use limited stop services instead of regular services is estimated.

Required infrastructural intervention, for implementation of limited stop services has been reviewed in the 5^{th} chapter. In this research it is assumed that TransJakarta is being operated as it is planned. The most important infrastructure characteristic for implementation of limited stop services is provision of passing lanes at the stops. Passing lane at the stop allows the limited stop buses to pass the regular buses.

6.2. Recommendations

One limitation of this research is that it is assumed passengers use the nearest bus stop (Euclidean distance). This might cause some errors, especially for longer distances. A more detailed travel pattern data increases the accuracy of the research.

For spatial analysis, area of land uses is used to generate attractiveness measure, however considering only area, might cause some errors, since it ignores high rise building or importance of each land use generator. A more detailed land use data helps to increase the accuracy of the results.

More detailed travel time information will increase the accuracy of evaluation of limited stop service, and would give this possibility to calibrate the travel time model.

Limited researches have been done in similar BRT systems in Bogota, or Curitiba. One of the causes of traffic in Jakarta is inappropriate distribution of land uses in the city, and integrated pattern of land use, and transportation system, make the trips shorter, and help with travel time. Further research is suggested to investigate the relationship between TransJakarta, and its surrounding land use pattern.

In order to improve methodology, and limited stop services, further research can be done in order to integrate limited stop services, and direct services with a multi modal transport system. Ojek is used as primary vehicle for people to reach their nearest bus stop, which could be replaced with other means of travel like bicycle. Feasibility of its implementation, and conditions in Jakarta should be studied.

One drawback of limited stop services is increase in waiting cost of some passengers. Further research is recommended to propose an efficient schedule to minimize waiting, bus run time, and operation costs.

LIST OF REFERENCES

Arias, C., Castro, A., Martins, W. C., Custodio, P., Diaz, J. C., Fjellstrom, K., … Zimmerman, S. (2007). *Bus Rapid Transit Planning Guide*. (L. Wright & W. Hook, Eds.)*The institute for transportation and development policy* (3rd ed.). New York: Institute for Transportation & Development Policy.

Bocarejo, J. P., Portilla, I., & Pérez, M. A. (2013). Impact of Transmilenio on density, land use, and land value in Bogotá. *Research in Transportation Economics*, *40*(1), 78–86. doi:10.1016/j.retrec.2012.06.030

Delmelle, E. M., Li, S., & Murray, A. T. (2012). Identifying bus stop redundancy: A gis-based spatial optimization approach. *Computers, Environment and Urban Systems*, *36*(5), 445–455. doi:10.1016/j.compenvurbsys.2012.01.002

Dimitriou, H. T., & Gakenheimer, R. (2011). *Urban Transport in the Developing World : A Handbook of Policy and Practice*. Cheltenham: Edward Elgar Publishing.

Ding, C. (1994). Impact analysis of spatial data aggregation on transportation forecasted demand: a GIS approach. *URISA Proceedings URISA*, 362–375. Retrieved from http://libraries.maine.edu/Spatial/gisweb/spatdb/urisa/ur94032.html

Eberlein, X. J., Wilson, N. H. M., Barnhart, C., & Bernstein, D. (1998). The real-time deadheading problem in transit operations control. *Transportation Research Part B: Methodological*, *32*(2), 77–100. doi:10.1016/S0191-2615(97)00013-1

El-Geneidy, A. M., & Surprenant-Legault, J. (2010). Limited-stop bus service: an evaluation of an implementation strategy. *Public Transport*, *2*(4), 291–306. doi:10.1007/s12469-010-0030-9

Ercolano, J. M. (1984). Limited stop bus operations : an evaluation. *Transportation Research Record*, (994). Retrieved from http://trid.trb.org/view.aspx?id=269874

ERIA. (2013). *Case study: preference survey in Jakarta*. doi:http://www.eria.org/RPR_FY2013_No.27_Chapter_3.pdf

ERIA Study team. (2010). *Current Status of ASEAN Transport Sector in ASEAN Strategic Transport Plan*.

Ernst, J. (2005). Initiating Bus Rapid Transit in Jakarta, Indonesia. *Transportation Research Record*, *1903*(1), 20–26. doi:10.3141/1903-03

Federal Transit Administration. (2006). *Applicability of Bogota's TransMilenio BRT System to the United States*. Retrieved from http://www.fta.dot.gov/documents/Bogota_Report_Final_Report_May_2006.pdf

Feng, W. (2014). *Analyses of Bus Travel Time Reliability and Transit Signal Priority at the stop to stop segment level*. Retrieved from http://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=2832&context=open_access_etds

Fox, H. (2000). *World Bank urban transport strategy review–Mass rapid transit in developing countries. Word bank, Washington DC* (p. 164). Retrieved from http://siteresources.worldbank.org/INTURBANTRANSPORT/Resources/uk_mass_transit_halcrow.pdf

Furth, P. G. (1987). Short Turning on Transit routes. Retrieved from http://www1.coe.neu.edu/~pfurth/Furth papers/1987 short_turning, Furth TRR.pdf

Furth, P. G., & Day, F. B. (1985). Transit routing and scheduling strategies for heavy demand corridors. In *64th Annual Meeting of the Transportation Research Board*. Retrieved from http://trid.trb.org/view.aspx?id=271167

Furth, P., & Rahbee, A. (2000). Optimal bus spacing through dynamic programming and geographic modelling. *World Transit Research*. Retrieved from http://www.worldtransitresearch.info/research/1057

Hidalgo, D., & Graftiaux, P. (2006). A critical look at majo bus improvements in Latin America and Asia: Case study TransMilenio, Bogota, Colombia. Retrieved from http://siteresources.worldbank.org/INTURBANTRANSPORT/Resources/Hidalgo-Graftieaux-BOGOTA.pdf

Hoback, A., Anderson, S., & Dutta, U. (2008). True Walking Distance to Transit. *Transportation Planning and Technology*, *31*(6), 681–692. doi:10.1080/03081060802492785

Hook, W. (2008). Bus Rapid Transit : An International View. In *Bus Rapid Transit: An International View*. Bronx, New York.

Human Transit: basics: walking distance to transit. (n.d.). Retrieved December 30, 2014, from http://www.humantransit.org/2011/04/basics-walking-distance-to-transit.html

Indonesia's urban studies: The Megacity of Jakarta: Problems, Challenges and Planning Efforts. (n.d.). Retrieved December 25, 2014, from http://indonesiaurbanstudies.blogspot.nl/2014/03/the-megacity-of-jakarta-problems.html

ITDP. (2013). *Evaluation of direct service pilot project in Jakarta*. Jakarta. Retrieved from http://toolkits.reeep.org/file_upload/12450_tmpphpps7g2e.pdf

Janić, M. (2014). Advanced Transport Systems (pp. 11–81). London: Springer London. doi:10.1007/978-1-4471-6287-2

Joewono, T. B., Santoso, D. S., & Ningtyas, D. U. (2012). The causal relationship of the service quality of the TransJakarta Busway. *Public Transport*, *4*(2), 77–100. doi:10.1007/s12469-012-0053-5

Khan, O. A., Ferreira, L., Bunker, J. M., & Parajuli, P. (2007). Analysing the degree of mode captivity in a multi-modal travel behaviour using stated preference data. Retrieved from http://eprints.qut.edu.au/9108/1/9108.pdf

Lam, W., & Morrall, J. (n.d.). Bus passenger walking distances and waiting times: A summer and winter comparison. In *RTAC Annual Conference Preprints* (Vol. 1). Retrieved from http://trid.trb.org/view.aspx?id=174504

Larrain, H. (2013). *How to design express services on a bus transit network*. Retrieved from http://www.brt.cl/webinar-how-to-design-express-services-on-a-bus-transit-network/

Leiva, C., Muñoz, J. C., Giesen, R., & Larrain, H. (2010). Design of limited-stop services for an urban bus corridor with capacity constraints. *Transportation Research Part B: Methodological*, *44*(10), 1186–1201. doi:10.1016/j.trb.2010.01.003

Levinson, H. S., Zimmerman, S., Clinger, J., & Gast, J. (2007). Bus Rapid Transit: Synthesis of Case Studies - Transportation Research Record: Journal of the Transportation Research Board - Volume 1841, Volume 1841 / 2003 Transit: Bus, Paratransit, Rural Public and Intercity Bus, New

Transportation Systems and Technol. Retrieved from http://trb.metapress.com/content/nw84g63hr7288787/

Levinson, H., Zimmerman, S., Clinger, J., Rutherford, S., Smith, R. L., Cracknell, J., & Soberman, R. (2003). Bus Rapid Transit, Volume 1: Case Studies in Bus Rapid Transit. *TCRP Report 90 , Transportation Research Board , Washington, USA*. Retrieved from http://www.nbrti.org/docs/pdf/tcrp_rpt_90v1.pdf

Madison Area Transportation Planning Board - City of Madison, Wisconsin. (n.d.). Retrieved August 17, 2014, from http://www.madisonareampo.org/

Madison BRT transit corridor study, proposed BRT travel time estimation approach. (n.d.). Retrieved August 17, 2014, from http://www.madisonareampo.org/documents/DBRTTravelTimeEstimationApproach.pdf

Miller, M. A., & Buckley, S. M. (2000). *Institutional Aspects of Bus Rapid Transit – A Macroscopic Examination*. Retrieved from http://www.path.berkeley.edu/sites/default/files/publications/PWP-2000-07.pdf

Murray, A. T., & Wu, X. (2003). Accessibility tradeoffs in public transit planning. Retrieved from ftp://131.252.97.79/Transfer/ES_Pubs/ESVal/travel_acessibility/murray_publicTransport_and_accessability.pdf

Nkurunziza, A. (2008). *Analysing Commuters ' Attitudes towards the Proposed Bus Rapid Transit System in Dar es Salaam , Tanzania : Using Stated Choice and Spatial Analysis . Analysing Commuters ' Attitudes towards the Proposed Bus Rapid Transit System in Dar es Salaam , Tanzani.*

Nkurunziza, A., Zuidgeest, M., Brussel, M., & Van den Bosch, F. (2012). Spatial variation of transit service quality preferences in Dar-es-Salaam. *Journal of Transport Geography*, *24*, 12–21. doi:10.1016/j.jtrangeo.2012.06.001

O'Sullivan, S., & Morrall, J. (1996). Walking Distances to and from Light-Rail Transit Stations - Transportation Research Record: Journal of the Transportation Research Board - Volume 1538, Volume 1538 / 1996 Pedestrian and Bicycle Research - Transportation Research Board of the National Acad. Retrieved from http://trb.metapress.com/content/b6376861r3854876/

Pen˜a, F. J., Jime´nez, A., & Mateos, A. (2013). A First Approach to the Optimization of Bogota´'s TransMilenio BRT System. Retrieved from http://oa.upm.es/26130/1/26130jimenez_INVE_MEM_2013.pdf(1).pdf

Pineda, A. F. alderrama. (2011). The map of TransMilenio, representation, System, and City. Retrieved from http://www.dasts.dk/wp-content/uploads/Andres-Valderrama-2011-The-Map-of-Transmilenio.pdf

Public Transport in Jakarta - (Indonesia). (n.d.). Retrieved January 26, 2015, from http://jakarta.angloinfo.com/information/transport/public-transport/city-transport/

Rogat, J., Hinostroza, M., & Ernest, K. (2009). Promoting Sustainable Transport in Latin America through Mass Transit Technologies (pp. 83–92). Algeria. Retrieved from http://inrets.fr/ur/lte/lesseminaires/ghardaia09/pdf/Ernest.pdf

Satiennam, T., Fukuda, A., & OShima, R. (2006). A study on the introduction of bus rapid transit system in Asian developing cities- A case study on Bangkok metropolitan administration Project. Retrieved from http://www.iatss.or.jp/common/pdf/en/publication/iatss-research/30-2-06.pdf

Schwarcz, S. (1998). *Service design for heavy demand corridors: Limited stop services*. Massachusetts Institute of Technology. Retrieved from https://www.google.nl/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=brt levinson

Sihombing, R. (2009). Travel time optimalization of TransJakarta buses corridor 1 Block M Kota based on cycle traffic light information. Jawa Timur. Retrieved from http://www.indii.co.id/news_daily_detail.php?id=6427

Silverman, N. C. (1998). Limited stop bus service at New York city transit. *Journal of Transportation Engineering*, *124*(6). Retrieved from http://trid.trb.org/view.aspx?id=542636

Sreedharan, S. (2013). Public Transportation. Retrieved July 30, 2014, from http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-Dynamic-Transport-Solution-PoV.pdf

Statistics Indonesia. (2010). *Statistics DKI Jakarta Provincial Office*. Retrieved from http://dds2.bps.go.id/eng/publications/publikasi2011.php

Susantono, B. (1998). Transportation Land Use Dynamics in Metropolitan Jakarta. *Berkeley Planning Journal*, *12*(1). Retrieved from https://escholarship.org/uc/item/2g41499w#page-2

Susilo, Y. O., Santosa, W., Joewono, Tr. B., & Parikesit, D. (2007). A reflection of motorization and public transport in Jakarta and metropolitan area. Retrieved from http://swqxwd103.secure.ne.jp/common/pdf/en/publication/iatss-research/31-1-06.pdf

Tétreault, P. R., & El-Geneidy, A. M. (2010). Estimating bus run times for new limited-stop service using archived AVL and APC data. *Transportation Research Part A: Policy and Practice*, *44*(6), 390–402. doi:10.1016/j.tra.2010.03.009

Tirachini, A. (2013). Estimation of travel time and the benefits of upgrading the fare payment technology in urban bus services. *Transportation Research Part C: Emerging Technologies*, *30*, 239–256. doi:10.1016/j.trc.2011.11.007

Transjakarta Under New and Improved Management - Institute for Transportation and Development Policy. (n.d.). Retrieved December 27, 2014, from https://www.itdp.org/transjakarta-under-new-and-improved-management/

Vuchic, V. R. (2005). *Urban Transit: Operations, Planning and Economics*. Retrieved from http://books.google.nl/books/about/Urban_Transit.html?id=pw6IRAAACAAJ&pgis=1

Wachyar, Y. P. (2014). *The study of urban poor non-poor accessibility to potential job opportunities in Jakarta Metropolitan area-Indonesia.*

Waukesha, W. (1957). Report on Bus Rapid Transit between Concord and Oaklad-San Fransisco. Retrieved from http://trid.trb.org/view.aspx?id=221909

Widadi, I. (2004). *Distribution of bus stops : case study busway system of Jakarta*. University of Twente. Retrieved from http://adlib.itc.nl/detail.aspx

Wirasinghe, S. C., & Vandebona, U. (2011). Route layout analysis for express buses. *Transportation Research Part C: Emerging Technologies*, *19*(2), 374–385. doi:10.1016/j.trc.2010.05.021

Wismadi, A., Soemadjito, J., & Sutomo, H. (2013). *Transport Situation in Jakarta* (pp. 29–58). doi:http://www.eria.org/RPR_FY2012_No.29_Chapter_4.pdf

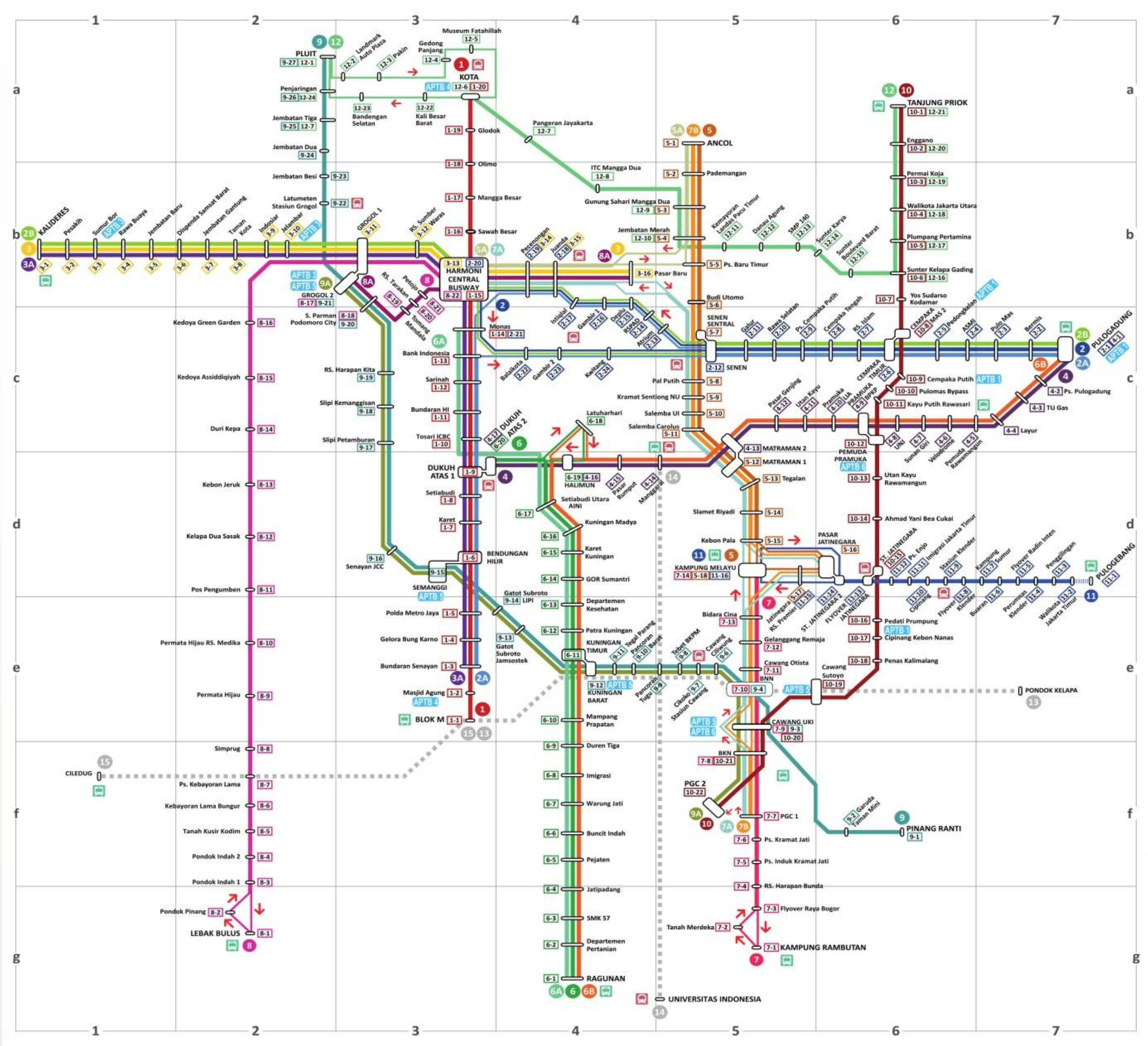
Wright, L. (2002). *Bus rapid transit*. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). Retrieved from http://discovery.ucl.ac.uk/112/1/BRT_e-book.pdf

Yagi, S., Nobel, D., & Kawaguchi, H. (2014). Time-Series Comparison of Auto/Motorcycle Ownership and Joint Mode and Destination Choice Models Based on Two Large-Scale Surveys in Jakarta. *Asian Transport Studies*, 46. doi:10.11175/eastsats.3.46

Yunita, R. (2008). TransJakarta: Putting on Lipstick While Running to Catch the Bus. *Sustainable Transport*, (20). Retrieved from http://trid.trb.org/view.aspx?id=883705

APPENDIX A

CURRENT TRANSJAKARTA MAP



APPENDIX B CROSS TAB ANALYSIS SAMPLE (BETWEEN TRANSFER, AND STOPS ON CORRIDOR 3)

			T3812		
			0	1	Total
O_stop	1	Count	94	41	135
		% within O_stop	69.6%	30.4%	100.0%
		% within T3812	56.0%	80.4%	61.6%
	2	Count	24	5	29
		% within O_stop	82.8%	17.2%	100.0%
		% within T3812	14.3%	9.8%	13.2%
	3	Count	5	1	6
		% within O_stop	83.3%	16.7%	100.0%
		% within T3812	3.0%	2.0%	2.7%
	4	Count	24	1	25
		% within O_stop	96.0%	4.0%	100.0%
		% within T3812	14.3%	2.0%	11.4%
	5	Count	15	1	16
		% within O_stop	93.8%	6.3%	100.0%
		% within T3812	8.9%	2.0%	7.3%
	6	Count	1	1	2
		% within O_stop	50.0%	50.0%	100.0%
		% within T3812	0.6%	2.0%	0.9%
	7	Count	2	1	3
		% within O_stop	66.7%	33.3%	100.0%
		% within T3812	1.2%	2.0%	1.4%
	8	Count	1	0	1
		% within O_stop	100.0%	0.0%	100.0%
		% within T3812	0.6%	0.0%	0.5%
	12	Count	1	0	1
		% within O_stop	100.0%	0.0%	100.0%
		% within T3812	0.6%	0.0%	0.5%
	13	Count	1	0	1
		% within O_stop	100.0%	0.0%	100.0%
		% within T3812	0.6%	0.0%	0.5%
Total		Count	168	51	219
		% within O_stop	76.7%	23.3%	100.0%
		% within T3812	100.0%	100.0%	100.0%