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A Study on the Well-being of Metro Manila MRT-3 Passengers Considering Actual and Perceived Conditions

by

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A Study on the Well-being of Metro Manila MRT-3 Passengers Considering Actual and Perceived Conditions

Abstract

The Metro Manila MRT-3 is an urban rail line strategically situated along EDSA, which connects the major business districts in the metropolis. Due to a number of factors, it has been facing congestion and unreliability problems for several years now, which may lead to productivity loss, health and safety risks and psychological effects for passengers.

This research study aims to investigate how the MRT-3 commute affects passenger well-being, and examine the factors that explain why people still continue to use it in spite of its negative conditions. It clarified the extent of the problem in terms of actual conditions on level of service and air quality, and passenger perception on commuting and its effects by employing various data collection methods, including observation surveys, $PM_{2.5}$ particle count monitoring survey and a questionnaire survey on commute characteristics and perception. It explored the role of mental adaptation on moderating the effects of commuting on passenger satisfaction and commuting stress. It also developed an evaluation framework for prospective countermeasures that considers actual and perceived conditions and how they impact passenger satisfaction.

In Chapter 3, an analysis of the level of service at the MRT-3 showed that passenger waiting time has become long and variable at the roadside and platform as a result of a combination of operations policies, poor schedule adherence and excessive passenger demand, with some stations incurring longer waiting times that others. A comparison of travel times between MRT-3, ordinary buses and air-conditioned buses also revealed that the MRT-3 is the fastest among them in spite of the long waiting time.

Chapter 4 tackled the air pollution problem in MRT-3 and buses along EDSA by investigating on passengers' $PM_{2.5}$ exposure while commuting. $PM_{2.5}$ particle counts were measured inside different public transport modes and MRT-3 stations over a 20-day period to determine the extent of the pollution problem and conduct comparisons between them. An intra-modal comparison of $PM_{2.5}$ particle count between five MRT-3 stations revealed that passengers are exposed to moderate to unhealthy levels of $PM_{2.5}$ while waiting at the roadside and platform of stations, with one station having significantly higher concentrations than the others. Moreover,

an intermodal comparison of $PM_{2.5}$ particle counts between MRT-3, ordinary bus and air-conditioned bus found that MRT-3 has the lowest $PM_{2.5}$ exposure if only in-vehicle time and concentrations inside the train are considered. However, the overall $PM_{2.5}$ exposure is increased if waiting time at the station is included in the comparison, making the levels at MRT-3 to be slightly higher than air-conditioned bus levels. This implies that passenger waiting time at the MRT-3 station should be reduced to lessen exposure time.

Chapter 5 investigated passenger perception on various service quality attributes and commute-related constructs and how they relate to each other. Nine latent factors were found to relate to passengers' commute – exogenous factors (commuting experience): perceived crowding, predictability, perceived air quality and perceived benefits; and endogenous factors (mediators and outcome): perceived risk, perceived service quality, awareness during the commute, mental adaptation and commuting stress. The model that explains the relationships between these factors was developed using structural equation modeling, where it was found that mental adaptation plays a role in reducing commuting stress, which could partly explain why passengers endure their negative commutes every day.

In Chapter 6, the results in the previous chapters about actual and perceived conditions were synthesized to aid in identifying appropriate countermeasures and to conduct an overall discussion on passenger well-being and equity. A new evaluation framework for assessing the impacts of these countermeasures was developed using a waiting time simulation model and a passenger satisfaction model, with aggregated passenger satisfaction as an original evaluation index. Explanatory variables for the passenger satisfaction model include actual and perceived variables, with mental adaptation as a control variable. Moreover, a dynamic waiting time simulation model that captures the characteristics of MRT-3 was used to estimate how such countermeasures would affect waiting time. A sensitivity analysis was conducted to estimate how the aggregated passenger satisfaction index changes by varying some explanatory variables. It was found that increasing vehicle capacity by 25% while controlling headway regularity and passenger density would drastically reduce waiting times, and subsequently increases passenger satisfaction. Combining all the countermeasures would increase neutral and positive ratings from around 40% to 80%. This highlights the importance of investing in hard infrastructure to increase the capacity as well as considering perceived conditions to improve passenger satisfaction.

Having constrained the definition of well-being to actual and perceived commuting impacts only, passengers were generally found to have poor well-being as a result of their MRT-3 commute. It was found that many passengers suffer long and variable waiting time, frequent tardiness at work, but have various levels of commuting stress and passenger satisfaction depending on their adaptation level. This research study contributes to the growing field of commuting and well-being research, and gives a unique insight on how to approach the congestion problem in a developing megacity.

In loving memory of my mother, Liza Paclibar Sehob

(July 27, 1955 – January 19, 2015)

ACKNOWLEDGEMENT

"Waiting is a form of imprisonment. One is doing time-but why? One is being punished not for an offense of one's own but for the inefficiencies of those who impose the wait. Hence the peculiar rage that waits engender, the sense of injustice. Aside from boredom and physical discomfort, the subtler misery of waiting is the knowledge that one's most precious resource, time, a fraction of one's life, is being stolen away, irrecoverably lost. ... Waiting can seem an interval of non-being, the black space between events and the outcomes of desires. It makes time maddeningly elastic, it has a way of seeming to compact eternity into a few hours" (Morrow, 1984).

My fascination with Metro Manila MRT-3 stemmed out when I was commuting daily from home to work almost seven years ago. Waiting for a long and unpredictable time for the train at one of the middle MRT-3 stations and enduring heavy road traffic was becoming unbearable, so I felt that I had to do something to improve the situation. Fortunately, I was granted the opportunity to pursue graduate studies in Tokyo, which I look up to for its efficient urban transport system. Living in this city, and observing and experiencing first-hand how the system works has widened my knowledge and given me valuable insight on how to address the problem in my home country.

This research would not have been possible without the help and encouragement of many people. Most of all, I am very thankful to my adviser, Professor Tetsuo Yai, for his guidance, continuous support and valuable advice. I am fortunate that we share similar interest in this research topic. He urged me to examine the problem from many different angles to make my work original and more useful. I am also grateful to Assistant Professor Mio Suzuki for her suggestions to improve my research especially in terms of data analyses.

I would also like to express my gratitude to the Transport Studies Unit (TSU) and Department of Civil Engineering professors, my fellow Doctoral students and TSU members for giving critically constructive advice and asking stimulating questions during my presentations and even informal discussions. I would like to thank my Committee members, Professor Yasuo Asakura, Associate Professor Daisuke Fukuda, Associate Professor Yasunori Muromachi and Associate Professor Jiro Takemura for pushing me to do my best and providing proper guidance to improve my work.

I am hugely indebted to the UP National Center for Transportation Studies, especially to Dr. Karl Vergel, Mr. Ivan Francis Orozco and Ms. Alorna Abao for their support in data collection and coordination, and to Dr. Regin Regidor for his advice when I was still formulating my research topic. I would also like to acknowledge the assistance of DOTC-MRT3 in providing information and allowing the surveys to be conducted, as well as MMDA and some bus companies for their support. Moreover, I would like to thank my friends, acquaintances and even strangers who distributed my questionnaire, and all the daily MRT-3 commuters who took time and effort to answer it. I have received positive feedback and inspiring compliments from some of the respondents thanking me for trying to improve their daily situation.

I would also like to recognize the Japanese government for financially supporting me through the Monbukagakusho scholarship, as well as the Tokyo Tech-Toshiba Collaborative Project for funding most of the surveys done for this research.

I would also like to thank Yai laboratory members, alumni and staff for creating a conducive environment to study and do research. I cherish the everyday moments at the laboratory, drinking parties and festivals that make research life more exciting.

I am also grateful to my alma mater, University of the Philippines-Diliman and my former professors at the Department (now Institute) of Civil Engineering, for honing my academic and social skills in my undergraduate years. I would also like to thank my former bosses and colleagues at Parsons Brinckerhoff Philippines, where I was exposed to a variety of real-life transportation projects. I sincerely thank my internship mentors at the United Nations ESCAP in Bangkok for widening my knowledge about real-world problems in transport and the bureaucratic aspect of project implementation. I would like to particularly thank Dr. Madan Regmi, Mr. Peter O'Neill and Ms. Jenny Yamamoto for our thought-provoking discussions about sustainable transport.

I would like to express my appreciation to my best friends and confidants, Rizza, Mike and Glenn, who remain close even if we live in different countries and rarely meet. I am grateful to Riu, who kept my sanity and happiness levels in check. My fellow students also deserve acknowledgment, especially the Filipino community at Tokyo Tech, for their friendship and support.

I would like to thank my immediate and extended family, including my father and siblings Alissa, Carlo, Angela, Yasmin and Miguel for their encouragement, love and support.

Lastly, I would like to express my sincere (albeit delayed) gratitude to my late mother who has had an enormous influence in my life, and whose recent passing has had an immeasurable impact. Thank you for inspiring me to pursue my dreams and having encouraged me to be independent. I wish I could have gone home more often. This is for you.

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1. Introduction

1.1. Overview of Metro Manila's MRT-3 and Its Challenges

Metro Manila is the chief metropolitan area and center of culture, economy, education, and government in the Philippines, and is composed of 16 cities and municipalities. With roughly 12 million inhabitants and a daytime population of 14.5 million due to in-migration of workers and employees from neighboring provinces and an area of 636 sq. km., it is the most populous and most densely populated region in the country.

Developing megacities such as Metro Manila are facing significant challenges due to rapid motorization (International Energy Agency, 2012) and deteriorating public transport systems, and the situation is expected to worsen as urban population continues to increase. These growing problems are a barrier to both economic and social inclusion, and have negative impacts on health and the environment (UN-HABITAT, 2013).

Similar to other metropolitan areas in developing countries, two emerging urban patterns can be observed in Metro Manila (Soehodho *et al.,* 2005), as illustrated in Figure 1.1. The first is sub-urbanization, which has led to the increase in the number of person-trips and trip distances, causing severe traffic congestion. The second pattern is the proliferation of informal settlers in the city centers as well as the establishments of big commercial centers along EDSA and other major corridors planned and ongoing relocation to far-flung areas i.e. poor accessibility to employment. These patterns lead to an increased demand for urban transportation facilities and services. Moreover, this may lead to social exclusion if not adequately addressed.

As a result, Metro Manila is lagging behind urban mobility in comparison to other cities. For instance, it ranked 64th out of 66 major cities worldwide in a comprehensive study on urban mobility, just below Bangkok and Jakarta (Arthur D. Little, 2011). The study assessed each city based on 11 indicators on mobility maturity and performance, including share of public transport and non-motorized modes, average speed of all modes, average travel time to work and transport CO_2 emissions. Metro Manila was classified as 'public, large and emerging' characterized by underdeveloped mobility and increasing car ownership, similar to Beijing and many Southeast Asian, Indian and African cities. A subsequent study (Arthur D. Little, 2014) saw its rank increase to 43rd out of 84 cities due to an expansion of criteria, but still slightly below the average score.

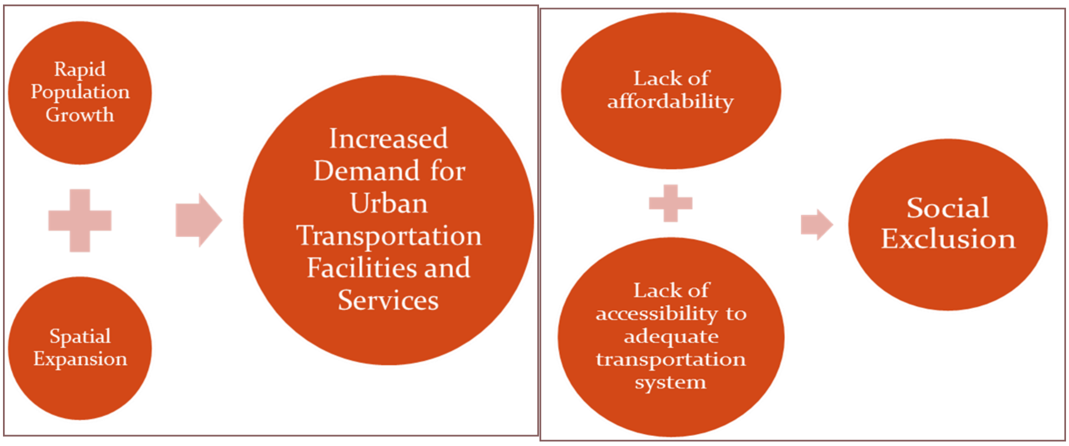


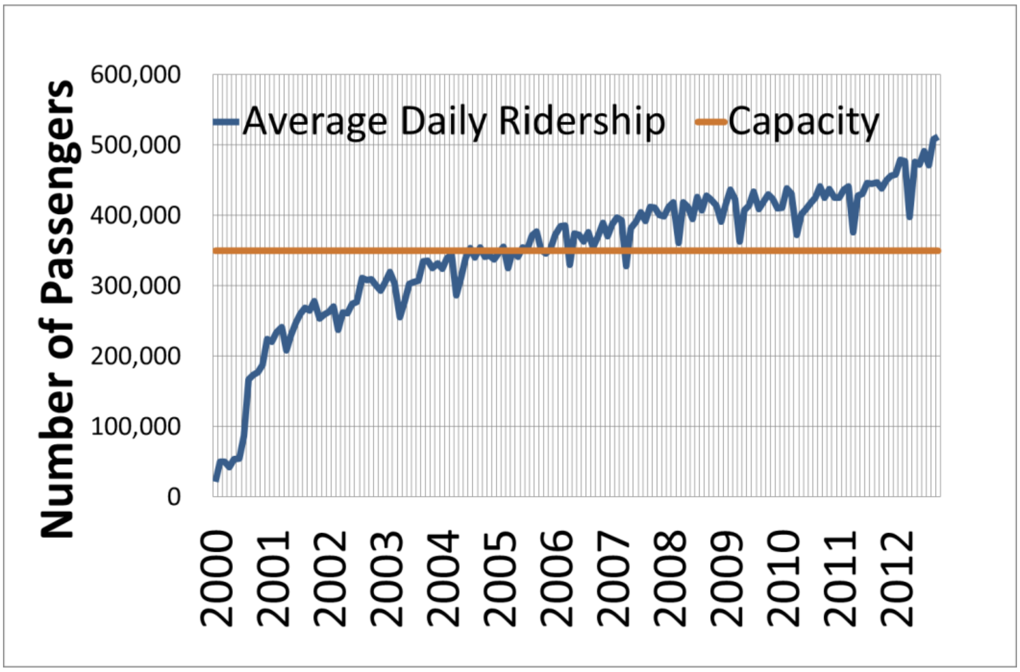
Figure 1.1. Emerging patterns and their effects in Metro Manila

Commuting during the morning rush hour is an inevitable task for many Metro Manila commuters, around 80% of which rely on public transport modes (Parikesit and Susantono, 2012). Given the predominant urban and land-use patterns previously described and heavy congestion in the public transport systems and roads, commutes are typically long, inconvenient, crowded and unreliable. While the present modal share of public transport is substantial, it is likely to decrease as people grow increasingly dissatisfied with poor public transport and as private modes become more affordable with rising incomes. Meanwhile, those who do not have a choice to switch to private modes of transport are putting themselves at risk of negative physiological and psychological effects associated with a negative commute.

Metro Manila is served by three urban rail lines and a commuter line, as seen in Figure 1.2. Among these lines, Metro Rail Transit Line 3 (blue line), or MRT-3, is probably the most critical. This is because its entire alignment runs along EDSA, where the major central business districts and other major landmarks of the metropolis are located, and subsequently it has the highest ridership. However, its level of service has been deteriorating since 2005 when its ridership exceeded its design capacity, as seen in Figure 1.3.

modified by the author; original figure by DOTC (2012)

Figure 1.2. Existing rail network in Metro Manila



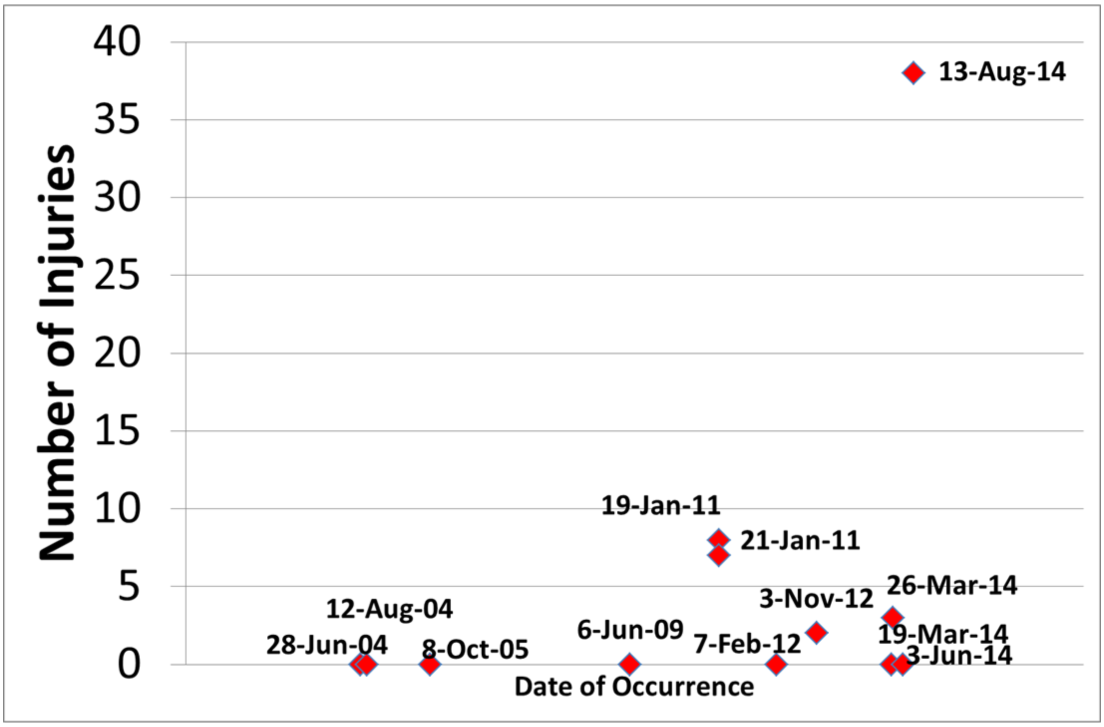
Data Source: DOTC-MRT3 (2012)

Figure 1.3. Annual ridership trend of MRT-3

This problem is multi-faceted and encompasses financial, political and institutional barriers, but it is mostly attributed to insufficient capacity with respect to passenger demand. Significant changes in infrastructure and operations to increase its capacity have not yet been implemented. Urban rail fares had also been kept constant from 2000 to 2014 amid inflation and increase of non-rail public transport fares making urban rail travel relatively cheaper, thus contributing to the increase of rail demand beyond capacity and deteriorating level of service. Even with the recently implemented fare increase in January 2015, urban rail fares are still relatively more affordable than other modes especially for longer trips.

As a result of the discrepancy between passenger demand and MRT-3 supply, many passengers spend a long time waiting at several stations during morning rush hours. The situation has become so severe that the queues have spilled out onto the roadside as the operator decided to limit the number of entering passengers onto the platform for safety and equity purposes. The trains are also packed beyond crush capacity and the passenger density reaches up to 12 passengers/sq.m. (Ebia and Ramirez, 2014).

There also have been several safety incidents in the past few years that have left several passengers injured (see Figure 1.4), with the most severe being a derailment accident in August 2014 that caused 38 injuries mostly on women, elderly and children aboard the first train car. Technical experts have pointed out that the MRT-3 system is suffering from old coaches and apparatus and that its system has not been updated since 2002 (Bondoc, 2014) and an official safety audit performed by Hong Kong MRTC in December 2014 revealed that MRT-3 has had increasing cases of broken rail and defects on facilities and equipment, which could lead to 'substantial casualties' (Arcangel, 2014).



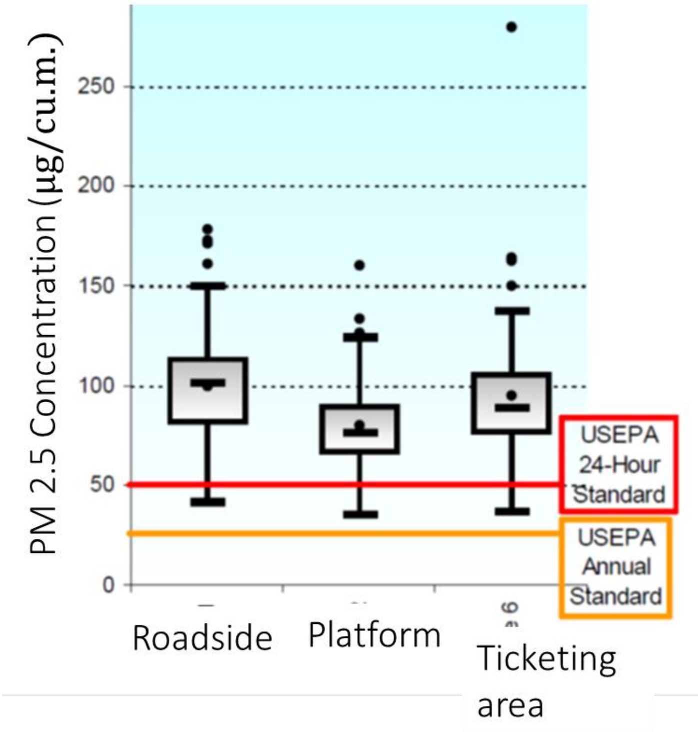
Data Source: Santos Jr., 2014

Figure 1.4. Safety incidents and corresponding injuries at the MRT-3

In spite of this, it is still relatively safer (at least statistically) than other road-based modes. According to official figures by Metropolitan Manila Development Authority, there is an average of 248 road accidents daily in Metro Manila (Medina, 2015), of which at least one is fatal (Frialde, 2014). For instance, there were 2,876 vehicles involved in road accidents in September 2014, with the most common vehicle type being private sedans (800), followed by buses (297), vans (280), trucks (271), taxis (257), sports utility vehicles (251), Asian utility vehicles (196) and passenger jeepneys (149). Moreover, the most accident-prone road is EDSA, where around 38% of road accidents in Metro Manila occur.

Moreover, exposure to particulate air pollution is also a matter of concern for Metro Manila dwellers, especially regular commuters. The Philippine government has recognized this concern, so it has released guidelines on PM_{10} and $PM_{2.5}$ values that are at par with international standards set by the U.S. Environmental Protection Agency (US EPA) and the World Health Organization (WHO).

While PM_{10} values in Metro Manila are regularly monitored by the government and are generally within the 24-hour guideline values, previous research suggest that $PM_{2.5}$ concentration levels are much higher than guideline values. Since the MRT-3 is located along EDSA, which has a heavy volume of vehicular traffic especially diesel buses, $PM_{2.5}$ exposure should be a major concern particularly among passengers who wait for a long time at the MRT-3. A previous research study by Simpas *et al.* (2011) of the Manila Observatory supports this hypothesis. As shown in Figure 1.5, it was found that the concentration values at the roadside, platform and ticketing area at one of the stations at MRT-3 (Guadalupe Station) are above the US EPA 24-hour and annual standards.



Source: Simpas et al., 2011

Figure 1.5. $PM_{2.5}$ concentration levels at MRT-3 Guadalupe Station

Several measures have been taken by the government to address air quality management, such as setting emission standards for mobile and stationary sources, anti-smoke belching campaigns, phasing out of leaded gasoline and establishment of $PM_{2.5}$ guideline values. However, other measures should also be implemented, such as the promotion of low emission vehicles, improvement and expansion of the public transport system and better traffic management (Villarin *et al.*, 2014).

1.2. Possible Explanations for Continuous Usage

Previous research has shown that the Philippines' unsustainable transport systems are associated with lost man-hours, additional fuel consumption, health costs and lost investment opportunities – estimated to account for PhP 140 billion in Metro Manila alone, or roughly 2% of the country's GDP in 2008 (NCTS, 2011). Particularly in Metro Manila MRT-3, passengers experience long and unpredictable waiting time and overcrowded conditions, which likely lead to lost productivity and opportunity cost, stress and anxiety, exposure to harmful levels of $PM_{2.5}$, and potential endangerment due to excessive crowding and outdated infrastructure. The potentially stressful and dangerous situation in Metro Manila MRT-3 is undoubtedly unacceptable were it to happen in more developed megacities such as Tokyo.

Table 1.1. Comparison of common travel modes along EDSA

Travel Mode	Travel Time	Waiting Time	Cost	Safety	Air Pollution	Space efficiency
MRT-3	Low	High	Low	Statistically safer; High incidence of minor crime	Negligible cause / Moderate to high exposure	High occupancy (~1,200 pax/veh); exclusive ROW
Ordinary Bus	High	Low	Low (but more expensive than MRT-3)	High accident rate; High incidence of minor crime	Main cause / High exposure	Medium occupancy (~50 pax/veh); 13% of vehicular traffic
Air-conditioned bus			Low (but more expensive than ordinary bus and MRT-3)		Main cause / Moderate to high exposure	
Car	Medium	N/A	High	Moderate accident rate; Low incidence of minor crime	Minor cause / Low exposure	Low occupancy (~1.8 pax/veh); 70% of vehicular traffic

It may seem puzzling as to why commuters put up with such conditions every day. A possible explanation could be MRT-3's relative superiority to other modes in terms of affordability, travel time and accessibility. To illustrate, Table 1.1 summarizes a comparison between common travel modes used along EDSA (which is Metro Manila's most critical carriageway and the location of MRT-3's alignment). For commuters who are more sensitive to monetary costs, MRT-3 is the most attractive because it is the cheapest mode among the three[1].

Another possible explanation is a psychological phenomenon called mental adaptation, which would imply that MRT-3 commuters may have become accustomed to using it daily and have changed their way of thinking about their commuting experience, which helps reduce the negative psychological effects of the commute. In the same vein, some researchers have found that travel mode choice also depends on psychological factors such as beliefs, attitudes, and habit rather than just the objective service level of the transportation system. (Fishbein & Ajzen 1975; Fujii and Kitamura, 2003). This is examined and discussed in further detail in Chapter 5.

Taking these into consideration, it is hypothesized that Metro Manila MRT-3 commuters choose to use MRT-3 because of its relatively better service quality in spite of the problems described, as outlined in Table 1.1, as well as psychological factors such as adaptation. In other words, MRT-3 commuters can be said to be captive in two ways: physical or forced captivity due to situational constraints, and attitudinal captivity due to behavior.

Thus in this research, the perception-based approach is deemed to be more appropriate given the situation in Metro Manila MRT-3 wherein morning peak commuters are assumed to have exhausted behavioral options to improve their situation, and that their only option left is to change their way of thinking about their commute. This assumption is confirmed in Chapter 5 and revisited in Chapter 6. It is assumed in this study that the decision to use the MRT-3 has already occurred so travel choice behavior, which is usually addressed in traditional approaches, is irrelevant. This approach considers experienced utility ('utility as a hedonic experience') over decision utility in evaluating countermeasures, which has recently been revived in policy appraisal studies as it could address some shortcomings associated with the traditional approach (Kahneman and Sugden, 2005).

1.3. Passenger Well-being

The term 'well-being' (also referred to as 'welfare') is a general term for the condition of an individual or group. It is most usefully thought of as the dynamic process that gives people a sense of how their lives are going, through the interaction between their circumstances, activities and psychological resources or 'mental capital', and is measured using a

[1] MRT-3 increased its fares in January 2015, but majority of the data collection surveys conducted for this research study was conducted before it was implemented. As of present, MRT-3 is the cheapest mode for most distances traveled, but ordinary bus is slightly cheaper for up to 8 km of travel.

combination of objective and subjective factors (UK National Accounts of Wellbeing, n.d.). High well-being would imply that the individual's experience is positive, while low well-being is associated with negative happenings.

Defining passenger well-being can be a daunting task, given that well-being itself has taken on various definitions ranging from the vague to the overly broad (Forgeard *et al.*, 2011). Dodge *et al.* (2012) point out that while well-being is a growing area of research, the question of how it should be defined remains unanswered.

There are several ways in which well-being is tackled in commuting literature. One is subjective well-being, refers to overall life satisfaction and how commuting and other related activities (e.g. in-vehicle activities, out-of-home activities) affect it. However, this definition encompasses many factors, and the effect of commuting may be difficult to isolate. Furthermore, a narrower definition of well-being is also being used in commuting literature, which focuses on daily work commute and how it affects satisfaction with the commute. This is referred to by Abou-Zeid (2009) as travel well-being, by Abou-Zeid and Ben-Akiva (2011) as commute well-being, and by Ettema *et al.* (2011) as satisfaction with travel (STS). Another approach to well-being research is through examining commuting stress. Novaco and Gonzalez (2008) conducted a comprehensive literature review on commuting and well-being, which essentially tackles how commuting stress due to a negative commute affects physical health and psychological adjustment.

Taking these into consideration, passenger well-being in this research's context refers to the state of an individual measured by the actual and perceived effects of MRT-3 commuting, and is concerned with how commuting affects passenger satisfaction and commuting stress, as well as potential health and safety risks and productivity loss. Furthermore, it implies that there is concern for the predicament of commuting and its effects on equity, and it captures the research's focus on passengers. Well-being is measured implicitly using actual and subjective measures including waiting time, travel time, $PM_{2.5}$ exposure, risk perception, commuting stress and satisfaction. However, the spillover effects of MRT-3 commute on overall quality of life are not discussed, unlike the concept of well-being that many researches usually imply.

1.4. Research Objectives and Thesis Outline

It is imperative to evaluate the commuting experience and its effects from the MRT-3 passengers' perspective because they are the direct users of the service. Aside from establishing the extent of the problem by measuring the actual level of service and $PM_{2.5}$ exposure, investigating how the conditions at the MRT-3 are perceived by its users would allow evaluation of psychological impacts, understanding their behavior and identification of countermeasures that would reduce their dissatisfaction with the service. In addition, only a few researches have been done on the effects of everyday commuting on commuters (Kluger, 1998; Lucas and Heady, 2002) and no formal studies have been conducted specific to Metro Manila MRT-3 commuters.

These points are taken into consideration in drafting the overall objectives of this research. In general, this research study aims to investigate how the MRT-3 commute affects passenger well-being, and examine the factors that explain why people still continue to use it in spite of its negative conditions. First, it seeks to clarify the extent of the problem in terms of actual conditions on level of service and air quality, and passenger perception on commuting and its effects by employing various data collection methods, including observation surveys, $PM_{2.5}$ particle count monitoring survey and a questionnaire survey on commute characteristics and perception. It also explores the role of mental adaptation on moderating the effects of commuting on passenger satisfaction and commuting stress. In addition, it intends to identify and evaluate prospective countermeasures that improve the situation by developing an original evaluation framework that considers the actual and perceived conditions and passenger satisfaction.

The overall thesis structure is given in Figure 1.7. The contents and specific objectives of each chapter are as follows:

Chapter 1 includes background information about the Metro Manila MRT-3 as well as the motivation to conduct the research.

Chapter 2 summarizes relevant studies and identifies research gaps that are addressed in the research study. This includes literature on commuting and passenger well-being, level of service, air quality, and passenger perception in the context of urban rail and other public transport modes, as well as previous studies on MRT-3.

Chapter 3 presents a clear picture of the current conditions with focus on passenger experience. Waiting time and its variability, queue length, in-vehicle travel time, feeder time, train frequency, passenger density, and passenger behavior are recorded through a variety of survey methods. Ridership trends are also examined and linked to the fare policy. Moreover, this chapter outlines policies implemented by the MRT-3 management and their impact on the service quality attributes experienced by the passengers.

Chapter 4 assesses the air quality problem by making comparisons of $PM_{2.5}$ exposure while waiting at the roadside and platform at several MRT-3 stations, and while riding the MRT-3, and air-conditioned and ordinary buses along EDSA. These intra-modal and intermodal comparisons take $PM_{2.5}$ exposure to be a combination of $PM_{2.5}$ particle levels, and exposure time, which is equivalent to waiting time and in-vehicle time measured in Chapter 3.

Chapter 5 aims to understand the perceived effects of the congestion and unreliability problem on the users of the system. Passenger perception is revealed using social survey techniques, and structural equation modeling is used to test the hypothesized model. Objective and latent constructs that are relevant to commuting using the MRT-3 are proposed and defined. The actual conditions presented in Chapters 3 and 4 are compared to passenger perception to determine whether there are gaps between actual and perceived conditions. Moreover, a model that explains the mechanism of how actual and perceived attributes affect commuting stress through several mediating constructs is developed and tested to attempt to explain why passengers still use the seemingly bad service in spite of long waiting time, crowding and safety concerns.

Chapter 6 identifies appropriate countermeasures to improve the situation. It proposes an evaluation framework that factors in passenger satisfaction as a way to measure the impacts brought about by the countermeasures. It also synthesizes the results of the previous chapters and conducts an overall discussion on passenger well-being and equity.

Chapter 7 summarizes and concludes this dissertation, and outlines recommendations and direction for future research.

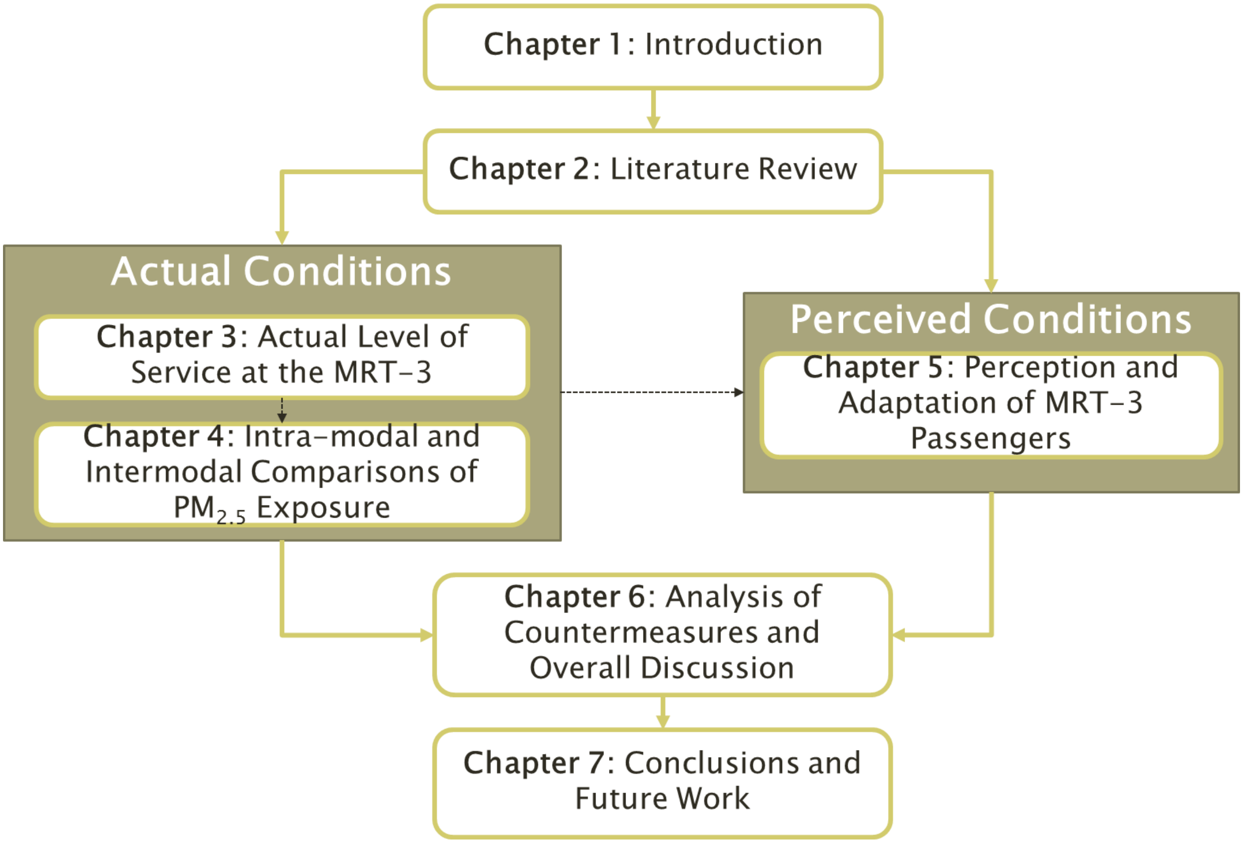


Figure 1.6. Overall thesis structure

1.5. Framework for MRT-3 Commute and Passenger Well-being

Figure 1.7 shows the conceptual framework considered in this study, which highlights the relationships between supply and demand, passenger perception and characteristics and external factors. As a supporting figure for Figure 1.6, it also shows the scope of each chapter as indicated by the broken lines.

There are many factors at play that shape the constructs presented in the Figure 1.7, but only the ones explicitly tackled in this research are included in the figure. Chapter 3 establishes the actual conditions in Metro Manila MRT-3 in terms of level of service by describing the supply characteristics, passenger demand, fare levels, waiting time, in-vehicle travel time and passenger density. Chapter 4 investigates on the $PM_{2.5}$ exposure at the MRT-3, ordinary bus and air-conditioned bus, which are all affected by the $PM_{2.5}$ levels along EDSA and the corresponding exposure times (in the form of travel time). The waiting time and in-vehicle time results in Chapter 3 serve as inputs to MRT-3 exposure times. Then, Chapter 5 explores the perceptions of passengers on their MRT-3 commute. The actual conditions influence passengers' perception on their MRT-3 commute to some extent, but this is moderated by individual characteristics. Moreover, a model explaining the effects of actual and perceived conditions on commuting stress is developed, with mental adaptation and individual characteristics as moderators. Chapter 6 presents a passenger satisfaction model with both actual and perceived conditions as explanatory variables, and uses this to evaluate countermeasures. Furthermore, it contains a synthesis and overall discussion of all aspects tackled in the previous chapters.

1.6. Research Timeline

This research study was conducted during a period when MRT-3 management implemented various policy changes to operations and fare that are beyond the researcher's control. As such, the types of surveys and their respective timings were decided in response to these changes. A timeline is presented in Figure 1.8.

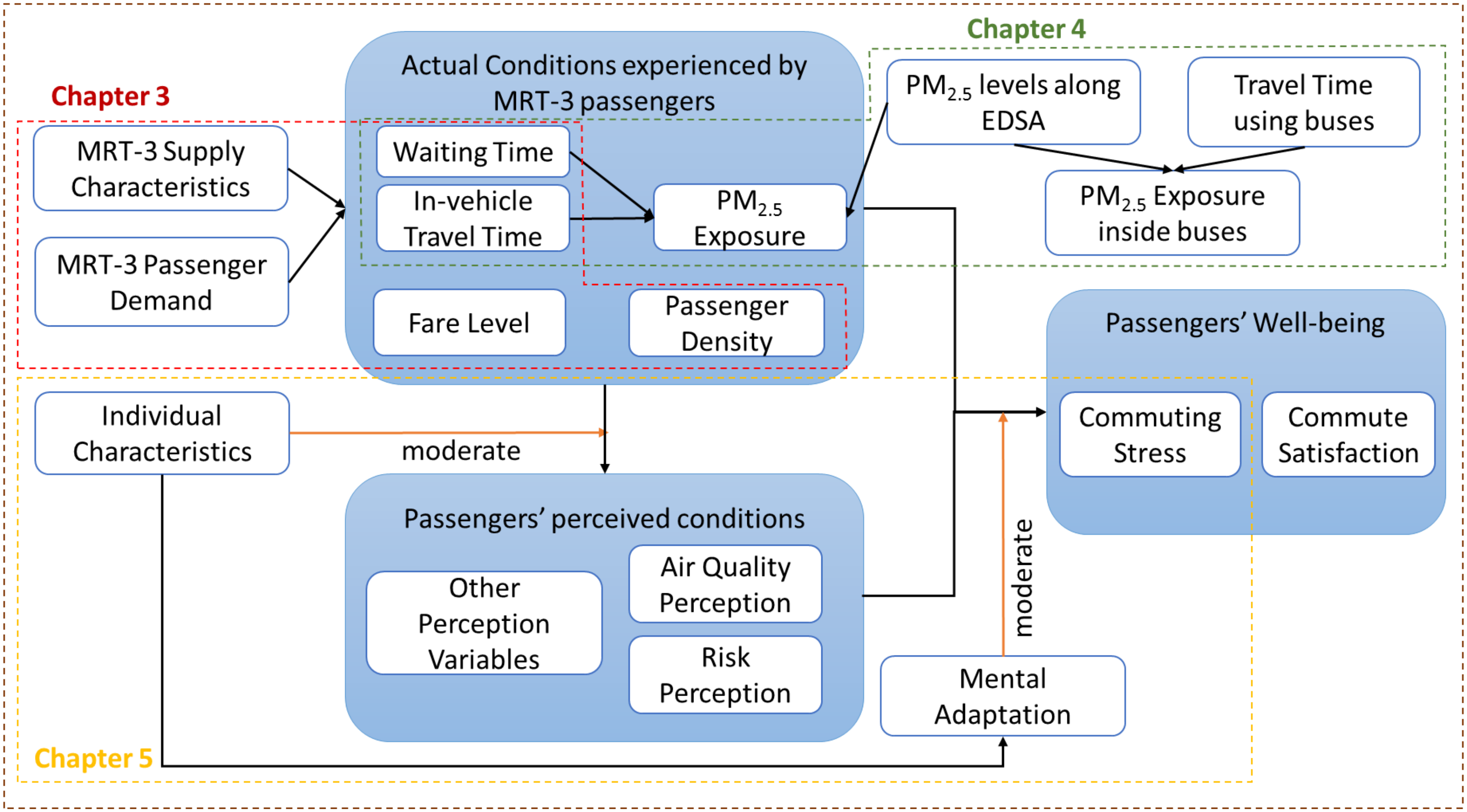


Figure 1.7. Conceptual framework

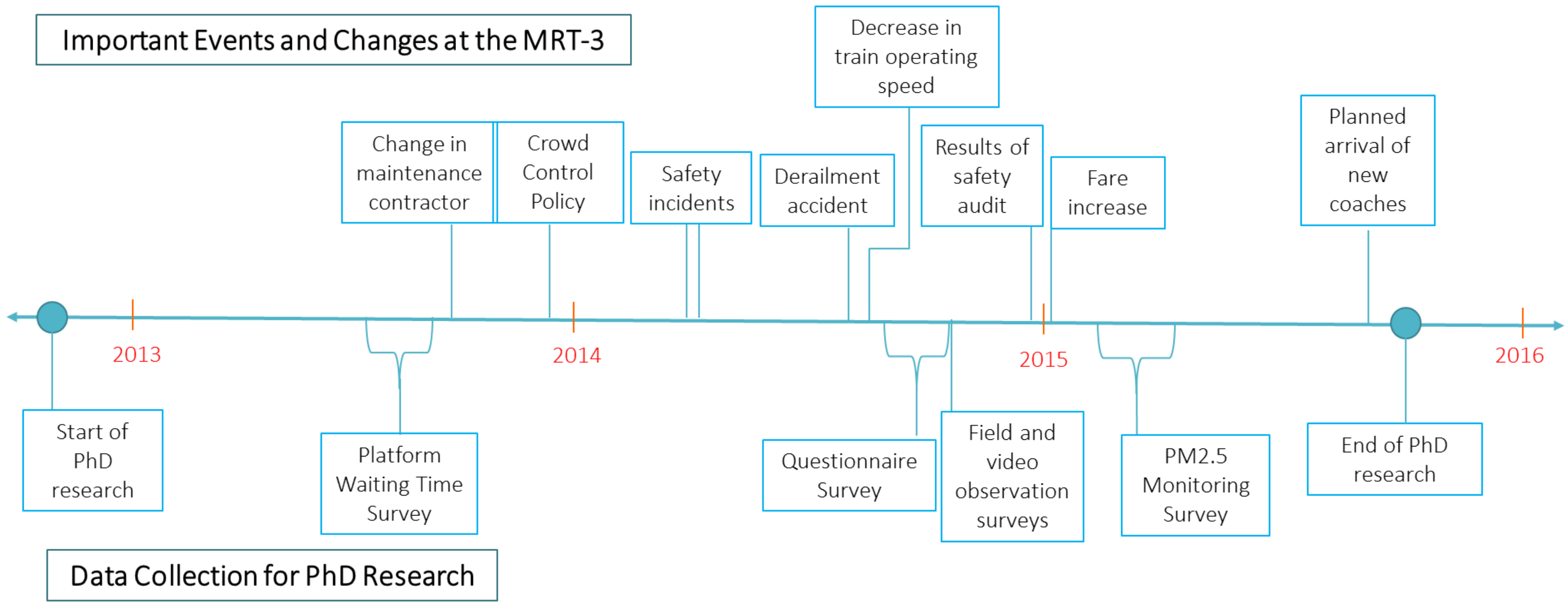


Figure 1.8. Data collection timeline and important events and changes at the MRT-3

2. Literature Review

This chapter presents a review of related literature on commuting and passenger well-being, level of service, air quality and passenger perception in the context of urban rail and other public transport modes. Previous studies on MRT-3 are also discussed.

2.1. Commuting and Passenger Well-being

In general, commuting is seen as an unhealthy, derived demand (Mokhtarian & Salomon, 2001). The effects of daily commuting on passenger well-being are highly relevant not only in health and social sciences, but also in transport and urban planning. Urban dwellers typically spend a considerable amount of time commuting every day, so it is of interest to investigate its impacts on health and psychological well-being. Kahneman *et al.* (2004) found in their study that commuting is the daily activity that generates the lowest level of positive affect, as well as a relatively high level of negative affect.

In line with this, there have been a number of studies that have focused on the relationship between commuting and passenger well-being, which was largely measured by overall well-being, commuting stress or passenger satisfaction (see Section 1.3 for more details on commuting and well-being).

2.1.1. Overall Well-being

Several studies have examined the link of commuting to overall well-being (also referred to as subjective well-being or SWB). Olsson et al (2013) identified factors that predict satisfaction with the work commute and found that it affects emotional well-being and happiness. They also found that travel mode sometimes does not directly affect satisfaction with the work commute, and mention in passing that this could be attributed to adaptation to adverse conditions. However, they did not elaborate on the effect of adaptation on this finding. Moreover, the research was conducted in Sweden, where respondents were found to be mostly positive or neutral about their commute. Mohd Mahudin (2012) wrote a dissertation about the effects of rail passenger experience on individual well-being, but she focused only on the actual and perceived crowding levels in the vehicle and not on other level of service attributes. She found that the different psychological components of crowding together with rated passenger density are predictive of commuters' stress levels and feelings of exhaustion. Stutzer and Frey (2008) pointed out that in standard economics, the burden of commuting is chosen when compensated either on the labor or on the housing market so that individuals' utility is equalized. However, they found that people with longer commuting time report systematically lower subjective well-being, implying that full compensation is not achieved. Brundell-Freij (2006) found that travel time costs tend to be higher for uncomfortable, unsafe, and stressful conditions. Choi *et al.* (2013) confirmed that commute time has a significant role on subjective well-being (SWB) in the United States. The analysis also finds a strong correlation between commute time and congestion, which suggests that effective policies to reduce congestion can be one method of improving SWB for large segments of the population.

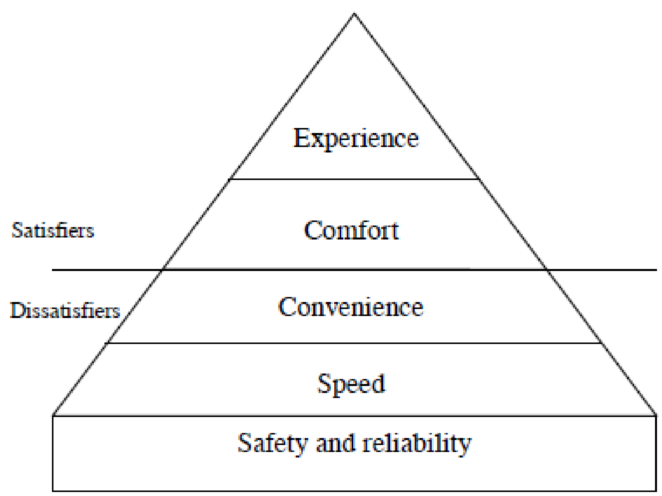
2.1.2. Commuting Stress

Studies in this field have also focused on the morning commutes and the effect of travel time, predictability and service quality indicators, personality traits, driving conditions and moderators such as gender and age on commuting stress (see Novaco and Gonzalez, 2008 for a detailed review, as well as Sections 5.2 and 5.3). Novaco *et al.* (1979) suggested the concept of commute impedance that links commuting attributes to commuting stress and it was defined as a behavioral restraint on movement or goal attainment. Objective stressors were related to physiological responses and the subjective indicators were associated with affective outcomes. Novaco *et al.* (1979, 1990) distinguished between objective impedance, a combination of time and distance between home and work, and the subjective components, obtained from self-report data requiring respondents to describe how various stimuli (traffic lights, stop signs, etc.) affected their trip to work. Koslowsky (1997) also contended that commuting stress for public transportation users have a number of factors, and can be perceived as a function of the number of stages in the commute (Taylor and Pocock, 1972), the crowded conditions of the commute (Aiello *et al.*, 1977), and the complexity of the journey to work (Knox, 1961).

2.1.3. Passenger Satisfaction

Satisfaction is a subjective construct based on the needs and expectation of the users of a service. It is also synonymous to commute well-being (Abou-Zeid and Ben-Akiva, 2011). Linking it to level of service attributes allows the identification of points to improve on as well as the value placed by passengers on such attributes in order to provide a better service, retain existing passengers and possibly attract new ones. There have been several studies that focus on creating a satisfaction model with level of service attributes as explanatory variables to achieve this purpose.

Peek and Van Hagen (2002) introduced the “pyramid of Maslow for public transport”, as seen in Figure 2.1. Similar to Maslow’s hierarchy of needs as a theory of psychology wherein the most basic needs (i.e. physiological needs) are the bottom, they propose a ranking of aspects that commuters consider for public transport. According to them, ‘dissatisfiers’ (the bottom half of the pyramid) are the requirements that should be present in public transport, otherwise commuters may become dissatisfied and stop using it altogether. On the other hand, the ‘satisfiers’ are extra service quality attributes that promote the use of public transport but are not as important as those at the base of the pyramid.



Source: Peek and Van Hagen, 2002
Figure 2.1. Pyramid of Maslow for public transport

Hensher *et al.* (2003) used a stated preference experiment and choice modelling to identify important attributes in perceiving service quality, and establish a way of measuring each attribute and identifying their relative importance in the overall calculation of satisfaction associated with existing service levels. They found that some of the attributes that are considered by passengers in measuring satisfaction are beyond the operator’s control and would need wider intervention.

Litman (2008) investigated the value transit travelers place on qualitative factors, such as comfort and convenience, which are traditionally ignored in evaluation studies in favor of quantitative factors such as price and travel time, thus undervaluing their impact. Moreover, he points out that the lack of emphasis given to service quality attributes, higher-income consumers who are willing to pay to use a high-quality public transit system may opt to use their car instead because such service is unavailable, which leads to further stigmatization of public transport, increase in car use and worse traffic problems in the society.

Fu and Xin (2007) proposed new performance index called Transit Service Indicator (TSI), which could be used as a comprehensive measure for quantifying the service quality of a transit system. TSI integrates multiple performance measures (e.g., service frequency, hours of service, route coverage, and travel time components) within a systematic framework. It takes into account spatial and temporal variations in travel demand, recognizing that quality of service is a result of interaction between supply and demand. Eboli and Mazulla (2007) used structural equation modeling to formulate to explore the impact of the relationship between global customer satisfaction and service quality attributes in bus transit, and calibrated the model using habitual bus passengers from the University of Calabria in Italy.

In the European Union, passenger satisfaction is assessed separately for stations and trains using different criteria (The Gallup Organization, 2011). Passenger satisfaction with railway stations is based on eight criteria: ease of buying tickets, provision of information about train schedules and platforms, personal security in stations, connections with other modes of public transport, car parking facilities, quality of facilities and services, cleanliness and maintenance of station facilities, and complaint handling mechanism. Meanwhile, passenger satisfaction with various features of trains is evaluated using eight criteria as well: personal security on board trains, length of time a journey was scheduled to take, comfort of seating areas, seating capacity, maintenance and cleanliness, punctuality and reliability, availability of staff on board trains, and provision of information on board trains.

A number of studies have also recently focused on commute satisfaction in developing countries, which typically have less adequate infrastructure and poorer conditions than developed ones. Ngatia *et al.* (2010) noted that commute satisfaction in Nairobi is significantly influenced by travel cost, service quality and safety. Tangphansankun *et al.* (2010) found that fare, comfort and convenience, and safety and security are main explanatory variables for commute satisfaction on Bangkok’s paratransit modes. Rahaman and Rahaman (2009) developed a model defining the relationship between overall satisfaction and service quality attributes in a rail section from Khulna to Rajshahi in southwestern zone of Bangladesh. They used factor analysis to extract significant factors from 20 service quality attributes which were rated on a 5-point Likert scale, and then regression analysis to correlate the extracted factors with satisfaction. Their findings show that overall service satisfaction depend on eight distinct service quality attributes: waiting time, spacing for moving in the train, environment inside the train, security inside the train, waiting arrangement, station information, security in the station and staff behavior.

All in all, it seems that the relationship between satisfaction and level of service attributes is highly contextual, with case studies with dissimilar characteristics yielding different results. Thus, it is important to develop a satisfaction model specific to a certain transit system or city. Fare was also not correlated with satisfaction in these studies, even though it is likely that people who find the service affordable or cost-effective (i.e. “you get what you pay for”) would be more satisfied. Control variables are also generally not included, which could explain differences in satisfaction ratings among passengers. Moreover, developing specific satisfaction models in terms of socio-economic characteristics, for example, could be useful to explain the effects of personal attributes on the valuation of service quality attributes.

In summary, commuting and well-being studies focus on three aspects: overall well-being, commute well-being or passenger satisfaction, and commuting stress. Moreover, most of these studies were conducted in developed cities, where the commuting conditions are not as severe as in Metro Manila MRT-3. A vaster approach including pollution exposure, waiting time, risk perception, fare levels, in-vehicle travel time and adaptation as predictors for commuting stress and passenger satisfaction has not been made.

2.2. Actual and Perceived Level of Service

Level of service, or service quality, in urban rail transport may be measured by a variety of attributes such as affordability, total travel time (i.e. in-vehicle travel time, waiting time, transfer time, access and egress time), headway, passenger density, service reliability, accessibility, and other more advanced measures such as information provision, marketing and promotion and connectivity with other modes. Other aspects such as comfort and image are also important, especially as higher-income people tend to place a social stigma against using public transport. Among these, the most crucial are total travel time, which is affected by other level of service attributes, and fare level, which is a main factor especially for low-income people (Van Oort, 2011).

2.2.1. Passenger Waiting Time

Total travel time has many components, such as in-vehicle time, access time, waiting time, and egress time. In general, travel time components other than in-vehicle time are valued more than it. Access time is valued 1.8-2.2 times larger than in-vehicle time (Van Der Waard, 1998; Wardman, 2001), while waiting time is valued from 1.5-3 times greater than in-vehicle time (Van Der Waard, 1998; Wardman, 2001; Mishalani *et al.*, 2006; Mohring *et al.*, 1987). Thus, passenger waiting time is a valuable component that deserves much attention in urban rail studies.

Passenger waiting time, which is one of the central points in this research study, has been well-studied. In conventional cases, the usual textbook assumption of taking half of the headway to be the average suffices when the capacity is adequate for the demand under a perfectly regular service as all passengers can always board the first vehicle. De Cea and Fernandez (1993) argue that the oversimplification of waiting time assumption is justifiable as it is impractical to go into a more complicated formulation for most purposes.

Regardless of headway regularity, the following equation can express the average waiting time, Tw_{ln}, for passengers in a scheduled service transportation systems, provided that passengers arrive in a uniform pattern and the available capacity is sufficient for the demand at any time interval (Cascetta, 2009).

$$Tw_{ln} = \frac{\theta}{\varphi_{ln}} \tag{1}$$

Where θ is equal to 0.5 if the headway is constant and equal to 1 if the headways are distributed according to a negative exponential random variable, and φ_{ln} is the available frequency for the transit line.

For longer headways such as in intercity transport services, some studies have considered that passengers arrive closer to the train departure time (e.g. Seddon and Day, 1974).

However, in congested networks, waiting time increases as the discrepancy between demand and capacity increases. It is therefore useful to forego the “sufficient capacity, constant headway” assumption and include the probability of being refused in the estimation of waiting time.

Cascetta (2009) also specified a function relating the average waiting time to the flow of users staying on board and those waiting to board a single line, such that it would account for the boarding refusal that arises from insufficient capacity. The expression is given as:

$$Tw_{ln} = \frac{\theta}{\varphi_{\ln(.)}}\left(\frac{f_{b(.)} + f_{w(.)}}{Q_{ln}}\right) \tag{2}$$

Where $\varphi_{\ln(.)}$ is the actual available frequency of line *ln* i.e. the average number of runs of the line for which there are available places, $f_{b(.)}$ is the user flow staying on board, $f_{w(.)}$ is the user flow willing to board, and Q_{ln} is the line capacity. This formula is only applicable for lines with insufficient capacity, that is, $f_{b(.)} + f_{w(.)} > Q_{ln}$. Assuming perfect service reliability would represent the outcome of the best-case scenario, as rail operation delays would worsen passenger delay due to waiting time.

The difference between equations 1 and 2 represents the extra waiting time caused by insufficient capacity. Lam *et al.* (1999a) refers to this additional waiting time as 'passenger overload delay,' which is defined as the time penalty that passengers will wait for the next coming vehicle when they cannot board the first coming vehicle because of insufficient capacity of in-vehicle links. This term has been used in subsequent studies (e.g. Wahba and Shalaby, 2005; Zhang *et al.*, 2010; Szeto *et al.*, 2011).

In congested and variable lines such as the MRT-3, passenger waiting time increases as the discrepancy between capacity and demand increases, thus it is imperative to include the probability of being refused service by the first vehicle. This has been the focus of several studies such as Lam *et al.* (1999a) and Shimamoto *et al.* (2005) which employ mathematical models to estimate it, as well as Mijares *et al.* (2013) which considers capacity constraints but with deterministic conditions. Moreover, uncertainty plays a big role in this phenomenon so it is important to capture the effects of daily random variation of the input parameters. For instance, Lam *et al.* (1999b) also used the Monte-Carlo technique to study the reliability of train dwell time at the Hong Kong MTR. Moreover, the average waiting time for an entire period lacks detail about how passenger waiting time changes according to arrival time at the station and how it propagates. It is important to consider the dynamics of the interaction between supply and demand because it has a big impact on how long the waiting time is.

It is also useful to employ the principles of queuing theory to account for the dynamics of the waiting time phenomenon and simulate waiting time. Simulation of waiting time can be done by considering the characteristics of the tracks, platforms, signals, rolling stock, and the timetable to determine capacity, as is usually employed in capacity analysis studies (see Abril *et al.*, 2008 for a detailed review), but Hansen (2000) notes that the expected track occupancy can be estimated using deterministic routes, train speeds, travel times, stop times and frequencies for design purposes. As such, modeling the details of the system characteristics is not necessary.

Hansen (2000) considered those characteristics and estimated the amount of train waiting time due to conflicting claims of routes at a station in case of delays by means of queuing theory and a max-plus algebra approach. However, he focused on waiting time delay due to train operations delay and did not consider passenger overload delay i.e. the case wherein demand exceeds capacity. Downton (1955) derived some equations to obtain the waiting time distribution for random arrivals and an arbitrary service time distribution in a bulk service queue, which is analogous to a single rail line, however only a single-server case was considered (note: a server is equivalent to a railcar door in a rail line).

It is also important to consider waiting time perception and its effects on commuters' well-being given that waiting time is generally valued higher than in-vehicle time. Osuna (1985) suggested that uncertainty is a major cause of the psychological stress associated with waiting. He defined W as a random variable for the waiting time with subjective probability distribution $F(w) = \Pr(W \leq w)$ He proposed that if an individual is not immediately served upon arriving and is uncertain about when he is going to be served, then he starts to build up stress with an intensity

$$E[H(W)|W > t] = \int_0^\infty H(u)dF^*(u) \tag{3}$$

Where $F^*(u) = \Pr(W \leq u|W > t)$ is the conditional distribution of W given that it is larger than *t*.

He also proved that the intensity of stress in a waiting situation is a non-decreasing function of the time the individual has been waiting with no further information about the time he will eventually be served.

LeClerc *et al.* (1995) found that waiting may only be coded as a loss if the wait exceeded some expected waiting time. This is analogous to Thaler's (1985) findings that spending money for routine transactions is not coded as a loss unless the price exceeds the normal or reference price. That said, it justifies the use of passenger overload delay instead of waiting time per se, indicating that passengers are indifferent to variations of waiting time as long as it does not exceed the headway, but sees it as a delay once it exceeds it (i.e. they are refused by the first train and have to wait for another). It was also found that even if waiting time is coded as a loss, losses of time are not perceived to be diminishing in value (i.e. constant absolute risk aversion).

Friman (2010) also found that overall satisfaction with public transport corresponded with the nature of the waiting time scenario, with negative waiting experiences eliciting a lower degree of overall satisfaction and worsened affective reaction among commuters.

Summing up, waiting time is estimated in many ways; models generally do not consider capacity constraints, which is unrealistic for crowded systems. Some studies have explicitly consider capacity constraints as well but usually incorporate advanced analyses such as transit assignment and operational optimization. Moreover, waiting time has been found to have psychological impacts, notably on stress and satisfaction.

2.2.2. Service Reliability

Service reliability is one of the main quality aspects of transport considered by users. Poor service reliability makes planning difficult and negatively impacts personal lives and economic efficiency. Thus, unreliability in public transport decreases its attractiveness and may drive away existing and prospective passengers.

Van Oort (2011) asserts that service reliability expresses whether the actual passenger travel experience meets the expected quality aspects such as waiting, travel time and comfort. On the other hand, variability refers to how much travel attributes change in time, and increase in variability makes travel stochastic rather than deterministic. Fillone (2005) notes that service reliability is characterized by the predictable arrival of vehicles, presence of the next mode when doing mode transfers, and non-disruption of service due to operational problems. Some studies on this area focus on the effect of congestion and variability from the viewpoint of the operator, using primary and knock-on train delays as indicators (e.g. Carey and Carville, 2000).

Following Van Oort (2011), the level of service reliability as perceived by the passenger depends on the system variability (objective) and the passenger expectation of this variability (subjective). In this sense, unreliability arises when the passenger does not receive the service that he expects. In line with this, it may be said that passengers who are accustomed to a punctual service (such as in Tokyo) may feel that the system is unreliable when the system experiences even a slight delay, but passengers who are used to a highly variable service (such as in Manila) may be more desensitized to the same amount of delay. He also notes that service reliability affects passengers in three ways: (1) extension of travel time components in-vehicle time and waiting time, (2) variability of travel time; and (3) the probability of finding a seat in the vehicle.

On the whole, reliability is defined in both objective and subjective ways in the literature. To be clear in this research, a distinction is made between subjective reliability (i.e. predictability) and objective reliability (i.e. variability).

2.2.3. Crowding

Conventionally, crowding is synonymous to passenger density. For instance, many countries with urban rail implement crowding thresholds based on the number of passengers in a certain area. An international comparison of standards is given in Table 2.1. It can be seen that the threshold for unacceptable crowding conditions vary from each country, with Asian countries generally being more tolerant towards high passenger density.

Another example of an objective measure of crowding is passengers in excess of capacity (PiXC), which is a crowding measure implemented in London for peak hour trips. It is the ratio of passengers travelling in excess of capacity on all services with respect to the total number of people travelling, and is expressed as a percentage. The current benchmarks to define the acceptable PiXC levels are 4.5% on either the morning or afternoon peak and 3.0% for both peaks (Office of Rail Regulation, 2011). Picture diagrams with easily understandable descriptions are also common measures of crowding, as seen in Figure 2.2.

Table 2.1. International comparison of crowding thresholds

Continent/Country/Company	**Planning Crowding Threshold**
Europe (UITP 2009),	4 passengers per sq.m.
Australia (Diec *et al* 2010)	4 passengers per sq.m. (normal), 1.6 passengers per sq.m. (comfortable level), 200% ratio between standing and seated

	passengers
United Kingdom	5 passengers per sq.m. (observed), 6 passengers per sq.m. (full load standing capacity)
USA (Federal Transit Authority)	4 passengers per sq.m (design load); 5 passengers per sq.m (normal); 6 passengers per sq.m. (crush load); 8 passengers per sq.m. (structural design)
Japan	4 passengers per sq.m, 8 passengers per sq.m. (crush condition)
Hitachi Monorail	4 passengers per sq.m. (normal condition); 6 passengers per sq.m. (full condition); 8 passengers per sq.m (crush condition)
China (AQSIQ 2004), Hong Kong, Philippines (DOTC, 2005)	8 passengers per sq.m.

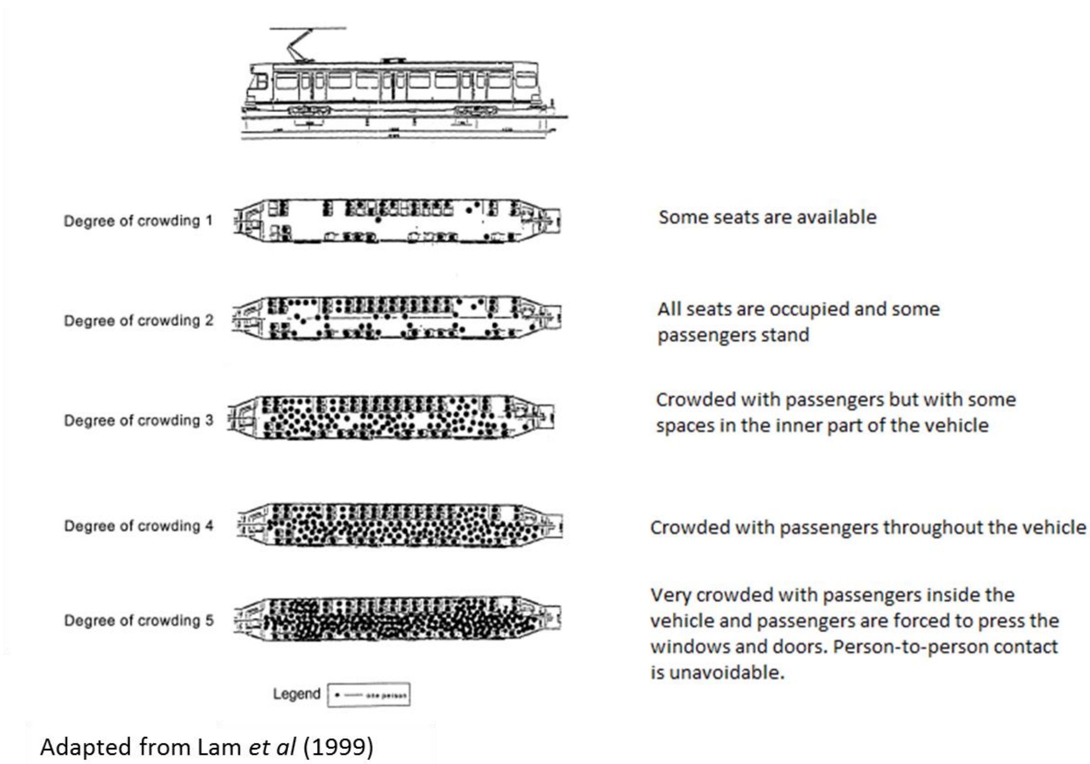


Figure 2.2. Different degrees of crowding inside the train

The differences in the indices used for objectively measuring crowding indicate that there is also a subjective aspect of crowding dependent on the comfort level and concept of personal space of the passengers. Li and Hensher (2012) conducted a literature review about subjective crowding measures in the context of passenger rail in order to understand the extent to which the (objective) standards are in line with what users perceive as acceptable levels of crowding. For instance, Cox *et al*. (2006) concluded that the perception of crowding is created from the interplay of cognitive, social and environmental factors, whereas density refers to objective physical characteristics of the situation. Evans and Lepore (1992) claimed that although perceived crowding is related to passenger density, they are not identical. Passengers' perceptions are subjective, which are influenced by many factors such as their personal characteristics and previous experience. Turner *et al*. (2004) highlighted that there are two dimensions of crowding: (1) objective: density and the available space, and (2) subjective: perceived crowding.

In Australia, Hirsch and Thompson (2011) identified eight factors that may influence the perception of rail crowding: (1) expectations based on previous travel experiences; (2) environment which includes weather (for example, perceived crowding would be overweighted in rainy conditions), and carriage such as the quality of the air conditioning system, air flow within the carriage, the presence and design of handholds for standing passengers, the seating layout and arrangement, the cleanliness of the carriage; (3) communication: poor quality of information provided to passengers would lead to increased feelings of crowding, along with frustration; (4) control/ options/ choice: the more perceived control a passenger has to make choices, the more positive view on his/her rail experience; (5) delays, identified as a primary factor influencing perceived crowding and would exaggerate the feeling of crowding; (6) risk (safety and public health), which is strongly related to the perceived cleanliness of the carriage environment, especially the holds and the seat coverings; (7) emotion: the perception and tolerance of crowding is influenced by a passenger's emotions prior to embarkation; and (8) behavior of fellow passengers (e.g., loud phone conversations, the odor of unclean passengers, noisy school children, and a general lack of etiquette) which would also exaggerate crowding.

Meyer and Dauby (2002) note that there seems to be a tradeoff between crowding and service reliability, as evident in the Japanese rail network, which has a highly effective rail system that can cope with enormous levels of demand. He argues that part of its success is attributed to passengers' willingness to accept a level of discomfort within densely packed trains when offset against the guarantee of reliable service. The evidence from the Japanese rail system implies the potential for mitigation of the effects of crowding through the assurance of predictability relating to journey characteristics.

There also seems to be a tradeoff between passenger waiting time and crowding. This was examined by Lam *et al.* (1999b) by creating a discomfort model using stated preference surveys wherein the tradeoff between the following were considered: degree of crowding (DOC2, 3 or 4) in the vehicle and additional in-vehicle travel time under DOC; and level of platform crowding (LOC2, 3 or 4) and additional on-platform waiting time under LOC1. They found that several passengers are willing to wait longer for lower crowding.

To sum up, crowding is both an objective and subjective construct described by passenger density and affective reactions to it. There are also different thresholds for crowding based on cultural nuances, with Asians generally having higher passenger density thresholds. There also tradeoffs between crowding and other level of service attributes.

2.2.4. Risk Perception

Perceived risk, or risk perception, is a concept of risk as a socially constructed attribute. Risk characteristics and individual differences have effects on shaping risk perception, as noted by Slovic *et al.* (1982, 1985) in their groundbreaking study on psychometric paradigm (see Table 2.4). This concept reflects the view that facts cannot be separated from values in policy-related science contexts.

In contrast, objective risk is a concept that risk is a physical given attribute of hazardous activities, substances or technologies, as rated by economic and technical experts and is largely based on statistical estimates of average annual fatalities. It reflects a view of scientific knowledge based on objective facts. It is commonly referred to as “correct” risk even if experts also used their judgment in determining it. A gap between the perceived risk and objective risk represents a discrepancy between what experts deem as most important and what the public demands from its government, which is highly relevant from a political standpoint especially in a democracy. A misjudgment of risk may lead to inappropriate decisions and an unsafe behavior or human error – risk perception is a critical antecedent of at-risk behavior. The link between risk perception and behavior is two-directional (Slovic, 2000).

Slovic *et al.* (1982, 1985) found that the psychometric paradigm (see Table 2.2) proved to be a good explanatory framework for laypersons' perceived risks of 81 hazards, specifically dread and lack of knowledge. However, experts' risk judgments were found to be not highly correlated with these risk characteristics; rather they are more closely correlated with technical estimates of annual average fatalities from the activities surveyed. This shows that there is a tendency for ordinary people to be more emotional rather than objective in perceiving risk

Slovic (2000) argues that risk perception varies with both the individual and the context. Individual perception of risk is not solely dependent upon the physical environment. Risk is seen as a result of what is believed to be the likely outcome, the chance of the outcome actually occurring and the level of concern if it does happen.

Table 2.2. Psychometric paradigm in risk perception (Slovic *et al*, 1982, 1985)

Risk Characteristic	**Relevant Question**
Voluntariness of risk	Do people face the risk voluntarily?
Immediacy of effect	To what is the risk of death immediate – or is death likely to occur at some later time?
Knowledge about risk	To what extent are the risks known precisely by the persons exposed to those risks?
Knowledge about risk	To what extent are the risks known precisely by scientific experts?
Newness	Is this risk level new and novel or old and familiar?
Chronic- catastrophic	Is this a risk that kills people one at a time (chronic risk) or a risk that kills large numbers of people at once (catastrophic risk)?
Common- dread	Is this a risk that people have learned to live with and think about reasonably calmly, or is it one that people have great dread for –on the level of a gut reaction?
Severity of consequences	When the risk from the activity in the form of a mishap or illness, how likely is it that the consequences might be fatal?
Control over risk	Risks can be controlled either by preventing mishaps or by reducing the severity of mishaps after they occur. To what extent can people, by personal skill or diligence, prevent mishaps or illnesses from occurring?
Control over risk	After a mishap or illness does occur, to what extent can proper action reduce the likelihood or number of fatalities?
Exposure	How many people are exposed to this risk in the (United States)?
Equity	To what extent are those who are exposed to the risks the same people as those who receive the benefits?

Future generations	To what extent does present pursuit of this activity or technology pose risks to future generations?
Personal exposure	To what extent do you believe that you are personally at risk from this activity, substance or technology?
Global catastrophe	To what extent does pursuit of this activity, substance, or technology have the potential to cause catastrophic death and destruction across the whole world?
Observability	When something bad is in the process of happening because of this activity, substance or technology, to what extent is the damage observable?
Changes in risk	Are the risks from this activity, substance or technology changing?
Ease of reduction	How easily can risks from this activity or technology be reduced?

There have been some studies that have examined risk perception in transport. Nordfjærn and Rundmo (2010) measured transport risk perception using 12 items on a seven-point Likert scale, and measured the probabilities and severity of consequences regarding transport accidents. The respondents estimated the probabilities of accidents with different modes of transportation for a person living in Norway (i.e. general risk perception as opposed to personal risk perception). The items covered both private means of transportation, such as private cars, bicycles and walking. In addition, the measure included public means of transportation, such as buses, planes and trains. The probability measures included response options ranging from (1) very unlikely to (7) very likely, whereas the measure of perceived consequences ranged from (1) certainly non-fatal to (7) certainly fatal. This instrument has shown good psychometric properties in several published studies carried out previously. They found that Norwegians have lower perceived probabilities of transport accidents in 2008 as compared to those in 2004. Moreover, the sample from 2008 also perceived higher severity of consequences regarding accidents by private and public means of transport. Worry, as well as the demand for risk mitigation and safety priorities in transport increased significantly in this period. Although not directly investigated in the study, this may imply that these variables are more correlated to severity of consequences rather than the probability of them occurring. This is the main reason why many people are against low-probability, severe-consequence technologies such as nuclear power, as these may have catastrophic potential.

To investigate the link between personality and risk perception on different modes of transport, Fyhri and Backer-Grondahl (2012) employed three-step hierarchic regression analyses with behavioral adaptations on each transport mode as dependent variables. Risk perception was measured using a 5-point Likert scale of the level of worry about accidents and unpleasant incidents, respectively.

Thomas *et al.* (2006) determined passenger perceptions of the relative safety of traveling by rail, compared to other modes of transport. They also inquired on safety preferences on factors relating to the car park and the way into the station; factors relating to railway stations and platforms; factors relating to trains and carriages, and a section on overall evaluations.

All in all, there are different ways to assess how risk is perceived. The psychometric paradigm is useful to evaluate risk perception according to risk characteristics. Moreover, for specific risks such as transport-related risks, straightforward questions on the probability and worry of a certain type of risk suffice. Aside from risk characteristics, individual characteristics also affect risk perception. Comparison with other modes is also helpful to gain insight on the relative risk perception of a certain mode.

2.2.5. Exposure to $PM_{2.5}$ while Commuting

Particulate matter, also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. It is made up of a number of components, including acids, organic chemicals, metals, and soil or dust particles. The US EPA (2008) notes that the size of particles is directly linked to their potential for causing health problems, with particles that are 10 μm in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. $PM_{2.5\text{-}10}$, or inhalable coarse particles, typically found near roadways and dusty industries, are larger than 2.5 μm and smaller than 10 μm in diameter, while $PM_{2.5}$, or fine particles, are smaller in diameter and usually found in smoke and haze, and can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

The US EPA (2008) also notes that there are a number of factors that affect the rate at which any vehicle emits air pollutants. Some of the most important are vehicle type and size, vehicle age and accumulated mileage, fuel used (gasoline, diesel, others), ambient weather conditions (temperature, precipitation, wind), maintenance condition of the vehicle, and type of driving (e.g., long cruising at highway speeds, stop-and-go urban congestion, typical urban mixed driving).

Weijers *et al.* (2004) note that these variations cause the temporal and spatial distribution of particle concentrations to be highly inhomogeneous.

Exposure to particulate matter is ever-present and involuntary, which makes it a significant health determinant. Air quality indices published by countries such as the United States and Japan, and organizations such as the World Health Organization, are based on scientific studies that investigated the health effects of particulate air pollution. For instance, several studies such as Beelen *et al.* (2008), Krewski *et al.* (2009) and Pope *et al.* (2002) have associated long-term $PM_{2.5}$ exposure with an increase in the long-term risk of cardiopulmonary mortality by 6–13% per 10 µg/m^3 of $PM_{2.5}$. Medina (2012) found that exposure to $PM_{2.5}$ reduces the life expectancy of the population of the European Region by about 8.6 months on average, and that average life expectancy in the most polluted cities in Europe could be increased by approximately 20 months if the long-term $PM_{2.5}$ concentration was reduced to the WHO (AQG) annual level of 10 µg/m^3.

However, some people are more vulnerable to the effects of particulate pollution, specifically people with pre-existing lung or heart disease, as well as elderly people and children. For example, the WHO Regional Office for Europe (2013) notes that exposure to particulate matter affects lung development in children, which may result in reversible deficits in lung function, chronically reduced lung growth rate and a deficit in long-term lung function. They also purport that there is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur.

As such, particulate matter pollution in transport microenvironments is an increasing cause of concern. There have been several studies that examined $PM_{2.5}$ and other pollutants in transport environments, mostly in the field of atmospheric environment. There are two groups of studies that are relevant to this research: (1) urban rail systems only, and (2) intermodal comparisons (e.g. bicycle, metro, bus, car, etc.).

Several studies focusing on $PM_{2.5}$ concentration (among other particulate matter) in metro systems are shown in Table 2.3.

In these studies, results generally show that underground stations and inside the train have higher levels of $PM_{2.5}$, even though an intuitive assumption would be that roadside and elevated stations are more exposed (Niewenhuijsen *et al*, 2007). This can be attributed to the ventilation systems in metro systems which tend to "trap" particulate matter such that they circulate in the limited space. The same can be said when comparing the inside of the trains with the platforms. Moreover, passenger areas have higher levels of particulate matter than station worker areas. Therefore, these locations need to be considered to accurately perform an intra-modal comparison for MRT-3.

Intermodal comparison studies on PM pollution have included various transport modes for both non-motorized and motorized modes, as well as private and public transport. Table 2.4 provides important details on some relevant studies.

In terms of intermodal comparisons, the results are quite intuitive. Passengers who walk or ride a bicycle generally receive the highest levels for a prolonged period of time, followed by bus and minibus, then metro, while private car users suffer the least. However, it is unclear if the same can be said for Metro Manila.

Table 2.3. Studies on PM pollution in urban rail systems

Author, Year	**Pollutants Measured**	**Location**	**Duration**	**Sampling**
Johansson and Johansson, 2003	PM_{10}, $PM_{2.5}$	Stockholm Metro	January to February 2000 (2 weeks); 12 hours	One underground station (platform)
Chillrud et al, 2004	$PM_{2.5}$	New York Subway	8-9 weeks each during the summer and winter campaigns; 8 hours	Monitored 38 students during the winter campaign and 41 during the summer campaign; also collected $PM_{2.5}$ samples in homes, outdoors and subway stations
Aarnio et al, 2005	PM_{10}, $PM_{2.5}$, OC, EC	Helsinki Metro	March 2004; six working days	Platform: Two underground stations (4 m and 1.5 m above the platform, respectively), and inside the subway cars
Seaton et al, 2005	PM_{10}, $PM_{2.5}$	London Underground	7 AM to 5 PM for three consecutive days (month and year not provided)	Three underground stations and driver's cabs
Kim et al, 2007	PM_{10}, $PM_{2.5}$	Seoul Metro (both station worker and passenger areas; 8 sites per station)	November 2004 to February 2005 (duration per site not indicated)	Total of 22 stations on 4 lines (underground: 14; ground level: 8)
Park and Ha, 2008	PM_{10}, $PM_{2.5}$, CO_2 and CO	Seoul Metro (inside the train and on the platform)	4 days in January, 13:00 to 16:00, total of 2709 monitoring instances	Total of 89 stations on 5 lines (underground: 65; ground level: 24)
Cheng et al, 2008	PM_{10}, $PM_{2.5}$	Taipei Rapid Transit System	October to December 2007; Weekends on weekdays at random; both rush hour and non-rush hour periods; 1 hour per sample	Four popular routes and five underground stations
Guo et al, 2014	$PM_{2.5}$, PM_1 including the characteristics of the PM	Shanghai Metro	Collection of samples and monitoring of PM levels for 10 hours	Several platforms of 3 highly contrasting stations

Table 2.4. Intermodal comparison studies on PM pollution

Author, Year	**Pollutants Measured**	**Location**	**Transport environment**	**Duration**	**Sampling**
Pfeiffer *et al*, 1999	$PM_{2.5}$	London, UK	Taxi and metro	7 days for taxi, 16 hours for metro	20 samples for taxi and 4 samples for metro
Adams *et al*, 2001	$PM_{2.5}$	London, UK	Bicycle, bus, car and London Underground	1st field study: July 1999 and February 2000 (3 weeks each); 30-60 min, 8 hour shift for personal samplers 2nd field study: Volunteers' own actual commute time	1st field study: three set routes 2nd field study: 24 volunteers monitored their exposure levels for during their actual commute
Chan *et al*, 2002a	PM_{10}, $PM_{2.5}$	Hong Kong	Railway transport, non-air-conditioned and air-conditioned roadway transport, marine transport	October 1999 to January 2000; all weekdays except on rainy days or when there is an episode of air pollution; 8:30-10am and 16:30-19:00 except taxi: 10:30-12:00	One journey for each mode during the sampling hours (average journey time ranges from 25-50 minutes)
Chan *et al*, 2002b	PM_{10}, $PM_{2.5}$, CO	Guangzhou, China	Subway, air-conditioned bus, non-air-conditioned bus, taxi	May and December 2001; weekdays; 14:00-16:30 and 17:00-19:30	One journey for each mode during the sampling hours (average journey time ranges from 30-53 minutes)
Gulliver and Briggs, 2003	TSP, PM_{10}, $PM_{2.5}$, PM_1	Northampton, UK	Walking vs car	November 1999 to April 2000; 6 minutes for car and 20 minutes for walking, 73 pairs of measurements	Two circular routes around 1 km
Gulliver and Briggs, 2007	TSP, PM_{10}, $PM_{2.5}$, PM_1	Leicester, UK	Walking vs car	January to March 2005, 33 pairs of measurements	Two circular routes 10km long

Author, Year	Pollutants Measured	Location	Transport environment	Duration	Sampling
Gomez-Perales *et al*, 2007	$PM_{2.5}$, CO and benzene	Mexico City, Mexico	Bus, mini-bus, metro	January to March 2003, three days a week for 10 weeks for both morning and evening rush hours; three modes measured simultaneously	Two urban corridors
De Nazelle *et al*, 2012	Black carbon, ultrafine particles, $PM_{2.5}$, CO_2 and CO	Barcelona, Spain	Walk, bus, bicycle and car	Simultaneous measurements for two modes, pairwise design; 3 peak periods and 2 off-peak periods; total of 172 trips	Two round trip commute routes
Both *et al*, 2013	$PM_{2.5}$, ultrafine particles, CO	Jakarta, Indonesia	Private cars vs public transportation (combination of different modes) for four different commuter groups	36 non-smokers for 93 days; two to three daily measurements for each subject; a surveyor accompanies the subject	Depending on the subject's origin and destination and mode used; daily activity was not modified

Some studies have related to PM pollution have also been conducted in Metro Manila. Vergel and Tiglao (2013) estimated the reduction in emissions of criteria pollutants (HC, CO, NO_2, PM and SO_2) and fuel consumption (diesel, gasoline, alternative fuel/biofuel) brought about by sustainable transport measures. They found that measures such as implementation of vehicle inspection, mass transit network expansion and travel demand management contributed to higher overall local emission reductions while the switch to CNG buses, mass transit network expansion and travel demand management measures resulted to significant reduction in fossil fuel consumption.

PM pollution monitoring was done in six Asian cities including Metro Manila (Kim Oanh *et al*, 2006) in the first phase of the Asian Regional Air Pollution Research Network (ARRPET) from 2001 to 2004. They found that in Manila, traffic sites have the highest $PM_{2.5}$ and PM_{10} concentration levels for both dry and wet seasons due to high emissions from vehicular fuel combustion, while upwind areas have the lowest concentrations. Concentrations were also generally lower than that in Beijing for both seasons and Hanoi during dry season, and similar to Bandung, Chennai and Bangkok. Manila also had the highest levels of soot among the six cities (at 49% and 52% of $PM_{2.5}$ in dry and wet season, respectively), which is mainly attributed to traffic sources. Leaded gasoline was phased out in Metro Manila in April 2000 and the Philippines nationwide in December 2000 (EMB, 2003), which led to a subsequent decrease in ambient Pb concentration.

As part of ARRPET Phase 1 (see Figure 2.3), Villarin *et al* (2004) measured the PM pollution in four locations in Metro Manila and they found that PM_{10} was dominated by fine particles ($PM_{2.5}$). Moreover, PM_{10} levels were in exceedance of the Clean Air Act's Guideline Value near roads, while $PM_{2.5}$ levels were in exceedance of the USEPA Standard all around Metro Manila. They concluded that traffic was the main contributing factor to fine particulate matter in Metro Manila.

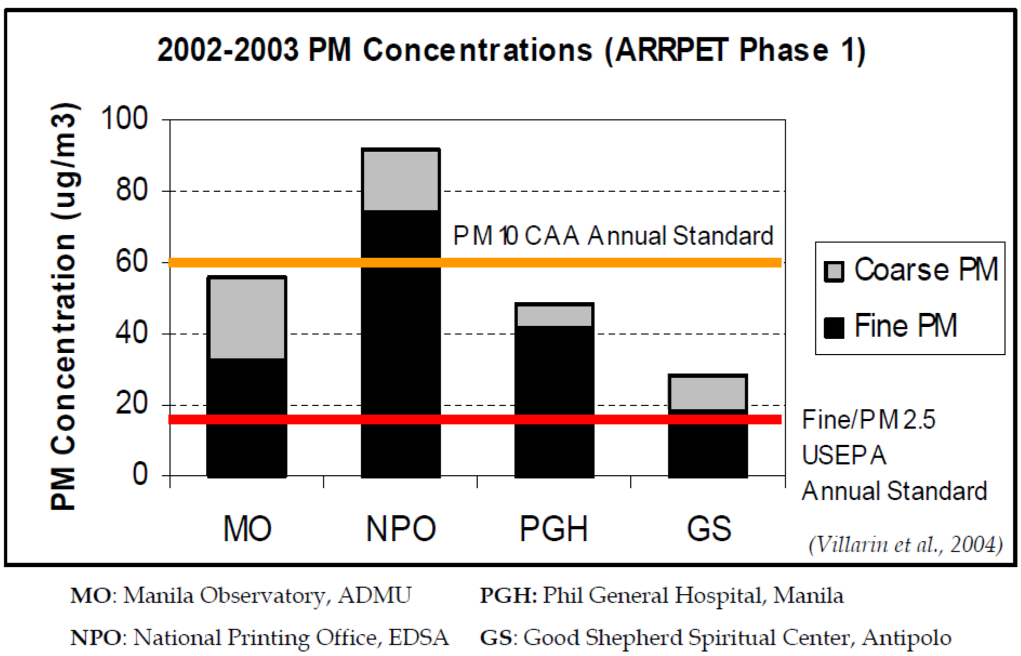


Figure 2.3. Measurement of ambient PM in Metro Manila

In summary, exposure to particulate matter is ever-present and involuntary especially in high-traffic areas such as Metro Manila. The type of mode used and the transport environment can impact on the amount of exposure received. Moreover, there is a potential equity issue in air pollution, with some people being exposed to more than others and not necessarily those that emit them.

2.3. Adaptation

In the context of commuting, adaptation is defined in two ways: physically or mentally. Van Oort (2011) mentions that when passengers perceive poor service reliability as a result of their experiences and expectations, they could adjust their physical behavior internally (within the public transport system), such as by changing their departure time, origin or destination stop, and/or route, or externally (options outside the public transport system), such as by changing their mode or cancelling their journey altogether. However, he states that when physical adaptation is not feasible or such strategies have been already been exhausted and the commuting situation is still below expectations, passengers would just accept the conditions and incur a welfare loss, due to additional travel time, variability and less comfort. However, changing one's perception on the negative commute to increase well-being could also set in, and this is referred to as mental adaptation.

As mentioned in Chapter 1, the hypothesis in this thesis is that passengers have already physically adapted to the system and thus no longer feasible. Mental adaptation (or in psychological terminology, hedonic adaptation) is the supposed tendency of humans to quickly return to a relatively stable level of happiness despite major positive or negative events or life changes (Brickman, 1971). According to this theory, as a person makes more money, expectations and desires rise in tandem, which results in no permanent gain in happiness. In a similar vein, as an individual experiences a better quality of public transport system resulting to a better commute, expectations and desires related to it also increase (i.e. passenger standards for service reliability). This may explain why passengers used to a high quality of service complain of seemingly minor delays or mishaps (as it deviates from their expectations), while those who are used to a low quality service may tolerate them more because they occur frequently. This model is designed around psychologists' conjecture that good and bad events may alter level of subjective happiness temporarily, but in the long run we adapt to changes in our lives from these experiences and our level of subjective happiness tends to adjust back to hedonic neutrality.

Frederick and Loewenstein (1999) note that hedonic adaptation is important because it serves as protection by reducing the internal impact of external stimuli. He asserts that the effects of constant stress are not only psychological, but also physiological, potentially causing destructive physiological concomitants, such as ulcers, circulatory disease, and viral infections. Hedonic adaptation may help to protect people who are facing stressors from these effects. They also proposed that hedonic adaptation to a negative stressor occurs through shifting adaptation level over time. It is an adaptive process in which the subjective intensity of a stressor is diminished by altering the stimulus level that is experienced as neutral. This implies that a condition that is initially experienced as hedonically positive or negative is now viewed as neutral. At first, anxiety is high, but repeated exposure to the stimulus causes adaptation level to that stimulus.

Stutzer and Frey (2008) noted that people might not be capable of correctly assessing the true costs of commuting for their wellbeing. They might rely on inadequate intuitive theories when they predict how they are affected by commuting. In particular, they may make mistakes when they predict their adaptation to daily commuting stress.

Mental (or hedonic) adaptation to improve well-being in the context of a negative commute has not been examined in detail. In their comprehensive literature review on commuting and well-being studies, Novaco and Gonzalez (2008) mentioned on the role of adaptation in improving well-being but only on physical and behavioral aspects. Olsson *et al.* (2013) found that travel mode sometimes does not directly affect satisfaction with the work commute, and mention in passing that this could be attributed to adaptation to adverse conditions. However, they did not elaborate on the effect of adaptation on this finding.

2.4. Equity

Equity is a subjective concept, but previous studies have used conventional inequality indices to quantify it. Cowell (2009) proposed three fundamental components for inequality measurement: (1) specification of an individual social unit depending on the context; (2) description of a particular attribute, or resources; and (3) a method of representation or aggregation of the allocation of resources among individuals in a given population. This principle of the basis of common inequality indices such as the variance, coefficient of variation, Gini coefficient, mean logarithmic deviation, Theil index, Herfindahl index, Atkinson index, Dalton index and the modified information-theoretic indices. Cowell further states that it is warranted that resources should be measurable using some index and comparable among different persons. While it is possible to make some progress in the study of inequality without measurability of the welfare index and sometimes even without full comparability, it is still preferable for resources to be both measurable and comparable.

In transportation, Levinson (2007) has used the Gini coefficient to assess the equity of delay and mobility in ramp metering. However, he failed to weight the values according to number of OD trips, thus the distribution of delay across all users cannot be accurately done. Moreover, the Gini coefficient places a questionable value on changes that may occur in different parts of distribution. A delay transfer from an individual with higher delay to someone with less has a much greater effect on the Gini coefficient if the two persons are near the middle rather than at the end of the distribution.

Ramjerdi (2006) emphasized on the importance of using several inequality measures in analyzing equity. He utilized the mean, range, variance, coefficient of variation, relative mean deviation, logarithmic variance, variance of logarithms, Theil, Atkinson, and Kolm indices, and Gini coefficient in analyzing the change in equity of welfare after the application of a specific policy. Given that different inequality measures have different properties with regards to transfer effects and ranking, his results yielded inconsistencies and he was not able to give a definite conclusion regarding the effect of the policies with regards to equity.

In the context of passenger waiting time, refused passengers who have higher delay tend to be concentrated on bottleneck stations, thus resulting in equity problems. The equity of passenger overload delay was examined implicitly by Shimamura *et al.* (2005) by incorporating the failure-to-board probability in their transit assignment problem. They defined a concept called of connectivity reliability as the probability of arriving at the destination without failing to board at any station, and thus measures congestion level. The Gini coefficient was then used as an equity measure of the connectivity reliability (and not of waiting time per se), and was stipulated as one of the objective functions in the bi-level programming problem for optimization with equilibrium constraints. Equity in waiting time due to queuing is also a topic of interest in the fields of telecommunications and computer systems (e.g. Avi-Itzhak and Levy, 2004) and consumer service (e.g. Goodwin et al, 1991).

Another prospective approach in measuring equity is through the use of distributional poverty gap measures, which are based on inequality indices and the theory of relative deprivation (Clark et al, 1981). So far, these measures are used to measure poverty, but could be extended to the concept of passenger overload delay.

In the context of environmental pollution, the differences in PM levels according to area or transport microenvironment may point to an environmental equity (or environmental justice) issue. Cutter (1995) defines environmental justice as equal access to a clean environment and equal protection from possible environmental harm irrespective of race, income, class, or any other differentiating feature of socioeconomic status. The US EPA officially defines it as the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies," and includes it as a major goal for the entire nation. Environmental equity ensures that marginal and minority groups do not bear a disproportionate burden of environmental problems, and determines whether planning policy and practice affecting the environment are equitable and fair.

In the context of air pollution, Mitchell and Dorling (2003) conducted an environmental equity study in the UK, and compared air pollutant (NO_x and NO_2) levels in British communities according to age, income and car ownership. They found evidence of environmental injustice in the distribution and production of poor air quality in Britain. Communities that have lower car ownership suffer from the highest levels of air pollution, while car-owning communities have better air quality. Pollution is also more highly concentrated in areas with younger population. They also found that communities that are most polluted and which also emit the least pollution tend to be amongst the poorest in Britain. However, they point out that the spatial distribution of those who produce and receive most of that pollution have to be considered simultaneously to analyze environmental justice more clearly.

2.5. Studies on Metro Manila MRT-3

There are several studies that have looked into the perception of service quality attributes of Metro Manila MRT-3 commuters.

Before the MRT-3's ridership levels reached capacity in 2005, the studies focused on how to increase ridership levels. During this time, the MRT-3 fare levels had been drastically reduced from PhP17-34 to PhP10-15 depending on number of stations traveled, but its fare levels were still higher than that of other road-based modes so the MRT-3 was not the preferred mode for people who only consider affordability.

Fillone (2001) assessed the immediate impact of MRT-3 on bus services along EDSA by conducting an actual before-and-after study on the service level of buses. He found that there was a statistically significant decrease in the mean and average passenger-kilometers of buses six months after the operations of MRT-3 began, which could indicate that modal shift from bus to MRT-3 occurred. Moreover, he found that MRT-3 resulted in an improvement in the mean and average travel speeds of buses, but he attributed this to the reduction of number of stops that the buses made rather than reduction of bus fleet. He also noted that the bus industry introduced more ordinary (i.e. non-air-conditioned) buses, which had lower fare than air-conditioned buses, to compete with MRT-3. However, the long-term effect of MRT-3 was not captured in this study, and it is possible that the improvement in level of service would induce demand.

Martinez (2002) investigated the potential of pricing and transit service quality improvement policies to promote urban rail. He developed a mode choice decision model and found the urban rail fare elasticity to be -0.7071. Among those who would stop using MRT-3, 74% will most likely shift to bus (air-conditioned & ordinary), 17% would shift to 'FX' mega taxi, 6% would shift to jeepney and 3% would opt to use their own car. He also found that if the total walk time (i.e. egress walk time + access walk time) is reduced by 1%, then 0.0524% of the travel demand for that area who are currently non-users would most likely shift to MRT-3. He also found that trip makers are more sensitive to travel time than fare. Market segmentation analyses according to trip purpose, trip length, income and frequency of use revealed that all market segments are willing to pay for additional fare for improved service. He also found that the fare elasticity is -0.3021 for less frequent riders, while it is estimated to be -0.3952 for more frequent ones. Elasticity for work trips was estimated to be -0.3891; for trips other than work, it is -0.3180.

Okada *et al* (2003) conducted a research study that aimed to identify the cause of low MRT-3 ridership from the viewpoint of accessibility and intermodality as well as to propose appropriate strategies. Using Item Response Method, they found that dissatisfaction and preference levels for improvements are quantified by considering human latent traits. They found that majority of people were satisfied with riding comfort and travel time, but are less satisfied with congestion and fare level. Moreover, they asked non-users about the reasons for not using MRT-3, and they found that the most common reason is the lack of network coverage to their desired destination, followed by inconvenient transfers between MRT-3 and feeder modes and expensive fare. They also found that passengers at that time were more sensitive to feeder access time and walking, stating that they can only tolerate up to 20 minutes of access time and 10 minutes of walking. They recommended improving accessibility to pedestrians and establishing a passenger terminal to make intermodal transfers easier. Considering passengers' human latent traits, they also recommended improving the amenity and level of service of MRT-3 to specifically target higher-income passengers.

De Langen, Alzate and Talens (2004) conducted a study on the effects of MRT-3 on the traffic conditions in Metro Manila as well as on its financial performance. They utilized the following data: (1) survey of MRT-3 passengers in November and December 2002 (504 respondents), (2) traffic data in the Epifanio de los Santos Avenue (EDSA) corridor in the 1997-2002 period; and, (3) ridership and financial data concerning the actual MRT-3 operation from DOTC.

They pointed out that one of the targets of the MRT-3 was to reduce congestion along the EDSA corridor. However, they found that MRT-3 has not attracted car drivers as 99% do not have their own car available for the trip, although 41% of them reported that their household owns at least one and that 27% made their trips as car passengers before. The authors pointed out that this would imply that the MRT-3 only reduced car occupancy or probably trip length, but it had no effect on the number of car trips made. Instead, they found out that the main modal shift induced by the MRT-3 is from other public transport modes. 67% (±6%) of the respondents indicate that previously their main mode of travel was by bus, 4% by taxi and 2% by jeepney. However, they noted that the large modal shift from bus to MRT-3 did not lead to a strong reduction in the number of buses plying the EDSA corridor. They offered a probable explanation for this: a significant part of the MRT-3 trips are either diverted or generated traffic. This is consistent with the answers given by the respondents about their travel routes in the past – 62% reported that they did not travel along the same route in the EDSA corridor before the MRT-3 line was opened. This indicates that the MRT-3 alleviated traffic from other parts of the metro and not just along EDSA. Thus, this would imply under a substantial fare increase, those who are priced off would probably choose another route and/or mode/s. This would also affect the feeder modes that serve MRT-3 as they would have lower ridership.

Users in 2004 were found to be generally satisfied with the level of service of the MRT- and its facilities. Almost all respondents (99%) indicated that the price level is fair, while the remaining 1% said that the price is low, implying that they would be willing to pay more for the use of the MRT-3. It is useful to note that the fare levels for MRT-3 at this time is cheaper than that of buses, which are the main public transport alternative along EDSA. In terms of waiting time at stations, a large majority of the respondents (93%, ±2%) said that the waiting time at MRT-3 stations is fair, 7% consider it low, and less than 1% is dissatisfied because it is too long. This is completely different from the issue in the recent years about prolonged waiting time due to overcapacity and poor operations.

Moreover, MRT-3 users were found to be generally satisfied with the travel time compared to other modes (e.g., bus, car or taxi). About 53% of the respondents rate the travel time using MRT-3 as very good, 46% as good, 1% as fair. The high level of satisfaction with the travel time reflected the fact travelling along EDSA by road-based modes take far longer time. For example, travel by bus from North Avenue to Taft Avenue (17 km) took more than an hour on average, while it is less than 30 minutes by MRT-3 at this time when waiting time was not as long. Apparently, the need for additional transfers when using the MRT-3 does not significantly diminish the attractiveness of the speed of travel by MRT-3, probably because of the high train frequency.

Fillone (2005) found that the light rail system, which includes MRT-3 is the most favorable public transport mode for car users and non-users alike, followed by the AUV/FX, the air-conditioned bus, the non-air-conditioned bus, the jeepney, and the taxi. However, when a car is included in a commuter’s choice set, he is most likely to choose it as his travel mode for morning peak period work trips.

Elumba (2014) used the analytic hierarchy process (AHP) approach to identify, weigh and rank the critical concerns of commuters that deserve immediate attention by the MRT-3 operators. The five major criteria were identified as pricing, timeliness, service, comfort and security, with each having its own sub-criteria. Findings show that more than 12% of the 142 respondents deem that pricing of the fare compared to other modes of transport in the city concerns them the most followed by security issues that specifically deals with the pick-pocketing inside the station and the trains while facilities like lavatory or more stations were all rated of low. These factors influence their perception and preference towards the system both positively and negatively depending on the quality they get and therefore recommended to be paid attention to.

Ganiron (2015) inquired regular commuters about their main reason for commuting using the MRT-3, and he found that majority of respondents found it cheaper than other modes. Other reasons include convenience and safety. He also found that 43% of respondents were concerned about the outdated engines, and others viewed the trains as too few or too slow. The author conducted his survey before the fare increase, and he found that majority of respondents viewed the fare levels as affordable, and only a few viewed it as too cheap.

Ebia and Ramirez (2014) remarked that MRT-3 passengers push each other and force themselves into the train even if the vehicle is already full, and that the crowding inside the train is so severe. They also pointed out that the everyday scenario at MRT-3 during peak hours encourages negative activities such as robbery, random sexual advances and fights among passengers, and that this situation characterized by delay and discomfort causes stress among passengers who are mostly employees and students. They considered the safe and comfortable crowding threshold in Metro Manila MRT-3 to be 4 passengers/sq.m., which they equated to 200 passengers per single coach (instead of the 394 passengers criteria used by DOTC-MRT-3).

All in all, there has been a shift to the type of research conducted for MRT-3 – initially, it was to increase ridership, but after the capacity was exceeded, the goal was to improve the poor level of service resulting from insufficient capacity with respect to passenger demand.

2.6. Chapter Summary

This review of related literature covered studies on passenger well-being (commuting stress and satisfaction), level of service attributes in urban transit (including passenger waiting time and its simulation, crowding, reliability and risk perception), adaptation, $PM_{2.5}$ exposure and its health effects, equity issues, and Metro Manila MRT-3.

It was discussed that well-being studies in commuting research have either focused on the overall well-being of passengers as a result of their commute or narrowed it down to commute satisfaction. The former definition is too broad and has many other factors affecting it (e.g. income level, job satisfaction), so a large number factors should be controlled to determine the effect of commuting on overall well-being. Meanwhile, the latter definition is more focused on the commute so it is easier to isolate the effect of commuting on it. Moreover, some well-being studies have also investigated commuting stress and its physiological and psychological effects as an indicator of well-being. Considering these points, this research takes into account both commuting stress and commute satisfaction as indicators of passenger well-being to concentrate the effects of the commute on passengers, but does not include overall well-being given that it is affected by many other factors.

Furthermore, several studies have identified numerous variables that affect commuting stress and passenger satisfaction, with the usual variables being travel time and individual characteristics. However, most passenger well-being studies are done in the context of developed countries or other cities with commutes that are not as severe as that of MRT-3, so some variables that are relevant to the MRT-3 are not included. Passenger waiting time is sometimes included as a part of travel time, singled out or not tackled at all. Moreover, travel cost is not usually considered in developed countries as a determinant of passenger well-being, but it is a relevant issue in developing countries especially for low-income passengers. Air quality and its relationship to passenger well-being in the context of commuting have not been tackled. Thus, this research considers waiting time, fare level, in-vehicle travel time, perception on air quality and risk, predictability and crowding as potential explanatory variables for commuting stress and passenger satisfaction in the context of a highly negative commute.

Adaptation in commuting research also usually refers to behavioral adaptation such as mode switching, but mental (or hedonic) adaptation has limited applications in the field. The effect of mental adaptation as a control variable for commuting stress and passenger satisfaction has not been tackled in detail. This research addresses this gap by including an adaptation analysis on both physical and mental aspects, with the latter included as a control variable for passenger well-being.

Studies on estimating waiting time typically do not consider capacity constraints. While passenger waiting time due to capacity constraints has been studied to some extent, these studies are mostly focused on equilibrium studies or operation improvement to optimize the headway. It also considers capacity constraints in waiting time simulation conducts Moreover, it contributes to broadening the realm of knowledge on Metro Manila MRT-3 as well as congested transit systems in general. This research does not require such advanced analysis on passenger waiting time so there is a need to create a simpler model that still addresses the dynamic and stochastic nature of the phenomenon.

Furthermore, exposure to $PM_{2.5}$ pollution while commuting is typically studied independently of other level-of-service attributes, and focuses mainly on just the concentration levels. Moreover, the waiting time phenomenon is absent in the areas considered in those studies and commutes are typically shorter. This is one of the gaps that this research study addresses. For instance, the link between prolonged waiting time and travel time is linked to $PM_{2.5}$ levels, to determine the $PM_{2.5}$ exposure. As such, this point is considered in this research,

Equity analysis also traditionally relies on inequality measures such as the Gini coefficient. Thus, the use of many inequality measures is not desirable, and a better approach would be to choose or create an appropriate equity measure that reflects the properties that the measure needs to possess. This could be done by considering the characteristics of the resource in question, and using or creating an appropriate index.

There are also limited studies on Metro Manila MRT-3, especially in recent times when the situation has significantly worsened. While the phenomenon being studied is unique in the context of MRT-3 at present, it could potentially happen in other developing megacities (urban rail or even BRT systems) where there is inadequate capacity with respect to demand and queuing into the station is inevitable.

On the whole, while the issues present in Metro Manila MRT-3 were discussed to some extent, none of the above studies have thoroughly addressed the research problems presented in this study. There have been no research studies that comprehensively examined the actual and perceived conditions and effects of daily commuting on passenger well-being, so it is imperative to conduct this comprehensive research study that addresses this gap and contributes to this emerging field.

3. Actual Conditions at the Metro Manila MRT-3

This chapter presents the actual conditions at the Metro Manila MRT-3 during the morning peak period from the viewpoint of passengers using various data collection methods including field and video observation surveys, and secondary data. This includes outlining operations policies and their impacts, passenger behavior while boarding and waiting, and measuring passenger demand, passenger density inside the train and total passenger waiting time (i.e. station access time and platform waiting time).

3.1. Introduction

Congestion and unreliability are worsening in Metro Manila MRT-3. Due to the inadequate infrastructure and excessive passenger demand, passengers usually have to wait for a long time during the morning peak period, with passengers at some stations incurring higher waiting times. The value of waiting time is usually perceived to be two to three times higher than in-vehicle travel time (Ben-akiva and Lehrman, 1985) so this may imply higher productivity loss for the passengers. Moreover, crowding levels are high as passenger demand is too large for the infrastructure, which may be unsafe and uncomfortable.

In a rail line with adequate capacity and perfectly regular service, the usual textbook assumption for passenger waiting time of taking half of the headway to be the average suffices because all passengers can always board the first vehicle. However, in congested and unreliable lines such as the MRT-3, passenger waiting time increases as the discrepancy between capacity and demand increases and services become irregular, thus it is imperative to include the probability of being refused service by the first (or succeeding) vehicle(s). This has been the focus of several studies such as Lam *et al*. (1999a), Shimamoto *et al*. (2005) and Mijares *et al*. (2013).

Due to the extreme conditions at the MRT-3, the conventional definition of passenger waiting time does not hold. We then define a term called “total waiting time” as the sum of two components: (1) station access time, and (2) platform waiting time. Station access time refers to the time spent queuing into the station from the time of arrival at the end of the queue to the time of arrival at the station turnstiles. Platform waiting time denotes the time spent waiting at the platform, from entry into the station turnstiles up to the time of boarding into the train.

The main objective of this chapter is to establish the extent of the congestion and variability problem in Metro Manila MRT-3 mostly from the passengers' viewpoint using various data collection methods. This includes the following:

- examining ridership trends
- outlining and discussing the policies on fare and operations
- observing passenger behavior when boarding and waiting
- measuring the level of service attributes (headway, station access time, platform waiting time, passenger density, etc.) and estimating their day-to-day variability

It intends to specify the problems and their probable causes, which may aid in formulating countermeasures that may alleviate them (to be discussed in Chapter 6).

Some studies on this research area focus on the effect of congestion and unreliability from the viewpoint of the operator, using primary and knock-on train delays as indicators (e.g. Carey and Carville, 2000), but this paper focuses on the delay and poor service experienced by passengers.

Chapter 3 is structured as follows: Section 3.1 gives a brief introduction on the background and objectives and presents some previous studies; Section 3.2 describes the methodology employed to collect the data; Section 3.3 examines ridership trends, and discusses on the fare policy and the immediate effect of the recent fare increase. Section 3.4 outlines the operations policies in place, Section 3.5 discusses about passenger behavior when boarding and waiting. Section 3.6 establishes the level of service experienced by passengers using the results of the waiting time and observation surveys; and finally, and finally, Section 3.7 summarizes and concludes the chapter.

3.2. Methodology

Several surveys were designed in order to obtain data regarding the actual level of service at MRT-3. The situation in MRT-3 is fluid as some changes in the operation policies occurred during the research period. Thus, there was a need to design surveys that are appropriate to the current issue at a certain point in time.

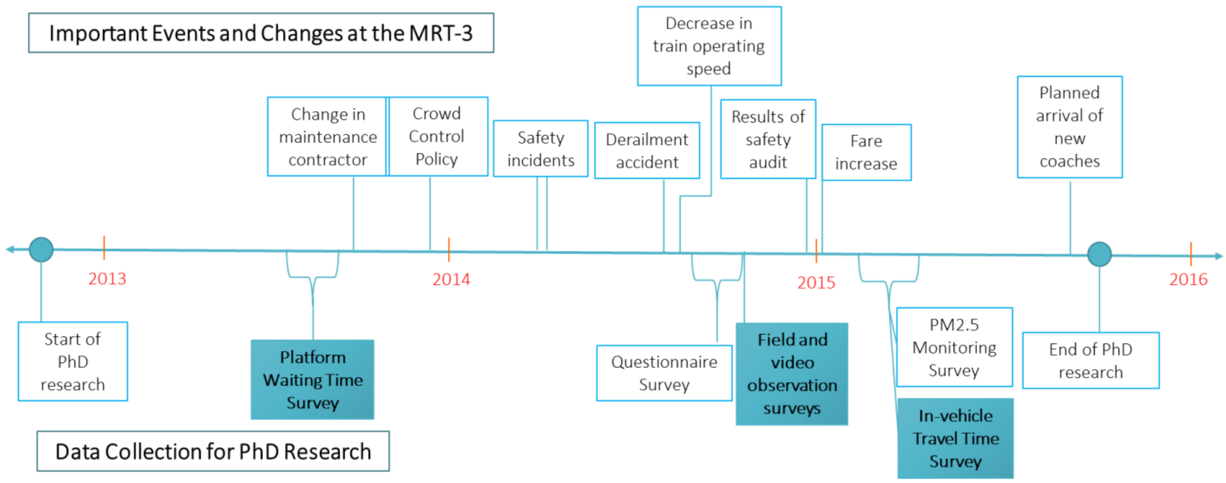


Figure 3.1. Timeline of surveys

Another important change occurred during the research period, which is a substantial fare increase implemented in January 2015. Due to the research timeline, surveys related to this chapter were conducted in 2013 and 2014 (except for the in-vehicle time survey in February to March 2015), and the fare increase was not anticipated in the research design. There have been talks of raising the fare as early as 2010, however, this was not taken into account in the design of surveys because there was no scheduled implementation at that time due to resistance by various social groups and politicians. The fare increase was eventually implemented in January 2015 amid resistance after data collection on level of service. This will be discussed in more detail in Chapter 6, wherein the effects of fare increase on ridership, passenger waiting time and passenger satisfaction are investigated.

3.2.1. Platform Waiting Time Survey

The first survey was performed in July and September 2013 at a time when high platform waiting time at the middle stations was the problem (also discussed in this author's master's thesis; see Mijares, 2012). Thus, it mainly focused on the platform waiting times at several stations at the MRT-3.

A series of video observation surveys was conducted on five regular weekdays in 2013 (July 10, and September 16, 19, 24 and 26) during the morning peak period from 6:30am to 9:30am in the peak direction (southbound) at the most critical stations (first five stations as revealed by preliminary inspection) in order to determine the platform waiting time and determine the causes of the phenomenon. The surveys were done by recording the live streaming CCTV website operated by DOTC MRT-3 (2013). Each station has four CCTV cameras focusing on the platforms and ticketing areas for both northbound and southbound directions, but the surveys only focused on the southbound platforms. To obtain the platform waiting time according to arrival time, a passenger was tracked for every one-minute interval of arrival time until he or she is able to board the train. There are some limitations to this method due to the locations of the cameras, low video quality and the slow video buffering of the website. Nevertheless, we were able to obtain data that is accurate up to one minute. Headways and dwell times for the entire duration were also recorded, but the data was only accurate up to a minute.

3.2.2. Field and Video Observation Surveys

Circumstances have changed in 2014 as highlighted in media reports that show roadside queuing at the MRT-3, which was not a common problem in the past years (GMA News, 2014). As such, field and video observation surveys were scheduled to capture the new phenomenon. These were done in coordination with University of the Philippines National Center for Transportation Studies (UP NCTS) on October 1, 2014 (Wednesday; regular weekday) from 5:30am to 9:00am at the North Avenue and Cubao Stations. These surveys consisted of total waiting time survey, passenger queuing, boarding and waiting behavior survey, and train operations survey.

3.2.2.1. Total Waiting Time Survey

A survey was conducted to determine the extent of total waiting time, which is the time spent waiting from the end of the queue into the station up to getting on the train. A surveyor was deployed as an MRT-3 passenger for every 15-minute interval from 6:45am to 7:30am at North Avenue Station and at 8:00am at Cubao Station, and he or she recorded the time spent completing every stage of queuing (e.g. arrival at the end of the queue, security check, ticket purchase, etc.). Surveyors were also equipped with a GPS tracker to track their exact location and how it changes over time.

3.2.2.2. Train Operations and Passenger Behavior Surveys

This survey aimed to summarize the policies implemented by MRT-3, identify the bottlenecks and record the train arrival and departure times through video recording and field observation.

This includes listing the train arrival and departure times at the station, the number of boarding and alighting passengers, and number of refused passengers on the platform. Passenger behavior while queuing, boarding and alighting, and inside the train was also noted.

3.2.3. In-vehicle Travel Time Survey

A survey on in-vehicle travel time using different public transport modes along EDSA, namely, MRT-3, ordinary bus and air-conditioned bus, was performed for 20 regular weekdays between February 2 and March 5, 2014. This survey was simultaneously performed with the $PM_{2.5}$ monitoring survey (to be discussed in Chapter 4). A surveyor recorded the running time and dwell time for the three modes including the locations of every stop.

3.2.4. Secondary Data

Secondary data was obtained from DOTC MRT-3 and its website, as well as surveys done for an undergraduate thesis (Ebia and Ramirez, 2014) at the UP NCTS.

3.3. MRT-3 Ridership and Factors Affecting It

This section presents the general ridership trends that arise due to the fare policy, O-D patterns, seasonality and population growth. A brief examination on the effect of the recent fare increase on ridership is also presented.

3.3.1. Fare Policy

One of the reasons for the excessive passenger demand is its affordable fare levels relative to other public transport modes. Thus, a discussion on fare policy and its effects on ridership is imperative.

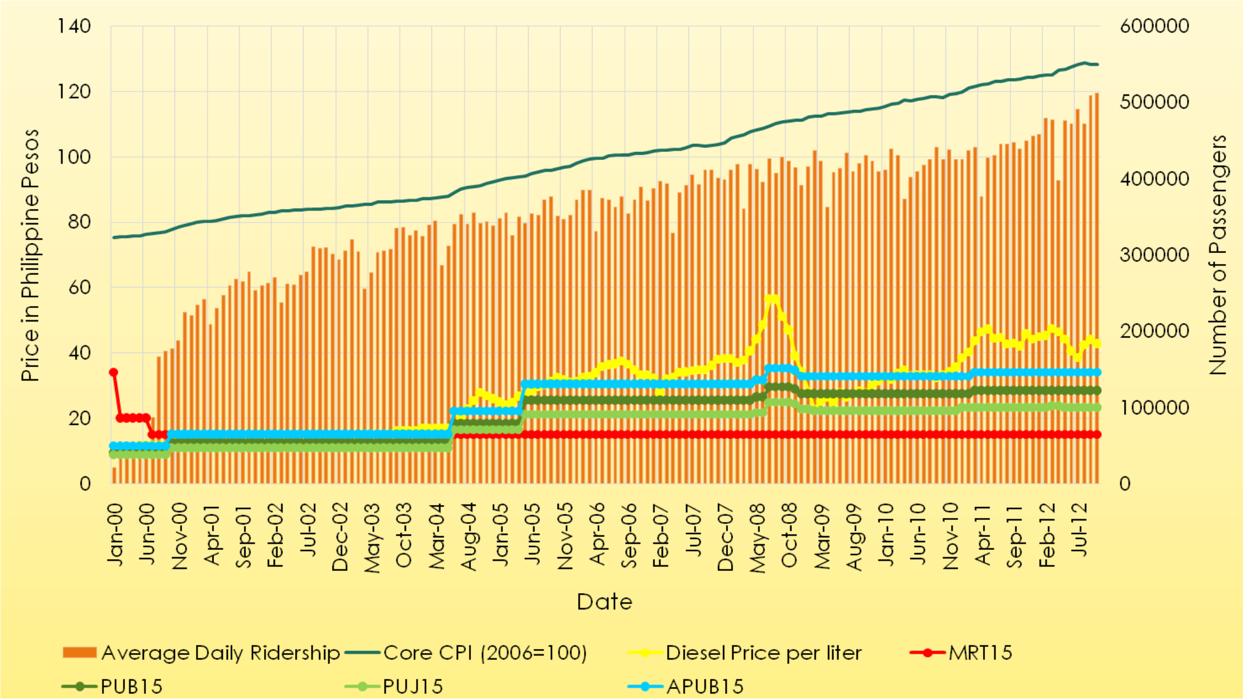
There is a stark difference in the salient features of fare policies of rail-based and road-based public transport modes, as outlined in Table 3.1.

Table 3.1. Fare setting objectives for rail and road-based public transport

Public transport mode	Fare-Setting Objectives		Consequences	
	Social Acceptability	Financial Viability	Impact on fares	Fiscal burden
Rail based	√		Artificially low fares	High subsidy
Road based	√	√	Profitable fare	No subsidy

Data Source: DOTC 2012

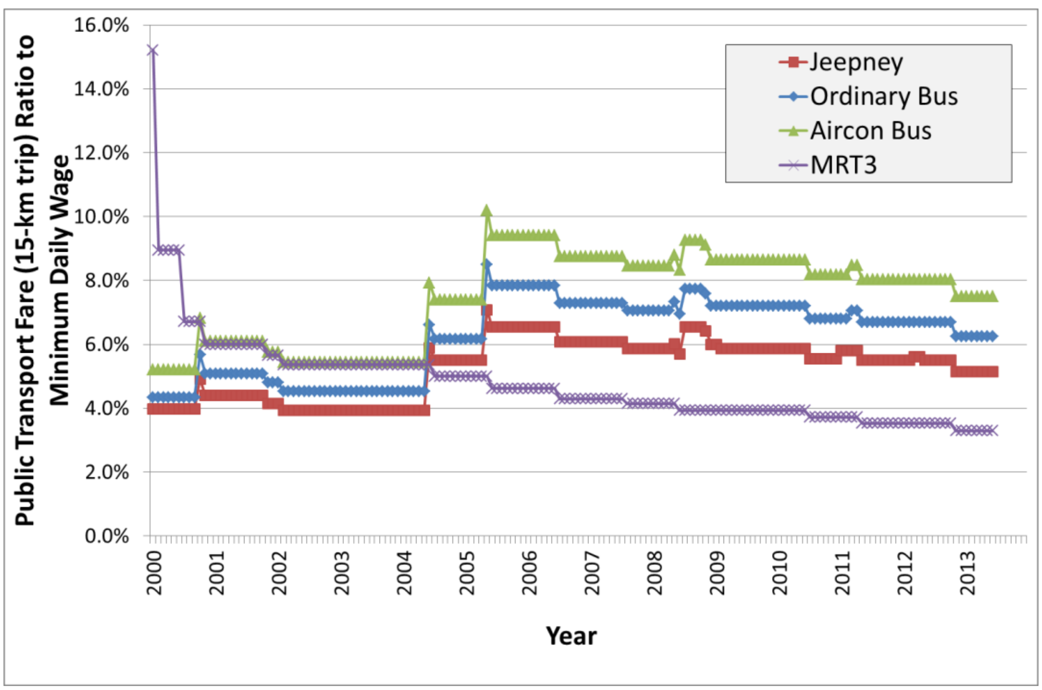
As a result, the government is a competitor that can artificially lower MRT-3 fares because it can rely on subsidies, as well as a fare and route capacity regulator of other public transport modes. This has resulted to a huge discrepancy in fare levels throughout the years. Figure 3.6 shows the difference in road-based and rail-based fare setting with respect to inflation and diesel prices, as well as the resulting MRT-3 ridership.



**15 stands for 15-km trips; PUJ – Public Utility Jeepney, PUB – Ordinary Public Utility Bus, APUB – Air-conditioned Public Utility Bus, MRT – Metro Rail Transit Line 3*
Data Sources: LTFRB, DOTC-Metrostar, World Bank, National Statistics Office, www.alternat1ve.com

Figure 3.2. Trend of fare levels, MRT-3 ridership, inflation and diesel prices from 2000-2012

Until around 2002, MRT-3 had attracted fewer passengers than expected because of high fare and poor connection with other transportation modes. While it was planned to attract car and bus users alike, they pointed out that there is a significant gap between actual demand and the estimated break-even point, which is 440,000 passengers daily. Fare levels initially ranged from Philippine pesos (PhP) 17 for 1-3 stations to PhP34 for 12 stations, but the target ridership was not achieved because it was significantly more expensive than bus fares, which was only PhP3 for the first 5 km (roughly 4 to 5 stations) and PhP0.67 for every kilometer thereafter. MRT-3 fares were then drastically reduced in mid-2000 to PhP10 for 1-3 stations to PhP15 for 12 stations, leading to a subsequent increase in ridership from 14% of the break-even point to 35%. By 2005, bus fares have increased to PhP8 for the first 5 km and PhP1.75 for every kilometer thereafter because of inflation and diesel price increase. On the other hand, MRT-3 fares remained the same, making it at par or even more affordable than bus depending on distance traveled. Consequently in 2005, MRT-3 ridership exceeded its capacity of 440,000 daily passengers, and ridership continues to increase until 2014 as the difference between bus fare and MRT-3 fare widened.



Data Sources: Department of Labor and Employment, LTFRB, MRT3 Metrostar Express

Figure 3.3. Public transport fare as a percentage of minimum daily wage

Moreover, minimum daily wage has been adjusted several times in the past decade or so to account for inflation and other factors. It can be seen in Figure 8 that travel by MRT-3 has become relatively cheaper for minimum-wage workers for a 15-km direct trip, while that of other modes have become relatively more expensive.

This also raises an important issue of inter-modal equity, that is, equity between modes. Non-rail users (either urban rail is not in their choice set or they are not able to ride because of lack of capacity, i.e. latent demand) pay more to use a lower-quality public transport mode like jeepney or bus. Prices of basic commodities, including fares for different modes of transport, have increased in the past 14 years and wages have also been adjusted for the rising cost of living. Given that urban rail fares have remained the same throughout this period, it has actually become relatively cheaper to use the rail over time with all these factors considered.

3.3.2. Seasonality and Population Growth

Analysis on seasonality was also performed and it was found that MRT-3 generally has higher ridership during the latter half of the year, with the peak at October. Ridership usually dips in April, probably due to the school summer break and hotter weather. The figure also shows the annual ridership trend, which is generally increasing for most months.

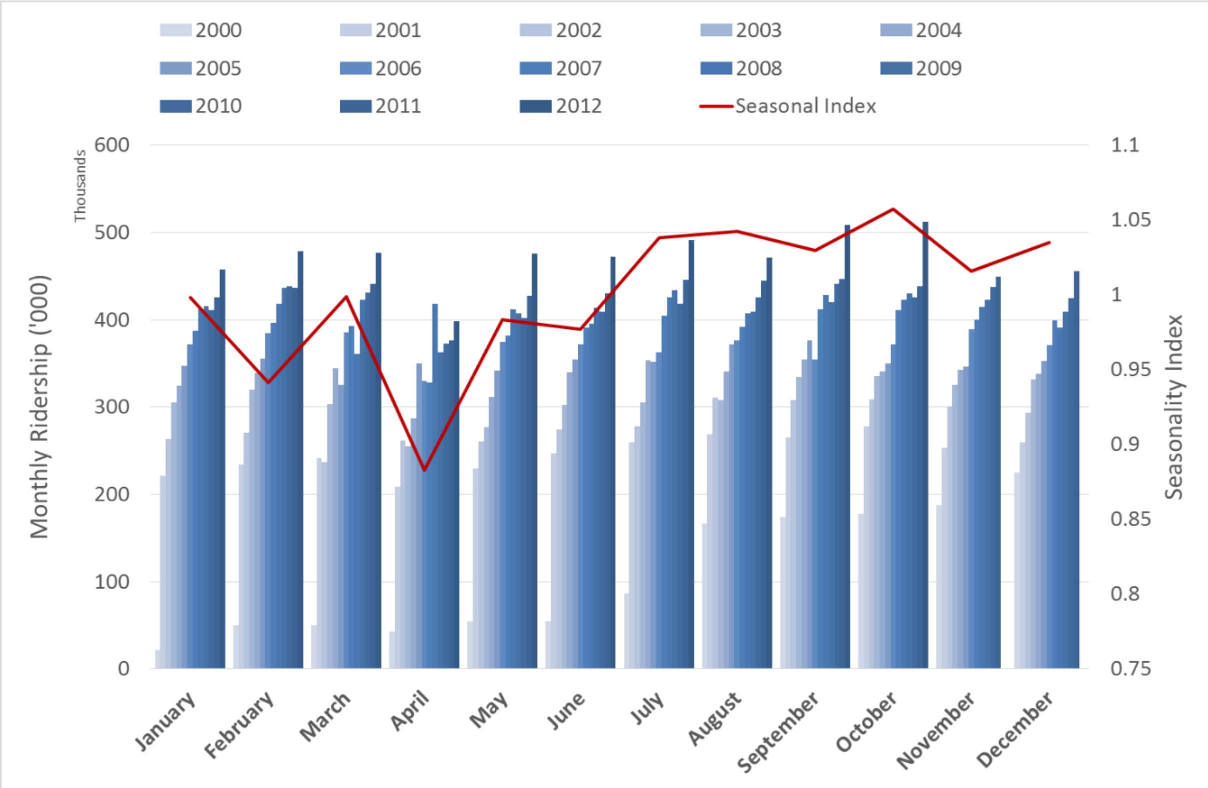


Figure 3.4. Monthly variation and seasonality

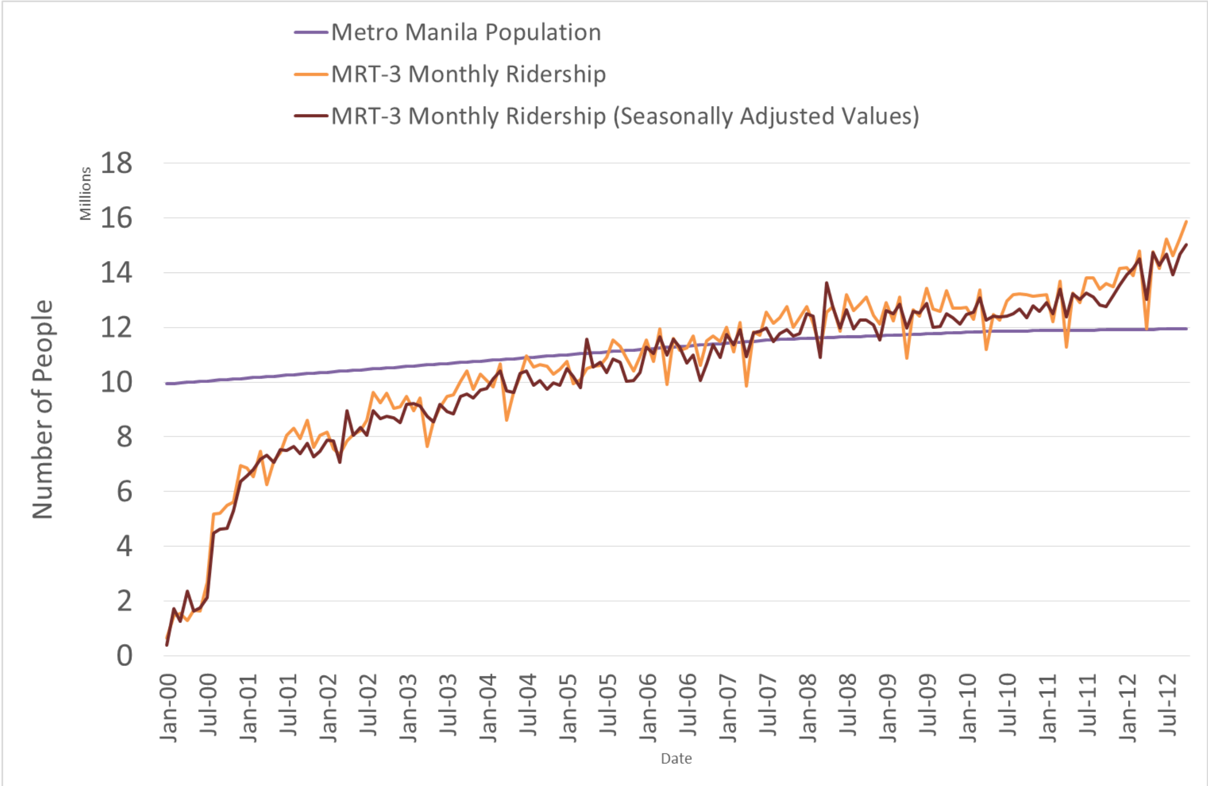


Figure 3.5. MRT-3 ridership and population increase

3.3.3. Morning Peak Ridership

Official ridership reports and observation surveys reveal that North Avenue (first station) has the highest demand in the morning peak period, with everyone heading southbound, and with most people getting off at the last three stations. Thus, focus is given to the southbound direction as it is the peak direction, although it is important to note that the northbound direction also experiences problems that are similar but not as severe.

Figure 3.6 shows the estimated passenger entries toward the southbound direction, with error bars indicating one standard deviation. It is based on official MRT-3 hourly ridership data for 22 regular weekdays in June 2013. The portion of passengers headed to the southbound direction was calculated based on O-D patterns derived from a previous study using stated preference survey data and gravity modeling (Mijares *et al*., 2013) and were calibrated using a previous MRT-3 boarding-alighting survey by Ebia and Ramirez (2014).

It should be noted that the official hourly ridership data only records entries at the station turnstiles (i.e. ticket gates) and does not account for roadside arrivals. As such, there is a time difference equivalent to the station access time between a passenger's actual arrival at the end of the station queue and his official arrival at the station. This implies that the official ridership data underestimates the real-time demand.

Figure 3.7 shows that the percentage of passengers arriving from 6 to 7AM has increased in 2013, based on a comparison of official MRT-3 hourly ridership data during the morning peak period between 2005 and 2013. Chi-square test was performed, and it was found that there is a statistically significant difference between 2005 and 2013 morning peak period station arrivals, implying that the morning peak period has spread earlier in all stations. This suggests that commutes are getting longer and more unpredictable, so more people are including a larger travel time allowance to ensure punctual arrival at the workplace.

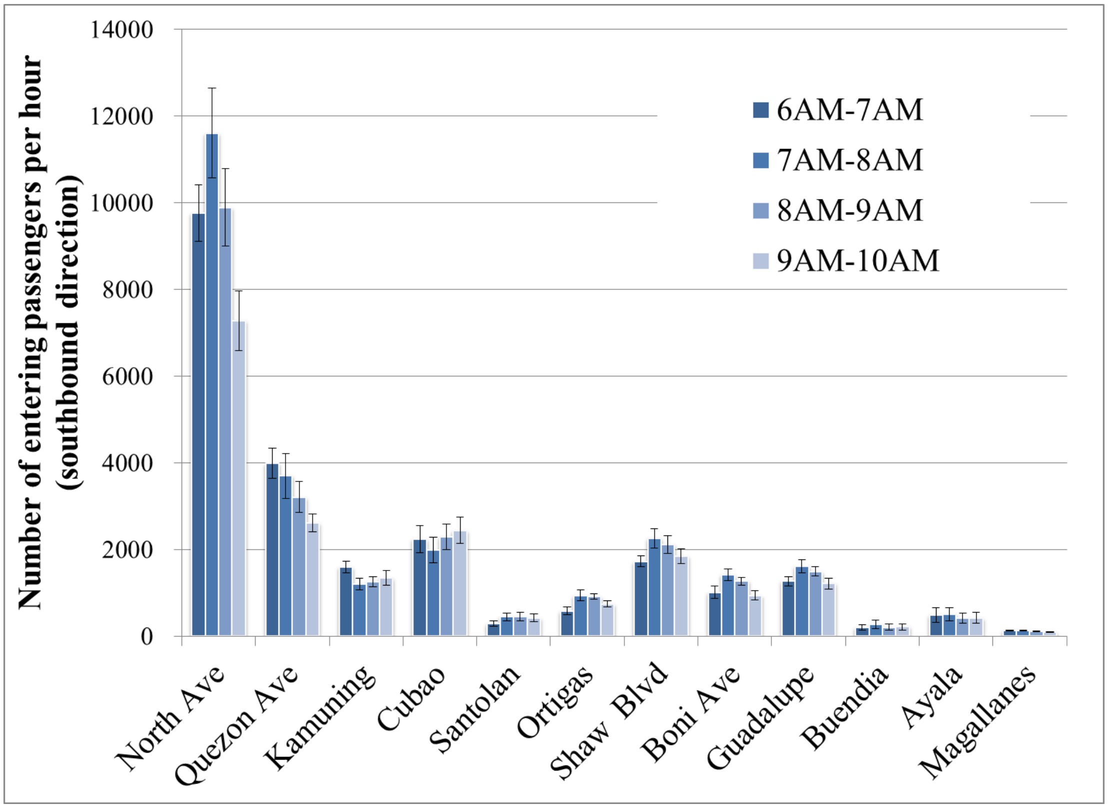


Figure 3.6. Estimated mean and standard deviation of station hourly passenger demand in 2013 (entries at the turnstiles headed to the southbound direction)

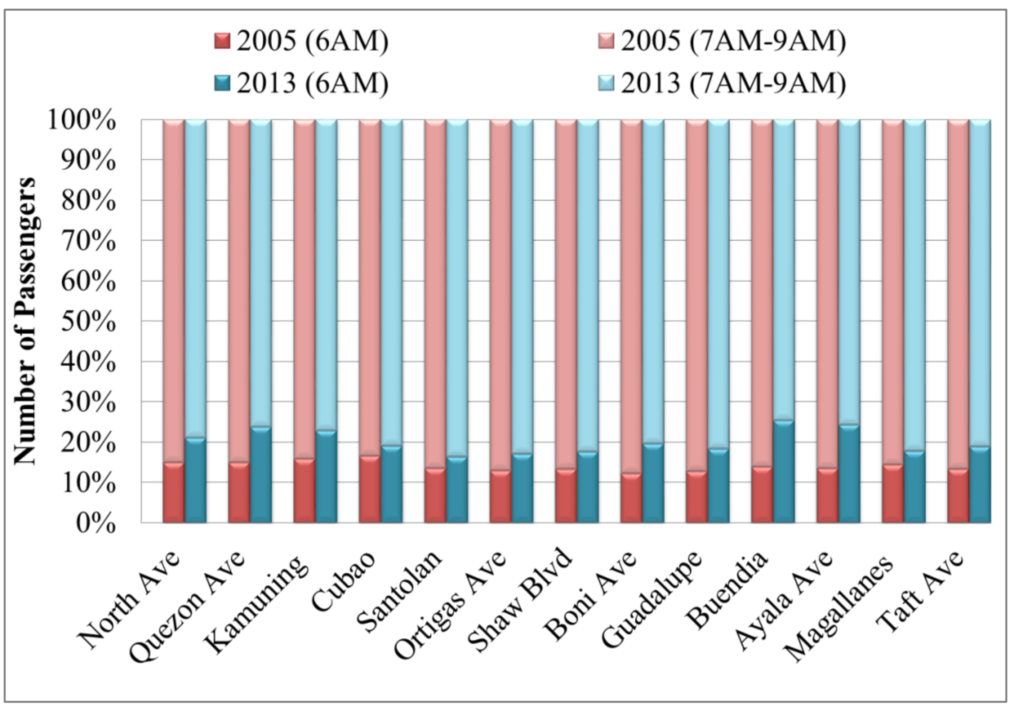


Figure 3.7. Comparison of morning peak period arrivals in 2005 and 2013

3.3.4. Fare Increase in January 2015

After many years of deliberation and amid widespread opposition, fare levels were finally increased by the government in January 2015. From a fare structure charging PhP10 for first 3 stations plus P0.50 for every station thereafter (rounded to the nearest peso), it was changed to PhP11 plus PhP1 formula, causing a fare increase ranging from 30% for short-distance trips to 87% for longer trips. As mentioned in Section 3.2, this was an unexpected major change in the context of this research study, so it was not accounted for in the design of surveys in 2013 and 2014. However, it is interesting to remark on the immediate effect of the fare increase on ridership.

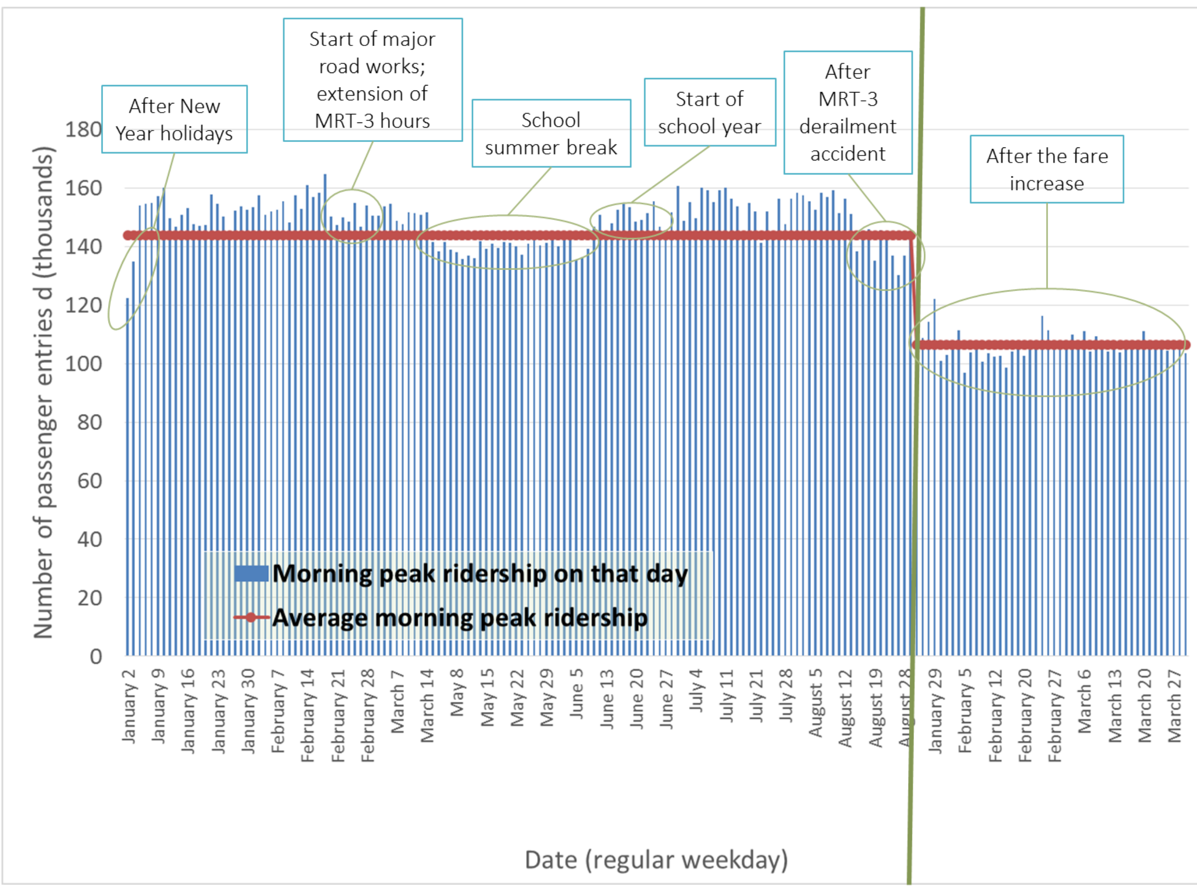


Figure 3.8. Morning peak period ridership trend from January 2014 to March 2015

Surveyors noted in February 2015 that the morning peak period queue lengths after the fare increase are less than that of previous queue lengths. To confirm this, hourly ridership data (entry and exit) was requested from DOTC-MRT3 from January 2014 to March 2015.

Only the data on regular weekdays from 6 AM to 10AM were included in the analysis. Due to some technical problems at the MRT-3, hourly ridership was not recorded by the management from March 17, 2014 to April 30, 2014 and from September 1, 2014 to January 25, 2015. Moreover, the available records on the time of writing is only up to the end of March 2015. All in all, there are 132 and 44 data points before and after the fare increase, respectively.

As seen in Figure 3.8, there are several events or periods that coincide with an observable increase or decrease in ridership. Most are yearly trends such as school summer break, however, notable changes also occurred due to certain incidents. Most notably, ridership was observed to decrease immediately after the derailment accident on August 13, 2014 until the end of the month. Due to technical difficulties, MRT-3 was not able to record the ridership figures from September 2014 until the third week of January 2015, so this decreasing trend could not be explored further. However, an observation survey was done in October 2014, and results suggest that the ridership recovered at least during that day.

Table 3.2. Fare elasticity of the MRT-3

		Before Fare Increase	After Fare Increase
Ridership	Weekday (daily)	560,416	401,009
	Morning peak period	148,608	105,830
	Average fare level (PhP)	12.50	20.50
Fare elasticity	Weekday (daily)	-0.44	
	Morning peak period	-0.45	

Table 3.2 shows the fare elasticity of MRT-3 for weekday and morning peak period ridership. The results are a bit larger than the frequently used Simpson-Curtin formula of -0.33. The data used only takes into account the demand figures from January to March 2015, and there could be a chance that the passenger demand would recover as the system reaches equilibrium. Nonetheless, it can be said that the fare increase induced a significant decrease in passenger demand, at least in the immediate term.

A possible explanation for this is the discrepancy between MRT-3 fare levels and its competitors (i.e. ordinary bus and air-conditioned bus). Figures 3.10 and 3.11 summarize the differences between the old and newly implemented fare policy as well as the fare levels for the same distance by ordinary and air-conditioned bus. It seems that the old MRT-3 fare structure is cheaper than air-conditioned bus for all distances, and cheaper than ordinary bus for more than five stations, but the same or slightly more expensive for less than five stations traveled.

However, the new MRT-3 fare structure is significantly more expensive than that of an ordinary bus for up to nine stations and that of an air-conditioned bus for up to six stations. It is still cheaper than both types of buses for longer distances but the fare difference is not that big as before. For people who only care about saving money and/or are more averse towards waiting and crowding, the fare increase may have caused the bus to be a more attractive option than MRT-3.

Considering that ordinary and air-conditioned bus are used as feeder access modes to MRT-3 as well, it may be useful to provide a comparison of the fare levels between using the bus as feeder plus MRT-3 as trunkline mode, and using just the bus for that trip component. Using only a bus instead of transferring to the MRT-3 would eliminate transfer time and additional base fare due to the change in transport mode. Before, it was economical to take the former option, but because of the fare increase, it could be cheaper and more comfortable to take the bus alone. The fare difference depends on how far ahead of the MRT-3 line the passenger would start his trip by bus.

Bus fares are comprised of two components: base fare, which is a flat fare covering the first 5 km; and incremental fare, which is an additional fare for every extra km traveled. Given this, passengers who use bus as feeder modes to North Avenue need to pay an extra base fare for using MRT-3, whereas those who use the bus entirely pay for the lower incremental fare.

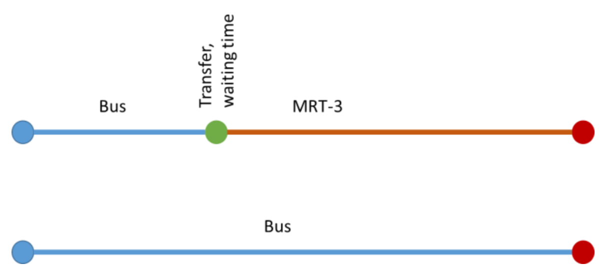


Figure 3.9. Illustration of using bus as feeder mode and MRT-3 as main mode vs. bus as main mode

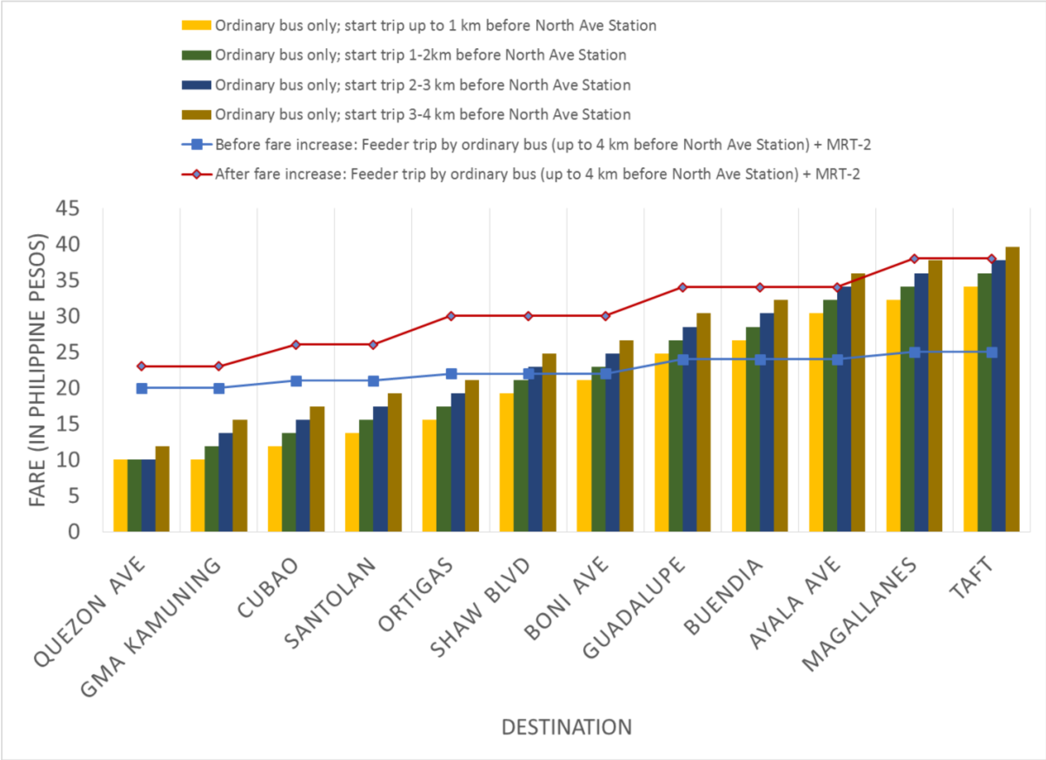


Figure 3.10. Comparison of fare levels using ordinary bus + MRT-3 and ordinary bus only

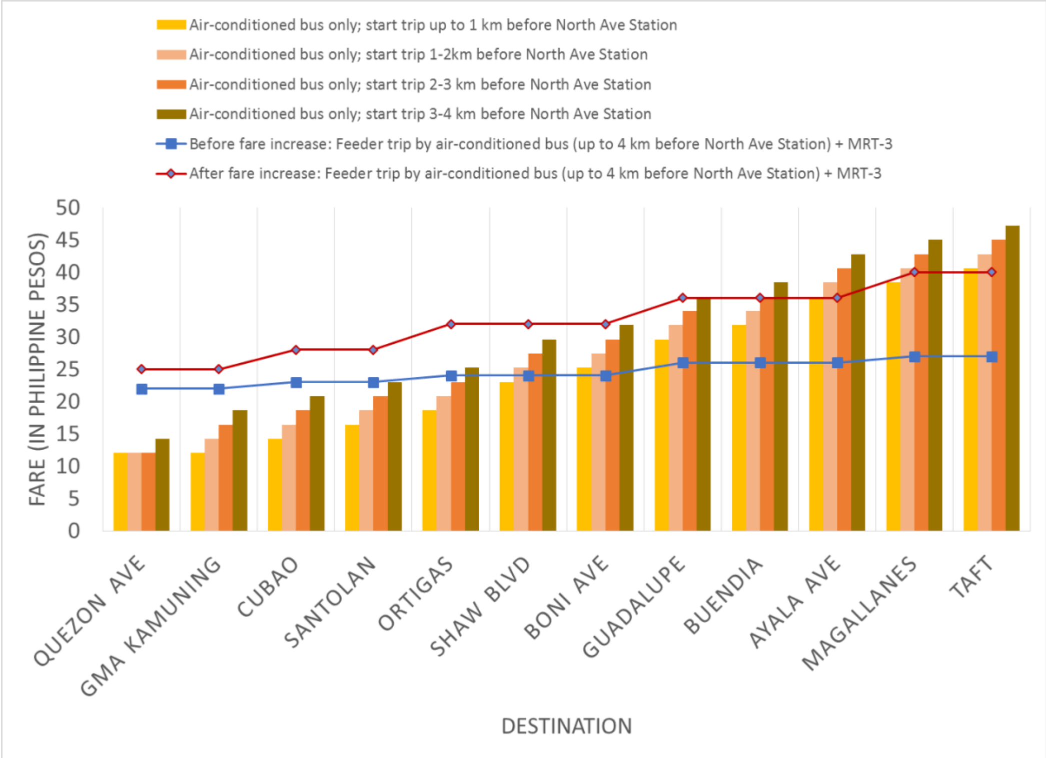


Figure 3.11. Comparison of fare levels using air-conditioned bus + MRT-3 and air-conditioned bus only

The effect of precipitation on ridership was also tested, but the t-test results suggest that there is no significant link between the two. Moreover, classes and work are suspended by the government when there is unusually heavy precipitation.

The average morning peak period ridership (6AM to 10AM) is observed to decrease for both passenger entry and exit data. The average decrease for entry data is at around 29%, while that of exit data decreased by 31%. It was observed that some stations have higher passenger entry and exit drops compared to others. For instance, North Avenue passenger entries only reduced by 15%, while that of Quezon Avenue, GMA Kamuning and Cubao Stations dropped by around 45%. Moreover, there is a higher than average decrease in end-to-end trips, as indicated by the significant drops in passenger exits at the terminal stations (i.e. North Ave and Taft Stations).

3.4. Operation Policies in Place

This sub-section outlines the operations policies that are put into place as a response to the control the increasing passenger demand and address safety concerns. As MRT-3's ridership continues to grow alongside Metro Manila's population, the system becomes more and more overburdened. To address this, DOTC MRT-3 implements several policies that offer technical solutions given the system's limitations on its infrastructure.

3.4.1. Crowd Control Policy

As part of their crowd control scheme, the MRT-3 operator has been implementing the "stop entry" policy since December 2013, in which the number of passengers on the platform is limited to 500 passengers at a time.

Security guards are deployed at certain entry points to control the entry of passengers, as seen in Figure 3.12. This policy aims to improve safety and passenger flow at the platform and into the train, and allows more passengers to board at subsequent stations. However, this has caused queues to extend onto the roadside especially at the northernmost terminal (North Ave. Station), as well as subsequent complaints from passengers. It was observed that there is inadequate space for queuing – stairs, northbound platform, pedestrian walkways and overpasses, and sidewalks – were used for queuing. This could be problematic from the viewpoint of safety prolonged standing load on stairs (which are generally designed for moving loads) and roadside queuing which forces passengers to occupy the sidewalks alongside vehicular traffic, which could cause prolonged exposure to air pollution and accidents.

(left: main entrance; right: entrance from northbound platform)
*Figure 3.12***.** Crowd control policy implementation at two entry points

Before this policy was implemented, the ticketing areas and station platforms were visibly more crowded (see Figure 3.13). After its implementation, platform crowding was reduced but this implied longer queuing at the roadside and stairways.

(left: September 2013; right: February 2015)
Figure 3.13. Comparison of platform queuing before and after crowd control policy implementation

Given that crush capacity of an MRT-3 train is at around 1,200 passengers, this means that the trains would be full by the time it arrives at the third station. As there are very few (if any) alighting passengers at the first five stations, the trains are packed full until then, and many passengers at the third to fifth station have to wait longer at the platform.

In addition, tickets can only be used within 99 minutes from entry from boarding station turnstile to prevent passengers from overstaying in the station; otherwise, a penalty would have to be paid. However, there is a possibility that passengers' tickets expire due to the excessive platform waiting time.

A comparison of the number of passenger entries at North Avenue Station before and after crowd control policy was implemented shows that there has been a substantial decrease in official passenger entries, as seen in Figure 3.14.

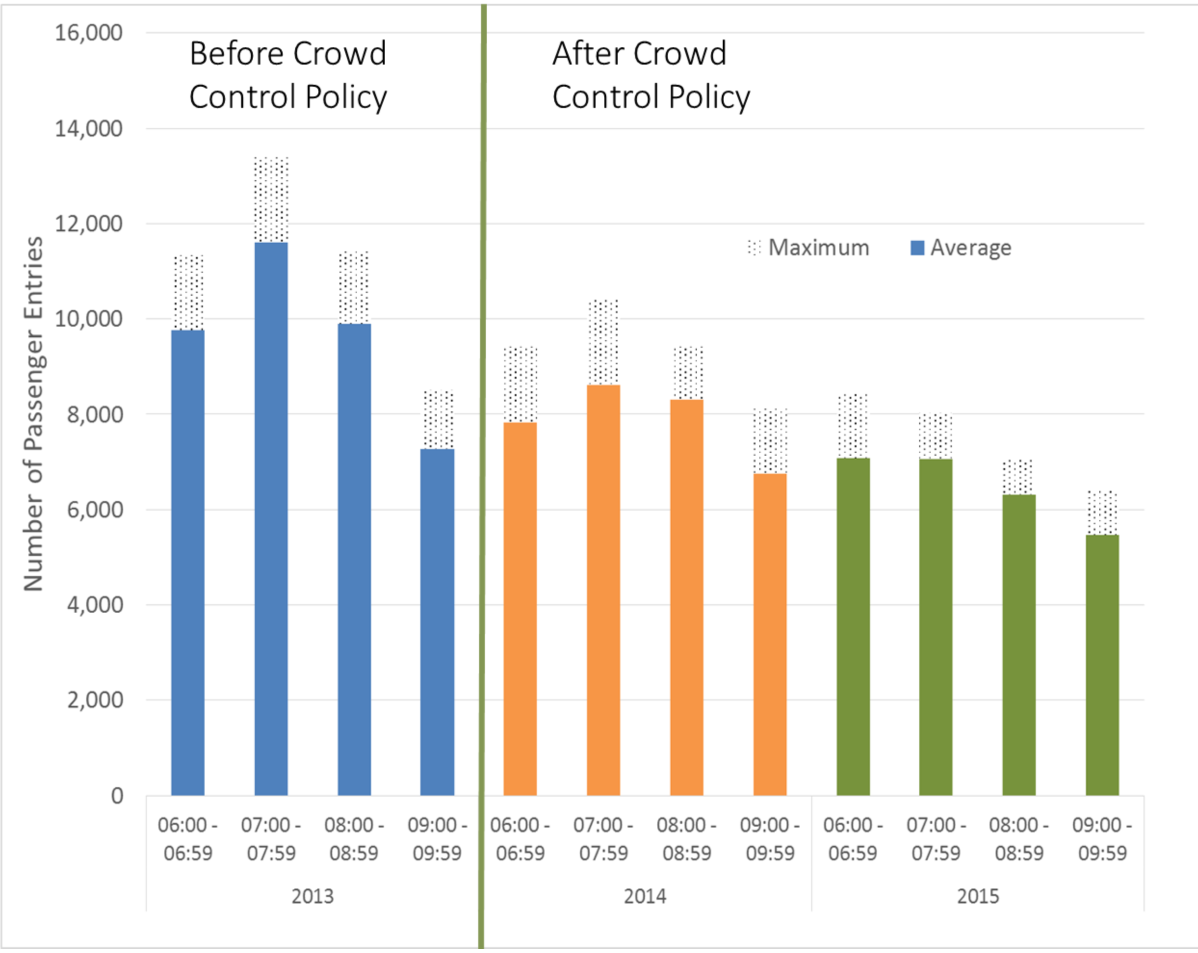


Figure 3.14. Hourly passenger entries at North Avenue Station before and after the implementation of crowd control policy

This may be attributed to the aforementioned crowd control policy implemented in December 2013. Since the number of passengers at North Avenue Station is limited to 500, the hourly entry at the station turnstiles is capped at around 10,000 passengers assuming 20 trains per hour. While this prolongs passenger waiting time at the first station (southbound direction), it allows the passengers to have a higher probability of boarding at succeeding stations. As a result, there was an increase in ridership in GMA Kamuning and Cubao stations. A slight increase in ridership is also observed in Ayala Avenue and Taft Stations, but all other stations have lower ridership. All in all, there was a 5% decrease in total ridership during the morning peak period (6:00 to 10:00 AM) with and without crowd control. A subsequent analysis on the daily ridership at the MRT-3 revealed that there are no spillovers of morning peak ridership to other time intervals.

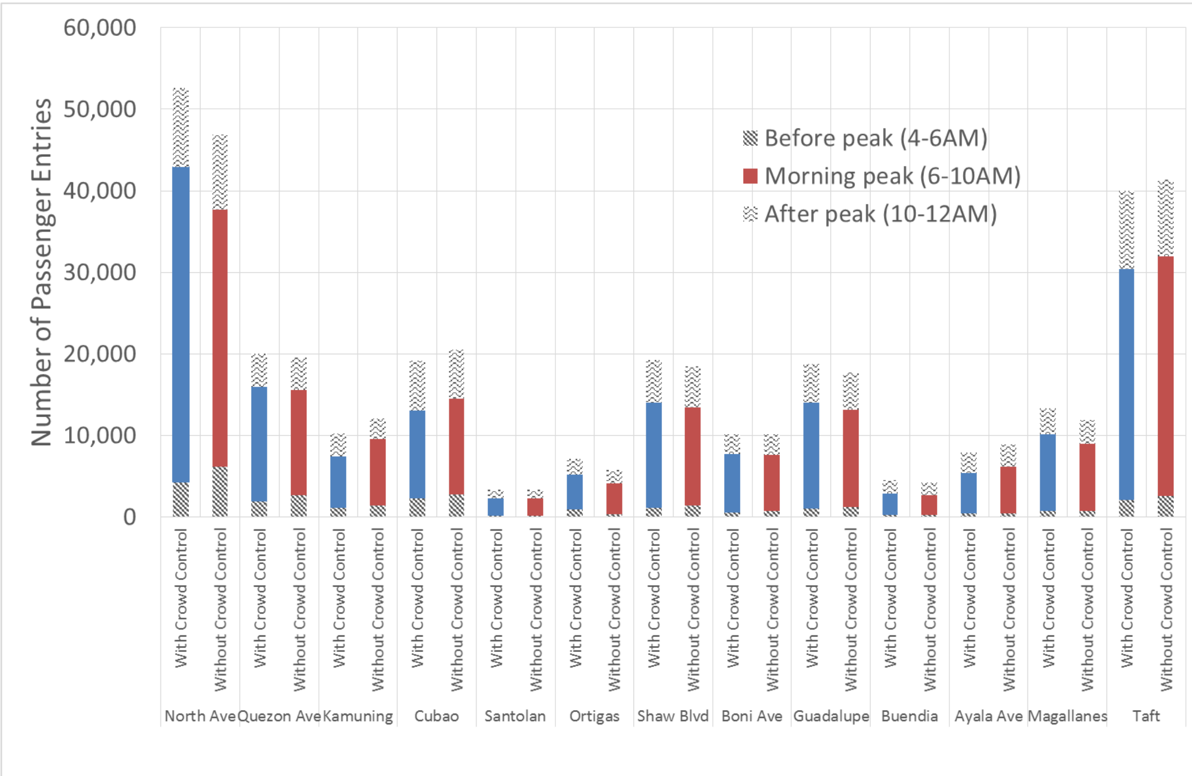


Figure 3.15. Station hourly passenger entries before, during and after the morning peak period,

3.4.2. Skipping Train Operations Policy

There are two kinds of trains that are dispatched from the terminal stations: regular trains and skipping trains. Regular trains stop at all stations, while skipping trains, as the name implies, skip the first two or three stations and starts loading passengers at the subsequent station. This demand-responsive policy intends to alleviate passenger queuing at downstream stations, but prolongs queuing for passengers at the skipped stations. There is no fixed daily schedule for the deployment of a "skipping train" because it is dependent on the conditions for the period in question. The MRT-3 management closely monitors the situation and dispatches a skipping train to congested stations as needed. Based on the surveys conducted in July and September 2013 and October 2014, "skipping trains" are deployed at different times of the day and roughly around every 30 minutes during the morning peak period ends, possibly depending on factors such as passenger demand at each station and availability of train sets. In a previous study, skipping train operations policy was found to increase equity of passenger overload delay by reducing the delay of overburdened passengers and increasing the delay of others, but reduces efficiency by increasing total passenger overload delay across the system (Mijares *et al*., 2013).

3.4.3. Train Speed and Headway Policy

The number of operating trains were increased from 18 to 20 trains in June 2014 to serve 2,364 more riders per hour. However, in August 2014, the train speed was decreased from 60kph to 40kph to address safety concerns that arose after an overshooting accident in the same month (Philippine Star, 2014). As a consequence, the published peak period headway was increased from 3 minutes to 4 minutes (DOTC-MRT3, 2014) and queues were reported to be longer especially at the northernmost terminal station. Dwell time was also published to be at around 20 to 30 seconds.

However, the observation surveys as well as secondary data (refer to Table 3.2) reveal that the actual headway and dwell times are significantly higher than the published values, which indicates lack of schedule adherence.

Table 3.3. Headway and dwell time during the morning peak period in the southbound direction

Variable	Average (*standard deviation*) in minutes		
	February 2014 (Ebia and Ramirez, 2014)	July and September 2013 (5 regular weekdays)	October 1, 2014
Headway	4.7 (*0.60*)	4.83 (*1.08*)	7.54 (*1.38*)
Dwell time at Cubao station	-no data-	0.87 *(0.35)*	2.00 (*1.27*)

3.4.4. Experimental Policies

With its existing infrastructure inadequate in servicing passengers, the MRT-3 management has begun looking into an alternative mode, the bus. While there are public utility buses running parallel to the MRT-3 alignment, they are generally more costly and less reliable so many commuters still prefer to use MRT-3. In March 2013, the MRT-3 management introduced an experimental bus system but was immediately stopped because of lack of coordination. This scheme was tried again in May 2014 with the use of an articulated bus that ran from North Avenue, made three stops along MRT-3, and continued to the Ninoy Aquino International

Airport. Since road congestion is severe in Metro Manila, these schemes were not successful in funneling some of the MRT-3 demand onto the express buses. It illustrates that even with equal fare levels and long queuing time, MRT-3 passengers prefer buses because the overall travel time is still lower. Nonetheless, another pilot study of a new express bus scheme is scheduled to be implemented in March 2015, with trips originating from Fairview, Quezon City and ending at Ayala Avenue Station in Makati.

Moreover, it also tested an experimental policy called express train scheme in May 2014 as a prospective solution to improve passenger congestion and travel time. In this scheme, an express train run starts at the first station (North Avenue), serves the next station (alternating between Quezon Avenue, Kamuning and Cubao Stations), and then continues on to major destination stations (Buendia, Ayala, Magallanes and Taft). Less stops translate to lower dwell time and thus shorter in-vehicle travel time. A total of 15 express trains ran within the 7:00-9:00am period were deployed (later moved to 6:30-8:00am) and also during the afternoon peak period (5:00-7:00pm), and regular trains were dispatched in between express train runs. However, the scheme was cancelled after an experimental run of three weeks despite positive feedback (Rappler, 2014) and replaced again by the skipping train operations scheme discussed in Section 3.4.2.

3.5. Level of Service Experienced by Passengers

This section presents the survey findings on the level of service experienced by passengers, with focus on the waiting time (both station access time and platform waiting time), in-vehicle travel time, and passenger density inside the train.

3.5.1. Station Access Time and Queuing into the Station

Queuing outside the station was observed at both North Avenue and Cubao Stations, with the former having longer queues that extend up to the roadside. The length of roadside queues were deduced through site inspection and video recording surveys. It was found that there are a total of six queues merging into the station turnstiles, of which four queues are from the southbound direction of EDSA and two queues from the northbound direction of EDSA. The northbound queues fall in line in a covered walkway and need to cross a pedestrian bridge to access the station. On the other hand, the southbound queues are mainly exposed to heat or rain, with only a few large parasols spaced several meters apart to protect them. This also serves as a loading and unloading area for public utility buses and FXs, but because the sidewalk space is already being used by the passenger queues, vehicles were observed to unload passengers on the road itself. Figure 3.16 shows this phenomenon, and it can be seen that the queue has exceeded 500 m, with people queuing at the roadside (northbound and southbound EDSA) and at the pedestrian overpass.

Figure 3.16. Queuing extends up to around 500 m from North Ave. Station

Moreover, there is another queue that goes from the northbound platform to a pedestrian walkway leading directly to the southbound platform (meaning that they skip the southbound turnstiles and do not need to pay for another ticket) to make a “round trip”. These passengers originate from downstream stations heading in the opposite direction. As it is less probable to get a seat at those stations, some passengers take the northbound train to North Avenue station, and then transfer to the southbound train; however, it is unclear whether all passengers on this queue are “round trip” passengers. At Cubao Station, queues also reached up to the roadside but only up to around 100 m at most. There are separate queues for men and women, probably to even out the distribution of the passengers on the platform because the first out of three cars can be used by women, while the other cars can be used by both men and women.

Figure 3.17 summarizes the total waiting time survey results (refer to Section 3.2.2.1 for the methodology) for North Avenue and Cubao Stations. Due to some limitations, only one surveyor was deployed for Cubao Station. Nevertheless, it is clear from the figures that a very long time is spent by passengers waiting from the roadside to the second level, with that waiting time component taking up the most time. GPS data shows that queues stop moving from time to time, which could be attributed to batch servicing (i.e. non-continuous) at the station entry points where they control passenger entries. As a result, passengers spend a disproportionate amount of time standing still at the sidewalks and staircases. Passengers are exposed to exhaust fumes as well as heat or rain, which may lead to exhaustion or more serious health impacts.

In addition, the queue length and total waiting time fluctuate during the period considered, depending on random factors such as passenger arrivals, train occupancy, and operator-side factors such as regular train and skipping train dispatch. On the other hand, there seems to be no problem with purchasing single journey tickets at both stations, probably because many regular passengers possess a stored value ticket and do not need to purchase one every time. Platform waiting time is also low for North Avenue Station because of empty regular trains. Meanwhile in Cubao Station, the surveyor was lucky that he arrived just in time for the skip train so he did not have to wait at the platform for a long time. However, it can be seen in the next subsection (Section 3.5.2) that platform waiting time at that station varies considerably. This means that his total waiting time would have increased had he arrived at a different time.

Figure 3.18 presents the cumulative roadside arrival and platform departure curves, which was estimated based on the queue lengths and assumed passenger density at the queue (based on visual observation in the video observation survey: around 4 passengers for every 3 m of queue length with a total of six queues) and calibrated using the total waiting time survey data presented in Figure 3.14. It shows that almost 12,000 passengers arrived at the roadside during the 90-minute interval, but only around 8,500 passengers are served, meaning that there is an average queue length of 3,500 passengers.

North Avenue Station (Station 1)

Starting Time of Surveyor	Length of one queue (total of six queues)	Total Waiting Time: Station Access Time						Total Waiting Time: Platform Waiting Time	Train Boarding Time of Surveyor	Total Waiting Time of Surveyor
6:45:00AM	375 m	17 min 22 sec	6 min 20 sec	34 sec	10 sec	54 sec	7 min 28 sec	3 min 55 sec	7:21:43AM	36 min 43 sec
7:00:00AM	310 m	26 min 43 sec	2 min 2 sec	2 min 23 sec	2 sec	1 min 15 sec	40 sec	2 min 9 sec	7:35:14AM	35 min 14 sec
7:15:00AM	330 m	19 min 6 sec	2 min 34 sec	1 min 0 sec	23 sec	37 sec	37 sec	2 min 29 sec	7:41:46AM	26 min 41 sec
7:30:00AM	430 m	21 min 51 sec	8 min 34 sec	1 min 33sec	59 sec	24 sec	24 sec	5 min 42 sec	8:13:52AM	43 min 52 sec

End of roadside queue → 2nd level → 3rd level (security check) → End of ticketing queue → Ticketing booth → Station turnstile → End of platform queue → Boarding the train

Cubao Station (Station 4)

Starting Time of Surveyor	Length of one queue (total of two queues)	Total Waiting Time: Station Access Time						Total Waiting Time: Platform Waiting Time	Train Boarding Time of Surveyor	Total Waiting Time of Surveyor
8:00:00AM	200 m	1 min 5 sec	2 min 1 sec	1 min 41 sec	38 min 49 sec	9 sec	1 min 45 sec	3 min 55 sec	8:50:14AM	50 min 14 sec

Roadside (access to ticketing booth) → 2nd level (end of ticketing queue) → Ticketing booth → Roadside (end of queue to the station) → 2nd level (security check) → Station turnstile → End of platform queue → Boarding the train

stages of queuing and corresponding time spent at each stage

Figure 3.17. Total waiting time survey results at North Avenue and Cubao Stations

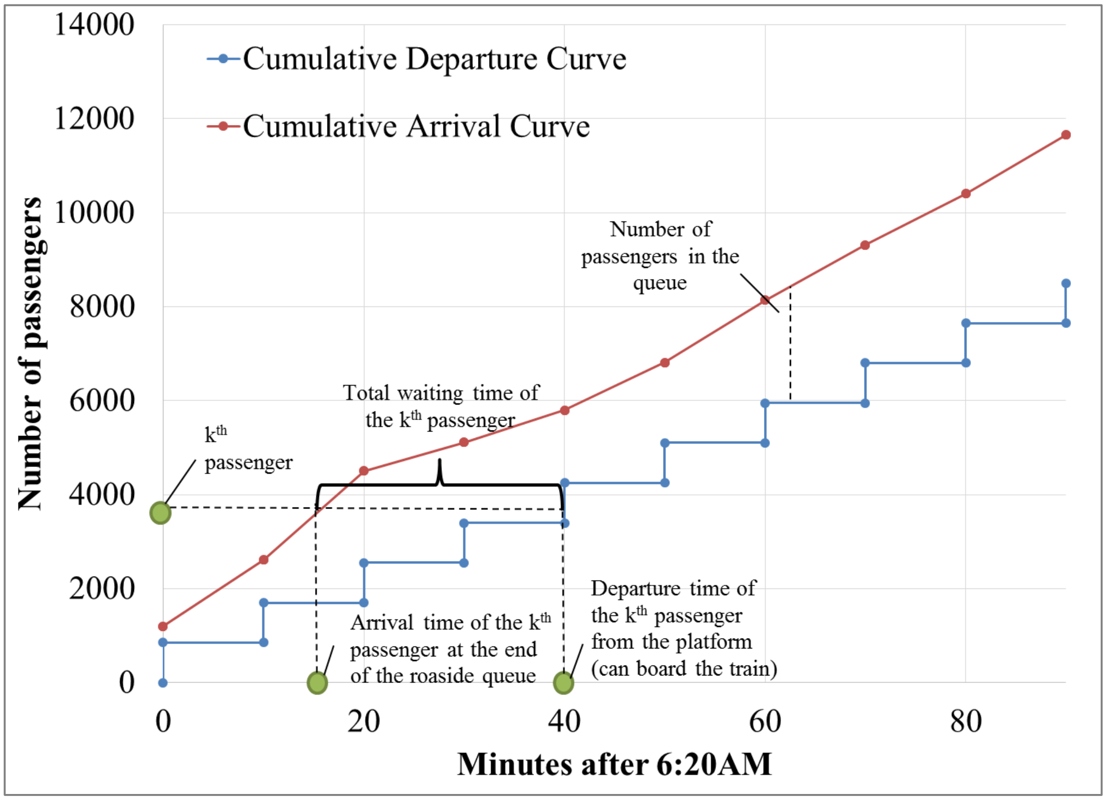


Figure 3.18. Estimated cumulative roadside arrival and platform departure curves at North Avenue Station

As a side note, there was a noticeable change in the queuing phenomenon after the implementation of the fare increase in January 2015, as seen in Figure 3.19 (a comparison can be made with Figure 3.16). However, due to time and resources constraints in the research timeline, a more detailed investigation was not made. This could be the subject of future work.

Figure 3.19. Queuing at MRT-3 North Avenue Station in February 2015 at 7:00 am

3.5.2. Platform Waiting Time and Its Variability

This sub-section focuses on the platform waiting time at the MRT-3. The first part outlines the results of the survey in 2013 when there was no crowd control policy in place (see Section 3.4.1 for more details on this policy), while the second part shows the situation in 2014 after the crowd control policy was implemented.

3.5.2.1. Survey Results in July and September 2013 (No Crowd Control Policy)

The results of the video observation survey indicate that some stations experience highly variable and long platform queuing times and many missed trains. For the first two stations, platform waiting time and its variability were not as severe. Since the platform waiting time survey was conducted before the crowd control policy was put in place, it was observed that platform waiting time and crowding is excessively high for passengers boarding at GMA-Kamuning, Cubao and Santolan-Annapolis Stations (3rd, 4th and 5th stations). The survey also shows that passengers at other stations (6th to 13th stations and northbound passengers) do not experience prolonged platform waiting time in general.

Figure 3.20. Screenshots of the passenger tracking survey at Cubao Station (4th station)

Figure 3.20 shows an example of a passenger who was tracked from the time she appeared on the frame up to the time she boarded the train. In this case, she waited for almost an hour until she was able to board the 11th train to arrive. There are two factors fueling this phenomenon: (1) on the demand side, trains are full by the time it reaches Cubao Station due to high upstream station demand so only a few passengers at Cubao can ride on each train, and the demand at this station is also high; and (2) on the supply side, only 11 out of 20 scheduled trains arrived so it effectively reduced the planned system capacity by 45%.

Figures 3.21 and 3.22 show that platform waiting time starts to increase for passengers arriving beyond 6:45am as more passengers arrive and trains become full by the time they reach those stations. It can be noted from Figure 11 that skipping train empties the platform at the Kamuning Station (3rd station). For example, the skipping train at 7:50 am on September 19 served passengers that arrived from 7:00am to 7:50 am, as denoted by the light blue dots. However, the same skipping train has a minimal effect on Cubao Station (4th station) because it is already full. Platform waiting time is seen to be highly variable as indicated by the standard deviation. This translates into many missed trains, which could make passengers weary and anxious.

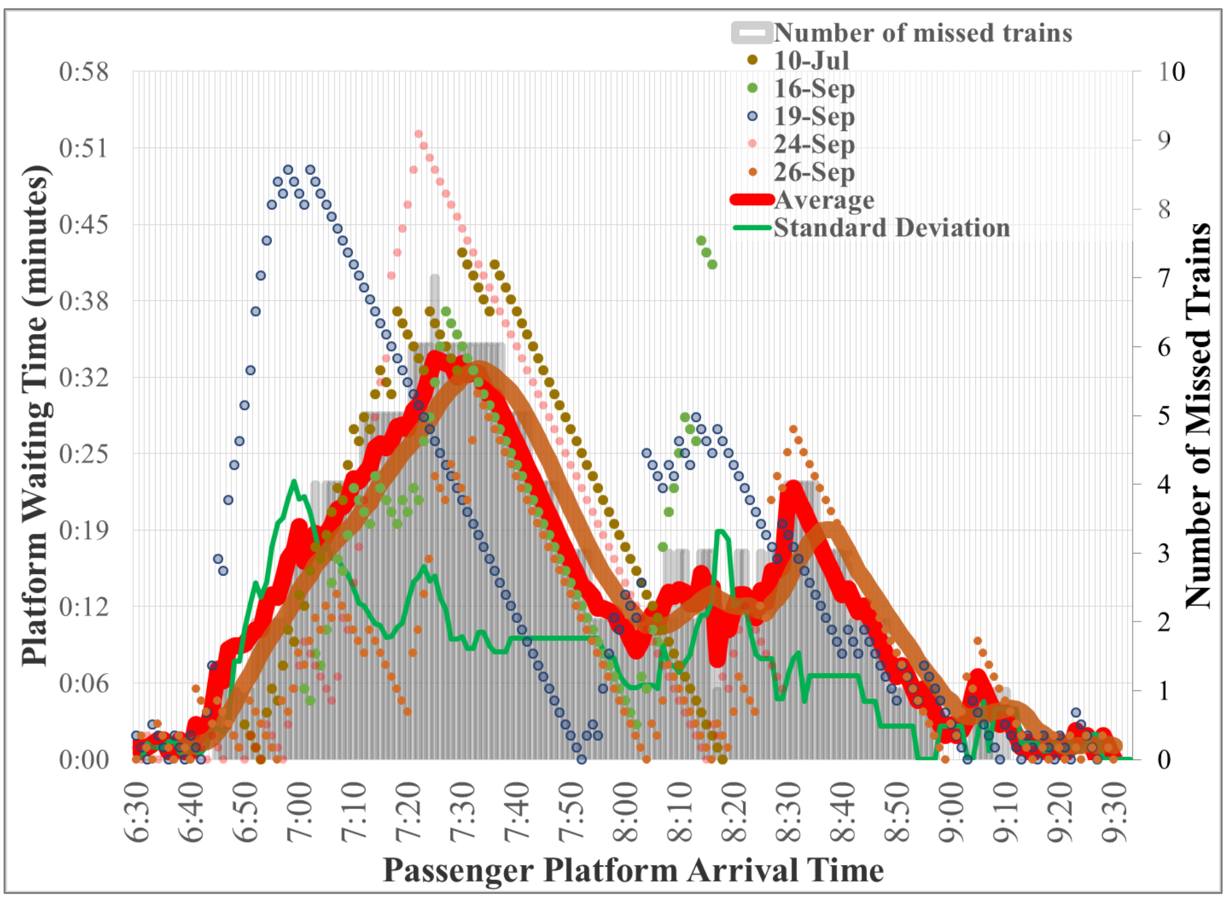


Figure 3.21. Platform waiting time at Kamuning Station in 2013 (3rd station; southbound)

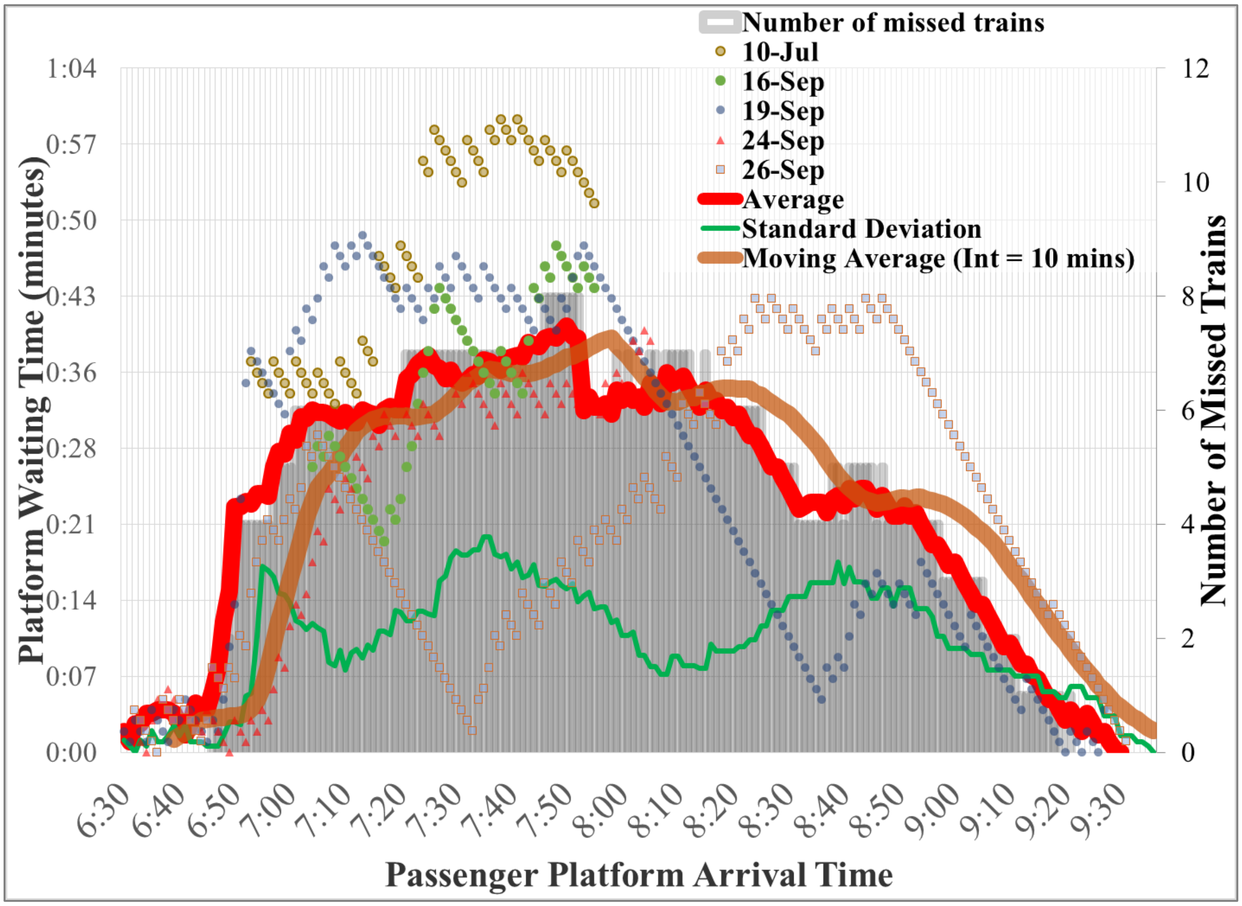


Figure 3.22. Platform waiting time at Cubao Station in 2013 (4th station; southbound)

The platform waiting times experienced by some passengers are very high considering that under a perfectly regular headway with adequate capacity, the average platform waiting time should just be equal to half the headway (around 2 minutes). In this sense, these passengers experience a passenger overload delay equal to the difference between actual platform waiting time and uncongested platform waiting time.

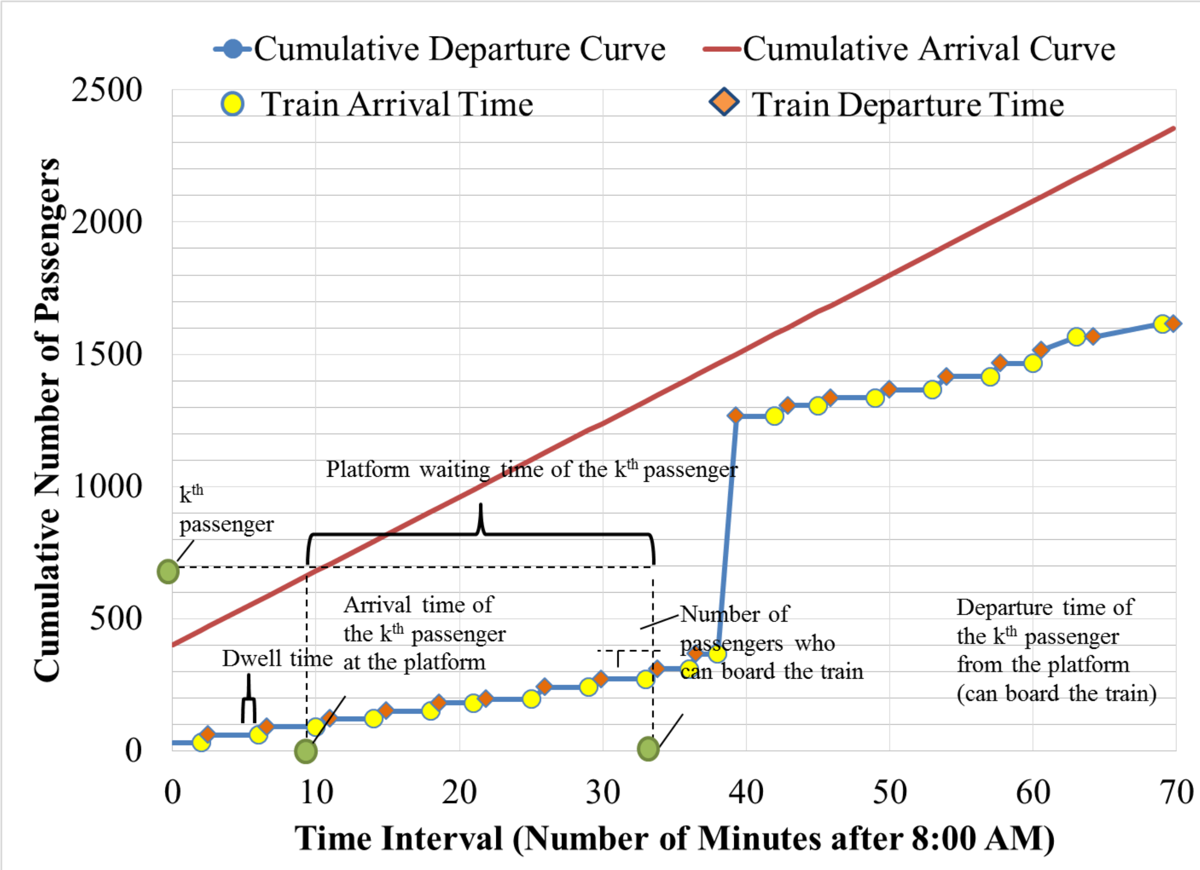


Figure 3.23. Cumulative platform arrival and departure curves at Cubao Station in September 2013 (without crowd control)

3.5.2.2. Survey Results in October 2014 (With Crowd Control Policy)

Figure 3.24 shows the severity of the platform waiting time at Cubao Station as confirmed by the October 1, 2014 (8AM to 9AM) survey. It implies that the platform waiting time can range from zero (if one arrives at the platform exactly when the skipping train arrives) to as high as an hour, on top of the station access time. It shows that around 1,800 passengers arrived at the platform during the survey period, but only 1,300 passengers were served. Even though a train arrives every five to seven minutes, only a few passengers (around 1 to 3 people per train door; total of 15 doors) can board because the trains are full and there are almost no passengers alighting at this station, and around 30 people are left on the platform queue per door (refused passengers).

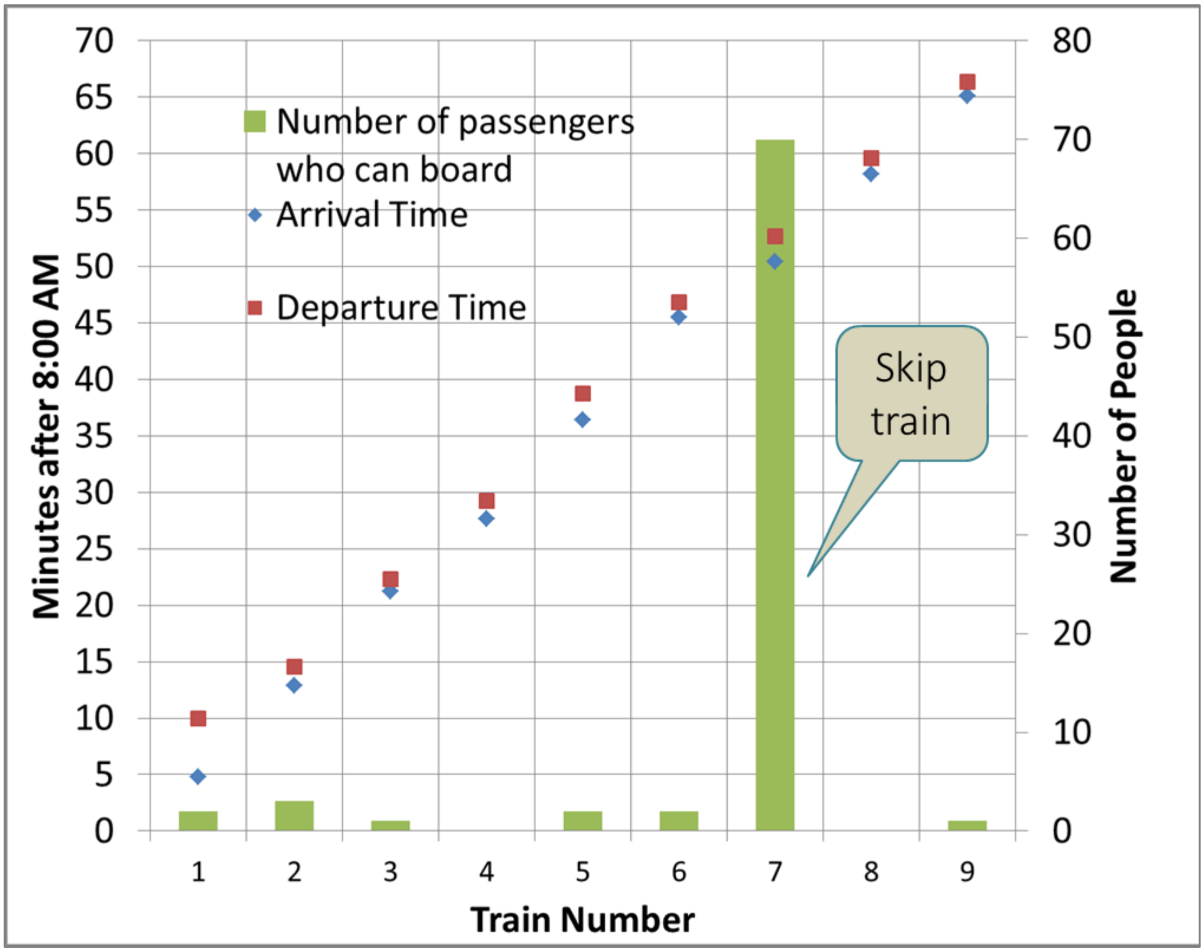


Figure 3.24. Train arrivals and corresponding number of passengers who can board at Cubao Station in October 2014 (with crowd control policy)

Only one skipping train arrived during the hour considered. It can be seen from Figure 3.24 that queuing at the platform dissipates after a skipping train arrives (7th train), however, queuing remains outside the station turnstiles. The trains that arrive after the skipping train are full and again, barely any passengers can board. In addition to the access time into the station (roadside queuing, buying tickets, etc.), passengers would have to wait for an invariable time (ranging from zero if there is no platform queue to up to almost an hour).

Based on a sample of 115 passengers arriving during the survey period, it was estimated that the average platform waiting time at Cubao Station is 19.92 minutes with a standard deviation of 17.67 minutes. 38 people had zero platform waiting time because they were allowed to enter the platform just in time for the skipping train, but there were 15 passengers who had to wait for 45 to 55 minutes at the platform. This illustrates the wide variability among passengers on the same day, which was also observed in the platform waiting time surveys in 2013.

What then, is the effect of crowd control policy implementation on platform waiting time at Cubao Station? Comparing Figures 3.20 and 3.22, it can be deduced that platform waiting time in October 2014 is similar or even worse for some passengers, but this cannot be pinpointed to the crowd control policy itself. Moreover, passenger demand at Cubao Station is almost the same between the two periods, as presented in Figure 3.12. Thus, the increase in platform waiting time in Cubao Station is most likely attributed to the lower train frequency (and consequently, larger headway) in October 2014. The larger headway is due to the decrease in operating train speed as a response to the derailment accident in August 2014. Thus, the change in train operations in 2014 rather than passenger demand itself is a more significant contributor to increased platform waiting time.

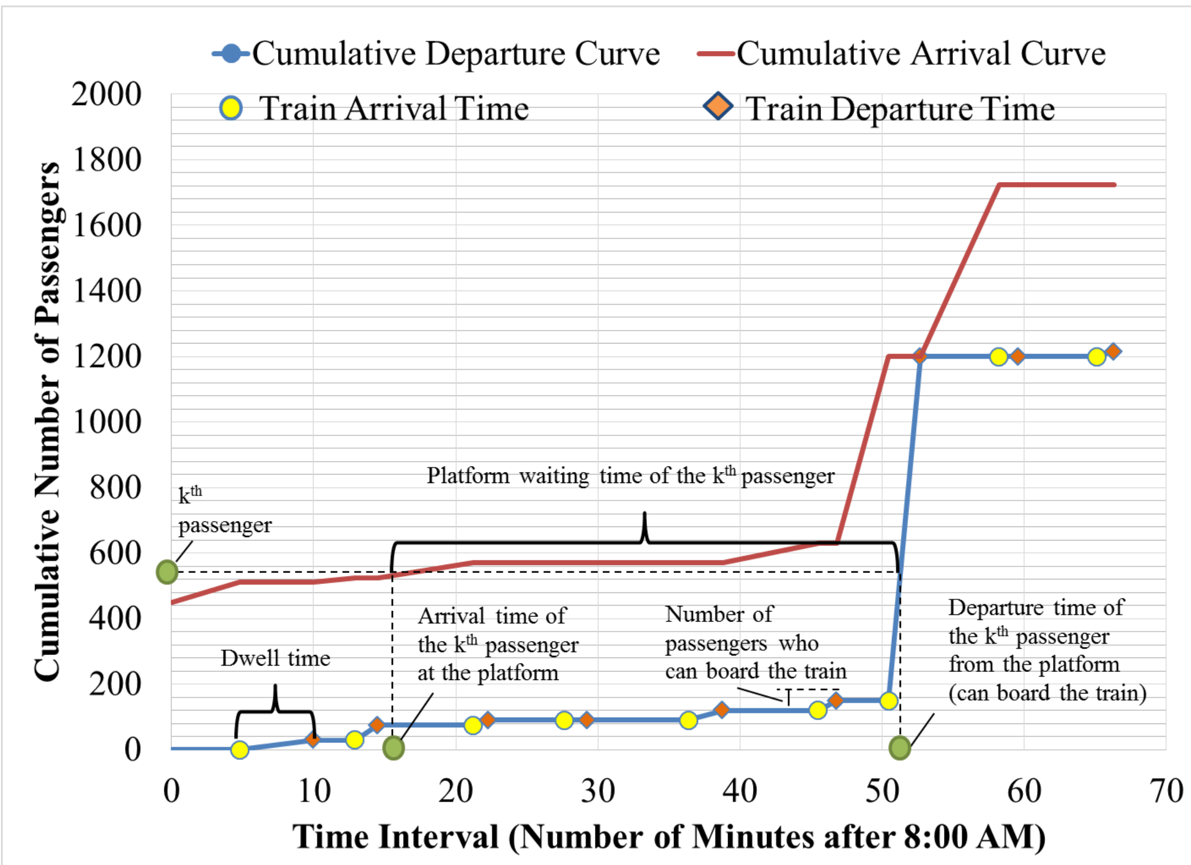


Figure 3.25. Cumulative platform arrival and departure curves at Cubao Station in October 2014 (with crowd control policy)

3.5.3. In-Vehicle Travel Time

In-vehicle travel time in February to March 2015 has increased for MRT-3 as a result of the lower operating speed discussed in Section 3.4.3. However, the average speed of MRT-3 is significantly better than that of air-conditioned and ordinary buses along EDSA even when waiting time is included, which explains why passengers still choose to wait. There were ten data points for each mode.

The results are compared to those of Fillone in 2005, and it can be observed that all modes have lower average travel speeds in 2015 (Table 3.4). This could be attributed to the population increase and rapid motorization trends in Metro Manila.

Table 3.4. Comparison of average travel speed of public transport modes along EDSA between 2005 and 2015

Mode	**Average Travel Speed (kph)**	
	Fillone (2005)	**Survey results along EDSA (2015)**
MRT-3	31.65 kph	23.54 kph (running speed only) 16.07 kph (with waiting time)
Air-conditioned Bus	13.57 kph	11.23 kph
Ordinary Bus	17.07 kph	10.87 kph

One-way ANOVA between groups was performed to determine whether there are significant differences between the three modes in 2015. In-vehicle travel time averages were taken as 42.3 minutes for MRT-3, 89.2 minutes for the air-conditioned bus, and 92.2 minutes for the ordinary bus. The results show that there is a significant difference between the in-vehicle travel times of the MRT-3 and both types of buses [$F(2, 29)=11.065$, $p=0.000$]. However, post-hoc testing using the Tukey test shows that there is no significant differences between ordinary and air-conditioned buses ($p=0.966$), implying that both types of buses have similar travel times. This is expected because both vehicles have the same route and stops.

3.5.4. Passenger Density

The phenomenon can be attributed in part to the boarding and alighting patterns on a regular train, which has an impact on the subsequent crowding (passenger density) inside the train.

Figure 3.26 shows these patterns on a regular (i.e. non-skipping) train during the morning peak period, while Figure 3.27 illustrates the passenger density inside one regular train car, which has a crush capacity of 394 passengers. Both figures are also based on the said survey by Ebia and Ramirez (2014). It can be noted from the Figure 3.26 that the first four stations have considerable passenger demand, but there are significantly less boarding passengers in the third and fourth stations. One contributor to this problem is that there are only a few alighting passengers at this station, which leads to heavy congestion inside the train. The regular trains are full of passengers until it reaches the first major destination station (6th station), where alighting passengers are replaced by new boarding passengers. It stays full until it reaches Ayala Station (9th station), which serve as a gateway to two major CBDs.

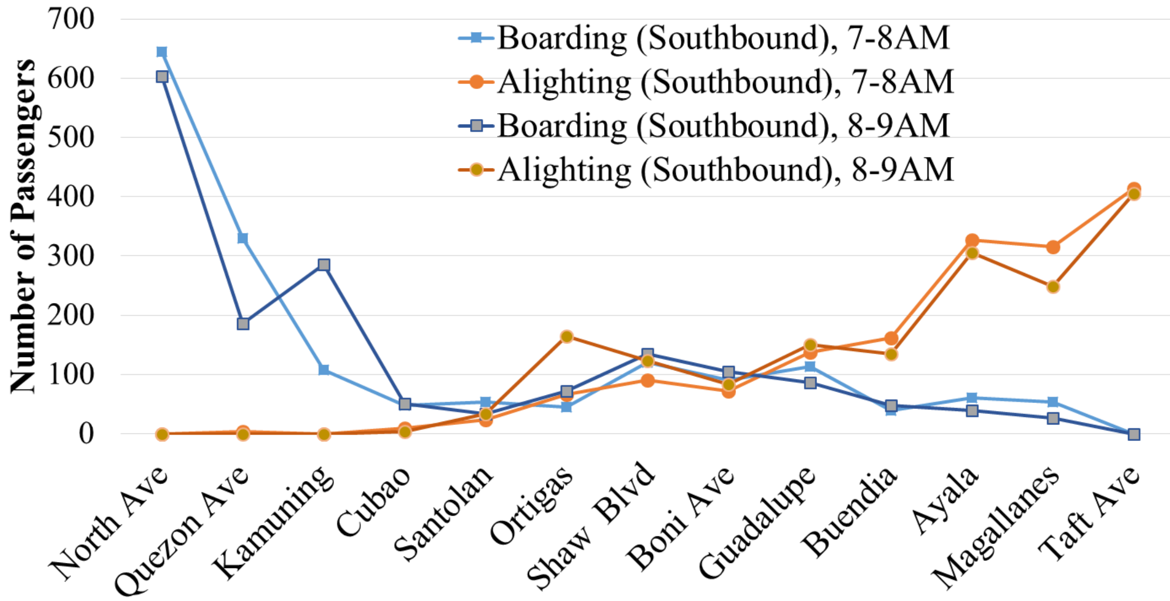


Figure 3.26. Boarding and alighting patterns of southbound passengers on a regular train from 7-9AM (based on Ebia and Ramirez, 2014)

However, the actual coach dimensions indicate that there is only 31.66 sq.m. of area per coach (including seat space; therefore standing area is only around 25 sq.m. if the seat space is deducted (assumption for seat space as measured from a photo: 1.8 m x 0.5 m x 8 long seats – see specifications in Table 1). The number of seats are also contradicting: an earlier document from DOTC-MRT3 states that there are 74 seats per coach, but this number has been increased to 80 seats in a later version of the document although there has been no change in the physical configuration of the train coach which has 8 long seats.

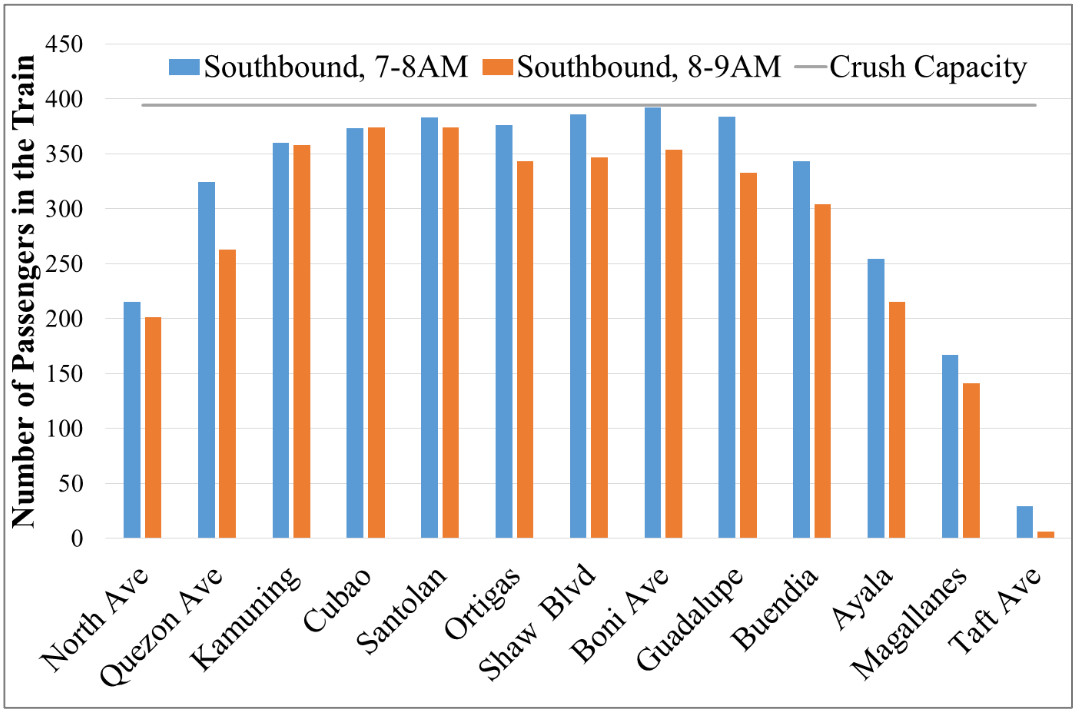


Figure 3.27. Passenger density in one train car (based on Ebia and Ramirez, 2014)

Table 3.5. MRT-3 train dimensions and specifications

Width of coach	2480 mm
Length of train	38300 mm
Number of seats	74
Number of standing passengers at 8 passengers/sq.m. (according to MRT3)	320 (standing area per coach is 40 sq.m. in this case)
"Real" passenger density of crush capacity	12.44 passengers/sq.m. (based on standing area of 31.66 sq.m. as computed from the dimensions)
Opening width of train doors (5 doors per coach)	End doors 2 doors 861mm Central doors 3 doors 1255mm

3.6. Boarding and Waiting Behavior

First In, First Out (FIFO) queuing is observed during queuing at the roadside and platform, except for priority passengers such as persons with disabilities, elderly, children and pregnant women. However, it was observed that once the train arrives, some passengers push their way to the front by shoving others. At Cubao Station, it was noticed that it was very difficult for alighting passengers to get off the train because passengers by the door block the exit and do not give way to let them out, possibly because those passengers may not be able to board back in or they might also assume that no one is getting off at that station. This is unlike the case in Tokyo where passengers by the door usually get off to let alighting passengers out more easily.

It is also interesting to note that passengers behave differently when choosing to board the arriving train or not. Passengers at the northern terminal station, North Avenue Station, are guaranteed an empty train every headway interval (except for skipping trains). As such, it was observed that not all passengers board the first train to arrive even if there is still space and instead choose to wait for the next train in order to get a seat. It is also one of the main reasons why there are “round-trip” passengers who choose to go to North Ave. station. Comfort is more important for this type of passengers, as they are willing to trade off additional waiting or in-vehicle travel time for a secured seat. This was observed for around 20 minutes, and it was deduced that around 5 to 10% of passengers choose to wait for the next train, which implies that there are remaining passengers at the platform and that less than 500 people would be allowed to get on the platform from the roadside queue, making the other passengers’ station access time longer. On the other hand, this phenomenon is beneficial to downstream passengers who have additional space

In contrast, passengers in the middle station, Cubao Station, force themselves into the train even if there is no more space by the train door, and passengers inside the train are observed to resist being pushed into the train to avoid even more cramped conditions. In this case, the choice of whether to board the oncoming train or choose to wait for the next train does not exist because it is physically (humanely) impossible to board the train. It is observed that passengers in the middle of the train do not move even if there seems to be space inside, with many passengers staying near the door presumably to allow themselves to alight more easily and avoid being cramped in the middle. This situation is similar to the observations made by Evans and Wener (2007), who found that there are physiological effects associated with crowding and personal space invasion. This observation indicates that there could be unused space that could be utilized more efficiently, and has implications on train seating designs. This is consistent with the results of a vehicle occupancy survey by Ebia and Ramirez (2013), which was presented in Figure 3.27.

3.7. Chapter Summary

This chapter presents a comprehensive overview of the congestion and unreliability problems in MRT-3 using a variety of data collection methods. It examines the ridership trends and outlines operation policies, which have impacts on the experience of passengers in terms of waiting time. In summary, it has tackled the following:

1) Ridership trends and discussion on fare policy
2) Existing policies for crowd control and train operations
3) Platform waiting time and its variability
4) Extent of total waiting time, including the proportion of platform waiting time at MRT-3 stations
5) Headway, dwell time, and their variability
6) Passenger behavior when boarding

MRT-3 has implemented policies that would like to improve train operations through crowd control and skip train. However, even with these policies in place, congestion, variability and waiting time is still high because the demand greatly exceeds capacity. Moreover, it was found that schedule adherence has become worse, with headway becoming longer and variables as a result of decreased train speed.

Comparing the situation in 2013 and 2014, it is clear that the combination of these policies actually worsen passenger experience at some stations, especially total waiting time at North Avenue Station, and that it does not improve platform waiting time in Cubao Station. This gives a strong support to the argument that the problem would not be alleviated further unless an increase in capacity and improvement in schedule adherence.

Long waiting times and severe congestion are unacceptable from the viewpoint of safety and welfare of passengers and the rest of society, so it is imperative to provide adequate solutions. This study could serve as a basis for drafting appropriate policies that would address the problems identified while taking into consideration the characteristics of its users. It was also found that fare increase has impacted ridership. A survey on the actual conditions as a result of this policy change should be conducted in the future.

4. Intra-Modal and Intermodal Comparisons of $PM_{2.5}$ Exposure

The main purpose of this chapter is to highlight the possible health effects of traveling using the MRT-3 as a result of exposure to $PM_{2.5}$. Moreover, it would like to compare the exposure levels between stations at the MRT-3 (intra-modal comparison) and between different public transport modes (intermodal comparison).

4.1. Introduction

$PM_{2.5}$ is one of the most harmful everyday pollutants to humans today. Due to its very small size, it can penetrate deep into the lungs, resulting in negative health effects such as respiratory illnesses and mal-influence to the human circulatory system (SIBATA Scientific Technology, 2013). Transport contributes to $PM_{2.5}$ concentration, and is also a main source of personal exposure to it.

Metro Manila commuters spend a considerable amount of time commuting especially in the morning peak period regardless of travel mode used. This is an increasing concern for MRT3 commuters who wait a long time on the roadside and platform and ride in poorly ventilated trains. Aside from lost productivity, discomfort and decreased overall well-being, commuters are potentially exposed to unhealthy levels of $PM_{2.5}$, which may lead to respiratory diseases. For instance, there are 155,081 reported disease cases and 15,682 deaths attributed to urban air pollution in the Philippines. The impacts of air pollution are summarized in the table below.

Table 4.1. Air pollution impacts on public health of Metro Manila

Morbidity	Mortality
10,000 excess cases of acute bronchitis	40–200 persons due to cardiovascular causes
300 excess cases of asthma	300–330 persons due to respiratory causes
9 excess cases of chronic bronchitis	

Source: DOH, 2004.

Concern for the levels of $PM_{2.5}$ in the country has been increasing. On March 7, 2013, the Philippine government started adopting $PM_{2.5}$ guidelines under Department of Environment and

Natural Resources (DENR) Administrative Order No. 2013-03 (DAO No. 2013-03). This administrative order established National Ambient Air Quality Guideline Value (NAAQGV) for $PM_{2.5}$ at 75 μg/m^3 (for 24-hour average exposure) and 35 μg/m^3 (for annual average exposure) which are equivalent to the first set of interim targets (IT-1) of the World Health Organization (WHO).

Therefore, it is imperative to quantify the concentration levels and extent to which MRT-3 passengers are exposed to $PM_{2.5}$, and also make a comparison between different travel modes.

Specifically, the objectives of this research chapter are:

(1) To conduct an intra-modal comparison of $PM_{2.5}$ exposure among MRT-3 passengers according to their boarding and alighting stations during the morning peak period
(2) To carry out an intermodal comparison of $PM_{2.5}$ exposure between different travel modes (i.e. MRT-3, ordinary bus and air-conditioned bus) along EDSA during the morning peak period

The measurements are conducted in terms of $PM_{2.5}$ particle count rather than the typically-used mass concentration. Several studies such as by Ruuskanen *et al*. (2001) and Tittarelli *et al*. (2008) state that particle count is an equally important indicator of air quality as mass concentration. Ruuskanen *et al*. (2001) suggested that both particle number and mass concentrations should be measured to provide a comprehensive assessment of urban air quality, as well as to investigate associations between air pollution and adverse health outcomes. Wichmann *et al*. (2000) even suggested that particle count is more closely correlated to adverse health effects than mass concentration. However, mass concentration still needs to be assessed because the government-issued safe levels are issued according to those units, so an appropriate conversion factor is used.

4.2. Methodology

This section discusses the methodology employed to address the objectives outlined in the previous section. The surveys were conducted in coordination with UP National Center for Transportation Studies (UP NCTS).

4.2.1. Equipment

The SIBATA $PM_{2.5}$ Cyclone for LD-5 equipment was used to measure $PM_{2.5}$ particle count instantaneously. It is a relative concentration method that measures the number of particles detected through light scattering. It was chosen mainly because of its simplicity and portability because the equipment should be carried throughout the commute using different modes at various locations. Particle counters are advantageous because of their mobility, low cost, ease of use and their ability to measure particle concentrations over short time intervals, which enables them to be used in assessing spatial and temporal variations in particle concentrations (Weijers *et al*., 2004) and providing good approximations of real exposure in various situations (Gouriou *et al*., 2004).

The equipment was programmed to measure the $PM_{2.5}$ particle count for every one-minute interval. The measurement is recorded manually by the surveyors and the equipment is started again to measure the succeeding $PM_{2.5}$ particle count. A GPS tracker and a timer were also taken by surveyors to simultaneously measure the geographical coordinates and timestamps, respectively.

Figure 4.1. SIBATA $PM_{2.5}$ Cyclone for LD-5 equipment

The measured values need to be multiplied with a K-factor to convert this data to mass concentration (absolute value). Filter sampling ideally needs to be conducted simultaneously to accurately measure the particle size distribution; however, this equipment is unavailable due to some constraints, so the usual K-factor value was estimated instead to convert the relative measurement. This assumption should suffice for the purpose of comparing different modes and points along the same road. However, being a main limitation, this is planned to be addressed in a future study wherein $PM_{2.5}$ samples would be collected along EDSA using a filter and subject to further laboratory analysis to determine their weight, and then used to convert the relative concentration assuming comparability.

4.2.2. $PM_{2.5}$ Exposure Measurement

$PM_{2.5}$ exposure in this research is composed of two parts: $PM_{2.5}$ levels and exposure time. As such, this analysis involves the particle count measurement using the relative concentration equipment, and the exposure times, which are equivalent to waiting time for roadside and platform $PM_{2.5}$ exposure and in-vehicle travel time for in-vehicle exposure. The exposure time values are taken from Chapter 3.

It would be useful to create a $PM_{2.5}$ exposure index that combines both components. As an initial idea, it could also be expressed as ratio of the weighted average of $PM_{2.5}$ level during the trip and exposure time (trip time), and the safe level of $PM_{2.5}$ and free-flow travel time. However, this type of exposure index would only have meaning if it can be related to health effects, which is not in the scope of this research and could be addressed in future work.

Thus, in this research, only PM2.5 levels are compared with guideline levels. On the other hand, a safe level of $PM_{2.5}$ exposure time is not considered, but higher exposure time is deemed to be less safe.

4.2.3. Preliminary Survey

A preliminary survey was conducted to establish the need for a full survey. This entails measuring the $PM_{2.5}$ particle count at the roadside, platform and ticketing area of some stations. Low values would contradict the initial hypothesis that commuters are exposed to unhealthy levels, while higher values would warrant further investigation.

Preliminary measurements done by Prof. Tetsuo Yai and UP NCTS on October 1 and 10, 2014 show that the $PM_{2.5}$ levels on the platform, gate and ground level of several MRT-3 stations are beyond the US Environmental Protection Agency (US EPA) and Japan Meteorological Agency limit of 35 $\mu g/m^3$. The general trend is that station areas with higher elevations such as platforms and gates have a higher $PM_{2.5}$ concentration than the ground level.

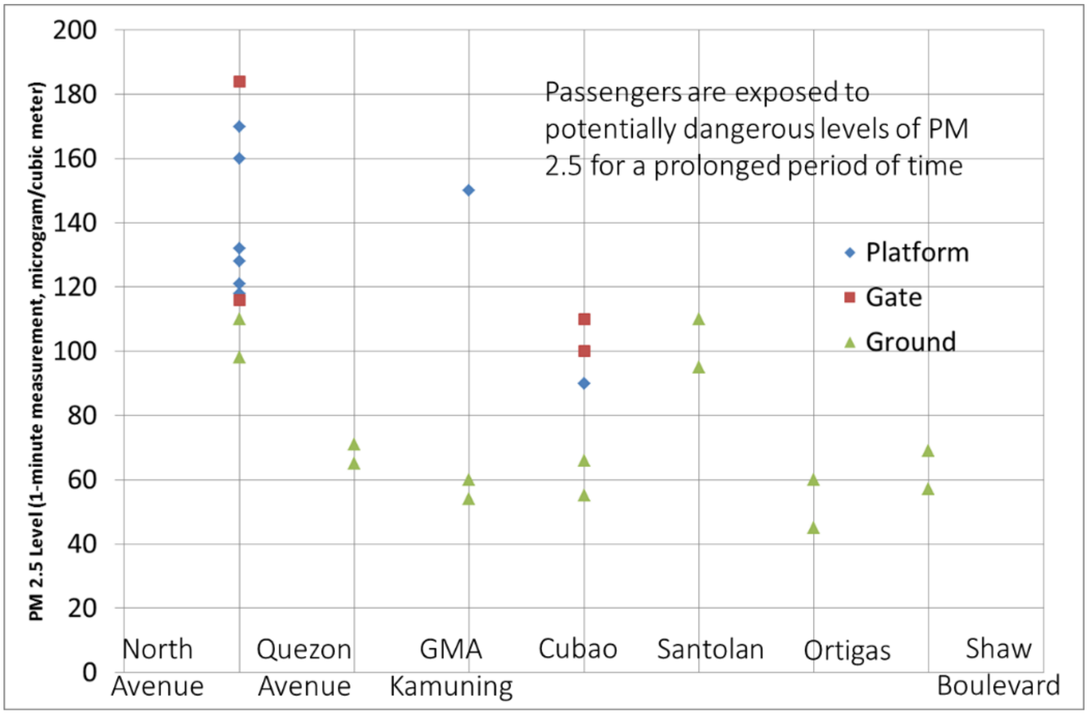


Figure 4.2. Preliminary survey results at several MRT-3 stations in October 2014

Given the severity of the measurements, a full survey was deemed necessary and expanded to other modes and inside the vehicles as well.

4.2.4. Full Survey

Survey permits were acquired from the MRT-3 operator and bus companies, and the exact survey schedule was adjusted to match their requirements. The survey was divided into two parts: intra-modal and intermodal. The survey schedule was finalized to be from February 2 to March 5, 2015 for 20 regular weekday mornings. A representative location of an ambient urban environment was also considered for background measurement.

Only one equipment was used due to availability issues, thus, measurements were not done simultaneously for different MRT-3 stations and travel modes. To increase the comparability between measurements at different stations and modes at various times within the morning peak period, measurements were repeated at least four times per mode or station, with the schedule randomized throughout the survey period (i.e. no consecutive measurements for the same station or mode). As such, each station and mode were sampled at least once every week. Due to logistic considerations, intra-modal survey was conducted first on every survey day, followed by intermodal survey (ordinary bus, air-conditioned bus or MRT-3 depending on the schedule). Table 4.2 provides the details of the survey schedule.

The survey was conducted after the implementation of a significant fare increase in January 2015 that increased the fare by around 23% to 87%. Surveyors reported that this policy change had a noticeable impact on the passenger demand and roadside queuing at the stations considered. As discussed previously in Chapter 3, it was found that roadside queuing began at around 6:20AM, but after the $PM_{2.5}$ survey was started, it was observed that roadside queuing started at a later time. Initially, the survey was started at 6AM, but after realizing the delayed start of heavy queuing, the survey was started on a later hour (from 7AM instead of 6AM) from the second week onwards. This change also caused the starting time of the $PM_{2.5}$ monitoring survey for intermodal comparison to be moved to about an hour later.

Table 4.2. Survey schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1	February 2	3	4	5	6
	North Avenue	Quezon Avenue	Cubao Station	Ayala Avenue	Taft Avenue
	MRT Ride	MRT Ride		Non-Air Conditioned Bus	Air Conditioned Bus
Week 2	9	10	11	12	13
	Quezon Avenue	Cubao Station	Ayala Avenue	Taft Avenue	North Avenue
	Non-Air Conditioned Bus	Air Conditioned Bus	Non-Air Conditioned Bus	Air Conditioned Bus	MRT Ride
Week 3	16	17	18	19	20
	Cubao Station	Ayala Avenue	Taft Avenue	HOLIDAY	Quezon Avenue
	Air Conditioned Bus		Air Conditioned Bus		
Week 4	23	24	25	26	27
	Ayala Avenue	Taft Avenue	HOLIDAY	Quezon Avenue	Cubao Station
		Non-Air Conditioned Bus			Non-Air Conditioned Bus
Week 5	March 2	3	4	5	6
			North Avenue MRT Ride	North Avenue MRT Ride	

4.2.4.1. Intra-modal Comparison

The intra-modal comparison focused on the roadside, ticketing area and platform of selected MRT-3 stations. Stations were identified according to their morning peak ridership and characteristics, and are highlighted in bold in Table 4.3. North Avenue, Quezon Avenue, Cubao and Taft Avenue stations were chosen because these stations have the most passenger entries during the morning peak period. Ayala Avenue Station was chosen as a representative for a basement station (it has more passenger entries than Buendia Station).

As seen in the survey schedule (Table 4.2), $PM_{2.5}$ levels at the roadside, ticketing area and platform of the selected stations were monitored every regular weekday for a month such that each station was sampled once every week. The surveyors carried the equipment on the roadside and then into the station at the ticketing area and platform and took 1-minute $PM_{2.5}$ particle count measurements along the way for around 30 minutes to simulate passenger exposure while queuing into the station.

Table 4.3. Location and elevation of MRT-3 station components

Station	**Location of concourse: fare gates, ticket booths, station control, shops, etc.**	**Location of Platform**	**Platform type**
North Avenue	**Level 3**	**Level 3**	**Side (terminus; with switch track)**
Quezon Avenue	**Level 2**	**Level 2**	**Side**
GMA-Kamuning	Level 2	Level 3	Side
Araneta-Cubao	**Level 2**	**Level 3**	**Side**
Santolan-Annapolis	Level 2	Level 2	Side
Ortigas	Level 3	Level 3	Side
Shaw Boulevard	Level 3	Level 2	Island
Boni Avenue	Level 1	Level 2	Island
Guadalupe	Level 2	Level 3	Side
Buendia	Level 1	Basement 1	Island
Ayala Avenue	**Level 2**	**Basement 1**	**Side**
Magallanes	Level 2	Level 3	Side
Taft Avenue	**Level 2**	**Level 1**	**Island/bay (terminus)**

*Level 1 denotes street level

4.2.4.2. Intermodal Comparison

Intermodal comparison was conducted by measuring the $PM_{2.5}$ levels inside different public transport modes while riding. Aside from the MRT-3, the ordinary bus and air-conditioned bus were chosen because they are the most commonly used public transport modes that traverses through EDSA. One round trip along EDSA was considered for each survey day. Given that the travel time along EDSA is different every survey day, the survey time also varies.

To facilitate spatial comparison, EDSA was divided into 44 locations spaced up to 400 meters apart, with each location representing a landmark (e.g. building, transit stop, etc.) or intersection. When the vehicle is moving, the location of measurements is spread over several meters (because the equipment is turned on for one minute), so the exact location is approximated to be located at one of the designated points. Other measurements are done at one exact location only when the vehicle is at rest.

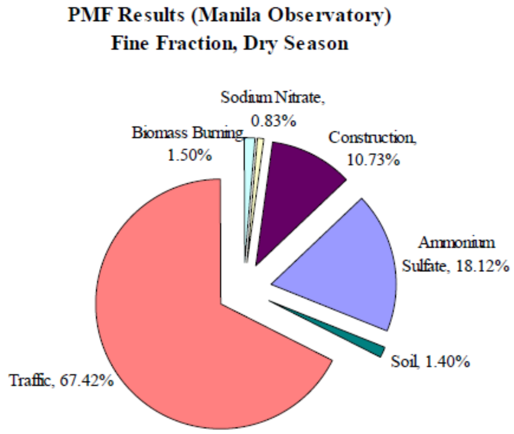
4.3. Results and Discussion

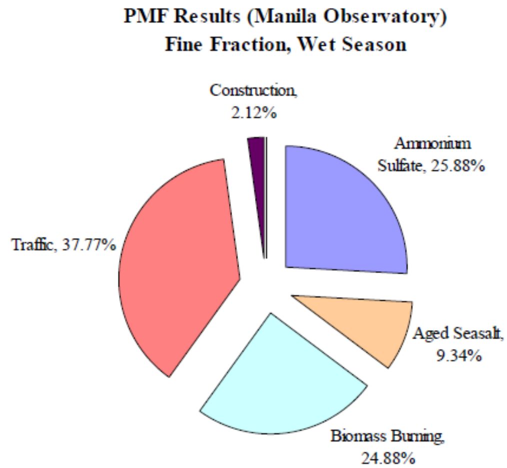
This section presents and discusses the results of the surveys previously described.

4.3.1. Converting Particle Count to Mass Concentration

As mentioned in Sub-section 4.2.1, the SIBATA Digital Dust Indicator ($PM_{2.5}$ Cyclone) equipment is a single-channel particle counter that counts particles less than 2.5 µm. A conversion factor, K, should be used to convert the particle count measurements into mass concentration to allow comparison with guideline values. A K factor equal to 1.0 µg/m^3/CPM is the recommended value by the manufacturer, but this is larger than typical values for road traffic environment. Since it was not feasible to measure K through another survey using a mass-measuring equipment and particle counter simultaneously, then an appropriate theoretical estimate was made.

The particle pollution along EDSA is predominantly caused by vehicular traffic. Similar findings are given by Manila Observatory (2006) for Katipunan Avenue in Quezon City. The $PM_{2.5}$ monitoring survey was conducted during the dry season, so the pie chart on the left in Figure 4.3 is used accordingly.





Source: Simpas et al., 2011

Figure 4.3. Particulate matter (fine fraction) sources in dry and wet seasons

The values used for estimating K are tabulated in Table 4.4. The sizes of diesel exhaust and ammonium sulfate were taken from literature. For other urban aerosol, it is generally accepted that in most cases, the $PM_{2.5}$ mass distribution and light scattering are dominated by particles with diameters in the size range 0.1–1.0µm (Molenar, 2005), so an average particle diameter of 1 µm is used. In other words, $PM_{2.5}$ could be composed of numerous small particles holding very little mass, mixed with relatively few larger particles which contain most of the total mass.

Table 4.4. Particle type and density

Particle type	Density	Size (Diameter)	Calculated Mass per particle	Percentage (Manila Observatory, dry season)
Diesel exhaust	1.1 – 1.2 g/cm^3 (Virtanen *et al*, 2002)	from a few nanometers to approximately 500 nm (0.5 µm) (Alföldy *et al*, 2009) → 0.25 µm	7.53 x 10^{-8} µg	67.42%
Ammonium sulfate	1.77 g/cm^3	1 to 3 µm → 1.5 µm	3.13 x 10^{-6} µg	18.12%
Other urban aerosol	1.65 g/cm^3 (Tuch *et al*, 2000)	1 µm	8.64 x 10^{-7} µg	14.46%

Following Tuch *et al.* (2000) and Tittarelli *et al.* (2008) among others, particles are assumed to be spherical. Using the values in Table 4.4, the effective particle mass = 7.43 x 10^{-7} µg which would translate to K=0.74 μg/m^3/CPM. Given that the whole survey length of EDSA is primarily characterized by high traffic volume, it is reasonable to assume that K holds for all measurement values. Even if the exact values of aerosol density and particle sizes may differ, Tittarelli *et al.* (2008) suggest that these are not of vital importance in comparison studies where relative concentration values are of interest.

4.3.2. Intra-modal Comparison

This sub-section aims to find out whether there are differences in $PM_{2.5}$ particle count between the selected MRT-3 stations and their corresponding elevation levels (refer to Figure 4.3 for the station description).

The scatter plots in Figures 4.4 and 4.5 and the descriptive statistics in Table 4.5 show that the ranges of particle count measurements for all stations and all floor levels are quite wide. This could be attributed to day-to-day variability, as well as the measurement method which only allowed for one measurement at a time. Nevertheless, the randomized survey schedule has attempted to improve the comparability between the stations and floor levels.

For the comparison between stations, it can be observed in Figure 4.4 that Taft Avenue has a noticeably higher average $PM_{2.5}$ particle count than the other four stations. Further testing using one-way ANOVA show that there is no significant difference between average particle count per minute (PCM) for North Avenue, Quezon Avenue, Cubao and Ayala Stations [$F(3, 178)=1.135$, $p=0.336$]. However, there is a significant difference between the station means when Taft Avenue Station is included in the analysis [$F(4,216)=6.577$, $p=0.000$], which confirms that it has a statistically significant higher average PCM than the other four stations. Tests of homogeneity using Levene statistic and robust tests of equality of means using Welch and Brown-Forsythe also support this conclusion. Post-hoc comparisons using Tukey HSD test also indicated this – the average $PM_{2.5}$ particle count at Taft Avenue was significantly different than the other four stations, but there are no significant differences between those four stations.

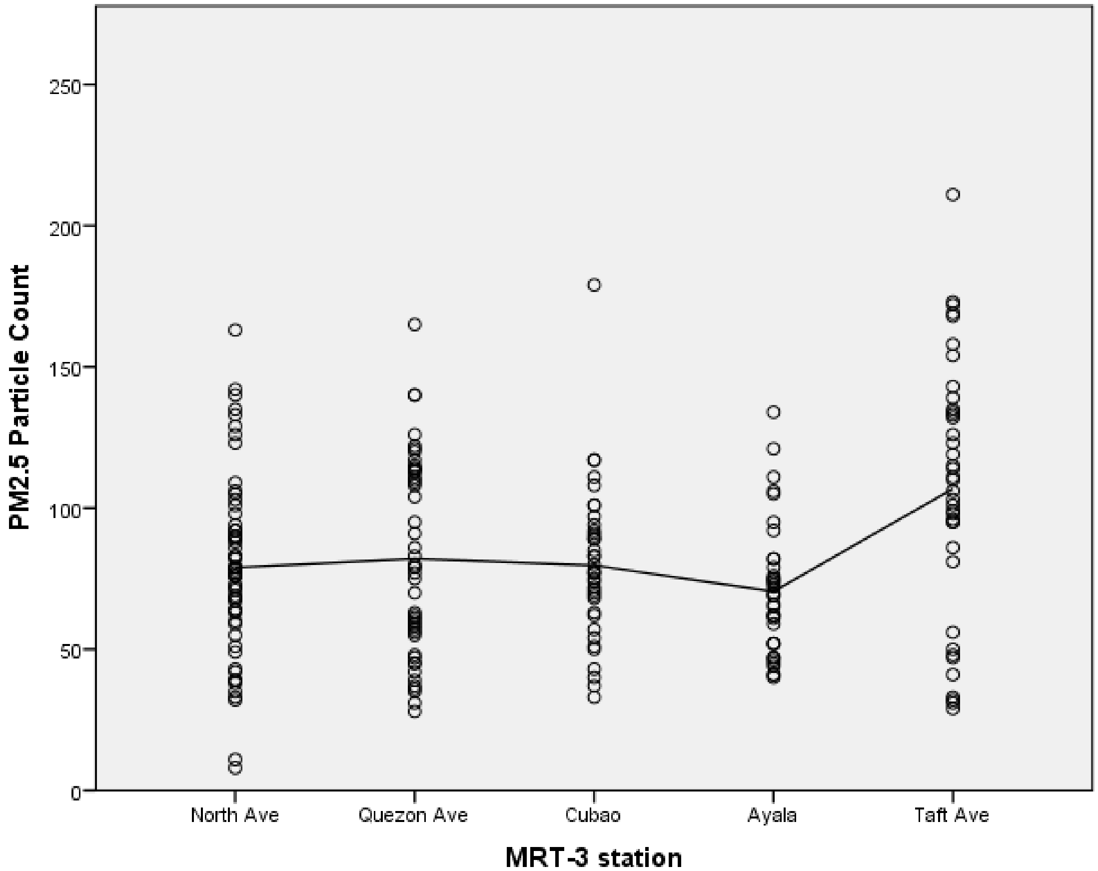


Figure 4.4. Scatter plot and means of $PM_{2.5}$ particle count at MRT-3 stations

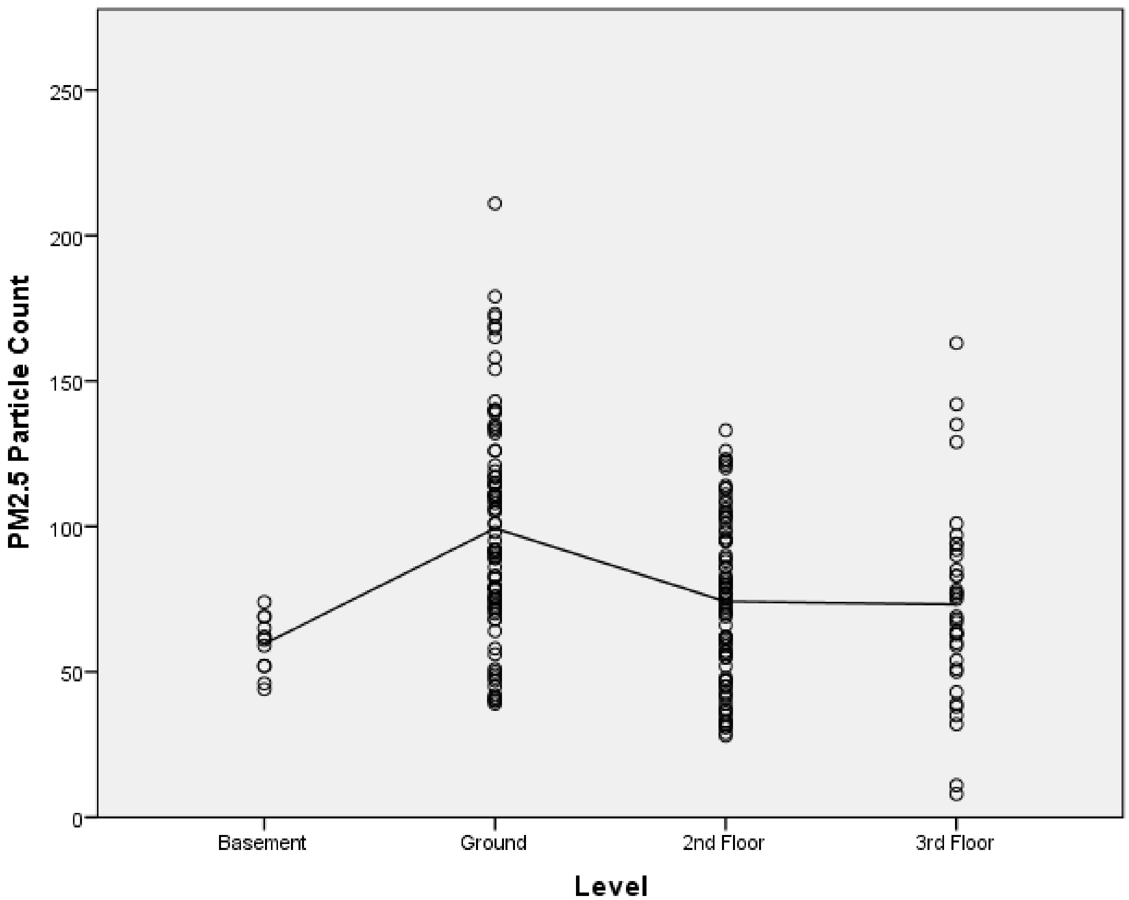


Figure 4.5. Scatter plot and means of $PM_{2.5}$ particle count at different station floor levels

Table 4.5. Descriptive statistics of $PM_{2.5}$ particle count by station and by floor level

Location		Mean Particle Count	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
By Station	North Ave	78.88	32.474	4.264	70.34	87.42	8	163
	Quezon Ave	82.10	34.419	4.968	72.11	92.10	28	165
	Cubao	79.68	27.211	4.414	70.74	88.63	33	179
	Ayala	70.47	22.913	3.717	62.94	78.01	40	134
	Taft Ave	106.82	45.819	7.337	91.97	121.67	29	211
By Floor Level	Basement	59.58	9.395	2.712	53.61	65.55	44	74
	Ground	99.28	37.589	4.007	91.32	107.25	39	211
	2nd Floor	74.14	28.652	3.126	67.93	80.36	28	133
	3rd Floor	73.19	33.257	5.467	62.10	84.28	8	163
Overall		83.20	35.156	2.365	78.54	87.86	8	211

Furthermore, a one-way between subjects ANOVA was conducted to compare the effect of floor level (basement, ground level, 2nd floor or 3rd floor) on $PM_{2.5}$ particle count. It was found that there is a statistically significant difference at the $p<0.01$ level for the different floor levels [$F(3,217)=12.497$, $p=0.000$]. Post hoc comparisons using Tukey HSD test show that the significant differences lie between the ground level and all the other floor levels, but that there are no significant differences between the means of basement, 2nd floor and 3rd floor.

Figure 4.6 shows the measured data points according to stations at various elevation levels. and classified according to floor level. For additional comparison, the average measured levels at the ground level while riding inside air-conditioned bus and ordinary bus are also shown. Generally, waiting passengers at the roadside are exposed to higher levels of $PM_{2.5}$ than air-conditioned bus passengers, but almost the same as ordinary bus passengers. The average measured levels inside the MRT-3 were also compared to the exposure levels for passengers waiting at the platform, and it was found that they are almost the same, probably because the train doors are open.

All in all, measurements at Taft Avenue Station and at the ground levels of each station are significantly higher than all other stations and floor levels.

4.3.3. Intermodal Comparison

Since there is only one equipment, measurements are done one at a time and an assumption of comparability between measurements needs to be made. As mentioned previously in Section 4.2.3, the 17 km length of EDSA from Paramount Building on North Avenue to Taft Avenue was divided into 44 points, all of which are either landmarks or intersections that are spaced 350 to 400 meters apart. Figures 4.7 to 4.10 show the comparison of the average particle count measurement between interiors of the MRT-3, air-conditioned bus and ordinary bus. The average values at each measurement location are colored based on the assumptions that the conversion factor K = 0.74 $\mu g/m^3$/CPM holds for all measured values, and that the US EPA table for 24-hour average values is applicable.

Table 4.6 shows the US Environmental Protection Agency (US EPA) standards for ambient air quality, which is used to relate the measured levels with the corresponding health implications and level of health concern. It is meant to be a reference for Figure 4.10.

Table 4.6. US EPA Air Quality Index for $PM_{2.5}$ Pollution

Air Quality Index (AQI) Category	Index Values	Revised Breakpoints ($\mu g/m^3$, 24-hour average)	Health implications
Good	0 - 50	0.0 – 12.0	Air quality is satisfactory and poses little or no health risk.
Moderate	51 - 100	12.1 – 35.4	Air quality is acceptable; however, pollution in this range may pose a moderate health concern for a very small number of individuals. People who are unusually sensitive to particle pollution may experience respiratory symptoms.
Unhealthy for Sensitive Groups	101 – 150	35.5 – 55.4	Members of sensitive groups may experience health effects, but the general public is unlikely to be affected. People with heart or lung disease, older adults, and children are considered sensitive and therefore at greater risk.
Unhealthy	151 – 200	55.5 – 150.4	Everyone may begin to experience health effects. Members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 – 300	150.5 – 250.4	These values trigger a health alert, meaning everyone may experience more serious health effects.
Hazardous	301 – 400	250.5 – 350.4	These values trigger health warnings of emergency conditions. The entire population is even more likely to be affected by serious health effects
	401 – 500	350.5 – 500	

Cut-offs based on US Environmental Protection Agency (2012), The National Ambient Air Quality Standards for Particle Pollution

Figure 4.7 provides a comparison of the $PM_{2.5}$ exposure between the three modes while riding in the vehicle, with in-vehicle travel time as the exposure time. The ordinary bus has not only the highest $PM_{2.5}$ levels, but also the longest in-vehicle travel time, making it the worst mode among the three in terms of $PM_{2.5}$ exposure. Air-conditioned bus comes in second, with $PM_{2.5}$ levels that are considerably lower than that of ordinary bus but slightly higher on average and more variable than that of MRT-3. Moreover, it has an in-vehicle travel time that is almost similar to that of an ordinary bus, making the exposure time approximately 90 minutes for a one-way trip.

If waiting time is included, ordinary bus still has the highest $PM_{2.5}$ levels and longest exposure time among the three modes, as seen in Figure 4.8. On the other hand, the ranking between air-conditioned bus and MRT-3 switches because the $PM_{2.5}$ levels at the roadside, ticketing area and platform of the station drives up the exposure levels.

Figure 4.9 shows the scatter plot of data points for each mode and location considered, as well as the averages and the US EPA limit. The variation in data is due to the fact that measurements were not done simultaneously. This potential bias was reduced by repeating measurements on different days for each mode. However, it is noticeable in the graph that ordinary bus passengers suffer from significantly higher $PM_{2.5}$ exposure than MRT-3 and air-conditioned bus passengers for almost all data points. Most data points also lie above the US EPA limit, which indicate that commuters are exposed to unsafe $PM_{2.5}$ levels most of the time during their morning peak period commute, with ordinary bus passengers getting the most exposure for the longest time. In addition, locations that have several bus terminals (around Cubao and Taft Avenue) and Pasig River (around Guadalupe) have the highest levels. The identification of pollution sources is beyond the scope of this research, but this could be addressed in future work in order to reduce the counts.

Figure 4.10 presents a comparison between the three modes in terms of average $PM_{2.5}$ levels according to location, wherein data points are color-coded according to Table 4.6. Most of the measurements for the MRT-3 are under the ‘moderate’ and ‘unhealthy for sensitive groups’ categories, while that of an air-conditioned bus is dominated by measurements under the ‘unhealthy for sensitive groups’ category, with some belonging to ‘unhealthy (lower bound)’ and ‘unhealthy (upper bound)’ categories. Meanwhile, ordinary bus still has a generally ‘unhealthy’ measurement profile. Comparing the three maps in Figure 4.10, it can be observed that riding the MRT-3 is the least hazardous for health because most locations are have the lowest levels of health concern, with the highest level being unhealthy (lower bound) for a few locations. Meanwhile, riding an air-conditioned bus is considerably more hazardous than riding the MRT-3 in terms of $PM_{2.5}$ exposure, with some locations along its route classified as unhealthy (upper bound), apart from the fact that the exposure time is also longer. Riding an ordinary bus exposes the commuters to the highest level of $PM_{2.5}$ exposure, with most of the locations along the route classified as unhealthy and very unhealthy. There are no averages that reach the hazardous levels except for some individual data points around bus stations in Cubao.

It can be seen that the measurements inside the air-conditioned bus and MRT-3 are more stable than that of the ordinary bus on a per trip basis because their windows and doors are closed. However, it is surprising that air-conditioned buses have relatively high particle counts – this may be attributed to old fleet and poor ventilation.

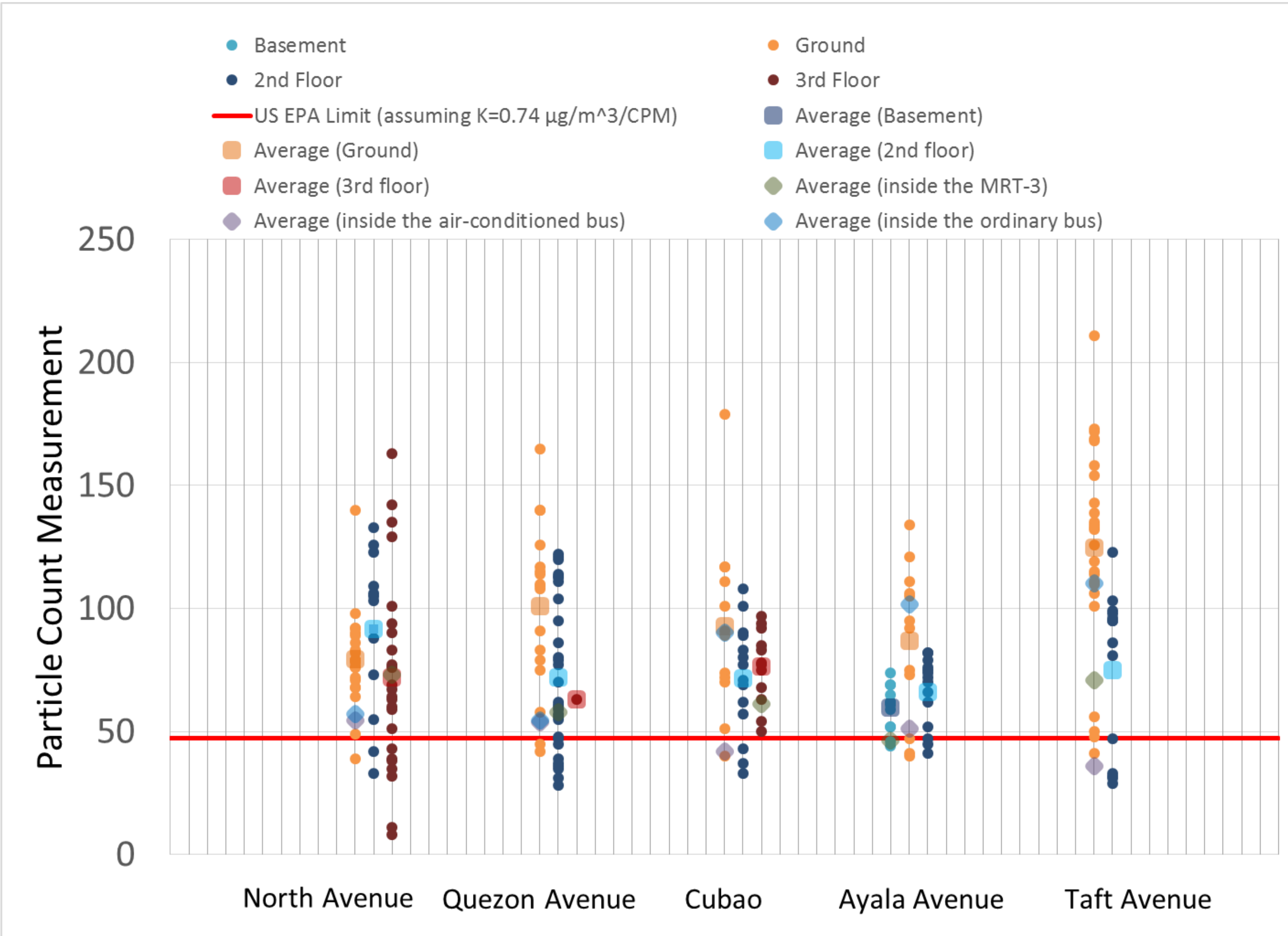


Figure 4.6. Intra-modal comparison of $PM_{2.5}$ particle count measurements between different stations and elevations

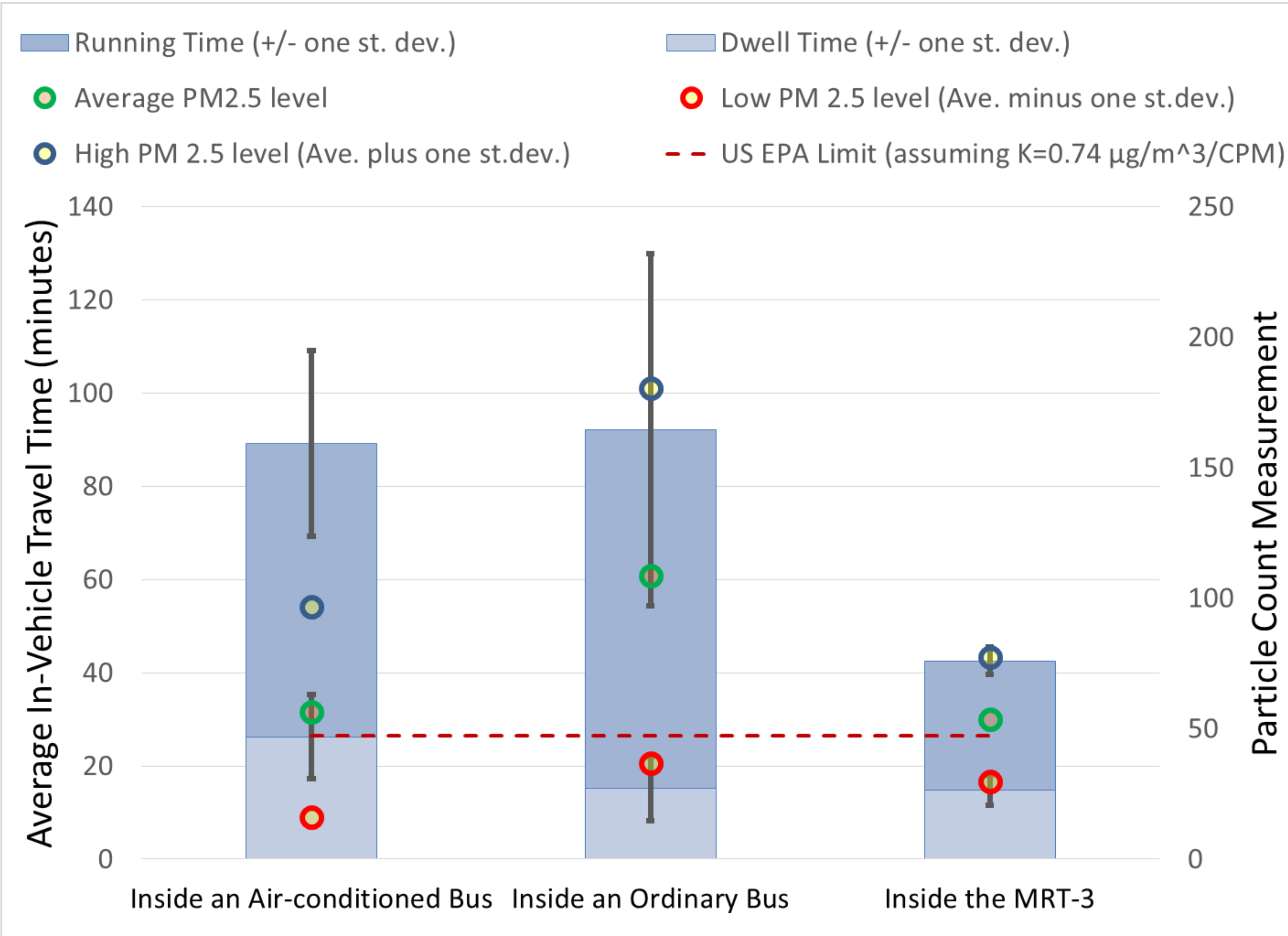


Figure 4.7. Intermodal comparison of in-vehicle time and $PM_{2.5}$ exposure for an average one-way trip

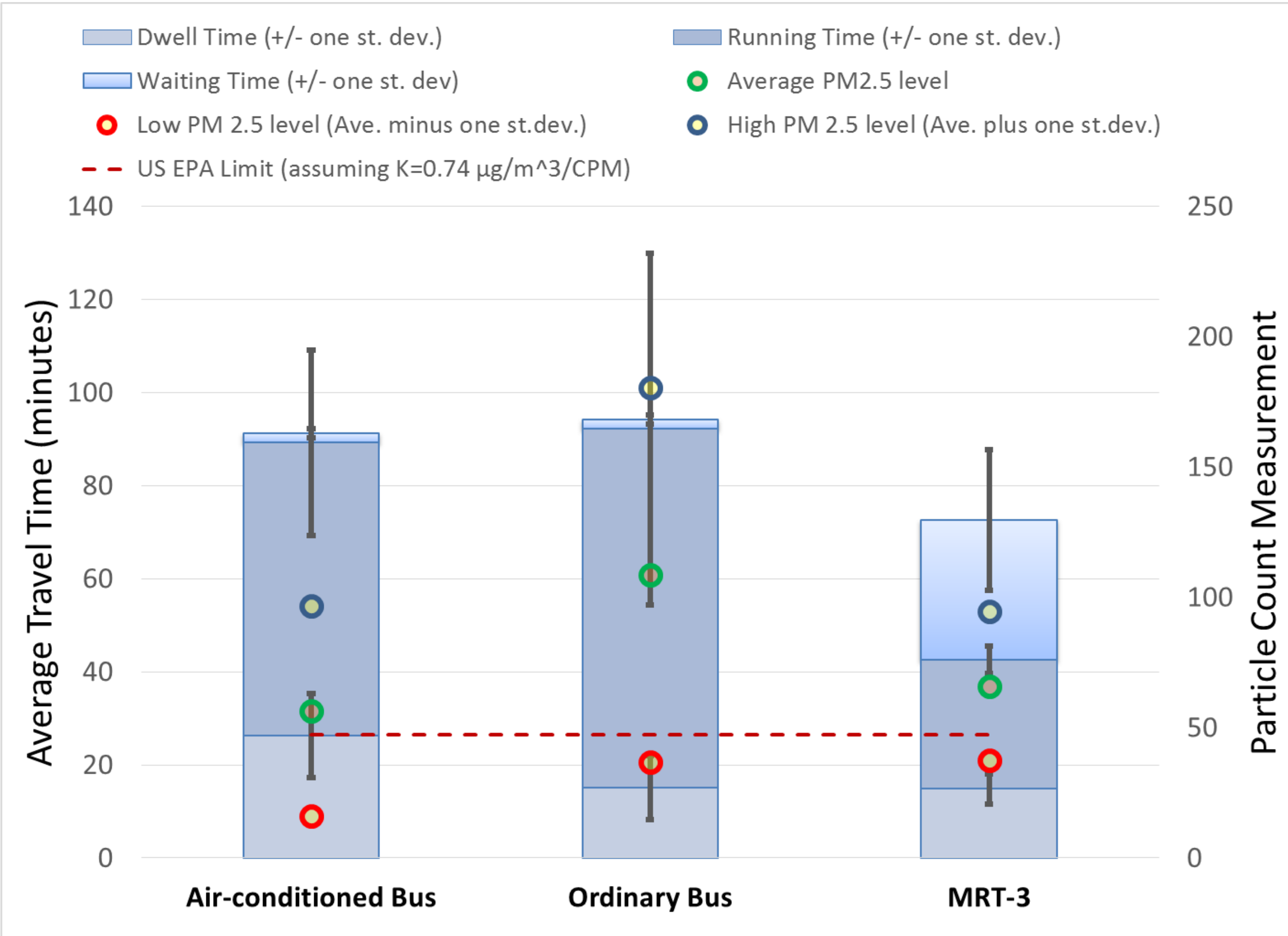


Figure 4.8. Intermodal comparison of travel time (including waiting time) and $PM_{2.5}$ exposure for an average one-way trip

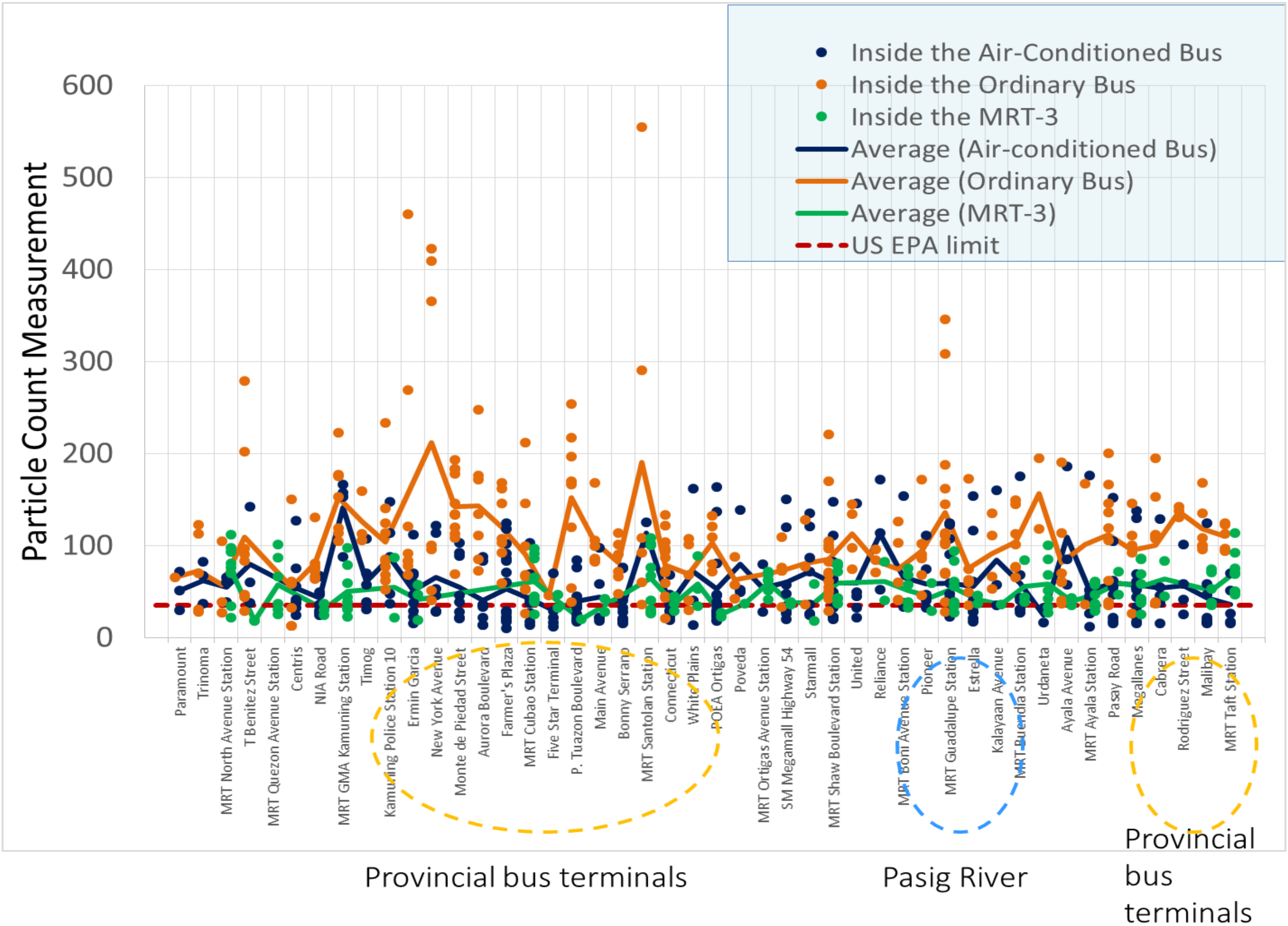


Figure 4.9. Intermodal comparison of $PM_{2.5}$ particle counts along edsa

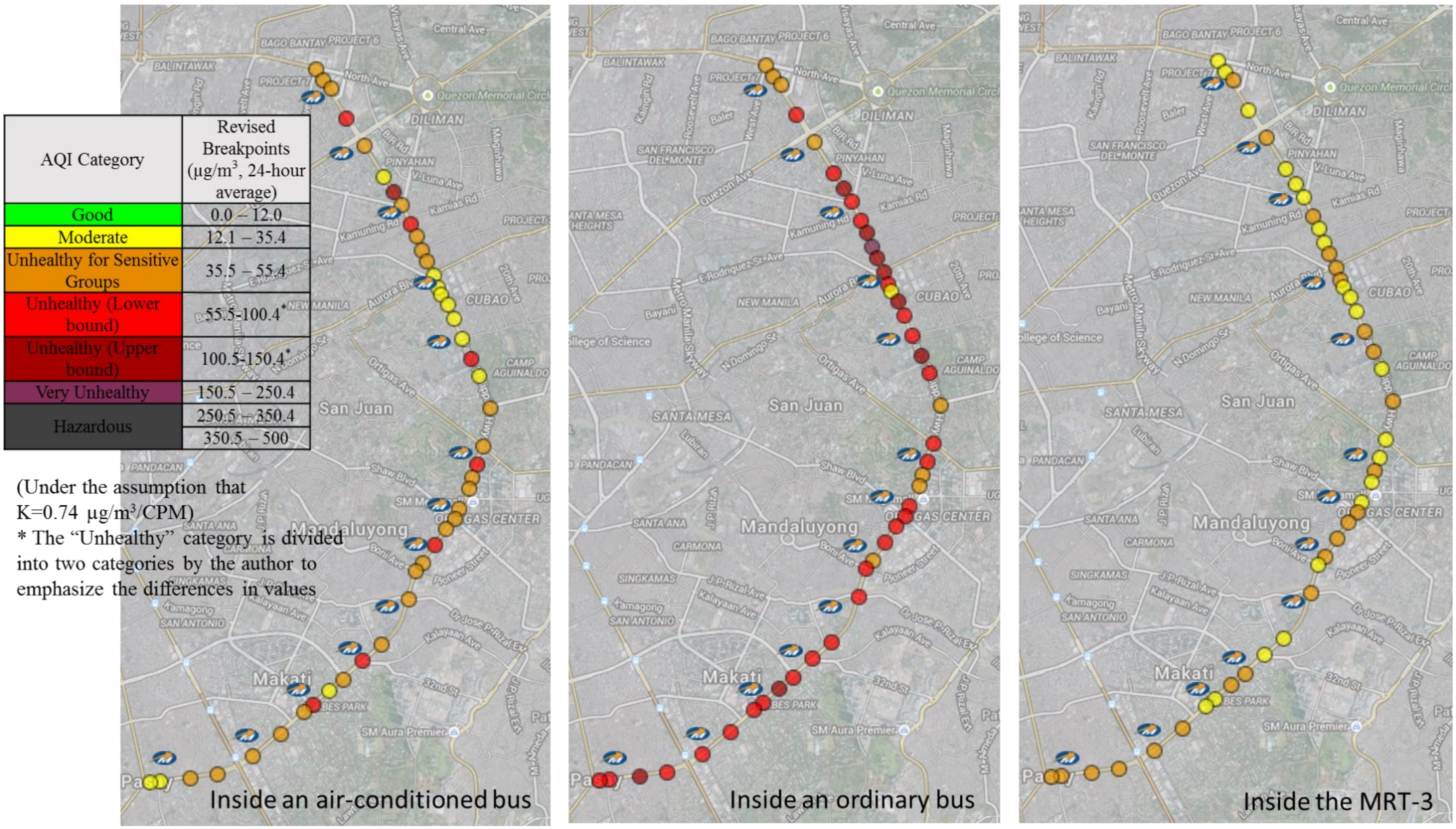


Figure 4.10. Comparison of measured particle count averages between the interiors of the MRT-3, air-conditioned bus, and ordinary bus

Although no surveys regarding the sources of $PM_{2.5}$ pollution along EDSA, scientific literature states that $PM_{2.5}$ contribution to ambient air quality from gasoline vehicles is normally negligible (US EPA, 2008), so diesel buses and other diesel vehicles are the most likely culprit for the high $PM_{2.5}$ emissions along EDSA.

Using data from the USEPA's MOBILE computer models that estimate the average emissions for different types of highway vehicles, it was assumed that the average $PM_{2.5}$ emissions when running is 0.274 grams/mile (or 0.62 grams/km) and 0.018 grams/min of idle time. However, bus speeds in the U.S. are typically higher, so the speed-specific $PM_{2.5}$ emission factors when the vehicle is running may be more appropriate. For this purpose, the values presented by Vergel and Tiglao (2014) in their Metro Manila study on the effect of sustainable transport measures on PM (not $PM_{2.5}$) emissions and fuel consumption are used. They stated that for speeds less than 10kph, diesel buses emit 2.4 g/veh.km and for speeds between 10-20kph, they emit 1.6 g/veh.km, and for speeds greater than 20kph, the emission reduces to 0.9 g/veh.km.

Estimates of the $PM_{2.5}$ emission from diesel buses and their corresponding travel time components are tabulated in Table 4.7.

Table 4.7. Dwell time, running time and estimated emissions

Mode	Dwell Time (min)	Average $PM_{2.5}$ emissions from idling (g)	Running Time (min)	Average Running Speed (kph)	Average PM emissions from running (g)	Waiting Time (min)
Air-conditioned Bus	26.25 (*9.07*)	0.47	62.95 (*19.92*)	16.20	27.2	2.5 (*1.01*)
Ordinary Bus	15.125 (*6.87*)	0.27	77.075 (*37.77*)	13.23	27.2	2.9 (*1.50*)
MRT-3	14.89 (*3.24*)	--	27.67 (*2.95*)	36.86	--	30.05 (*15.1*)

It is also necessary to make a distinction between the $PM_{2.5}$ pollution that is caused by vehicular traffic and pollution that would exist even without vehicular traffic. This is referred to as background concentration, which may be defined as those pollutants arising from local natural processes together as well as those transported into an airshed from afar, which may be natural or anthropogenic in origin (McKendry, 2006).

An appropriate background site is difficult to find in Metro Manila being an urban metropolis. In its studies of PM pollution in Metro Manila, the Manila Observatory (2006) considered a small rural town called Gabaldon in Nueva Ecija (a province in Central Luzon) as the background site for Metro Manila PM pollution. It was found that the average $PM_{2.5}$ concentration at this site is 11 μg/m^3, which is way below the US EPA limits and the measured values along EDSA.

4.3.4. Comparison with UP Diliman Measurements

In a separate study, the UP-NCTS measured the particle counts at an area in UP Diliman, which is proposed to be the future location of the UP Centennial Dormitory. The study area is located on the corner of Laurel Avenue and Apacible Street. Apacible Street has light traffic volume, but Laurel Avenue has a moderate to high traffic volume because it is part of several jeepney routes. Jeepneys run on diesel fuel, so the $PM_{2.5}$ emissions is expected to be high as well, but not as high as that of EDSA where the traffic volume is significantly higher. The differences in $PM_{2.5}$ particle counts between MRT-3 roadside/platform and UP Diliman roadside were tested using an independent t-test. Due to the unequal sample sizes (MRT-3 has more samples), 54 random samples were drawn from MRT-3 roadside values. It was found that there is statistically significant difference between the two regardless of whether equal variances are assumed or not ($F=14.763$, $p=0.000$), wherein UP-Diliman has an average particle count of 103.83 cpm (sd=52.83 cpm) and that of MRT-3 roadside is 131.31 cpm (sd=22.61 cpm).

However, due to the differences in the timing of the surveys and day-to-day variation, the results are inconclusive.

4.3.5. Relationship with Meteorological Data and Traffic Volume

Particle concentration levels may be affected by meteorological data such as temperature, precipitation and wind speed. There was no precipitation during the entire $PM_{2.5}$ monitoring survey, so variability due to rain can be ruled out. The average wind speed was 7.96 kph (sd=3.44 kph) at 8:00 AM and 11.02 kph (sd=5.18 kph) at 11:00 AM, in which values ranged from “calm” to “moderate breeze” on the Beaufort scale. The average temperature at 8:00 AM is 27.55^{0}C (sd=1.50^{0}C) and 32.4^{0}C (sd=2.50^{0}C).

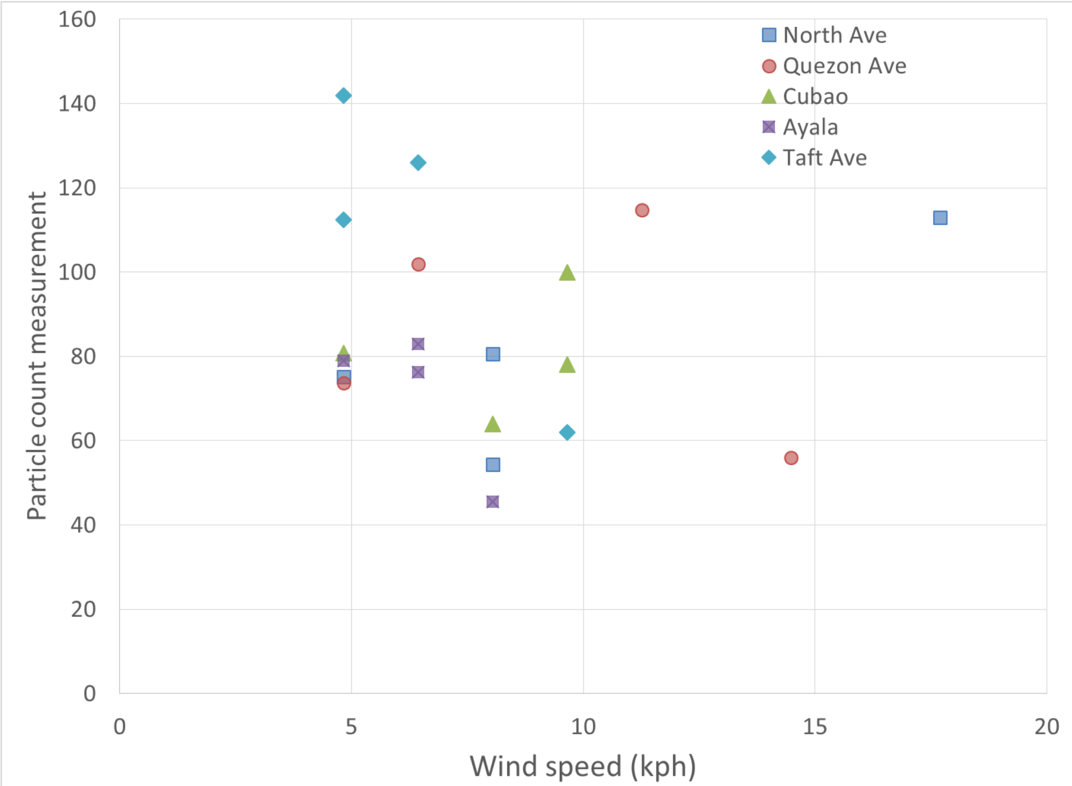


Figure 4.11. Relationship of particle count with wind speed

Each data point corresponds to the average particle count at the station considered for 30 minutes (average of 10 to 12 one-minute measurements). Contrary to theory and the results of other studies (e.g. Tittarelli *et al*, 2008; Schichtel, 1998), the measured particle count is not inversely correlated to wind speed, although the highest counts per station were measured on days with lower wind speed. Thus, there could be some other factor that affects $PM_{2.5}$ count day-to-day variability, which is likely to be traffic volume on the survey period.

Ideally, correlation analysis of the $PM_{2.5}$ data with EDSA traffic volume should be performed; however, the government agency in charge of recording traffic volume (MMDA) did not have archive of traffic counts, and that they can only provide the data for a week from March 15 to 21, 2015 (the original data request was for 2014-2015 data). Nevertheless, the provided data (although outside of the scope of the survey) could be of use in subsequent analysis. The data was collected through a manual count of video monitoring at MMDA Orense (near MRT-3 Guadalupe Station).

EDSA is a divided carriageway, often consisting of 12 lanes (6 in either direction), with the elevated railroad MRT-3 serving as its median for 16.7 km out of its total length 23.8 km. It can be noted from Figure 4.12 that both northbound and southbound directions have almost the same traffic levels, indicating that there is no clear peak direction unlike in MRT-3 where southbound direction dominates. It seems that the morning peak is quite long, with sustained high levels of vehicular traffic from 7:00 to 10:59 AM. There is some daily variation in traffic, with Monday (March 16) being the most congested and Friday (March 20) being the least congested.

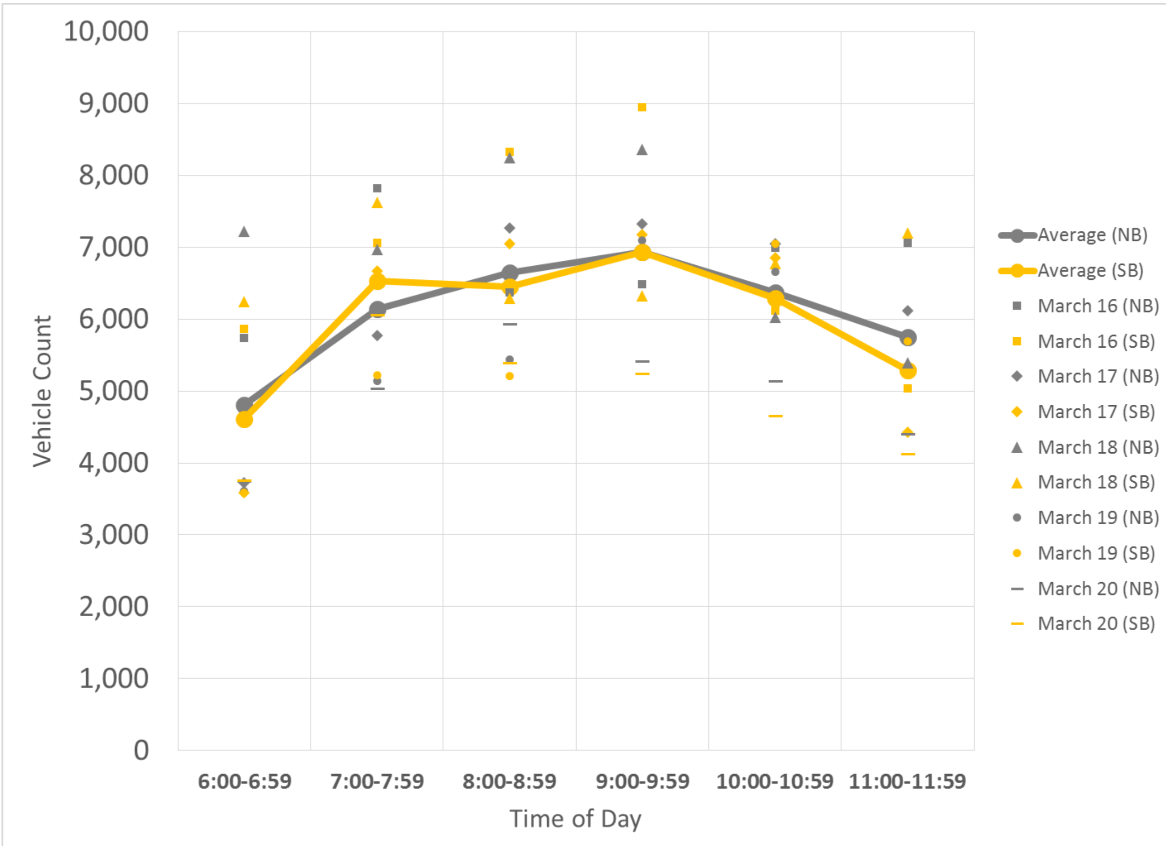
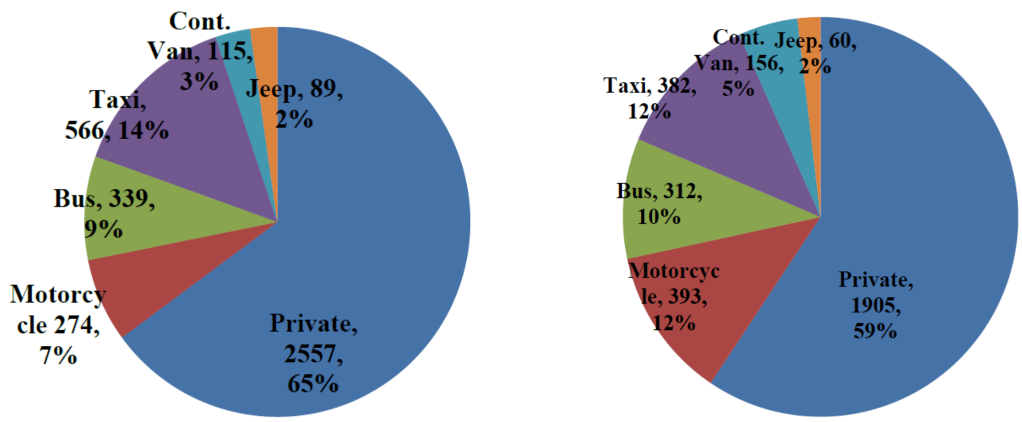


Figure 4.12. Official MMDA vehicle count at EDSA from March 16 – 20, 2015

This data could be used to provide traffic background data assuming that these conditions hold for the survey period in February 2 to March 5, 2015. Relating these counts to the corresponding weekday measurements (i.e. Monday traffic data to Monday $PM_{2.5}$ particle count data) yields inconclusive results.

The MMDA data also did not have a breakdown of the type of vehicles plying EDSA. In a previous study, Baron *et al* (2012) counted the number of different vehicles along EDSA during from 7 to 8AM in both directions using video count at the same location as the MMDA vehicle counts.



Northbound (left) and Southbound (right)

Figure 4.13. Percentage of different types of vehicles plying EDSA from 7:00-8:00 am

This indicates that buses only comprise a relatively smaller percentage of total traffic in EDSA in terms of number as compared to private cars. Even in terms of passenger car units, where PCU for bus is 3.5, private cars occupy more space than buses for both directions (bus dimensions = 2010 mm by 6990 mm compared to standard car dimensions = 1695 mm by 4410 mm). In terms of $PM_{2.5}$ emissions, most buses are powered by diesel while private cars are usually powered by gasoline, so it is likely that a reduction of diesel buses (and other vehicles) would result in a decrease in $PM_{2.5}$ pollution.

4.4. Chapter Summary

This chapter has presented intra-modal and intermodal comparison of $PM_{2.5}$ particle counts and exposure time along EDSA. Intra-modal comparison was performed at the roadside, ticketing area and platform of five major stations, while intermodal comparison was done for ordinary bus, air-conditioned bus and MRT-3. A relative concentration measurement equipment was used and measurements were done one mode or station at a time on 20 regular weekday mornings from February to March 2015. Theoretical computations based on secondary empirical data were used to convert relative concentration to mass concentration.

Intra-modal comparison of $PM_{2.5}$ exposure has shown that the $PM_{2.5}$ particle count means at Taft Avenue Station and at the ground level of each station are statistically higher than other stations and floor levels. However, it was found that there are no significant differences between the means at the other stations (North Avenue, Quezon Avenue, Cubao and Ayala Stations) and floor levels (basement, 2nd floor and 3rd floor). Moreover, since passengers at some stations spend considerably longer waiting times than others, the overall exposure levels are different.

Results of the intermodal comparison have shown that $PM_{2.5}$ concentration along EDSA are mostly at unhealthy levels with ordinary buses having the highest levels, followed by air-conditioned bus, then MRT-3 if only in-vehicle time is considered and waiting time is ignored. Exposure to $PM_{2.5}$ while riding inside the MRT-3 is at moderate to unhealthy levels depending on location, but passengers are exposed to higher $PM_{2.5}$ levels while waiting at the roadside, ticketing area and platform.

There is day-to-day and spatial variation of $PM_{2.5}$ particle count, but there is no clear relationship with wind speed data.

5. Passengers' Perception of Their Commuting Experience and Its Effects

This chapter focuses on the deteriorating level of service at the Metro Manila MRT-3, and the perception of regular morning peak period passengers on their commuting experience and its effects on them. In general, it aims to identify the gaps between actual conditions and perceptions.

5.1. Introduction

As presented in the previous chapters, MRT-3 passengers endure adverse conditions such as long waiting time and exposure to unhealthy levels of $PM_{2.5}$. This may imply that passengers suffer productivity loss, as well as anxiety and stress from waiting for a long and uncertain period of time (Osuna, 1985) and enduring crowded conditions (Mohd Mahudin *et al.*, 2012). In terms of air quality during their commute, it is unclear whether people are aware or concerned about it.

This chapter aims to describe the travel patterns, demographics and individual characteristics of regular MRT-3 morning peak period passengers and how these characteristics affect their perceptions. It also seeks to investigate the associations between passenger perceptions on their everyday morning commute and their mental adaptation to the system.

A theory on how Metro Manila MRT-3 commuters perceive and respond to a daily negative commute and examine its validity using structural equation modeling is proposed and tested. Specifically, it focuses on exogenous latent constructs involved in daily morning commute (i.e. perceived crowding, perceived air quality, predictability and perceived benefits), exogenous observed variables (total waiting time and feeder access time), and their direct and indirect effects on endogenous latent variables (perceived risk, perceived service quality, mental adaptation, awareness during the commute and commuting stress). It seeks to develop a measurement model through exploratory and confirmatory factor analyses to measure the latent constructs involved in perceptions in commuting experience, and investigate the relationship of the latent and observed variables through path analysis.

It also intends to test whether perceived risk, perceived service quality, awareness during the commute and mental adaptation mediate the relationship between the perceived commuting experience (i.e. perceived crowding, perceived air quality, perceived benefits, predictability and total waiting time) and commuting stress. Moreover, it would like to examine whether multi-group moderation occurs for age, experience, gender, income level, and presence of flextime policy. These moderators would provide additional insight and enhance the understanding of the relationships between the exogenous and endogenous variables.

5.2. Rationale for Indicators

It is hypothesized that MRT-3 passengers perceive their daily morning commuting experience and its effects according to nine latent constructs (four exogenous and five endogenous) and two exogenous observed variables. In order to aid in formulating the appropriate indicators and the hypotheses, extensive literature review was done. The definitions and relevant studies for each construct are provided in this section.

5.2.1. Exogenous Latent Constructs

Perceived crowding is a latent construct composed of observed variables that relate to the negative affect of crowding, that is, intrusion on personal space, feeling of discomfort and being cramped. Crowding is conventionally synonymous to passenger density as cited in many studies (e.g. Freedman, 1975); however, there are individual differences on the definition of "crowding" among passengers (Cox *et al.*, 2006; Mohd Mahudin *et al.*, 2012). In the context of this research, it is assumed that while MRT-3 has the same average passenger density inside its trains during the entire morning rush hour period, perceived crowding differs among passengers depending on their threshold.

Predictability reflects the variability of the service as well as the level of familiarity of passengers with the system. Seligman and Miller (1979) suggested that people who cannot control their environment may be satisfied with being able to predict it. Although passengers may control various aspects of the commute including the departure time from home, which feeder modes to take or using a less crowded station, unpredictability of arrival time at the boarding station and at the workplace may still exist. According to Kluger (1998), an unpredictable commute may contribute to perceptions of fear or lack of enjoyment with the commuting experience. In other words, the effects of a commute that has some of the objective characteristics of being stressful (e.g. long travel time, many transfers) and is unpredictable will lead to much greater commuting stress than if it were predictable.

Perceived benefits refer to the advantages of using MRT-3 relative to other alternatives as perceived by passengers. These could denote savings in travel time and costs, and increase in comfort, safety, security, accessibility and reliability as compared to other alternatives.

Perceived air quality pertains to passengers' rating on the air quality at the MRT-3. It represents their awareness and concern about their exposure to air pollution during their commute. Previous studies have shown that visual and olfactory characteristics of air have a significant impact on perceived air quality, so the absence of black exhaust fumes may lead one to think that the air quality is good (Saksena, 2011). However, preliminary surveys conducted by the authors at the roadside and platform of MRT-3 have shown that $PM_{2.5}$ levels (which are invisible to the naked eye) exceed US EPA levels, with platform levels being higher than roadside levels. Perceived air quality could have a significant effect on perceived risk, perceived service quality and commuting stress.

5.2.2. Exogenous Observed Variables

Total waiting time refers to the time spent from arriving at the end of the queue at the station until getting on the train, and is the sum of station access time and platform waiting time. It is a critical component of total trip time, and was found to be valued around two to three times more than in-vehicle travel time (Mohring *et al*, 1987). Osuna (1985) pioneered research on the relationship between waiting and stress, and presented a model that describes the psychological cost of waiting which states that length and uncertainty of waiting time are its major causes. Platform waiting time at the MRT-3 has been studied and shown to be disproportionately high in the middle stations (Mijares *et al*, 2013, 2014). Access time is also a critical part of total waiting time as ocular surveys have shown that queues into the station frequently spill onto the roadside. Furthermore, MRT-3 passengers are not provided any information by the operator on how long their waiting time is and have to rely on intuition and previous experience to estimate it.

Feeder access time is defined as the time spent in traveling from the origin to the boarding station. Most feeder modes that lead to the boarding station are road-based (e.g. jeepney and bus) and are therefore subject to road congestion, which can be severe during the morning peak period. Thus, it affects the arrival time at the boarding station, which might add to the commuting stress that passengers may experience. While this variable not exactly part of the theory that we would like to test, we have included it as a control or a potentially confounding variable to isolate the effects of MRT-3 commuting experience on the endogenous variables.

5.2.3. Endogenous Latent Constructs

Perceived risk (or risk perception) is characterized as the intuitive judgment of individuals and groups of risks in the context of limited and uncertain information (Slovic, 1985). In the context of this research, perceived risk is defined as the subjective assessment of objective risk, which is the probability of the occurrence of a safety incident causing fatalities and/or injuries, and how concerned passengers are with the consequences. Overestimation of risk would cause unnecessary anxiety in passengers (Evans and Morrison, 1997), such that they would hesitate to use MRT-3 or feel stressed. Meanwhile, an underestimation of risk would make it more attractive, and thus cause an increase in demand. This is a potentially dangerous situation because the rail mode has a higher objective risk due to higher passenger density, making catastrophic accidents and minor incidents more likely to happen, while passengers are unknowingly exposing themselves to danger.

Perceived service quality refers to how passengers rate the service of MRT-3 based on their individual standards, which could be shaped by previous experiences, interpersonal comparisons and expectations. Transit service quality was measured by Eboli and Mazulla (2011) using both passenger perceptions and transit agency performance measures involving the main aspects characterizing a transit service.

Awareness during the commute denotes the level of attentiveness during the commute. This, in turn, would increase commuting stress as more cognitive load is expended. The congested and variable situation leads passengers to become more aware during the commute leading to an increase in commuting stress, but at the same time, passengers may get mentally adapted or habituated to the situation as their experience increases, thus reducing their commuting stress.

Commuting stress refers to the emotional and physical strain of commuting to work or school in the morning. Novaco *et al.* (1979) suggested the concept of commute impedance, which is defined as a behavioral restraint on movement or goal attainment. Novaco *et al.* (1979, 1990) distinguished between objective impedance, a combination of time and distance between home and work, and the subjective components, obtained from self-report data requiring respondents to describe how various stimuli (traffic lights, stop signs, etc.) affected their trip to work..

Koslowsky (1997) describes a model wherein objective stressors were related to physiological responses and the subjective indicators were associated with affective outcomes, and points out that some critical moderator variables such as predictability and time urgency should be accounted for.

Mental adaptation is referred to as a change made to deal with an unsatisfactory commuting situation. There are two types of adaptation: (1) physical (or behavioral) adaptation, which means changing their behavior or the situation itself; and (2) mental adaptation, which refers to changing their way of thinking about it (Punpuing and Ross, 2001). Mental adaptation is similar to hedonic adaptation in psychology, which is defined as the psychological process by which people become accustomed to a positive or negative stimulus, such that the emotional effects of that stimulus are attenuated over time. The situation in MRT-3 is largely out of the passengers' control because there are many external factors that affect it. Passengers have already physically adjusted their commuting behavior through physical adaptation strategies such as changing their departure time from home, but the situation is still bad, so the only way to cope is to mentally adapt to the situation. In this research, mental adaptation refers to a reduction of the affective intensity of unfavorable circumstances (i.e. long, crowded and unpredictable commute) that occur on a regular basis. It refers to the level of being accustomed to the negative stressor and means of coping.

5.2.4. Other Indicators

The frequency of lateness and its corresponding monetary penalty are indicators of direct money loss from a long and unpredictable commute.

Perceived length of commute refers to how long an individual perceives his or her morning commute regardless of how long it actually is in terms of time or distance. Satisfaction denotes an individual's contentment with his or her commute based on personal expectations. Several moderators related to socio-economic characteristics, travel habits and workplace environment may have an impact on the relationships between commuting experience and its effects.

Gender. Social role theory suggests that men are more willing than women to take risks because men are socially expected to engage in risky behavior (Powell and Ansic, 1997), and that women are typically seen as more expressive and emotional than men (Eagly, 1987). This may imply that women have higher perceived risk and commuting stress.

Income level. In general, people with lower income have more pressing problems to think of due to their financial situation, and their level of standard for service quality may be lower since they would typically only care about taking the most affordable mode. Taking these into consideration, it is assumed that lower-income commuters may be less sensitive to deteriorating level of service and commuting stress and view the situation as more favorable as long as they perceive that they are getting some benefits from it.

Experience. As an activity is repeatedly performed, individuals become more familiar and knowledgeable about the system. Thus, commuters who have used MRT-3 for a longer time on a daily basis are expected to be more adapted and less stressed with their commutes.

Age. Older and younger people may have differences in perceiving their commute and its effects. For instance, older people could get more easily exhausted, thus increasing their commuting stress.

Flextime policy is increasingly being put in place in Metro Manila companies to allow workers to have some leeway for their work schedule. Lucas and Heady (2002) investigated the effect of a flextime working environment on driver stress, feelings of time urgency, and commute satisfaction for commuters in a large-city environment. For people without flextime policies at their workplace, workers need to arrive at the office at a certain fixed time so lack of predictability may affect their punctuality at the office, which may lead to monetary penalties for late arrival. That said, the negative relationship between predictability and stress is expected to be stronger for commuters without flextime policies.

5.3. Modeling Framework

The modeling framework for the measurement and structural models are discussed in this section.

5.3.1. Hypothesized Measurement Model

A measurement model was first specified to evaluate the adequacy of the proposed model in explaining the underlying observed data. It was hypothesized that the MRT-3 passengers' daily morning commute experience is defined by nine different latent factors, wherein each latent factor is represented initially by three to five indicators. The indicators were formulated using the rationale in Sections 2.1, 2.2 and 2.3, and given as 7-point Likert-scale statements.

5.3.2. Hypothesized Structural Model

In this part, we hypothesize how the exogenous and endogenous factors relate to each other. These were based on the discussion given in Section 5.2 as well as intuition. The hypotheses are summarized below:

H1. Perceived risk is increased by perceived crowding, and is reduced by predictability, perceived air quality and perceived benefits.

Higher crowding levels increases the incidence of crime, accidents and health impacts (Cox et al. 2006). Predictability is hypothesized to reduce perceived risk, as perceptions of less predictability are expected with more fear (Peters *et al.,* 2004). Perceived air quality would reduce perceived risk because of the known health effects associated with poor air quality. Fischhoff *et al.* (1978) suggested that individuals weigh perceived benefits against perceived risk. This implies that passengers would still use the MRT-3 even if they deem it to be risky because of the perceived benefits that they receive, and would be expected to reduce their commuting stress.

H2. Perceived service quality is positively affected by predictability, perceived air quality and perceived benefits, and is negatively affected by perceived crowding, perceived risk and total waiting time.

In the context of Metro Manila, Fillone *et al.* (2005) they found that total travel time, total in-vehicle travel time order, safety and security, service reliability, and comfort are the significant indicators for their assessment of urban travel. In this research, predictability is synonymous to service reliability and comfort is represented by perceived crowding, and perceived risk captures safety and security. Total waiting time is also a common explanatory variable for perceived service quality (e.g. Litman, 2008). Moreover, additional indicators (perceived air quality and perceived benefits) are hypothesized to affect perceived service quality. Intuitively, the sensory and psychological evaluation of air quality while commuting could affect it, while higher perceived benefits relative to other mode could influence an individual to improve it as well.

H3. Perceived crowding increases awareness during the commute.

Since crowding is linked to increased crime and incidents, a passenger's awareness is expected to be heightened as perceived crowding is increased to prevent such things from occurring.

H4. Perceived benefits, perceived service quality and predictability promote mental adaptation, while perceived crowding and total waiting time hinder mental adaptation. Moreover, the longer a passenger has been using MRT-3 for his or her daily commute, the more mentally adapted he or she is.

Mental adaptation is generally faster for positive experiences and slower for negative ones (Lyubomirsky, 2011), so it is expected that positive aspects of the commute would promote adaptation and negative aspects would impede it. Moreover, adaptation to negative experiences is expected to set in as time passes by and the exposure to the stressor is repeated (Frederick and Loewenstein, 1999).

H5. Awareness during the commute, perceived risk, perceived crowding, feeder access time and total waiting time increase commuting stress, while perceived benefits, perceived air quality, predictability and perceived service quality decrease it.

Commuting stress has been shown to be affected by waiting time (e.g. Osuna, 1985), predictability (e.g. Evans *et al*., 2002), travel time and perceived service quality (e.g. Novaco *et al.*, 1990). Moreover, positive aspects of the commute such as perceived benefits and perceived air quality could reduce commuting stress.

H6. Awareness during the commute, mental adaptation, perceived risk and perceived service quality partially mediate the relationship between perceived crowding and commuting stress.

In other words, perceived crowding directly affects commuting stress and indirectly affects it through mediators. As mentioned in the previous hypotheses, perceived crowding are postulated to influence the above-mentioned factors, and these same factors are hypothesized to affect commuting stress, so partial mediation between perceived crowding and commuting stress through those factors is expected.

H7. Interaction effects between some exogenous variables exist such that predictability negatively moderates the relationship between perceived crowding and total waiting time, and commuting stress, respectively.

Predictability has been shown to moderate the effect of travel time on commuting stress (Kluger, 1998), so it may also moderate the impacts of total waiting time (a travel time component). Moreover, there is a tradeoff between reliability and crowding levels as seen in mass transit systems where people endure crowded conditions for a predictable commute, so predictability may dampen the effect of perceived crowding on commuting stress.

H8. Multi-group moderation occurs for gender, age, income level, experience, presence of flextime policy and lateness penalty.

This is hypothesized because individual characteristics usually influence the relationships among actual and perceived variables. Differences in perception according to these factors have been found: age (e.g. Aldwin *et al.*, 1996), gender (e.g. Novaco *et al*, 1990), experience, (e.g. Lyubomirsky, 2011), flextime policy and time urgency (e.g. Lucas and Heady, 2002), and income levels (e.g. Brantley *et al.*, 2002).

5.4. Methodology

5.4.1. Questionnaire Survey

Data collection was performed in September 2014. This was before the substantial fare hike in January 2015, which could have had a substantial effect on the demand and commuting experience at the MRT-3. Section 1.6 shows the timeline of the survey relative to significant events or changes at the MRT-3.

The researchers teamed up with the University of the Philippines National Center for Transportation Studies (UP NCTS) to conduct the questionnaire survey. It was conducted mostly online through spreading the survey link through news forums, social networking sites, online groups and e-mail blasts to make it as random as possible. 145 (68.7% of respondents) chose to take the English version of the questionnaire, while the rest answered in Filipino. On-site interviews were also done to specifically target passengers above 40 years old to attain a more balanced age profile. Respondents had an option to receive a compensation of PhP100 in the form of pre-paid cellphone load, and 120 respondents chose to avail it. Data screening was also performed to eliminate unengaged respondents and outliers.

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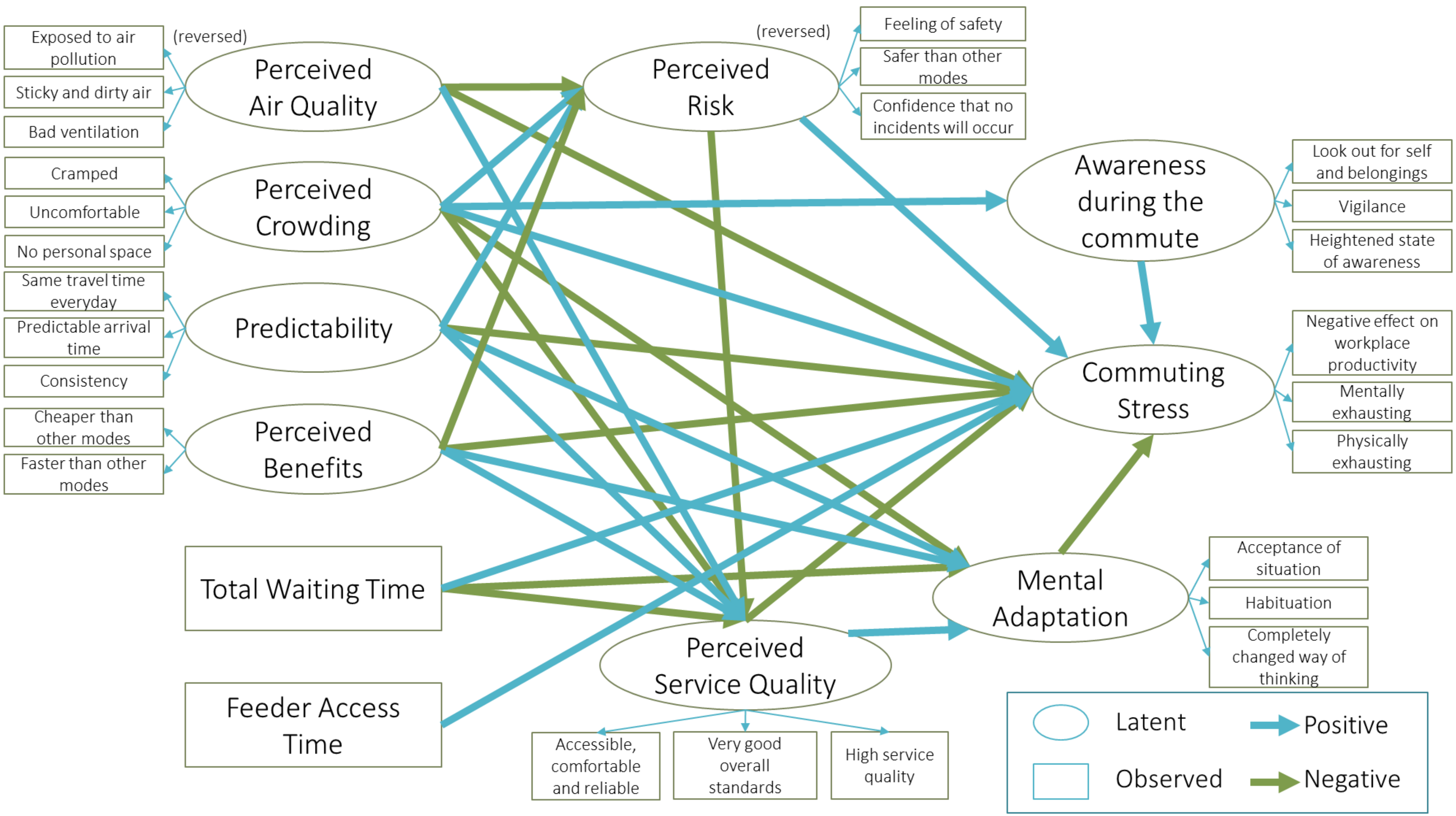


Figure 5.1. Hypothesized measurement and structural model

Among 211 regular morning peak hour commuters of Metro Manila MRT-3, 119 (56.4% of respondents) are females, 84 (39.8% of respondents) earn below PhP20,000 a month, 127 (61.6% of respondents) are below 30 years old. 55 (26.1% of respondents) have been using the MRT-3 for their everyday morning commute for more than 5 years, while 48 (22.7% of respondents) have used it for less than two years. Comparison of the sample data's gender and age profile with that of Metro Manila residents reveals that there is a slight oversampling of younger commuters (61.6% vs. 48.5%), but this is expected given the survey method used. Nonetheless, it was deemed appropriate as a representative sample of morning peak commuters.

5.4.2. Fundamental Data Analysis

This part shows the commute characteristics, physical adaptation and perception of MRT-3 commuters. Using a variety of basic statistical methods such as cross-tabulation, chi-square tests and curve estimation, correlations between perceived constructs, differences between perception according to socio-economic characteristics and work environment policies, as well as relationships between perceived and actual conditions were explored. All analyses were done using IBM SPSS 22.0 (IBM Corp., 2013).

5.4.3. Advanced Data Analysis using Structural Equation Modeling

Exploratory factor analysis (EFA) and Cronbach's alpha coefficients were used to test the proposed factor structure and its internal consistency using IBM SPSS 22.0 (IBM Corp., 2013). Principal axis factoring and Promax rotation with Kaiser normalization was employed and the number of extracted factors was fixed to nine factors as hypothesized. Some indicators that did not load to their intended latent factors or were cross-loading were removed until a clean pattern matrix was obtained (a minimum factor loading of 0.400 was set).

The resulting factor structure in the EFA was inputted into AMOS 22.0 to perform confirmatory factor analysis (CFA) to assess the indicator reliability, construct validity, and convergent and discriminant validity. Based on the recommendations of Hu and Bentler (1999), the following goodness-of-fit indices and their corresponding thresholds were used: *p*-value of the model (>0.05); chi-square/degrees of freedom (CMIN/DF; <3), goodness-of-fit index (GFI; >0.90), adjusted GFI (AGFI; >0.80), comparative fit index (CFI; >0.95); root-mean-square error of approximation (RMSEA; >0.05); and p-value of the null testing that

RMSEA does not exceed 0.05 (PCLOSE; <0.05) and standardized root mean residual (SRMR; <0.09).

Upon achieving sufficient model fit, composite measures were imputed from the confirmatory factor analysis based on the Data Imputation (Regression) function in AMOS 22.0 (Arbuckle, 2013). This procedure is a well-known data imputation method that uses the estimated parameters from a factor analysis to define linear combinations of observed variables that generate factor scores. It uses the following formula proposed by Bartlett (1937):

Given a factor loading matrix Λ, a factor covariance matrix Φ, and a residual covariance matrix Ψ, and data vector of interest y_i.

$$\widehat{f_i} = (\Lambda'\Phi^{-1}\Lambda)^{-1}\Lambda'\Psi^{-1}y_i \tag{4}$$

For example, the latent variable "Crowding" has three indicators based on the CFA measurement model, which are: (1) cramped; (2) uncomfortable; and (3) no personal space. Using regression imputation, we can get a single composite score for "crowding" using the factor loadings, factor covariances and residual covariances of the three observed indicators. This simplifies the analysis by shifting focus onto the relationships between latent variables instead of individual indicators and their error terms, and allows further analyses such as cluster analysis using composite indicators.

The hypothesized structural model was then subjected to path analysis testing using structural equation modeling with the composite measures as variables. This technique is appropriate for testing the complex relationships that we have hypothesized in Section 5.3.2. The goodness-of-fit indices for the model were assessed and regression coefficients were checked for significance and proper signs.

Mediation analysis was performed using a bootstrapping procedure, a nonparametric resampling technique for testing mediation, in AMOS 22.0. First, the prospective mediator was removed from the model, and the model was run to get the direct effects of the independent variable on the dependent variable and ensure its significance. Then, the bootstrapping procedure was set up with 2,000 bootstrap samples and 95% bias-corrected confidence level. The model was run again with the prospective mediator in the model, and the direct and indirect effects are extracted from the output file. Mediation exists if the indirect effects are significant. For full mediation, the direct effects becomes insignificant once the mediator is added to the model while for partial mediation, the direct effects are significant with and without the mediator in the model.

Multi-group moderation was performed by forming groups in AMOS 22.0 based on the categorical variable of interest, then using their respective standardized estimates and critical ratios for differences between parameters. A macro spreadsheet by Gaskin (2012) was used to facilitate this computation. Moderation was also performed to check for interactions between exogenous variables. The effect of model misspecification on bias of standard error estimates seemed to be minor in general.

It is necessary to outline the assumptions made in this analysis. First, most of the indicators (with the exception of total waiting time and feeder access time) are ordinal 7-point Likert scale data. Following convention, it is assumed that these variables can be treated as continuous ones given that they are measures of continuous underlying constructs and that the scale is longer than the usual 5-point Likert scale. Transformations were not used as they tend to make data interpretation difficult.

A minimum sample size ratio of five respondents per indicator was aimed for to satisfy the requirements of CFA and SEM (Kline, 2011), which translates to a minimum sample size of 160 for the 32 initial indicators.

Some indicators are noticeably skewed (e.g. crowding, service quality, commuting stress) thus violating the multivariate normality assumption that is required in SEM using maximum likelihood (ML) estimation. It is widely recognized that multivariate normality of observed variables is usually violated in practice (e.g., Micceri 1989), so several studies have looked into the consequences of doing this. Fortunately, previous research (e.g. Boomsma, 1983; Hau & Marsh, 2004) suggests that ML estimation tends to be robust in terms of parameter estimates.

5.5. Results of Fundamental Data Analyses

Prior to conducting more advanced statistical analyses, the basic relationships are examined first.

5.5.1. Basic Commute Characteristics and Physical Adaptation

Survey respondents spend an average total waiting time of 29.99 minutes (st. dev. = 15.16 minutes), average number of stations traveled of 7.03 stations (st. dev. = 2.738), with 66% heading to the southbound direction, average feeder access time of 41.35 minutes (st. dev. =

26.68 minutes) with an average of 1.50 feeder access transfers (st. dev. = 0.70 transfers), and an average total trip time of 118.44 minutes (st. dev. = 41.323 minutes). This indicates that a substantial part of their commute is spent on waiting and transfers.

Table 5.1. MRT-3 commute characteristics of the respondents

Variable	Minimum	Maximum	Mean	Standard Deviation
Total waiting time at the MRT-3	5 minutes	60 minutes	29.99 minutes	15.16 minutes
Feeder access time (home to boarding station)	3 minutes	180 minutes	41.35 minutes	26.68 minutes
In-vehicle travel time at the MRT-3	4.5 minutes	40 minutes	28.11 minutes	10.92 minutes
Total trip time (home to workplace)	30 minutes	240 minutes	118.44 minutes	41.32 minutes
Number of stations traveled	1 station	12 stations	7.03 stations	2.73 stations

Table 5.1 summarizes the commute characteristics of the respondents, with focus on the travel time components during their commute. It can be seen that passengers spend as little as five minutes to as large as 60 minutes, and in-vehicle travel time for an average distance of 7.03 stations (approximately 9.8 km) is approximately as long as waiting time at the station.

The questionnaire survey also indicate that passengers have already adapted physically by changing their travel behavior in one or more ways due to the severity of their morning commute – 90% have switched to an earlier departure time, 19% have changed their boarding station to a less crowded one, 19% have moved to another residence and 5% have moved to another workplace. It should be noted that such behavioral adaptation strategies are subject to constraints specific to each individual's circumstances. Questions on time urgency at the workplace were also asked. 31% of respondents were late to work for more than 10 times in the past month, while 30% were late for 4-9 instances. Given that 71% of respondents incur a monetary penalty for late arrival, this translates to lost salary as well as non-monetary penalties for late arrival such as poor reputation and lower productivity.

Only 17% of respondents can usually ride on the first arriving train, while 15% of respondents need to wait for four or more trains before being able to ride, as seen in Figure 5.2. Moreover, it was found that more than 60% of the respondents have been late to work for at least four times due to their MRT-3 commute, with 31% being late for more than 10 times, as illustrated in Figure 5.3. Given that 71% of respondents incur a monetary penalty for late arrival, this translates to lost salary as well as non-monetary penalties for late arrival such as poor reputation and lower productivity.

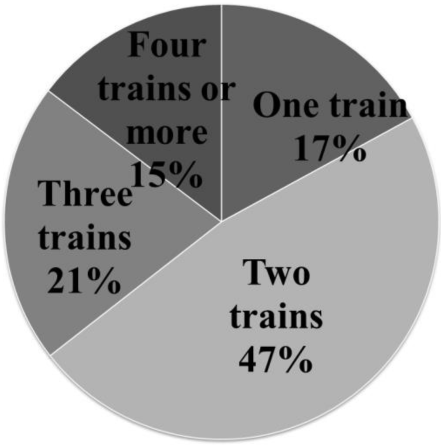


Figure 5.2. Average number of trains waited for before being able to board

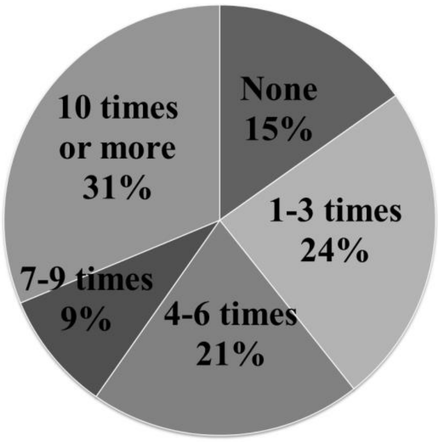


Figure 5.3. Frequency of tardiness in the past month due to MRT-3 commute

The questionnaire survey results also reveal that many passengers have already adapted physically by changing their travel behavior in one or more ways due to the severity of their morning commute – 90% have switched to an earlier departure time, 19% have changed their boarding station to a less crowded one, 19% have moved to another residence and 5% have moved to another workplace.

Figure 5.4 shows that feeder access time, which is affected by road congestion conditions and number of transfers, is perceived as less variable than total waiting time, indicating that the latter is more unpredictable and could thus lead to higher anxiety and loss productivity.

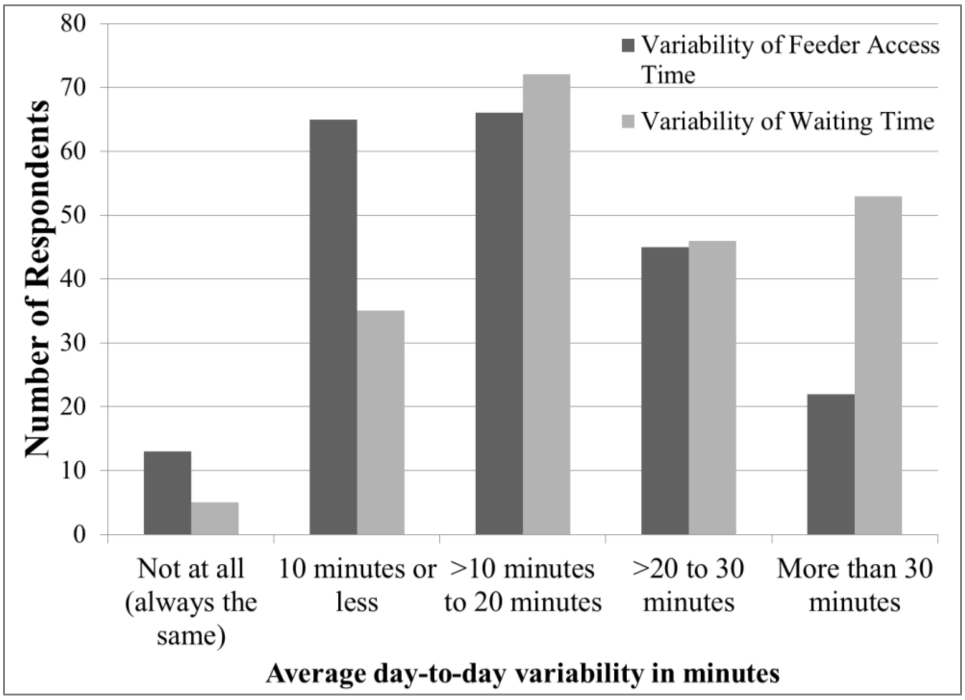


Figure 5.4. Perceived variability of feeder access time and total waiting time

The questionnaires also asked about passenger perception about their commute using a 7-point Likert Scale. Figure 5.5 show their perceptions about crowding, length of commute, predictability, commuting stress, service quality and satisfaction. It was found that majority of respondents find their commute long and crowded. The responses to the predictability indicators were mixed, indicating that several passengers may be used to this everyday situation and know what to expect. Most respondents are also mentally and physically exhausted due to their commute, and dissatisfied with the poor service quality of MRT-3.

The latent constructs and their corresponding indicators, including the means and standard deviations of the raw data responses, are presented in Table 1. The values for the indicators for perceived air quality and perceived risk were reversed in subsequent analyses. Note that indicators that would eventually be eliminated in the factor analyses (i.e. Adapt2, Stress1, Stress2, ServQua4, ServQua5 and Benefits3) were not included to save space.

Table 5.2. Latent constructs and proposed indicators

Latent Construct	Scale Item (To what extent do you agree or disagree with the following statements regarding your daily morning commute using the MRT-3? Scale of 1-7: 1 – Strongly disagree; 7 – Strongly agree)	Indicator Name	Mean	Standard deviation
Perceived Air Quality (reversed scale)	I am exposed to air pollution while waiting to ride the MRT-3 at the roadside, ticketing area and platform	AirQua1	5.28*	1.768*
	The air feels sticky and dirty	AirQua2	5.32*	1.770*
	The ventilation is bad in MRT-3	AirQua3	4.99*	1.636*
Awareness during the commute	I am confident that MRT-3 will not experience any major incidents	Aware1	6.22	1.223
	I always look out for myself and my belongings when using the MRT-3	Aware2	6.15	1.186
	Commuting in MRT-3 requires me to be vigilant and street-smart	Aware3	5.98	1.177
Predictability	I leave home and arrive at work or school at the same time every day	Predict1	3.51	1.666
	I can predict when I will arrive at the station if I leave home at a certain time	Predict2	3.41	1.602
	My commute to work or school is consistent on a day-to-day basis	Predict3	3.50	1.608
Mental Adaptation	Commuting in this situation is part of normal everyday life	Adapt1	3.84	1.574
	I have become used to this everyday situation	Adapt3	3.99	1.703
	I have completely adapted to commuting in this situation	Adapt4	3.92	1.669
Perceived Risk (reversed scale)	I feel that MRT-3 is a safe transport mode	Risk1	4.17*	1.540*
	Using MRT-3 is much safer to use than road-based transport modes	Risk2	4.08*	1.475*
	I am confident that MRT-3 will not experience any major incidents	Risk3	4.21*	1.569*
Perceived Service Quality	MRT-3 is an accessible, comfortable and reliable form of transport	ServQua1	2.63	1.482
	The service in MRT-3 has very good standards in all aspects	ServQua2	2.48	1.232

Latent Construct	Scale Item (To what extent do you agree or disagree with the following statements regarding your daily morning commute using the MRT-3? Scale of 1-7: 1 – Strongly disagree; 7 – Strongly agree)	Indicator Name	Mean	Standard deviation
	MRT-3 has a high service quality all in all	ServQua3	2.62	1.424
Commuting Stress	My commute negatively affects my productivity at the workplace or in class	Stress3	5.27	1.482
	My commute is very stressful and mentally exhausting	Stress4	5.46	1.577
	I feel physically exhausted because of my commute	Stress5	5.59	1.544
Perceived Benefits	MRT-3 allows me to save money because it is cheaper to use than other modes	Benefits1	4.97	1.547
	MRT-3 allows me to avoid being stuck in road traffic because it is faster than other modes	Benefits2	5.12	1.552
Perceived Crowding	MRT-3 is very cramped and crowded	Crowding1	5.72	1.547
	I am uncomfortable when there are many other passengers in the MRT-3	Crowding2	5.75	1.473
	I do not have enough personal space when using the MRT-3	Crowding3	5.80	1.495

*values not reversed

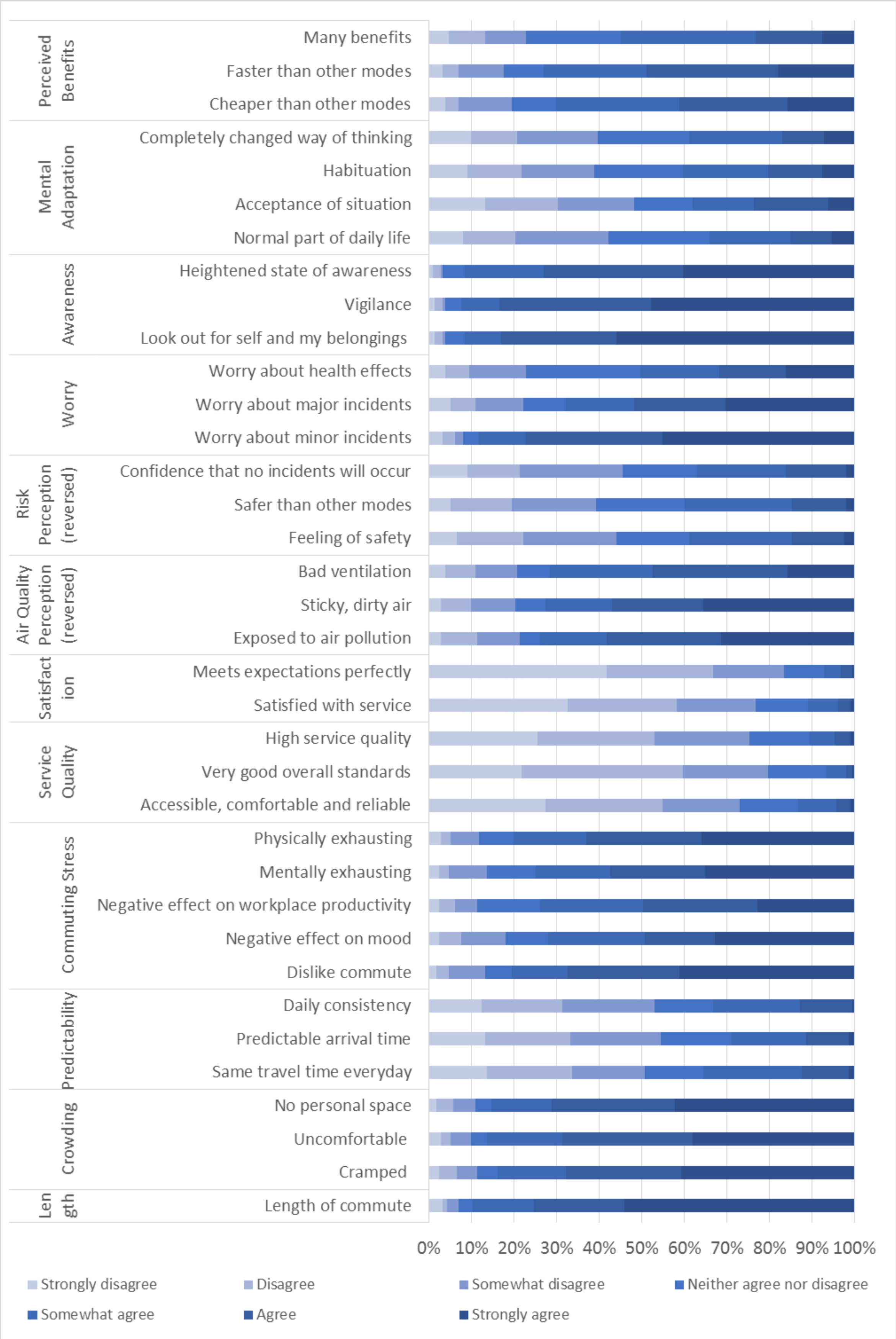


Figure 5.5. Distribution of responses regarding perception

5.5.2. Relationship between Travel Time and Perceived Length of commute

A curve was fitted to find out the gap between actual conditions (total travel time) and perceived conditions (perceived length of commute). The inverse relationship between total travel time and length of commute and the corresponding parameter estimates denote that people perceive their commute as long to very long past around the 70-minute mark. It also shows that only a few respondents perceived their trip as short.

The equation was found to be:

Perceived Length of Commute = b_0 + (b_1 / Travel Time in minutes)

Where b_0 =6.733 (p-value =0.000) and b_1 = -71.467 (p-value=0.003)

R-square =0.043; Adjusted R-square =0.038; Standard Error =1.408

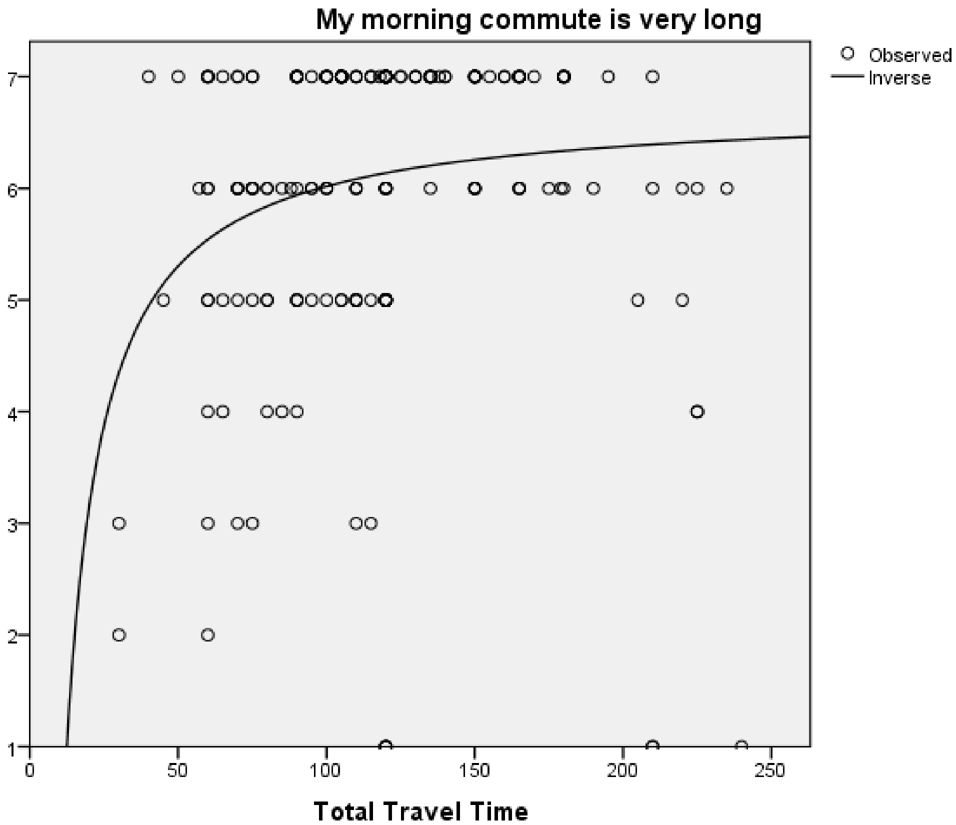


Figure 5.6. Relationship between total travel time and perceived length of commute

5.5.3. Relationship between Perceived Air Quality, $PM_{2.5}$ Particle Count and Waiting Time

Statistical analyses were performed to relate changes in $PM_{2.5}$ particle counts and waiting time to air quality perception. This would be useful in drafting countermeasures through a more realistic approach as to how reduction of $PM_{2.5}$ particle counts or waiting time and would affect air quality perception.

The scatter plot of $PM_{2.5}$ particle count measurements at each station including their corresponding means are plotted in Figure 5.7.

It should be noted that the measurements for North Avenue, Quezon Avenue, Cubao, Ayala and Taft Avenue stations were performed at the roadside, ticketing area and platform as part of the intra-modal comparison survey. However, all the other stations do not have such measurements, so the values inside the ordinary bus were used instead because these are the most similar to the roadside measurements.

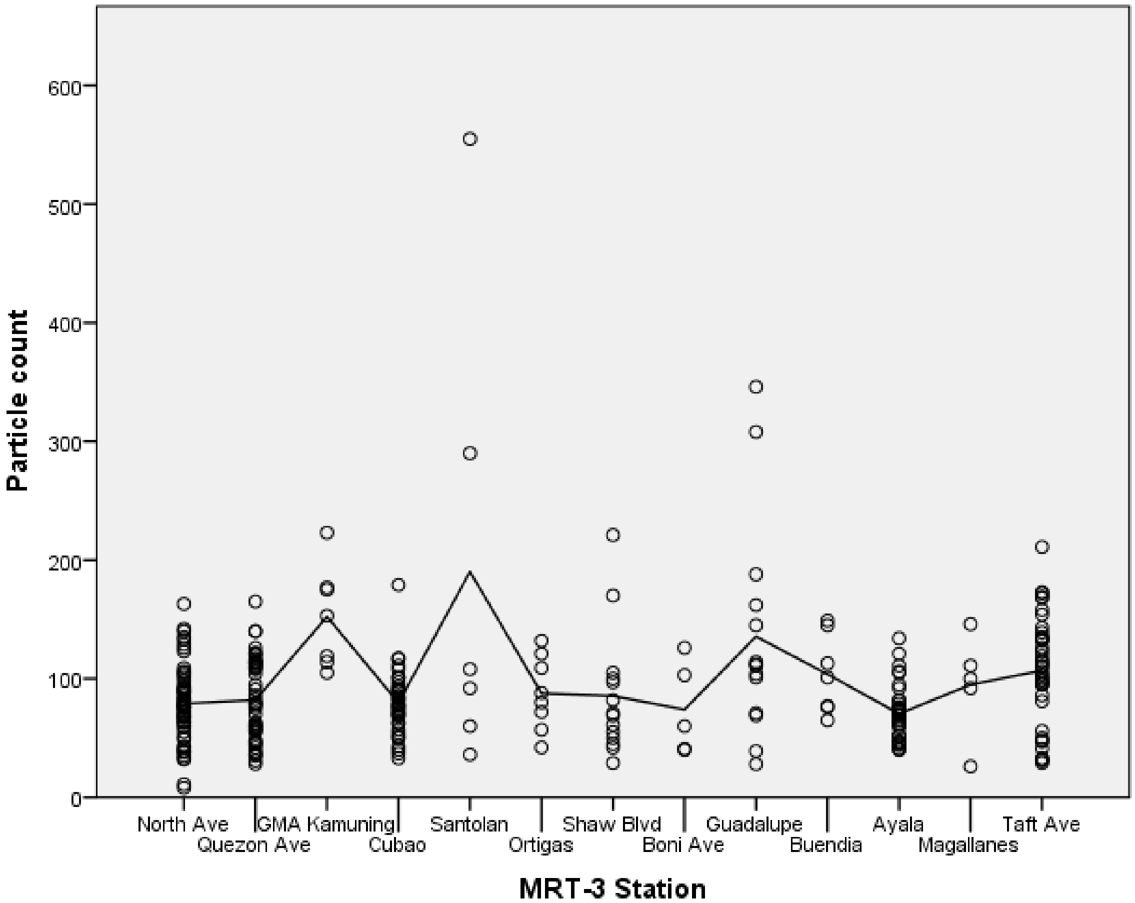


Figure 5.7. Scatter plot and mean $PM_{2.5}$ particle counts at MRT-3 stations

One-way ANOVA between stations revealed that there is a significant difference between the means of particle count [$F(12,274)=5.787$, $p=0.000$]. Post-hoc comparisons using the Tukey HSD test showed that the differences lie between GMA Kamuning, Santolan, Guadalupe and Taft Avenue Stations.

Moreover, one-way ANOVA between subjects was used to test the effect of boarding station (which have different $PM_{2.5}$ levels) and air quality perception. It was found that there was no significant difference between any of the stations [$F(11, 199)=1.098$, $p=0.364$].

It is also of interest to know whether there is a difference on relating waiting time with $PM_{2.5}$ particle count according to the MRT-3 station used when boarding. However, it is seen in Figure 5.8 that there is no apparent and logical trend between air quality perception and waiting time according to boarding station. Some stations even have a counterintuitive relationship between waiting time and air quality perception (i.e. air quality perception would improve if waiting time is increased).

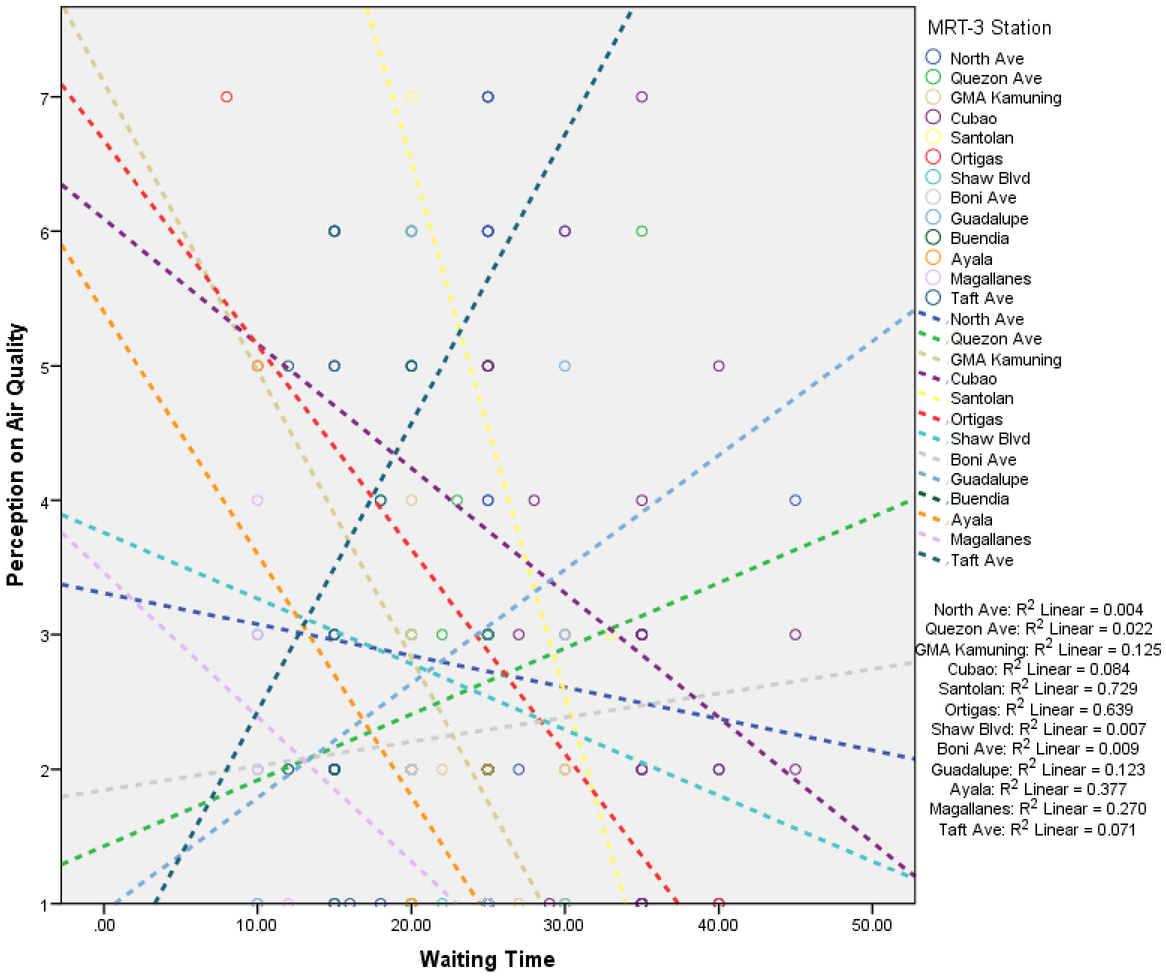


Figure 5.8. Scatter plot between air quality perception and waiting time and fitted linear regression line for each station

The difference may lie in individual characteristics. Two-step cluster analysis was performed to classify the respondents according to air quality perception and $PM_{2.5}$ particle count. Results show that there are three clusters: low particle count and low air quality perception; low particle count and high air quality perception, and high particle count and varied air quality perception.

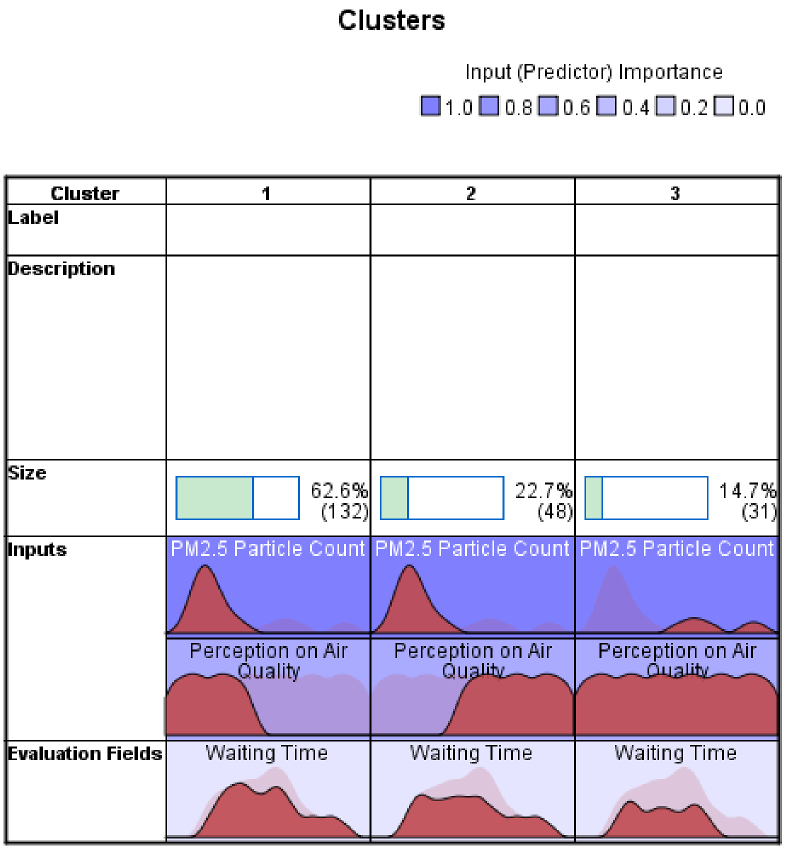


Figure 5.9. Cluster analysis with $PM_{2.5}$ Count and air quality perception as variables

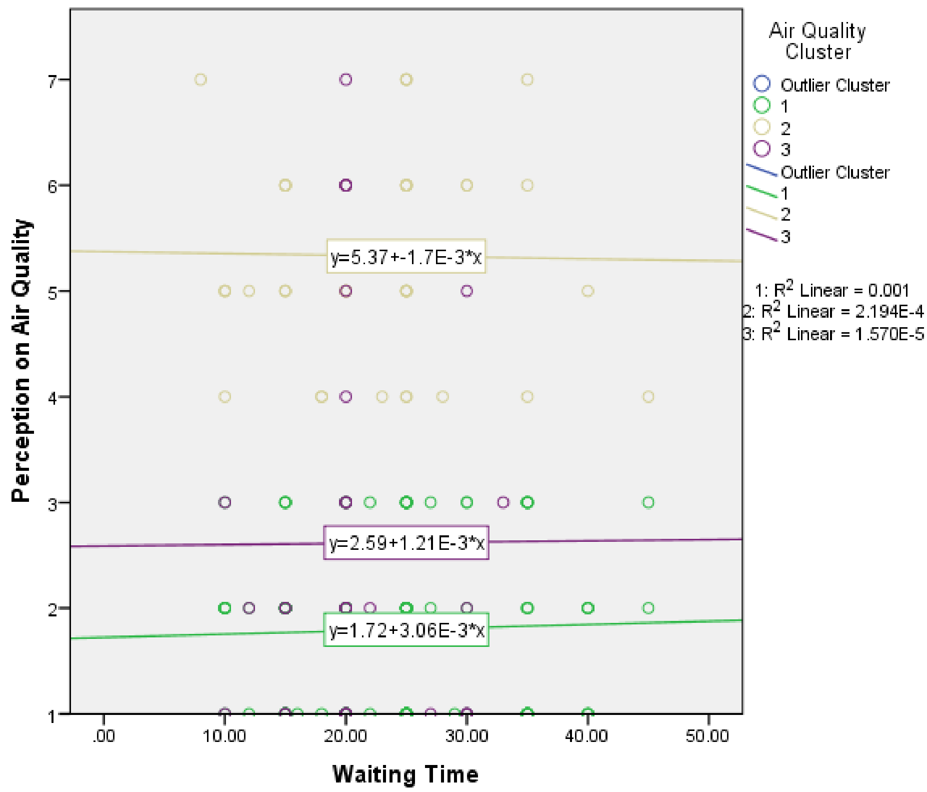


Figure 5.10. Scatter plot between air quality perception and waiting time and fitted linear regression line for each cluster

The lack of statistically significant relationships between the air quality perception and exposure-related measurable data (i.e. waiting time and average $PM_{2.5}$ count at boarding station) implies that air quality perception is linked to other individual differences rather than exposure-related measurable data. This finding is consistent with previous studies which show that visual and olfactory characteristics of air have a significant impact on perceived air quality, so the absence of black exhaust fumes (like $PM_{2.5}$ which is invisible to the naked eye) may lead to better ratings of air quality (Saksena, 2011).

5.5.4.Relationship between Perception on Air Quality and Worry on Health Effects

Differences according to socio-economic characteristics were also looked into, but no sensible relationships were uncovered. However, it was found that air quality perception is linked to worry about health effects, as seen in Figure 5.11.

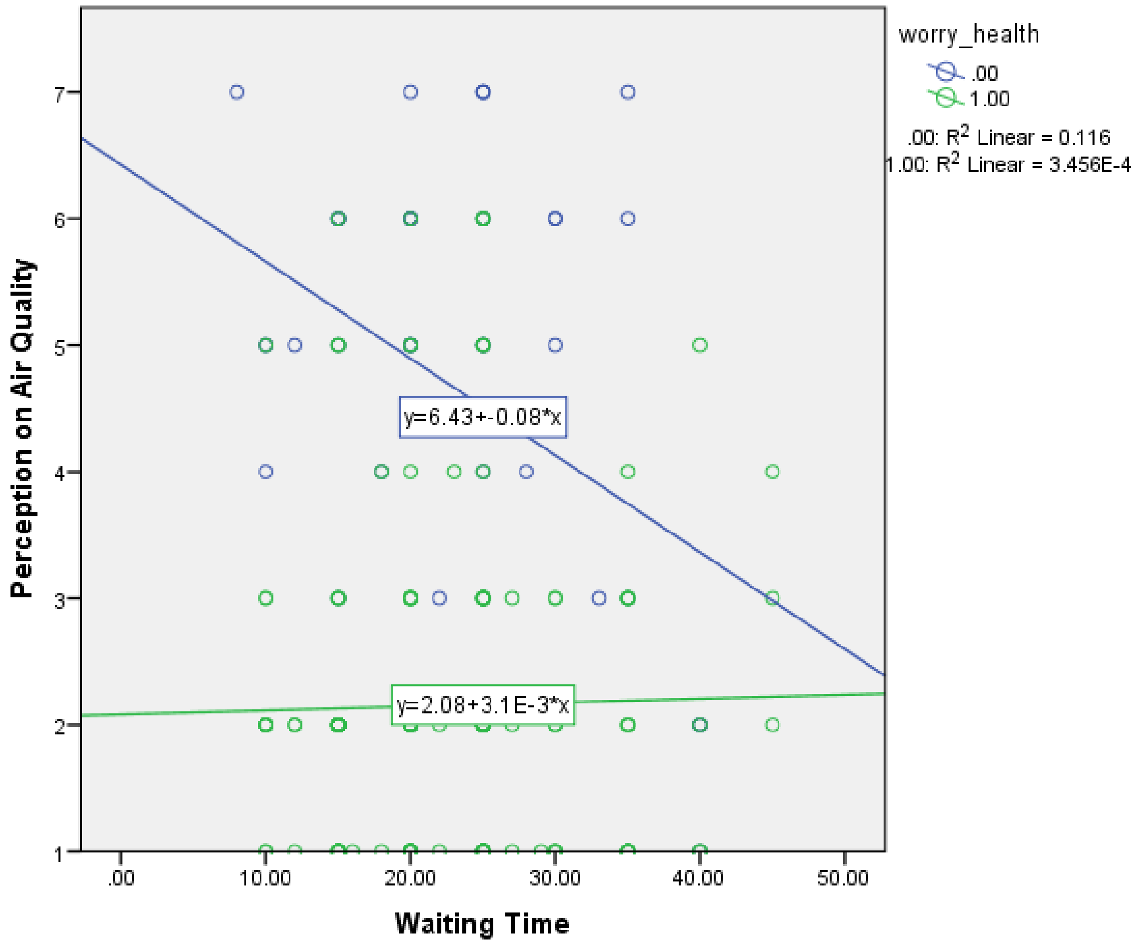


Figure 5.11. Scatter plot between air quality perception and waiting time and fitted linear regression line for each group (0= no worry about health effects; 1 = has worries)

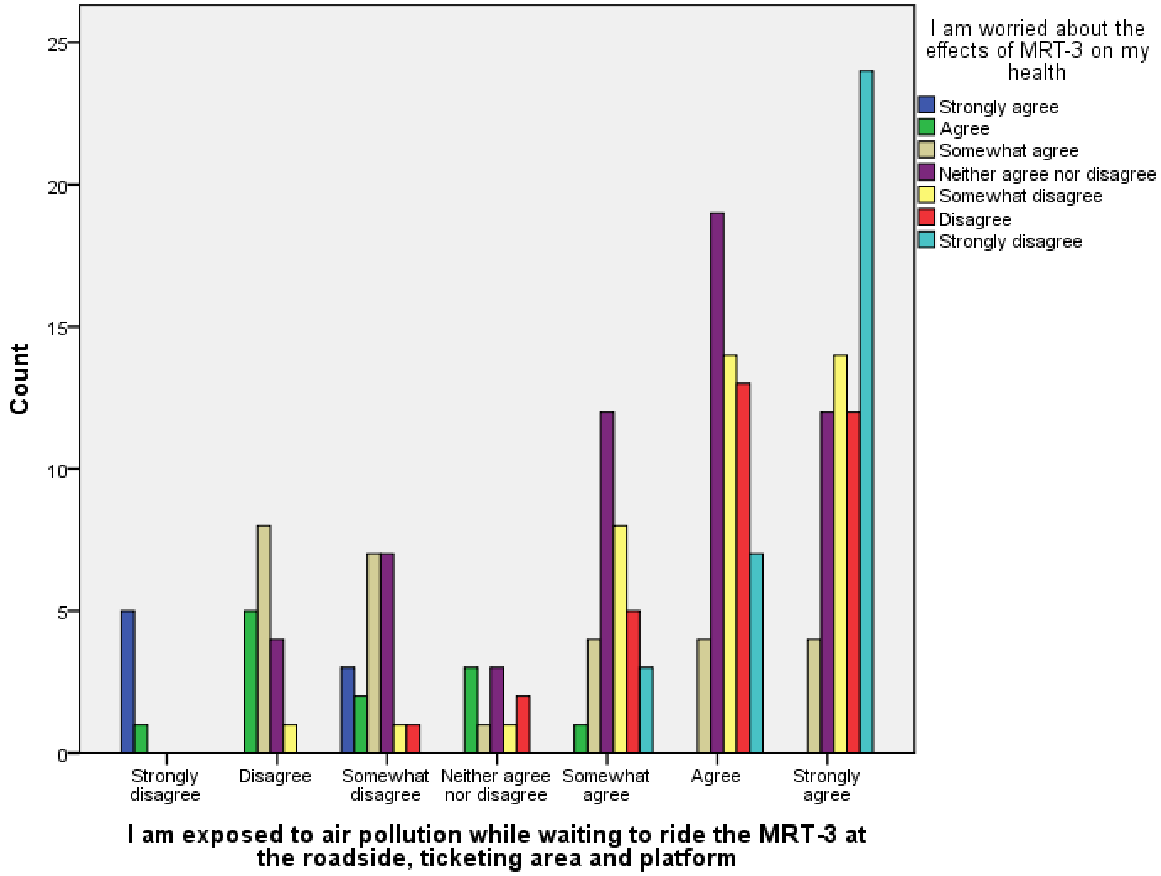
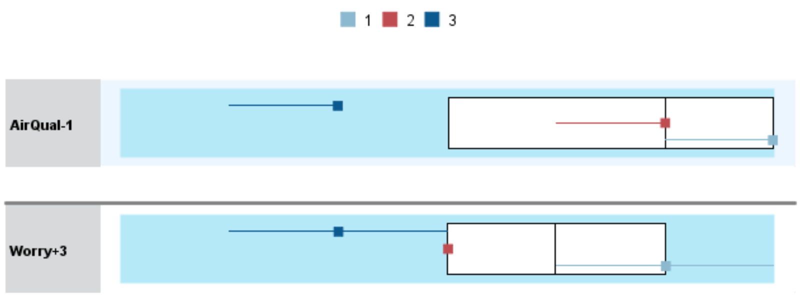


Figure 5.12. Relationship between perceived air quality while waiting and worry about the health effects of MRT-3

Cluster analysis (two-step cluster) was performed to categorize the respondents. It was found that respondents can be grouped into three clusters based on their perceived air quality and worry about health effects.



Note: Air quality is reversed in scale

Figure 5.13. Cluster analysis of respondents according to perceived air quality and worry about health effects

The largest group (44.5%; light blue in Figure 5.13) are those who perceive very low air quality and are thus worried about its effects on their health. The second largest group (32.2%; red in Figure 5.13) perceive slightly better air quality but are only moderately worried about its health effects. The rest of the respondents (23.2%; dark blue in Figure 5.13) seem to be oblivious to the poor air quality and not worried about its potential health effects. However, as Chapter 4 has established, air pollution is at unhealthy levels while waiting at the MRT-3, which has potential negative effects on health.

Further comparisons between the clusters showed that there were no significant differences in other variables among the three groups. Nevertheless, this information is useful in targeted campaigns to promote awareness about air pollution at the MRT-3.

5.5.5. Differences on Perception based on Socio-economic and Workplace Characteristics

Statistical hypothesis tests were also conducted to determine whether there are differences in perception according to the socio-economic characteristics and workplace environment of the respondents. Chi-square test for independence test was used, with the general null hypothesis being:

H_0: There is no significant difference on the (*outcome variable)* between the groups based on the (*categorical variable)*.

Transformation of some outcome variables was performed (i.e. commuting stress to a 5-point Likert Scale, satisfaction into a 4-point Likert scale, and risk perception to a 6-point Likert scale) because some cells are less than 5 and thus not feasible for Chi-square test.

Table 5.3 shows that there are significant differences in some outcome variables for presence of flextime policy at work, age and income level. For respondents with flextime policy at their workplace, commuting stress and lateness frequency are significantly lower than their counterparts. This may be due to lower time urgency which leads to lower stress levels as well as a flexible time frame when they can arrive without being considered late.

A comparison between younger (less than 30 years old) and older people reveals that the younger people perceive higher risk, higher commuting stress and lower satisfaction levels than the older ones. These significant differences may be explained by an intrinsic developmental process wherein older age makes most problems more trivial (Aldwin *et al*, 1996).

Table 5.3. Differences on outcome variables between groups

Outcome Variable	Categorical Variable	Pearson Chi-square value	Asymp. Sig. (2-sided)	Gamma value (Ordinal x Ordinal)	Approx. Sig.	Remarks
Lateness Frequency (1: no instances; 5: Ten or more instances per month)	Flextime Policy	22.698	0.000	*NA*	*NA*	1% significant; those without flextime have higher values
	Lateness Penalty	3.631	0.458	*NA*	*NA*	NS
	Gender	7.133	0.129	*NA*	*NA*	NS
	Age	2.867	0.580	-0.045	0.662	NS
	Income	5.496	0.240	0.045	0.656	NS
	Experience	5.771	0.217	0.097	0.328	NS
Satisfaction (1: very dissatisfied; 4: satisfied)	Flextime Policy	2.120	0.548	*NA*	*NA*	NS
	Lateness Penalty	3.554	0.354	*NA*	*NA*	NS
	Gender	2.900	0.407	*NA*	*NA*	NS
	Age	13.517	0.004	0.255	0.012	1% significant; older people are more satisfied
	Income	6.964	0.073	-0.232	0.027	10% significant; those with lower income have higher satisfaction levels
	Experience	0.823	0.844	0.093	0.384	NS
Commuting Stress (1: not stressed; 5: very stressed)	Flextime Policy	9.878	0.043	*NA*	*NA*	5% significant; those without flextime have higher values
	Lateness Penalty	7.041	0.134	*NA*	*NA*	NS
	Gender	4.753	0.314	*NA*	*NA*	NS
	Age	15.177	0.004	-0.369	0.000	1% significant; younger people have higher stress

Outcome Variable	**Categorical Variable**	**Pearson Chi-square value**	**Asymp. Sig. (2-sided)**	**Gamma value (Ordinal x Ordinal)**	**Approx. Sig.**	**Remarks**
	Income	19.864	0.001	0.053	0.585	5% significant; higher income people are likely to be not stressed at all or very stressed (not increasing)
	Experience	4.640	0.326	-0.062	0.573	NS
Adaptation (1: not adapted; 7: very well-adapted)	Flextime Policy	1.238	0.975	*NA*	*NA*	NS
	Lateness Penalty	7.786	0.254	*NA*	*NA*	NS
	Gender	5.558	0.475	*NA*	*NA*	NS
	Age	7.599	0.269	-0.006	0.949	NS
	Income	1.702	0.945	-0.102	0.280	NS
	Experience	3.045	0.803	-0.003	0.974	NS
Risk Perception (1: very low to low risk; 6: very high risk)	Flextime Policy	2.712	0.744	*NA*	*NA*	NS
	Lateness Penalty	7.713	0.170	*NA*	*NA*	NS
	Gender	14.117	0.015	*NA*	*NA*	5% significant; females have higher values
	Age	20.049	0.001	-0.402	0.000	1% significant; younger people have higher values
	Income	6.340	0.275	0.061	0.520	NS
	Experience	4.498	0.480	0.036	0.710	NS

Females also perceive higher risk than males, which is consistent with other quantitative studies on risk perception and gender role theory (Gustafson *et al.*, 1998). Other studies also found a significant difference in commuting stress for gender with females being more stressed (e.g. Novaco *et al.*, 1990), but no such result was found in this research study.

Contrary to intuition, there is no significant difference on adaptation between those with less experience (less than two years) and those with more experience on commuting with

MRT-3. This may be accounted for by individual differences on adapting to situations – some adapt quickly while some may take a very long time, if at all. Moreover, there seems to be no significant difference in adaptation based on the categorical variables tested.

5.5.6. Correlation between Perception Indicators

Spearman rank-coefficient test was performed on all indicator variables that represent latent constructs related to commute perception.

Table 5.4. Spearman rank-correlation coefficient test results for the latent constructs

Latent Construct related to Commute Perception	Length	Crowding	Air Quality	Predictability	Risk Perception	Worry	Awareness	Commuting Stress	Adaptation	Benefits	Service Quality	Satisfaction
Length	1	.307**	-.292**	-.080	.154*	.223**	.135*	.353**	-.218*	-.135	-.106	-.132
Crowding	.307**	1	-.584**	-.092	.213**	.398**	.350**	.453**	-.259**	-.055	-.251**	-.299**
Air Quality	-.292**	-.584**	1	.100	-.194**	-.459**	-.348**	-.512**	.246**	.069	.260**	.341**
Predictability	-.080	-.092	.100	1	-.146	-.146	-.060	-.176**	.191*	.116	.113	.216**
Risk Perception	.154*	.213**	-.194**	-.146	1	.290**	.227**	.243**	-.190**	-.136	-.273**	-.306**
Worry	.223**	.398**	-.459**	-.146	.290**	1	.466**	.411**	-.185	-.032	-.176*	-.254**
Awareness	.135*	.350**	-.348**	-.060	.227**	.466**	1	.347**	-.112	.046	-.202*	-.282**
Commuting Stress	.353**	.453**	-.512**	-.176**	.243**	.411**	.347**	1	-.333**	-.101	-.286**	-.357**
Adaptation	-.218*	-.259**	.246**	.191*	-.190**	-.185	-.112	-.333**	1	.335	.390**	.396**
Benefits	-.135	-.055	.069	.116	-.136	-.032	.046	-.101	.335**	1	.244**	.209
Service Quality	-.106	-.251**	.260**	.113	-.273**	-.176*	-.202*	-.286**	.390**	.244**	1	.700**
Satisfaction	-.132	-.299**	.341**	.216**	-.306**	-.254**	-.282**	-.357**	.396**	.209	.700**	1

*1% significance (2-tailed); **5% significance (2-tailed)
Interpretation: .00-.19 "very weak" ; .20-.39 "weak"; .40-.59 "moderate"; .60-.79 "strong"; .80-1.0 "very strong"

Table 5.4 provides the correlations between latent constructs and their corresponding statistical significance. Note that it was assumed that their respective indicators have equal weights. (Analysis using SEM in Section 5.6 addressed this and determined the actual weights).

It was found that there are no very strong correlations between the latent constructs. A strong positive correlation is seen between service quality and satisfaction. Moderate negative correlations are found between air quality, and crowding, commuting stress and worry, respectively. Moderate positive correlations exist between worry, and awareness and commuting stress, respectively, as well as between crowding and commuting stress. Benefits and predictability have statistically insignificant correlations with most constructs, but benefits are weakly and positively correlated to adaptation and service quality while predictability is weakly and positively correlated to satisfaction. Adaptation is also found to have a weak negative correlation with commuting stress, and weak positive correlations with both satisfaction and service quality. A significant correlation does not necessarily mean cause and effect, but this matter was addressed in the SEM.

5.6. Results of Structural Equation Model

The analyses using structural equation modeling were divided into three parts: first, an exploratory factor analysis (EFA) was conducted to uncover the underlying structure of the latent constructs and variables; then, a confirmatory factor analysis (CFA) was performed to test whether measures of the latent construct are consistent with the hypothesized nature of that construct; and finally, a path analysis was performed using composite variables from the CFA to provide estimates of the magnitude and significance of hypothesized causal connections between the latent constructs.

5.6.1. Exploratory Factor Analysis

IBM SPSS 22.0 (IBM, 2013) was used to prepare data and perform exploratory factor analysis. The indicators loaded onto the latent factors as hypothesized, but a total of six indicators were eliminated (i.e. Adapt2, Stress1, Stress2, ServQua4, ServQua5 and Benefits3) to improve model fit. The Kaiser-Meyer-Olkin measure of sampling adequacy was found to be 0.869. For the Bartlett’s test, the approximate chi-square was found to be 5770.877. Reliability was also tested using Cronbach’s alpha. The results are summarized in Table 5.5.

Table 5.5. Results of the exploratory factor analysis

Latent Construct	Indicator Name	Factor Loading	Cronbach's alpha	Cumulative variance explained (%)
Perceived Air Quality (reversed scale)	AirQua1	.938	0.953	35.565
	AirQua2	.992		
	AirQua3	.859		
Awareness during the commute	Aware1	.943	0.926	50.183
	Aware2	.942		
	Aware3	.784		
Predictability	Predict1	.959	0.952	59.065
	Predict2	.887		
	Predict3	.954		
Mental Adaptation	Adapt1	.899	0.944	67.321
	Adapt3	.976		
	Adapt4	.874		
Perceived Risk	Risk1	.956	0.939	72.833
	Risk2	.959		
	Risk3	.833		
Perceived Service Quality	ServQua1	.934	0.935	76.987
	ServQua2	.875		
	ServQua3	.922		
Commuting Stress	Stress3	.750	0.949	80.818
	Stress4	.897		
	Stress5	.923		
Perceived Benefits	Benefits1	.939	0.920	83.563
	Benefits2	.898		
Perceived Crowding	Crowding1	.713	0.941	85.435
	Crowding2	.686		
	Crowding3	.826		

5.6.2. Confirmatory Factor Analysis

The remaining indicators in the EFA pattern matrix were then inputted into AMOS 22.0 to perform confirmatory factor analysis (CFA). The model was found to have sufficient fit, as indicated in Table 5.6. Figure 5.14 shows the standardized estimates and covariances for the CFA.

Table 5.6. Goodness-of-fit indices for the measurement model using CFA

	Value	**Remarks**
P-value	0.778	>0.05, OK
Chi-square/degrees of freedom (CMIN/DF)	0.932	<3, good
GFI	0.921	>0.90, good
AGFI	0.895	>0.80, OK
CFI	1.000	>0.95, great
RMSEA	0.000	<0.05, good
PCLOSE	1.000	>0.05, OK
Standardized RMR	0.0223	<0.09, OK

Measurement invariance was tested as a prerequisite for constructing composite variables and performing multi-group SEM, and to ensure that the measurement model is operating the same and that the underlying construct being measured has the same theoretical structure for each group under study (i.e. language used in the survey, and the proposed multi-group moderators). Both configural and metric invariance were tested to validate that the factor structure and loadings are sufficiently equivalent across groups. Configural invariance was tested by running both fully constrained and unconstrained models with the data split across groups and comparing the chi-square differences between the models, and the results are summarized in Table 5.7.

Metric invariance was also tested by comparing the estimates and doing a pairwise comparison. To ensure this, there needs to be at least one indicator for every latent construct whose estimated coefficients do not have any significant difference between groups (i.e. language used, gender, experience, age). This procedure was performed for all groups, and it was found that metric invariance holds.

These results prove that the measurement model is invariant across different groups, and thus comparisons and subsequent analyses (i.e. multi-group moderation) of those scores are acceptable and yield meaningful interpretation.

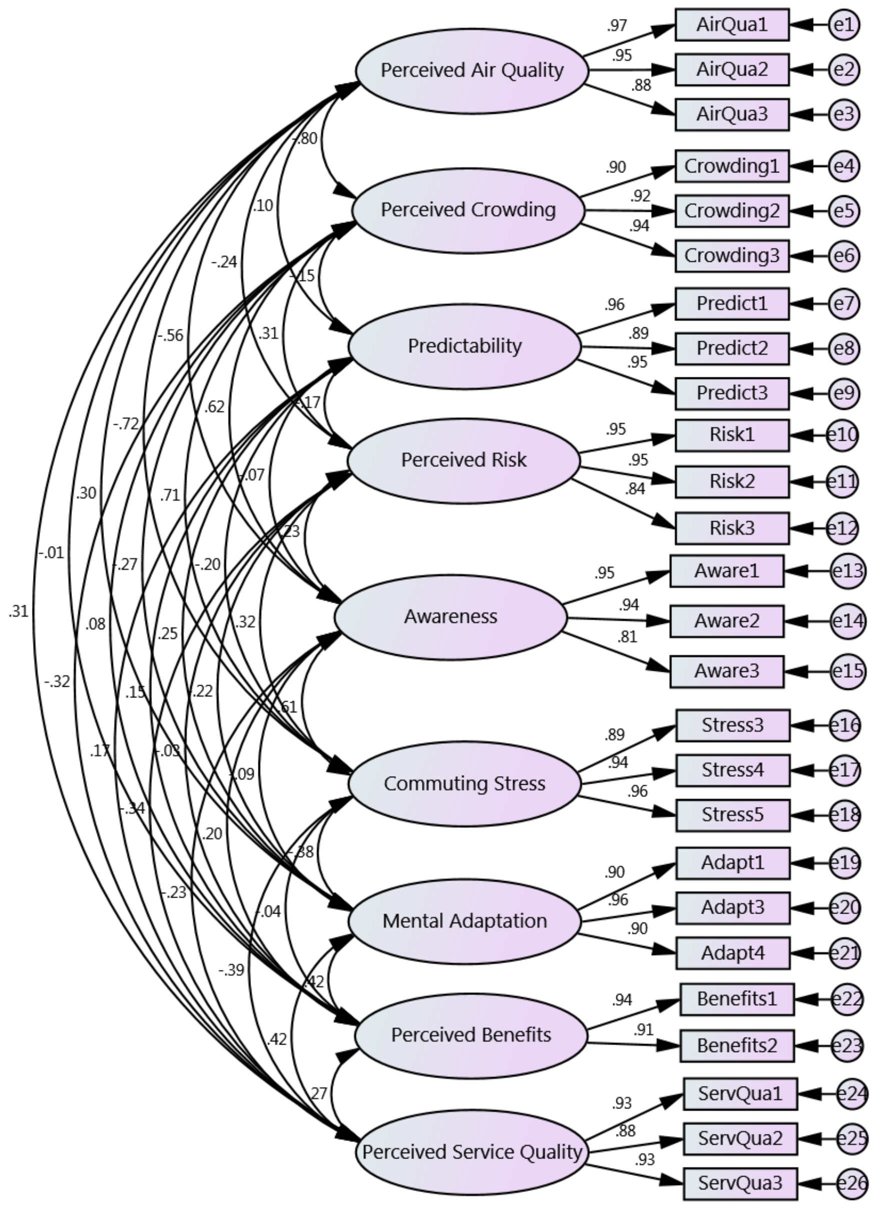


Figure 5.14. Measurement model using confirmatory factor analysis (standardized estimates)

Table 5.7. Configural invariance between groups

Model Description	Groups	χ^2	df	$\Delta\chi^2$	Δdf	p-value	Invariant?
Unconstrained	Language used: English (n=145) and Tagalog (n=66)	628.900	526	31.17	26	0.220	Yes
Fully constrained		660.070	552				
Unconstrained	Gender: Male (n=103) and Female (n=108)	582.332	526	35.357	26	0.104	Yes
Fully constrained		617.689	552				
Unconstrained	Experience: Low (n=92) and High (n=119)	553.736	526	26.431	26	0.440	Yes
Fully constrained		580.167	552				
Unconstrained	Age: 18 to 30 (n=130) and above 30 (n=81)	592.145	526	34.333	26	0.127	Yes
Fully constrained		626.478	552				
Unconstrained	Income level: Low (n=84) and Medium/High (n=127)	578.344	526	33.484	26	0.149	Yes
Fully constrained		611.828	552				
Unconstrained	Flextime Policy: Without (n= 103) and With (n= 81)	551.409	526	26.184	26	0.453	Yes
Fully constrained		577.593	552				

5.6.3. Structural Equation Modeling (Path Analysis)

Multicollinearity among the independent variables was checked before proceeding with the path analysis. Using the variance inflation factor (VIF) as indicator, and a value below 10 indicates that multicollinearity issues are not a problem (Kutner *et al.*, 2004). Table 5.8 presents the results of the multicollinearity tests, and the VIF values indicate that multicollinearity does not exist.

Table 5.8. Multicollinearity test results among independent variables

Independent Variable	Variance Inflation Factor (VIF); Dependent Variable					
	Perceived Crowding	Perceived Air Quality	Perceived Benefits	Predictability	Total Waiting Time	Feeder Access Time
Perceived Crowding		1.046	3.345	3.337	3.384	3.410
Perceived Air Quality	1.013		3.278	3.304	3.284	3.316
Perceived Benefits	1.037	1.049		1.034	1.060	1.061
Predictability	1.054	1.076	1.053		1.068	1.077
Total Waiting Time	1.031	1.032	1.041	1.031		1.039
Feeder Access Time	1.019	1.022	1.023	1.019	1.019	

The sample data was found to fit well with the hypothesized structural model according to the goodness-of-fit indices shown in Table 5.9.

Table 5.9. Goodness-of-fit indices for the structural model

Measure	Value	Remarks
P-value	0.155	>0.05, OK
Chi-square/degrees of freedom (CMIN/DF)	1.353	<3, good
GFI	0.982	>0.90, good
AGFI	0.927	>0.80, OK
CFI	0.993	>0.95, great
RMSEA	0.041	<0.05, good
PCLOSE	0.598	>0.05, OK
Standardized RMR	0.0332	<0.09, OK

Table 5.10 shows the estimates of the full SEM model. Analyses on mediation, interactions and multi-group moderation were also performed as outlined in Section 5.4.3. The hypotheses presented in Section 5.3.2 are confirmed or refuted based on these results:

H1. Perceived crowding has a positive effect on perceived risk, while predictability has a negative effect. Perception on air quality has an insignificant effect on it.

H2. An increase in perceived benefits has a positive effect on perceived service quality, while crowding and perceived risk have negative effects. Predictability, perception on air quality, and total waiting time have insignificant effects on it.

H3. Perceived crowding significantly increases awareness during the commute.

H4. Perceived benefits, perceived service quality and predictability positively affect mental adaptation, while perceived crowding has a negative effect on it. Total waiting time has an insignificant effect on mental adaptation.

H5. Awareness during the commute, perceived crowding and total waiting time positively affect commuting stress. Meanwhile, predictability, perception on air quality and adaptation reduce commuting stress. Perceived benefits, perceived service quality, perceived risk and feeder access time are insignificantly related to commuting stress.

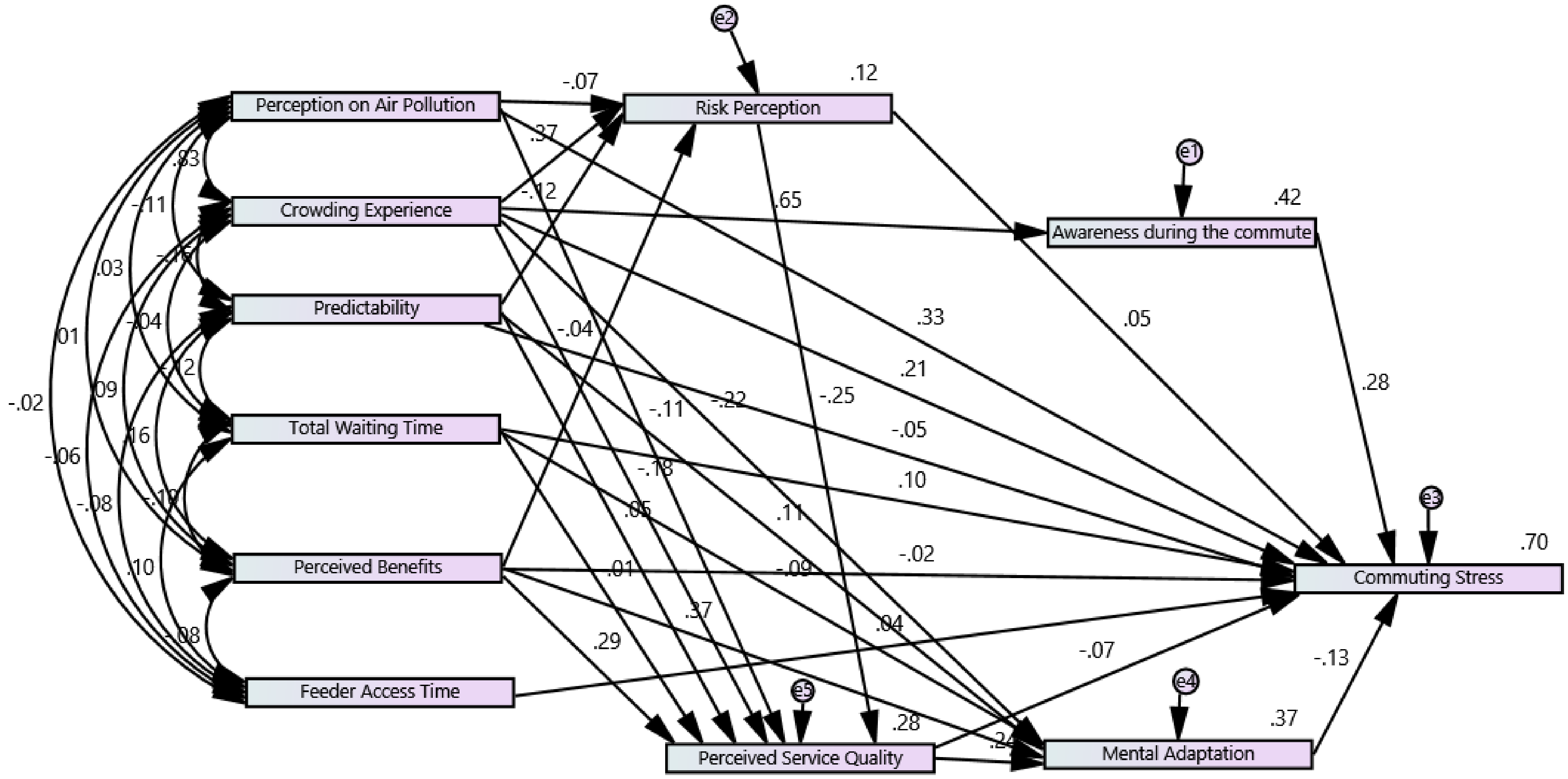


Figure 5.15. Results of structural model using path analysis (standardized estimates)

Table 5.10. Results of the structural equation modeling (path analysis)

Relationship			Unstandardized Estimate	Standardized Estimate	S.E.	C.R.	P	Remarks
Perceived Risk	←	Predictability	-.110	-.125	.058	-1.901	.057	10% sig
	←	Crowding	.365	.358	.119	3.061	.002	1% sig
	←	Air Quality	.053	.065	.095	.557	.578	NS
Perceived Service Quality	←	Total Waiting Time	.001	.007	.005	.121	.904	NS
	←	Risk Perception	-.246	-.255	.061	-4.065	***	1% sig
	←	Air Quality	.083	.105	.085	.984	.325	NS
	←	Predictability	.043	.050	.053	.815	.415	NS
	←	Benefits	.278	.291	.058	4.805	***	1% sig
	←	Crowding	-.183	-.185	.109	-1.672	.094	10% sig
Awareness during the commute	←	Crowding	.547	.650	.044	12.402	***	1% sig
Mental Adaptation	←	Crowding	-.227	-.222	.061	-3.708	***	1% sig
	←	Benefits	.366	.369	.058	6.280	***	1% sig
	←	Service Quality	.248	.238	.064	3.866	***	1% sig
	←	Total Waiting Time	-.008	-.088	.005	-1.596	.111	NS
	←	Predictability	.101	.114	.050	2.011	.044	5% sig
Commuting Stress	←	Awareness	.318	.281	.056	5.633	***	1% sig
	←	Mental Adaptation	-.120	-.130	.044	-2.703	.007	1% sig
	←	Risk Perception	.046	.049	.039	1.171	.242	NS
	←	Air Quality	-.253	-.332	.053	-4.783	***	1% sig
	←	Crowding	.195	.205	.076	2.571	.010	1% sig

Relationship		Unstandardized Estimate	Standardized Estimate	S.E.	C.R.	P	Remarks
←	Service Quality	-.066	-.069	.044	-1.496	.135	NS
←	Feeder Time	.002	.044	.002	1.148	.251	NS
←	Total Waiting Time	.009	.102	.003	2.621	.009	1% sig
←	Benefits	-.016	-.018	.041	-.392	.695	NS
←	Predictability	-.040	-.049	.033	-1.219	.223	NS

NS – not significant

H6. Awareness during the commute positively and partially mediates the positive relationship between perceived crowding and stress. This implies that awareness accounts for the positive relationship between perceived crowding and commuting stress, but there is still a direct relationship between the two. In addition, mental adaptation negatively and partially mediates the positive relationship between perceived crowding and commuting stress.

H7. Predictability negatively moderates or dampens the positive relationship between perceived crowding and commuting stress, as well as that of total waiting time on commuting stress. This means that the effect of perceived crowding and total waiting time on commuting stress is reduced as the predictability is increased.

H8. Multi-group moderation occurs for gender, age, income level, experience and flextime policy.

- Gender: The effects of perceived risk on perceived service quality and of perceived crowding on mental adaptation are negative for females, but are insignificant for males. Perceived air quality has a significant effect on reducing commuting stress for females but has an insignificant effect on males, while perceived crowding has a stronger effect at increasing commuting stress for males.
- Experience: MRT-3 commuters who have used it for a longer time tend to be more adapted than their less experienced counterparts, with mental adaptation having a greater effect on reducing commuting stress. Perceived crowding also has a stronger effect on perceived risk for commuters with less experience, while awareness has a stronger effect on commuting stress for commuters with more experience. Perceived

benefits also have a stronger effect at reducing commuting stress for more experienced passengers.

- Age: Total waiting time hinders mental adaptation for younger people but not for older people. Awareness during the commute, total waiting time and perception on air pollution have positive effects at increasing commuting stress for younger people, while crowding increases commuting stress more for older people.
- Flextime Policy: Awareness during the commute has a stronger positive effect on commuting stress for commuters with flextime policy at their workplace. Predictability has a significant effect at reducing perceived risk and increasing perceived service quality for those without flextime policy. Moreover, perceived benefits increase adaptation for commuters without flextime policy.
- For income level groups, higher income passengers have stronger awareness when the perceived crowding level increases, probably because they would be more prone to pickpocketing as they presumably have more valuables with them. Moreover, the relationship between perceived crowding and stress is also more pronounced. This indicates that higher income passengers tend to be more sensitive to crowding and may be willing to pay to decrease it.

Table 5.11. Goodness-of-fit indices for the re-estimated structural model

Measure	Value	Remarks
P-value	0.044	>0.05, OK
Chi-square/degrees of freedom (CMIN/DF)	1.321	<3, good
GFI	0.956	>0.90, good
AGFI	0.880	>0.80, OK
CFI	0.985	>0.95, great
RMSEA	0.016	<0.05, good
PCLOSE	1.000	>0.05, OK
Standardized RMR	0.0373	<0.09, OK

The insignificant relationships were removed, and the model was re-estimated to achieve the final model. The goodness-of fit indices are tabulated in Table 5.11. Figure 5.16 shows the simplified model, while Table 5.12 presents the new model estimates, which is almost the same as the estimates in Table 5.10.

Table 5.12. Results of the re-estimated structural equation model (Path Analysis)

Relationship			Unstandardized Estimate	Standardized Estimate	S.E.	C.R.	P	Remarks
Perceived Risk	←	Predictability	-0.111	-0.126	0.058	-1.919	0.055	10% sig
	←	Crowding	0.31	0.304	0.067	4.624	***	1% sig
Perceived Service Quality	←	Risk Perception	-0.249	-0.258	0.06	-4.122	***	1% sig
	←	Benefits	0.292	0.306	0.057	5.152	***	1% sig
	←	Crowding	-0.278	-0.281	0.062	-4.485	***	1% sig
Awareness during the commute	←	Crowding	0.547	0.65	0.044	12.376	***	1% sig
Mental Adaptation	←	Crowding	-0.222	-0.217	0.062	-3.59	***	1% sig
	←	Benefits	0.373	0.376	0.059	6.342	***	1% sig
	←	Service Quality	0.249	0.24	0.064	3.868	***	1% sig
	←	Predictability	0.11	0.124	0.05	2.195	0.028	5% sig
Commuting Stress	←	Awareness	0.331	0.293	0.058	5.724	***	1% sig
	←	Mental Adaptation	-0.171	-0.184	0.038	-4.521	***	1% sig
	←	Air Quality	0.249	0.327	0.053	4.651	***	1% sig
	←	Crowding	0.219	0.23	0.074	2.943	0.003	1% sig
	←	Total Waiting Time	0.01	0.115	0.003	2.922	0.003	1% sig

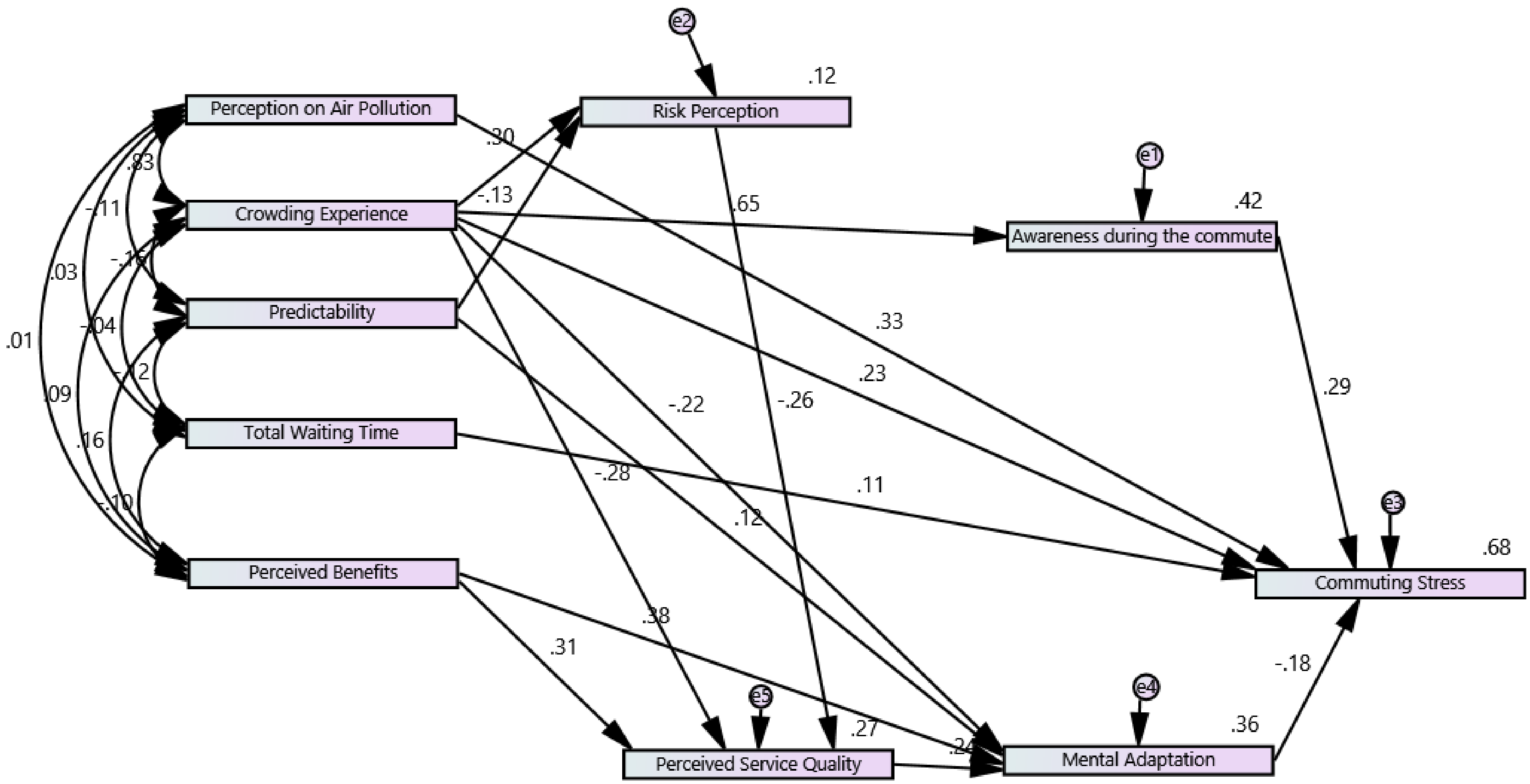


Figure 5.16. Final structural equation model of commuting experience and its effects

It can be seen from the estimates that awareness has the highest effect on commuting stress among all the variables that affect it, and that mental adaptation reduces it to some extent.

5.7. Chapter Summary

In summary, this chapter provides great insight on the behavior and way of thinking of regular morning peak period MRT-3 passengers, which could aid in designing appropriate policies.

Questionnaire survey results showed the socio-economic characteristics, physical adaptation strategies and time urgency. Nine latent factors were found to relate to passengers' commute – exogenous factors (commuting experience): perceived crowding, predictability, perceived air quality and perceived benefits; and endogenous factors (mediators and outcome): perceived risk, perceived service quality, awareness during the commute, mental adaptation and commuting stress. Fundamental statistical analyses were performed to examine the relationships between perceived and actual conditions, as well as to test the correlation and differences among perception variables. For instance, it was found that air quality perception is not linked to $PM_{2.5}$ particle count, waiting time, or socio-economic characteristics, but is related to worry about health effects.

A model that provides an explanation on how passengers' perception on their commuting experience are measured and related to each other was developed using structural equation modeling. This model describes the mechanism of how commuting experience affects commuting stress through some mediating factors. It was found that total waiting time significantly contributes to commuting stress, while mental adaptation reduces it. Multi-group moderation was also shown to occur for gender, age, income level, experience and flextime policy. These findings provide good insight for designing appropriate policies for the MRT-3.

There are several implications for this research. Information about the scheduled arrival of trains and estimated waiting time should also be provided to passengers to increase predictability and reduce commuting stress. The introduction of flextime policy in the workplace would reduce time urgency and thus commuting experience. The differences between gender, age, income level also have to be taken account when designing policies.

It was confirmed that mental adaptation plays a major role at reducing commuting stress in spite of the negative commuting experience, and this effect is stronger for people with more experience. Mental adaptation can be a two-edged sword – on one hand, it allows people to cope with a negative commuting experience, but on the other hand, people become complacent and habituated to the situation that they may not be motivated to demand for better service from the operator. This may imply that commuters are prone to being abused in the sense that even if the transit operator provides a bad service, people are going to get used to it in the long run and still avail of the service. It sets the standards low, and since commuters are willing to deal with an unsatisfactory situation anyway, improvements are not being demanded for as strongly as they should. People may underestimate the risks associated with traveling in a crowded and polluted environment as they grow accustomed to it. This illustrates the resilience of the Filipinos, which has been observed not only in commuting but also with other issues such as poverty and natural disasters.

Longitudinal data could be more suitable for this research instead of cross-sectional data to see how perception, attitude and behavior change over time and capture adaptation more accurately. This could be the focus of future research.

6. Analysis of Proposed Countermeasures and Overall Discussion on Passenger Well-being

This chapter is split into two parts. First, it identifies some countermeasures to improve the situation by reducing waiting time and subsequently improving passenger satisfaction, and evaluates them using a framework that considers actual and perceived conditions in relation to well-being. In the second part, it synthesizes the results from the previous chapters on level of service, air quality and passenger perception, and discusses equity and passenger well-being.

6.1. Introduction

The previous chapters have highlighted the adverse conditions at the MRT-3. It was shown that passenger waiting time is long and variable, that $PM_{2.5}$ exposure is at unhealthy levels and exacerbated by prolonged waiting at the roadside and platform, and that passengers perceive their commute to be negative but its effects on commuting stress are dampened by adaptation.

The perception-based approach for evaluating countermeasures was deemed to be more appropriate given the situation in Metro Manila MRT-3 because its morning peak commuters have already exhausted such options to improve their situation. It was established in Chapter 1 (Introduction) that the MRT-3 is still the cheapest, safest and fastest travel mode relative to other options, and it was revealed in Chapter 5 (Passenger Perception) that 90% of commuters have already moved their departure time to an earlier time, with the rest employing other physical adaptation tactics. As such, the only feasible choice for them is to change their perception or way of thinking about their MRT-3 commute. On the other hand, the traditional approach (choice) assumes that people make a choice on for example, travel mode, departure time or residential location, which was established as unavailable for Metro Manila MRT-3 commuters and thus assumed to be inapplicable to the situation at the said urban rail line.

Only short-term and realistic countermeasures that can be directly implemented by the MRT-3 operator are considered in this study. While it is apparent that the ultimate long-term solution to these problems is to develop a broad and integrated public transport network, the MRT-3 operator and the Philippine government are facing several constraints that encompass many aspects, notably lack of financial resources and political will. In addition, countermeasures that can improve all the critical factors presented in the previous chapters (i.e. level of service, air quality and perception) should ideally be considered. However, this research only focuses on analysis of countermeasures that change waiting time due to limitations in resources that are needed to construct detailed models that would demonstrate air quality and perception. For instance, reducing $PM_{2.5}$ exposure at the MRT-3 would require a regional approach because of the multiple factors that affect it (i.e. natural and anthropogenic factors that involve more than just the vicinity of EDSA). As such, reducing $PM_{2.5}$ exposure should be the duty of the Philippine government and is beyond the responsibility of the MRT-3 operator and should involve a wide-scale effort. Moreover, it was established in Section 5.5.2 that there is no clear relationship between $PM_{2.5}$ particle count and perceived air quality, which implies that passengers cannot accurately perceive it, and thus, it could not be accounted for in the perception-based approach. However, addressing the $PM_{2.5}$ pollution problem is necessary even if they cannot be perceived by laypersons because they have detrimental effects on health and society. Thus, it should be noted that the perception-based approach should be complemented by actual improvements (e.g. reduction of $PM_{2.5}$ levels) regardless of whether they can be perceived or not. Additionally, it is difficult to address countermeasures that change perception because it is affected not just by actual conditions but by a multitude of factors such as personality, socio-economic characteristics, beliefs and cultural upbringing.

Moreover, as an extension of the analysis, an index for equity of passenger waiting time is proposed in Section 6.3.1. Environmental equity is also briefly discussed in the same sub-section. An overall discussion on passenger well-being that synthesizes the results of the previous chapters as well as the first part of this chapter is then given in Section 6.3.2. This sub-section highlights the main findings and discusses its overall implications on passenger well-being. Section 6.4 concludes this chapter.

6.2. Analysis of Countermeasures

This section seeks to analyze some countermeasures in terms of how they affect passenger satisfaction though an original framework.

6.2.1. Methodology

Figure 6.1 presents a novel approach to evaluating countermeasures in terms of waiting time and passenger satisfaction. The top part of the figure (in dotted boxes) represents the passenger satisfaction model, which contains both actual (fare, in-vehicle time, waiting time and its variability) and perceived conditions (perceived risk and air quality) as explanatory variables, and mental adaptation as a control variable. These variables were hypothesized to influence passenger satisfaction after considering the results in the previous chapters as well as the literature review (see Section 2.1.3). This model is used to estimate aggregated passenger satisfaction, which represents the number of people who are satisfied, neutral and dissatisfied as a result of the countermeasure. This is used as an index for evaluating countermeasures compared to the baseline case. On the bottom part of the figure, three different countermeasures are outlined: fare increase, capacity expansion and proportional crowd control policy, all of which have impacts on passenger waiting time. The countermeasures work by changing input variables to the waiting time simulation model, which in turn estimates waiting time and its variability, and the change in those attributes would lead to a corresponding change in passenger satisfaction. Moreover, a sensitivity analysis is performed to assess how change in some attributes (in-vehicle time, perceived risk and perceived air quality) would affect aggregated passenger satisfaction.

A brief explanation on how the countermeasures affect passenger waiting time and satisfaction is given. Fare increase is based on the actual fare policy change that was implemented in January 2015 (see Section 3.3.4 for more details). In the figure, it is seen that fare increase changes the fare attribute in the passenger satisfaction model, as well as passenger demand in the waiting time simulation model, which change waiting time and its variability and subsequently, passenger satisfaction. It should be noted that a demand model was not used for this; instead, the demand change due to the fare increase is based on actual ridership data after the implementation of the fare increase. Other countermeasures also change input variables of the waiting time simulation model: capacity expansion modifies the vehicle capacity and the headway; and proportional crowd control policy introduces a new operations policy. It should be clarified that the interaction between passenger demand and level of service is not modelled.

Figure 6.2 outlines the procedure for the analyses and clarifies the input and output data for each stage.

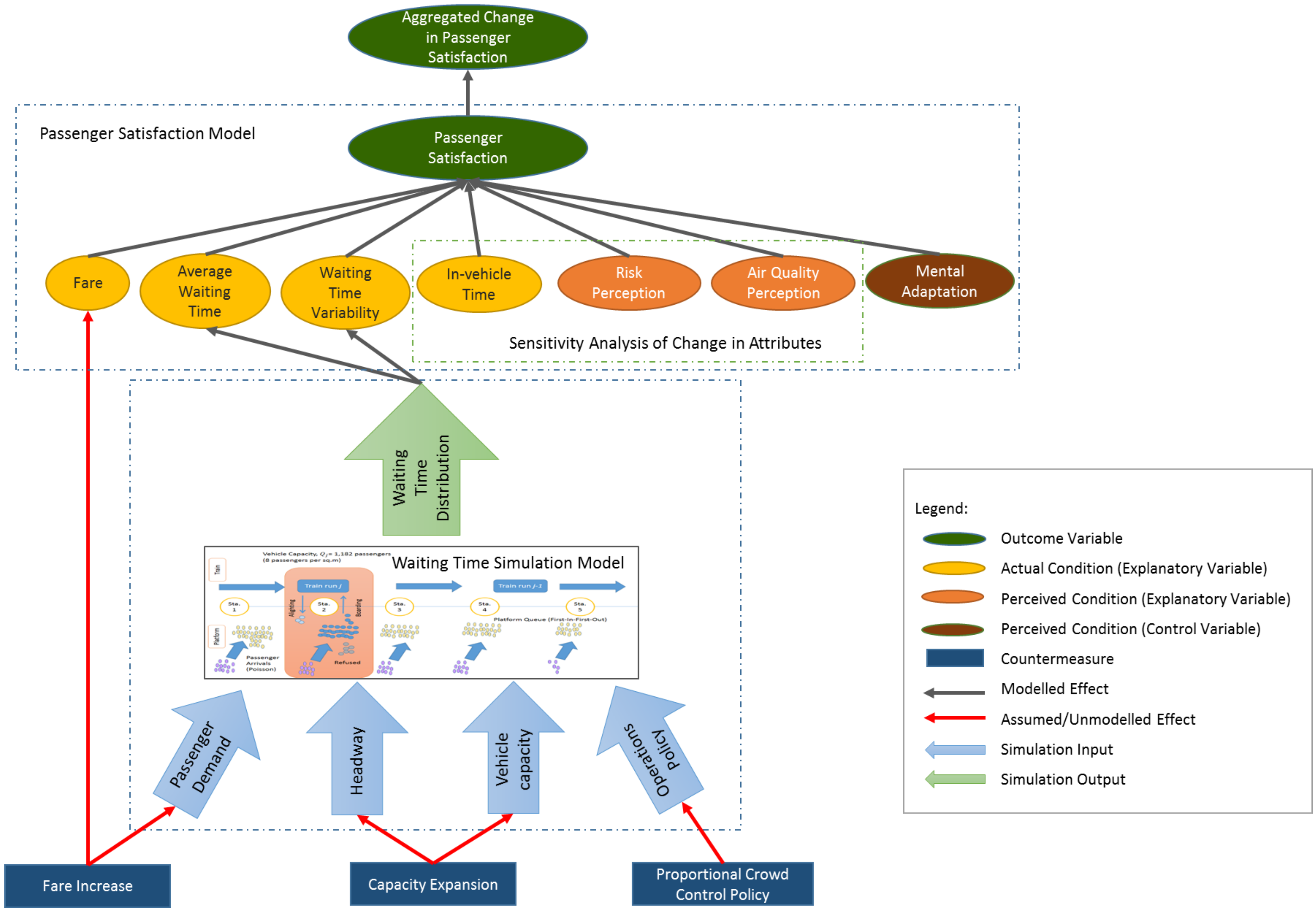


Figure 6.1. Evaluation framework for analyzing the impacts of countermeasures

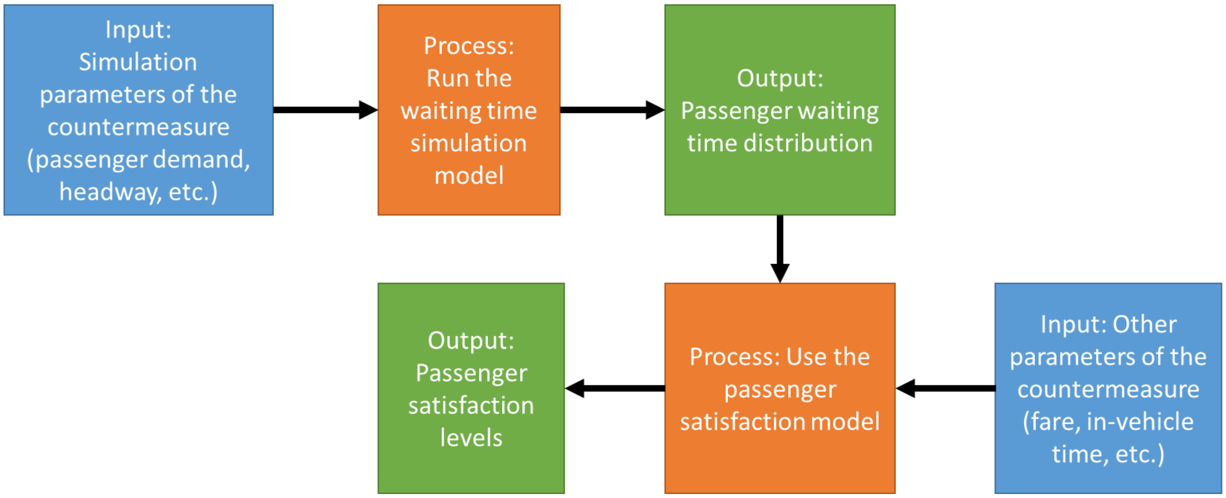


Figure 6.2. Procedure for evaluating countermeasures

6.2.2. Waiting Time Simulation Model

The purpose of the train operations simulation model is to estimate the effects of countermeasures the probability distributions of passenger waiting time. Its development and application to the relevant countermeasures are discussed in this section.

The model attempts to simulate the MRT-3 with focus on passenger waiting time. Figure 6.3 outlines the procedure of the simulation.

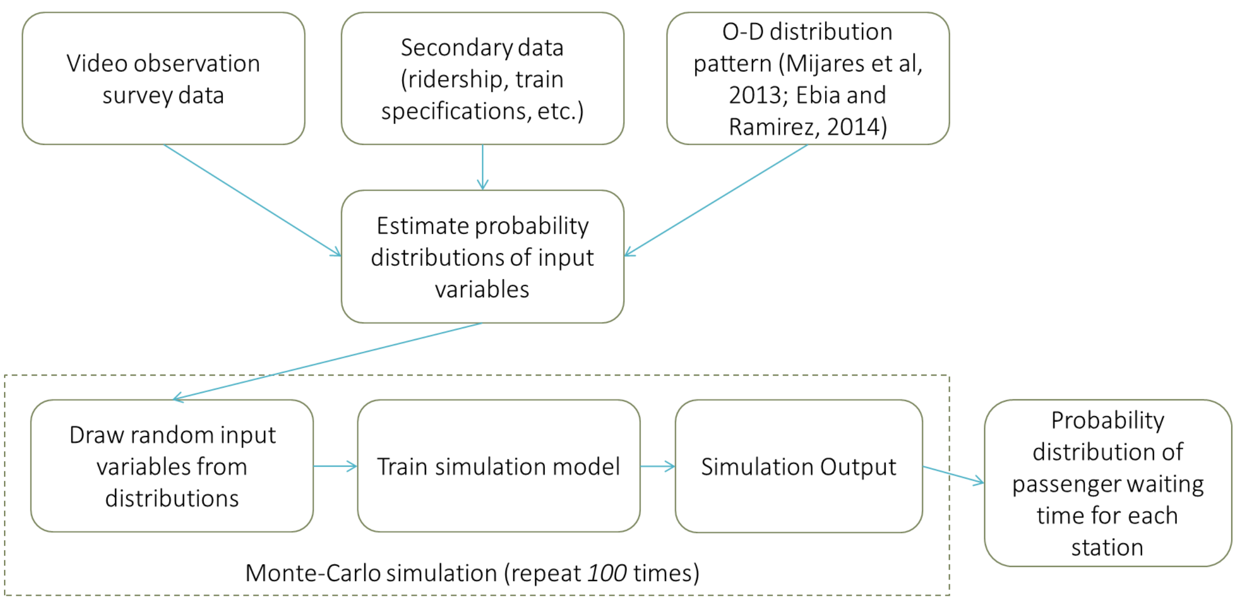


Figure 6.3. Train simulation procedure

All data processing was performed using a commercial software package for Monte-Carlo and discrete-event simulation (Matlab and Simevents R2013A by The Mathworks, Inc.). The model employs a hybrid type of simulation i.e. a combination of event-based and time-based simulation, and uses variable-step solver and ode45 (Dormand-Price).

The model considered the first five stations in the southbound direction, which are the most critical stations for the morning peak period. The inputs of the model are the following:

- Probability distribution of the station hourly passenger demand
- Probability distribution of headway
- Number of train cars
- Operation policy (e.g. limiting the number of passengers who can ride)

Fixed elements of the model

- maximum train car occupancy
- fixed part of the dwell time: opening/closing doors, starting/stopping the engine
- variable part of the dwell time: passenger boarding rate; proportional to the number of boarding passengers
- running speed

Figure 6.4 shows train service, and arrival boarding, alighting and refusal of passengers for the first five stations of the simulation model.

Some factors are not considered in the model. For instance, the possibility of knock-on delay and train bunching that usually occurs in high-frequency lines is not included. This is done by limiting the minimum headway to 3.5 minutes, which was determined by trial and error. In addition, the effect of supply on demand is also not considered because that would entail a passenger demand model, which is beyond the scope of this study. Thus, passenger demand is only based on historical data. Alighting passengers are also not considered, because the observation survey revealed that there is a very minimal alighting (if any) in those stations. Moreover, it only considers a one-directional urban rail line, it is essentially similar to an elevator where most passengers get on the first station and most people get off at floor levels closer to the end of the route and so less people can board after the first few stations. It should also be noted that the waiting time simulation model behaves such that increasing the number of train cars would yield a higher overall capacity than by decreasing the headway assuming the same passenger demand. This is because dwell time is reduced if there are more train cars, while decreasing the headway may lead to train bunching.

Figure 6.5 shows how passenger waiting time is obtained through the use of cumulative passenger arrival and departure curves. The κ^{th} passenger who arrives at time t_h will board the train at a time specified the inverse function $D^{-1}(\kappa)$, and the waiting time for a passenger that arrives at t_h is equal to $D^{-1}(A(t_h))-t_h$. This was measured in the model by assigning a timestamp to each passenger and tracking their arrival and departure at the platform.

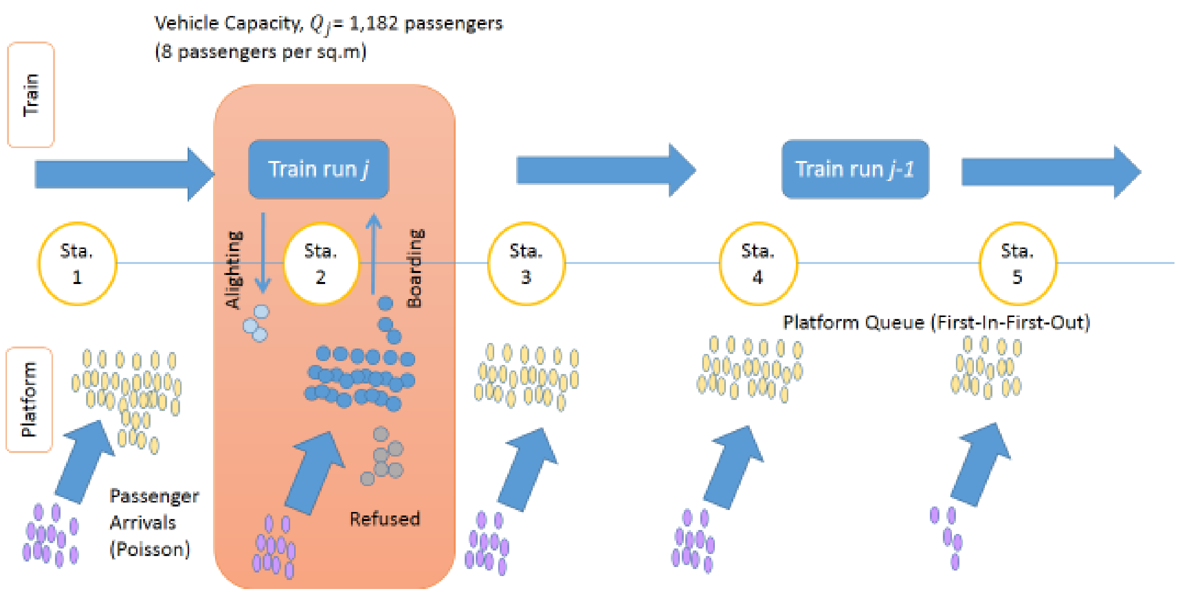


Figure 6.4. Illustration of the simulation model

The following equations are used to compute for waiting time. The available train capacity C_{rj} for train run j at station r is:

$$C_{rj} = Q_j - \sum_{i=1}^{r-1} B_{ij} + \sum_{i=2}^{r} A_{ij} \tag{5}$$

where Q_j is the vehicle capacity of train run j, B_{ij} and A_{ij} the number of boarding and alighting passengers at station i for train run j, respectively

The number of passengers that can depart from the boarding station i is:

$$B_{ij} = min(C_{ij}, x(h_{i,j})) \tag{6}$$

Where $x(h_{i,j})$ is the queue length at $h_{i,j}$ (time of arrival of train run j at station i)

The number of refused passengers (if any) is:

$$R_{ij} = x(h_{i,j}) - B_{ij} \tag{7}$$

The conservation principle, $(A(t) \geq D(t)\ \forall t \in T)$ holds. The queue length at time *t* is:

$$x(t) = A(t) - D(t) \tag{8}$$

The κ^{th} passenger that arrives at time t_h will board the train at a time specified the inverse function $D^{-1}(\kappa)$.

Queuing time for a passenger that arrives at t_h:

$$W(t_h) = D^{-1}(A(t_h)) - t_h \tag{9}$$

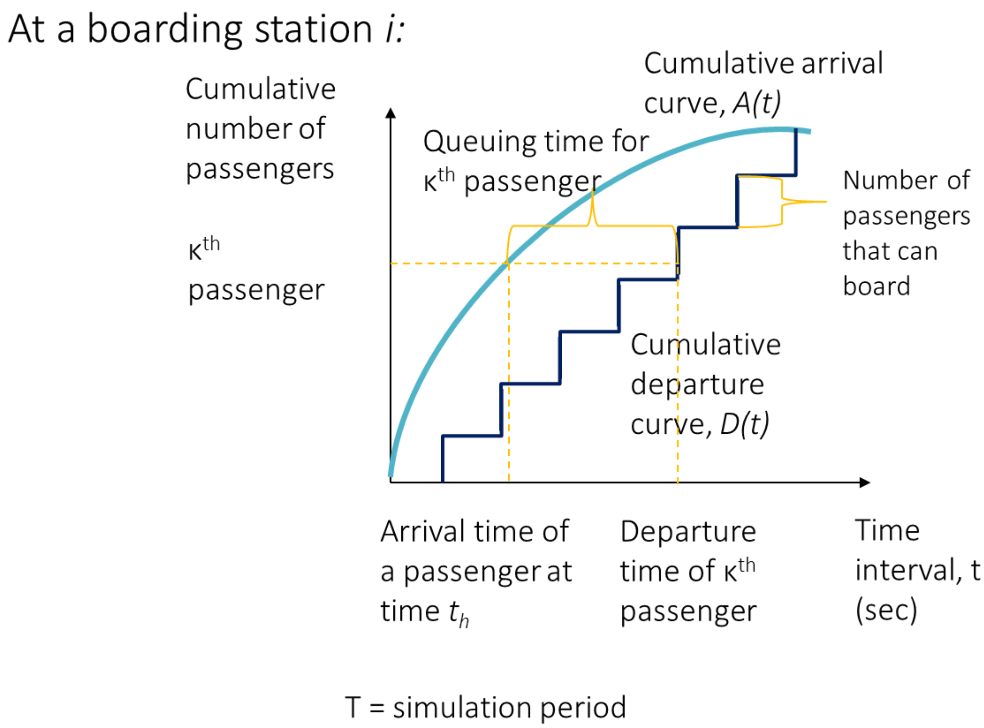


Figure 6.5. Illustration on how to obtain passenger waiting time

The basic assumptions are outlined as follows. For the deterministic passenger arrival case, uniform arrivals within a 15-minute period are assumed. The arrival rate for each time interval is based on raw survey data from Ebia and Ramirez (2014) and actual MRT-3 hourly passenger counts (DOTC-MRT3, 2013) to simulate the without crowd control demand. Figure 6.5 shows that the cumulative arrival curves per station, where the upper line represents the average demand plus one standard deviation, and the lower line represents the average demand only.

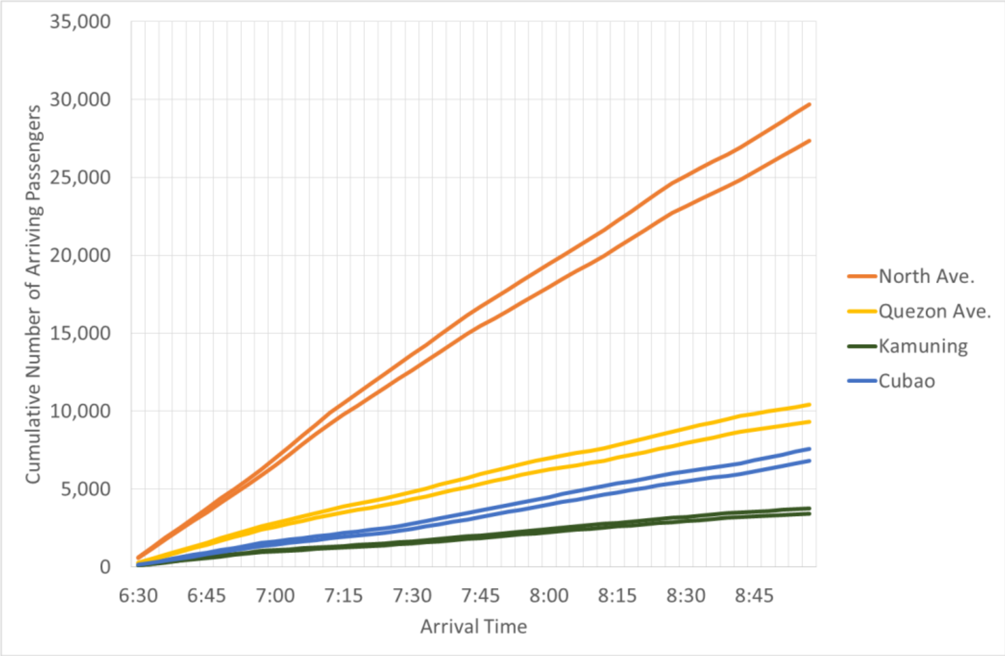


Figure 6.6. Cumulative arrival curves per station (deterministic case)

For the stochastic passenger arrival case, station hourly passenger demand was assumed to follow a normal distribution with mean and standard deviation equal to those values provided in Figures 6.6 or 6.7 (depending on the countermeasure tested). Passengers are then assumed to arrive randomly within the time interval considered, but hourly arrival patterns are followed. The usual way to do this is to assume that the passenger arrival rate follows a Poisson distribution, which is equivalent to passenger interarrival times that are distributed exponentially. The general formula for the probability distribution is $p_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$, where $p_n(t)$is the probability of n (integer≥0) arrivals in a time interval of length t, and λ is the average arrival rate (see Gross *et al*, 2008 for detailed derivation).

In the simulation model, λ varies every hour for the entire length of simulation time, which is three hours for the morning peak period from 6:30 to 9:30 am). The parameter λ for the Poisson distribution is drawn from the normal distribution of passenger demand for every station and hour for each simulation run.

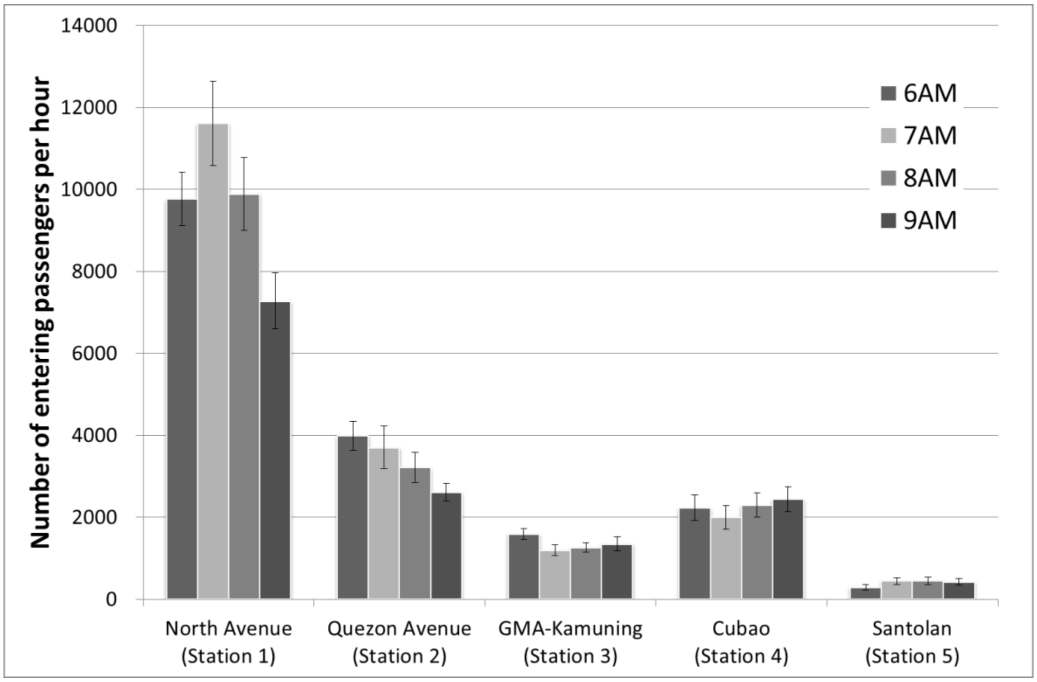


Figure 6.7. Mean and standard deviation of hourly passenger demand in 2014 (stochastic case)

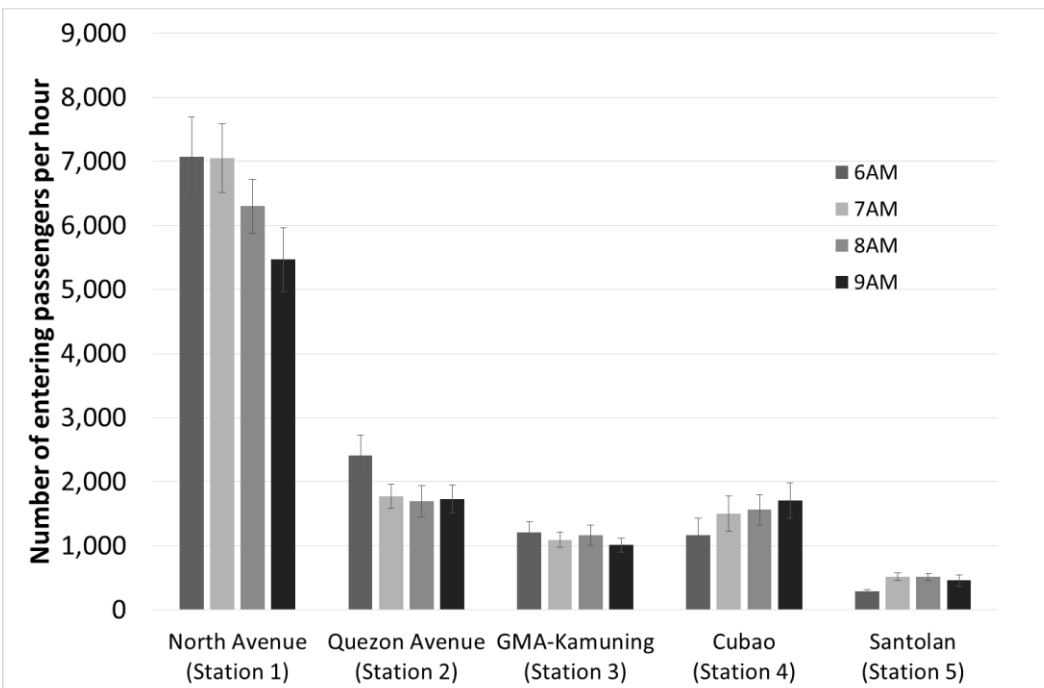


Figure 6.8. Mean and standard deviation of hourly passenger demand in 2015 (stochastic case)

The O-D pattern matrix was taken from a previous study using stated preference survey data and gravity modeling (Mijares *et al.*, 2013). This was then adjusted using the video survey and a previous MRT-3 boarding-alighting survey (Ebia and Ramirez, 2014) as it was observed that the actual number of alighting passengers was very low for the stations and direction considered. This was used for to estimate the alighting probability at each station with a discrete distribution. It can be observed from Figure 6.7 that passenger demand highest at Station 1, and that alighting is insignificant in the next four stations, which leaves a small excess vehicle capacity to serve passengers in downstream stations.

For the case of irregular headways, actual data was used to estimate its distribution. The best fit is a lognormal distribution with parameters of $\mu = 1.528$, $\sigma = 0.334$ and truncated at 3 minutes (minimum headway at the MRT-3). Meanwhile, for the deterministic case, the supply side is assumed to have perfect schedule adherence, meaning that a perfectly regular headway of 3.5, 4 or 4.5 minutes is assumed depending on the scenario. Lower headways are not considered to reduce the probability of bunching of trains and knock-on delay, and this was tested in the simulation model by finding the minimum headway in which trains can adhere to the schedule given the demand pattern. It was found that this occurs at 3 minutes, so the minimum headway considered is 3.5 minutes.

As described in Figure 6.3, the Monte-Carlo technique was used to account for daily variability of input parameters. The model was run 100 times per scenario and the statistics were summarized afterwards. For each run, a random value is drawn for each input variable, and the corresponding frequency distribution of waiting time is obtained.

Skip train operations is implemented by deploying an empty train is to the third or fourth station every 30 minutes or so to alleviate excessive crowding. This was fixed to every 10th train for simplification. Moreover, the maximum capacity of the train depends on the passenger density considered (either 6 or 8 passengers/sq.m).

The base case results for Cubao Station (4th station), which has the highest and most variable waiting time is shown in Figure 6.9. To facilitate data presentation, the arrival time axis was divided into 5-minute intervals. The box-and-whisker plot shows the median, upper and lower quartiles, maximum values and outliers (less than 1.5 times of upper and lower quartiles). It can be seen that the medians are highest between a certain period typically occurring from 7:30 to 8:45 am (i.e. “peak of the peak”), and that there are many outliers outside this period, indicating that passenger delay may extend to earlier and later periods at times. To put this into perspective, passengers at these stations need to wait for up to 10 trains, and at extreme conditions (i.e. outliers), up to 15 trains.

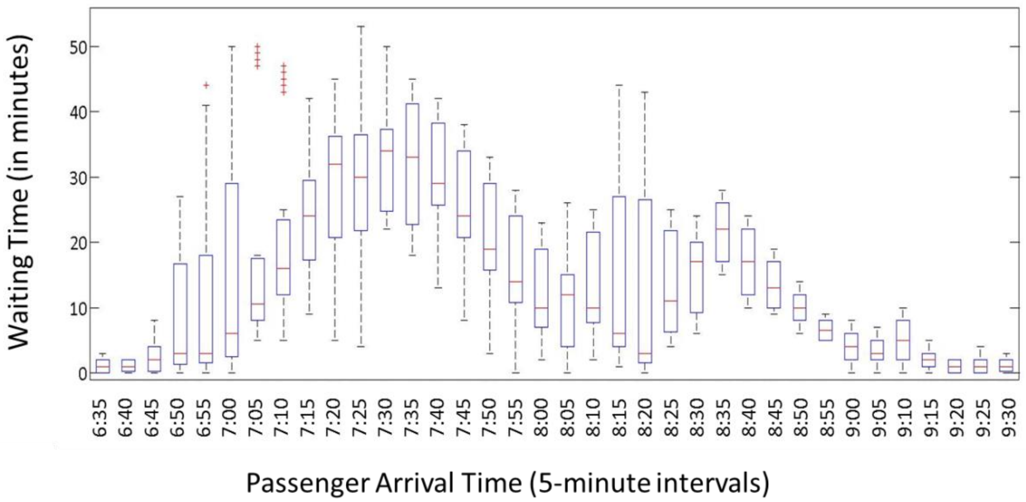


Figure 6.9. Box-and-whisker plot of passenger waiting time at Cubao Station (base case)

Actual data shown in Figure 6.9 was used to calibrate the parameters in the model, which were the operational train speed and fixed part of the dwell time. The in-vehicle time is assumed to be deterministic based on the calibrated operational train speed of 34 kph. However, due to lack of detailed actual data (e.g. passenger inter-arrival times, waiting time for each passenger) that is required to test the dynamic waiting time simulation data, model validation could not be performed. As an alternative, the waiting time simulation model was tested to confirm whether it can replicate the theoretical average waiting time, which is equal to equation 1 (see Section 2.2.1) for the demand<capacity case, and is given by equation 2 (see Section 2.2.1) for the demand>capacity case. Hypothetical parameters were used in this exercise, with the waiting time simulation run 50 times per scenario for a simulation period of one hour where the demand and capacity per train run are constant and there is randomness in the passenger arrival pattern. The average waiting time for the simulation runs was then used in the y-axis and plotted against the theoretical results. This type of comparison should suffice in testing whether the model can replicate theoretical conditions.

Figure 6.10 shows the results of this exercise, which was performed by comparing the observed waiting time with the expected results given by the formulas. The lower waiting times (below three minutes) represent the case where capacity is greater than the demand and headway is regular, in which the expected waiting time is equal to half the headway. Meanwhile, the larger values represent the opposite case, so passenger overload delay is expected. As seen in Figure 6.10, the simulation model generally overestimates waiting time, as random passenger arrivals are assumed in the model. All in all, it can be concluded that the model is valid given that the R-squared value is very high and the observed results only slightly deviate from the theoretical value.

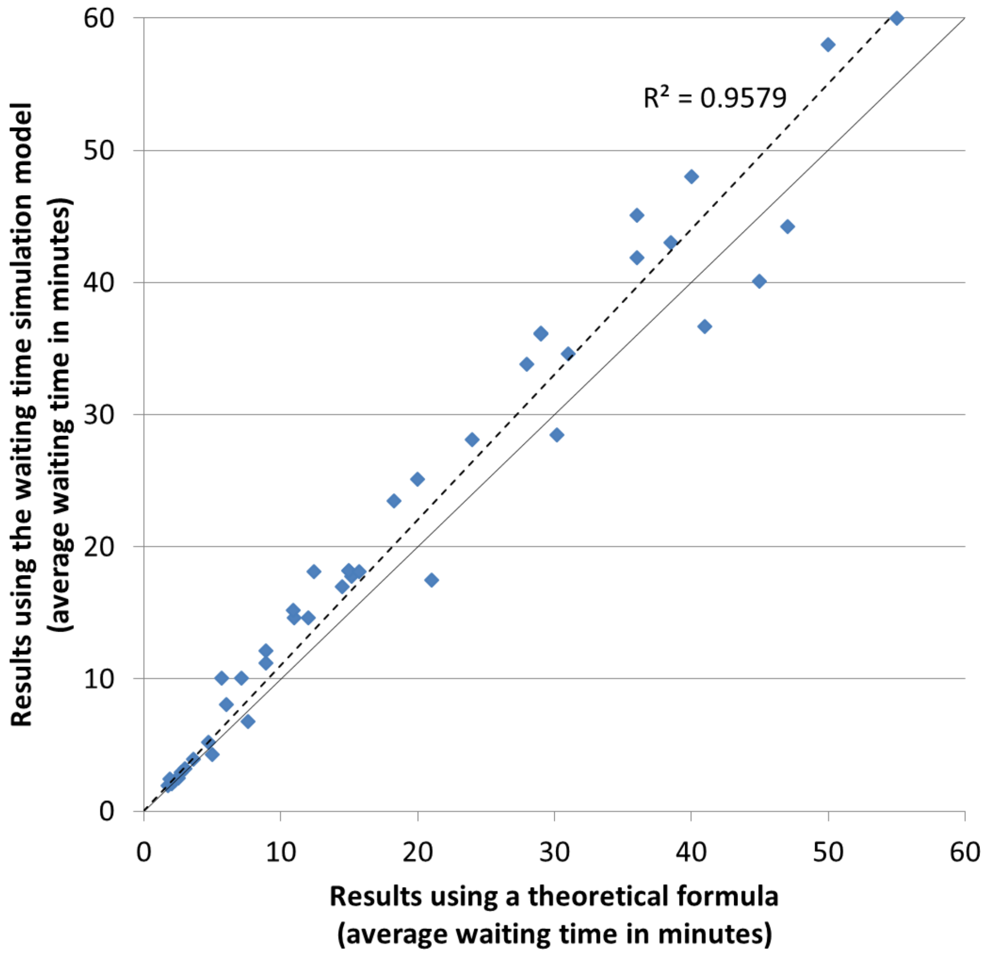


Figure 6.10. Comparison between theoretical and simulated average waiting time

Moreover, the conditions for the simulation model are changed according to the countermeasure, which is necessary because of the different circumstances involved (see Table 6.1).

Table 6.1 Conditions of the simulation model when evaluating countermeasures

Scenario	**Demand**	**Passenger arrival process**	**Monte-Carlo simulation?**	**Headway**	**Number of train cars/doors**	**Passenger Density**	**Skip Train**
Capacity Expansion	Figure 6.7 (demand before the fare increase)	random	Yes	Perfectly regular (see scenarios in Table 6.3)	4 train cars; 20 train doors	6 and 8 pax/sqm (see scenarios in Table 6.3)	None
Fare Increase	Figure 6.8 (actual demand after the fare increase)	random	Yes	Lognormal	3 train cars; 15 train doors	8 pax/sqm	Every 10 trains
Proportional Crowd Control	Figure 6.6 (demand before the fare increase; deterministic)	uniform	No	Perfectly regular (4.5 minutes)	3 train cars; 15 train doors	8 pax/sqm	Every 10 trains
Combination	Figure 6.8 (actual demand after the fare increase)	random	Yes	Same as capacity expansion	4 train cars; 20 train doors	Same as capacity expansion	None

6.2.3. Development of the Passenger Satisfaction Model

A passenger satisfaction model is developed to evaluate the countermeasures' effect on commute well-being. Following Abou-Zeid (2009), commute (or travel) well-being is defined as overall satisfaction with the commute, and is synonymous to commute satisfaction, happiness and utility with the travel mode used.

There are two ways to measure the value placed by passengers and potential customers on level of service attributes. Stated preference studies, which query respondents on how much they value a particular feature using hypothetical situations, are commonly used because of their flexibility but may be problematic because people may not necessarily do as they say they would. Revealed preference studies, on the other hand, evaluate the choices people actually make when facing trade-offs between various attributes using direct observation. Kroes and Sheldon (1988) point out that revealed preference survey is clearly the more appropriate method for deriving utilities they also have some limitations that restrict their general suitability, such as difficulty in obtaining adequate variation in revealed preference data to examine all variables of interest and inappropriateness in evaluating situations that do not exist yet. While both methods have their merits and limitations, the revealed preference method was chosen because it is more realistic and appropriate in assessing how current users value the level of service attributes that they actually experience when using the MRT-3.

Moreover, it is assumed that passengers have exhausted all options to modify their commute internally and externally so traditional choice on departure time or mode, for example, are not considered. However, they have a choice on how satisfied they are with the service that they get on a daily basis. As such, satisfaction level is used to investigate the value placed by passengers on level of service attributes.

Ordered logit model was chosen considering that passenger satisfaction is an ordered variable. This has also been used in general satisfaction studies by economists such as Alesina *et al*. (2004), Blanchflower and Oswald (2000), Theodossiou (1998), Winkelmann and Winkelmann (1998). Countermeasures are then evaluated using the change in individual satisfaction ratings and the aggregated passenger satisfaction.

The utility function of the ordered logit model has the following form (Greene and Hensher, 2010)

$$y_i^* = \beta' x_i + \varepsilon_i \tag{10}$$

For all $i = 1, \ldots, n$

in which the continuous latent utility or 'measure,' y_i^* is observed in discrete form through a censoring mechanism;

$$\begin{aligned} y_i &= 0 \quad \text{if } \mu_{-1} < y_i^* \leq \mu_0 \\ &= 1 \quad \text{if } \mu_0 < y_i^* \leq \mu_1 \\ &= \cdots \\ &= J \quad \text{if } \mu_{J-1} < y_i^* \leq \mu_J \end{aligned} \tag{11}$$

The vector x_i is a set of K covariates that are assumed to be strictly independent of ε_i; β is a vector of K parameters that is the object of estimation and inference.

Responses on satisfaction are assumed to be ordinally comparable only and not cardinally, that is, the relative difference between category levels are unknown but the respondents interpret each possible answer in the same manner.

The passenger satisfaction model has the proposed form

$$y_i^* = \beta_c C_i + \beta_t T_i + \beta_w W_i + \beta_v V_i + \beta_R R_i + \beta_Q Q_i + \beta_a A_i + \varepsilon_i \qquad (12)$$

For all $i = 1, \ldots, N$; in which the continuous latent utility, y_i^*, (passenger satisfaction) is observed in discrete form through a censoring mechanism

As previously discussed in Section 6.1, fare, in-vehicle travel time, waiting time and its variability, perception on risk and air quality, and adaptation are hypothesized to influence passengers' satisfaction with their MRT-3 commute. It was also shown in Chapter 5 that the relationship between air quality and risk perception is not statistically significant, so they are considered to be independent variables in the model (see Table 5.10). Table 6.2 shows the proposed explanatory variables and the expected results in general and according to income.

Table 6.2. Proposed explanatory variables and expected results

Explanatory Variable	**Variable Name**	**Variable type**	**Expected Results**	
			General	**Differences between Income groups**
Total fare (MRT-3 and feeder modes)	*C*	Continuous	Lower fare → Higher sq/sat rating	Low income → higher effect
Total in-vehicle travel time (MRT-3 and feeder modes)	*T*	Continuous	Lower in-vehicle travel time → Higher satisfaction rating	Medium/High income → higher effect
Average waiting time at the MRT-3	*W*	Continuous	Lower waiting time → Higher satisfaction rating	Medium/High income → higher effect
Waiting time variability	*V*	Ordinal (1-5 scale)	Lower variability → Higher satisfaction rating	Medium/High income → higher effect
Risk perception	*R*	Ordinal (1-7 scale)	Lower risk perception →Higher satisfaction rating	Medium/High income → higher effect
Perception on air quality	*Q*	Ordinal (1-7 scale)	Higher perception on air quality→ Higher satisfaction rating	Medium/High income → higher effect
Adaptation Level	*A*	Ordinal (1-7 scale)	Higher adaptability → Higher satisfaction rating	No difference

There were three statements on service quality and two statements on satisfaction in the questionnaire survey described in Section 5.4. The response frequencies are shown in Figure 6.11.

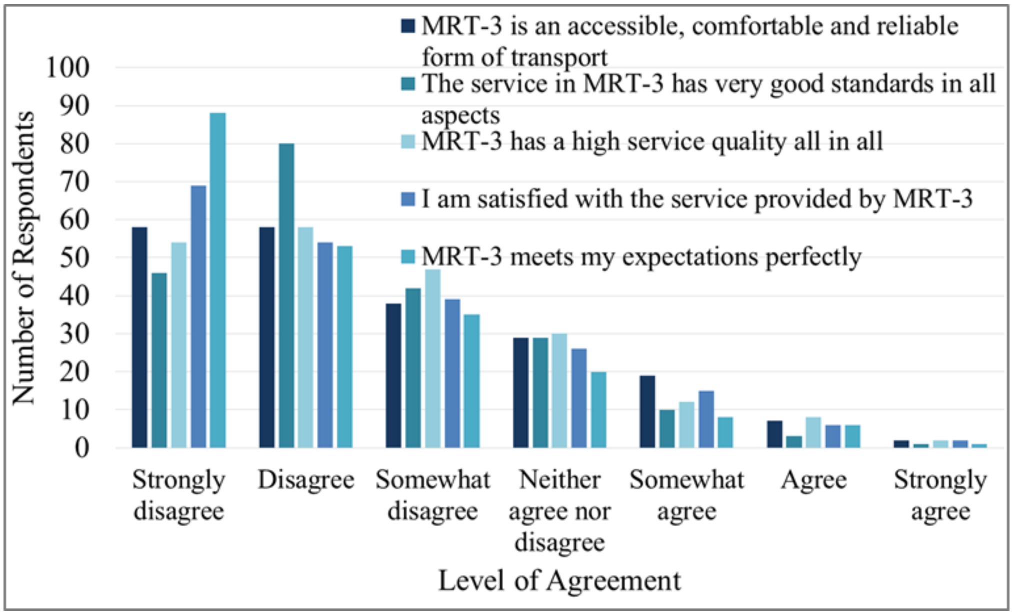


Figure 6.11. Frequency response distribution of service quality and satisfaction indicators

Different ways of recoding the data were tried until model fit was improved. Eventually, recoding into a 4-point scale was necessary due to address the disproportionate number of respondents who gave high satisfaction ratings (from 5 to 7 out of 7), as well as to interpret the results more easily and intuitively. This is illustrated in Table 6.3.

It is important to note that 'somewhat dissatisfied' and 'neutral' are bulked together as 'neutral'. While this may seem misleading at first, this was done in order to sufficiently estimate the model given that only a few people rated MRT-3 favorably. Moreover, it is argued that it is acceptable from a planning perspective for passengers to have a few complaints (i.e. 'somewhat dissatisfied') and this would not significantly impact passenger well-being.

Each indicator was then tested as the outcome variable for the ordered logit regression. A comparison between the log-likelihood and parameters of the each resulting model revealed that the statement "I am satisfied with the service provided by MRT-3" produces the best model fit, having the most number of significant parameters and highest log-likelihood value. Moreover, this statement fits the definition of passenger satisfaction most closely.

Table 6.3. Recoding of passenger satisfaction into a 4-point Likert scale variable

Level of Agreement	**Frequencies**	**Cumulative %**	**Old Variable**	**New Variable**
Strongly Disagree	69	32.7	1	1
Disagree	54	58.3	2	2
Somewhat Disagree	39	76.8	3	3
Neither agree not disagree	26	89.1	4	
Somewhat agree	15	96.2	5	4
Agree	6	99.1	6	
Strongly Agree	2	100.0	7	

Moreover, the model was segmented according to two income groups: low income (monthly salary ≤ PhP20,000) and medium- to high-income (monthly salary > PhP20,000), in order to assess the effect of income differences. The model estimates for the different models are provided in Table 6.4. It should be noted that all tests (e.g. chi-square, test of parallel lines) were deemed acceptable for all three models.

Table 6.4. Parameter estimates for the passenger satisfaction model

Model	**Estimated Thresholds, κ_j (Level of Significance)**			**Parameter Estimates, β_j (Level of Significance)**						
	Satisfaction Levels			Predictor Variables						
	1	2	3	Total Fare	Total In-Vehicle Travel Time	Waiting Time	Waiting Time Variability	Perception on air quality	Risk perception	Adaptation
Full model	-6.204 (1%)	-4.341 (1%)	-1.574 (1%)	-0.062 (1%)	-0.018 (1%)	-0.072 (1%)	0.191 (NS)	0.234 (1%)	-0.366 (1%)	0.396 (1%)
Low-income group	-10.230 (1%)	-7.636 (1%)	-5.151 (1%)	-0.134 (1%)	-0.013 (5%)	-0.070 (5%)	0.234 (NS)	0.334 (5%)	-0.311 (10%)	0.203 (5%)
Med/ high-income group	-4.191 (1%)	-2.490 (1%)	0.756 (1%)	-0.032 (5%)	-0.019 (1%)	-0.079 (5%)	0.256 (NS)	0.212 (5%)	-0.385 (1%)	0.466 (1%)

The results in Table 6.4 are as expected in Table 6.2, except for waiting time variability which turned out to be insignificant. To interpret the results, it should be noted that a positive coefficient would mean a proportional odds ratio less than one, thus implying that higher cumulative scores on the satisfaction scale are more likely. Similarly, a negative coefficient would denote lower cumulative scores.

It was found that when evaluating the satisfaction level with their MRT-3 commute, passengers consider the total fare paid for the trip rather than just the fare paid at MRT-3. This was also the result for in-vehicle travel time – the in-vehicle travel time at the MRT-3 alone is statistically insignificant but the total travel time (excluding waiting time at the MRT-3) is. This implies that respondents evaluate their satisfaction with MRT-3 on the basis of their entire morning commute rather than just the portion traveled via MRT-3. However, when it comes to waiting time, only waiting time at the MRT-3 is statistically significant, probably because waiting time at other modes is not as large.

Moreover, the values of in-vehicle time and waiting time are given in Table 6.5.

Table 6.5. Values of in-vehicle travel time and waiting time

Model	**'I am satisfied with the service provided by MRT-3'**	
	Value of in-vehicle travel time (PhP/min)	Value of waiting time (PhP/min)
Full model (N=211)	0.29 *(1%)*	1.16 *(1%)*
Low-income group only (N=84)	0.10 *(5%)*	0.59 *(5%)*
Medium-/high-income group only (N=127)	0.59 *(1%)*	2.18 *(1%)*

Waiting time is valued around four times larger than in-vehicle travel time for all groups, implying a strong aversion to waiting. This estimate is slightly higher than previous studies (e.g. Mohring *et al.*, 1987; Mishalani, *et al.*, 2006) which have found waiting time to be valued as 1.5 to 3 times higher than in-vehicle travel time, probably because the waiting time at the MRT-3 is typically longer and the waiting environment is generally unfavorable. Moreover, higher income passengers have around four times larger values of in-vehicle time and waiting time than their low-income counterparts, which is just as expected because people with higher income generally regard commuting time as having more monetary value.

The aggregated passenger satisfaction is calculated based on the predicted probabilities for the satisfaction categories in order to estimate the changes in satisfaction levels as a result of the countermeasures.

The predicted probability equation for ordered logit model is given as:

(13)

$$P(Y_i > j) = \frac{\exp(X_i\beta - \kappa_j)}{1 + [\exp(X_i\beta - \kappa_j)]}, \qquad j = 1, 2, 3$$

Which implies that

$$P(Y_i = 1) = 1 - \frac{\exp(X_i\beta - \kappa_1)}{1 + [\exp(X_i\beta - \kappa_1)]}, \qquad very\ low\ satisfaction$$

$$P(Y_i = j) = \frac{\exp(X_i\beta - \kappa_{j-1})}{1 + [\exp(X_i\beta - \kappa_{j-1})]} - \frac{\exp(X_i\beta - \kappa_j)}{1 + [\exp(X_i\beta - \kappa_j)]},$$

$$j = 2\ (low\ satisfaction)\ and\ 3\ (neutral)$$

$$P(Y_i = 4) = \frac{\exp(X_i\beta - \kappa_3)}{1 + [\exp(X_i\beta - \kappa_3)]}, \qquad moderate\ to\ high\ satisfaction$$

Table 6.6. Predicted response categories

		Predicted Response Category				*Total*
		1.00	2.00	3.00	4.00	
Satisfaction (Full Model)	1.00	47	18	4	0	69
	2.00	22	15	16	1	54
	3.00	2	13	46	4	65
	4.00	0	3	14	6	23
Total		*71*	*49*	*80*	*11*	*211*
Satisfaction (Low income model)	1.00	16	4	1	0	21
	2.00	9	4	10	0	23
	3.00	1	6	18	1	26
	4.00	0	2	9	3	14
Total		*26*	*16*	*38*	*4*	*84*
Satisfaction (Medium/high income model)	1.00	31	14	3	0	48
	2.00	13	11	6	1	31
	3.00	1	7	28	3	39
	4.00	0	1	5	3	9
Total		*45*	*33*	*42*	*7*	*127*

The predicted response categories are given in Table 6.6. It can be observed that the model generally underestimates the higher satisfaction ratings, but the overall prediction rating is acceptable.

Due to the accuracy bias in the measurement of the passenger satisfaction parameters, the predicted probabilities themselves cannot be used directly to evaluate the countermeasures. Thus, there is a need to sum these probabilities based on some threshold to determine the aggregated passenger satisfaction index. To do this, a cumulative probability threshold of 55% is used to classify respondents into 'strongly dissatisfied', 'dissatisfied', 'neutral', and 'satisfied'. In other words, the cumulative probability to belong in a certain category should be at least 55%. The number of people falling into each category are summed up, and referred to as the aggregated passenger satisfaction index.

6.2.4. Evaluation of the Proposed Countermeasures

A train operations model was created to estimate passenger waiting time under certain conditions. The effects of countermeasures that impact passenger waiting time directly or indirectly are estimated through the said model. The passenger satisfaction model is then used to estimate the changes in aggregated passenger satisfaction index, which refers to the number of passengers who are positive or neutral about their commute after the implementation of each countermeasure.

The changes in the explanatory variables are estimated for each proposed countermeasure. Adaptation is ignored because it is a control variable that allows for individual characteristics to enter into the model. Waiting time variability is also not included because it was found to be insignificant in the model.

The changes in the predictor variables are done individually rather than on average. It was noticed in the survey data that respondents using the same boarding station have different estimates of their average waiting times. This could mean that some respondents usually experience a higher waiting time than other respondents using the same boarding station. Taking this into consideration in assessing the impacts of countermeasures, the respondents' waiting time were changed based on their boarding station and whether they fall near the mean, minimum or maximum waiting time for their boarding station. For example, a respondent using North Avenue as boarding station and who has an estimated waiting time near the mean waiting time for that station would reduce his waiting time to equal the mean waiting time simulated for the countermeasure in question. Table 6.7 shows the respondents' waiting time according to station used.

Table 6.7. Descriptive statistics of waiting time according to boarding station

Boarding Station	N	Mean Waiting Time	Std. Deviation	Minimum Waiting Time	Maximum Waiting Time
North Ave	68	26.49	4.98	16.00	45.00
Quezon Ave	31	22.199	4.81	18.00	40.00
GMA Kamuning	17	21.12	2.87	20.00	30.00
Cubao	24	34.54	5.49	25.00	45.00
Santolan	4	28.25	5.68	20.00	33.00
Ortigas	4	12.00	3.56	8.00	15.00
Shaw Blvd	12	17.25	3.55	15.00	25.00
Boni Ave	11	13.64	5.955	10.00	30.00
Guadalupe	10	17.20	7.35	10.00	30.00
Ayala	4	17.50	6.455	10.00	25.00
Magallanes	9	14.67	5.10	10.00	25.00
Taft Ave	17	15.41	2.15	12.00	20.00
Total	**211**	**22.90**	**7.81**	**8.00**	**45.00**

6.2.4.1. Capacity Expansion

This simulation model was then used to assess the effect of the government's proposed capacity expansion program. In this project, the government will acquire an additional 43 light rail vehicles and improve the configuration from a 3-car train arriving every 4.5 minutes to a 4-car train arriving every 2.5 minutes. This would increase the design peak capacity of 23,600 pphd (passengers per hour per direction) to 32,160 pphd (Department of Transportation and Communications, 2014). The proposed expansion scheme was checked for feasibility (i.e. if it will work perfectly without exogenous delays). It should be noted though that a smaller headway would increase the probability of primary and knock-on train delays. As this phenomenon is beyond the scope of this study, the headway was extended to 3.5 minutes to include adequate slack time to account for the variation of dwell time with respect to from boarding and alighting passengers and thus prevent primary and knock-on train delays. Moreover, dwell time is effectively capped at a maximum value by setting the boarding and alighting rate as constant. It was assumed that the service is perfectly regular. Vehicle capacity is computed under the assumption that each train coach has 74 seats and that there is 40 sq.m. of standing space, which is consistent with the train specifications provided by MRT-3.

Under the same demand and headway, a passenger density of 6 passengers/sqm with 4-car trains would be equivalent to 8 passengers/sq.m. with 3-car trains for the same headway. Thus reducing the passenger density under capacity expansion would negate the effect of increasing the vehicle capacity; in other words, it would not improve the base case unless the headway is also reduced. For this reason, test scenarios are created by varying the headway (and not the passenger density). Moreover, crowding is a normal part of morning peak period, so it is assumed that passengers would find it acceptable to travel at 8 passengers/sq.m.

For scenario testing, a minimum headway of 3.5 minutes up to a maximum of 5 minutes are tested in increments of 0.5 minutes. Additionally, the case wherein the passenger demand increases by 10% is also considered to test the sensitivity of waiting time due to induced demand. This is an important point given that the proposed scheme seeks to attract modal shift from road-based modes, address latent demand, and serve the increasing population in Metro Manila.

For the ideal case of perfectly regular headway of 3.5 minutes and passenger density of 8 passengers per sq.m. (which would subsequently result in the highest capacity among the scenarios), it was found that passenger delay would be eliminated *on average*. There would still be extreme cases wherein a high waiting time would results due to high passenger demand, but on average, the waiting time would be equal to the headway. This is also the case even if the demand is increased by 10% and the headway is increased to 4 minutes, as seen in Figures 6.12 and 6.12. In these figures, the summary statistics for 5-minute intervals of arrival time are shown in box-and-whisker plots plotting the expected waiting time that would occur 25% to 75% of the time. The red points are considered as outliers. The plots also show that this capacity expansion scenario would greatly decrease waiting time as compared to the base case shown in Figure 6.9.

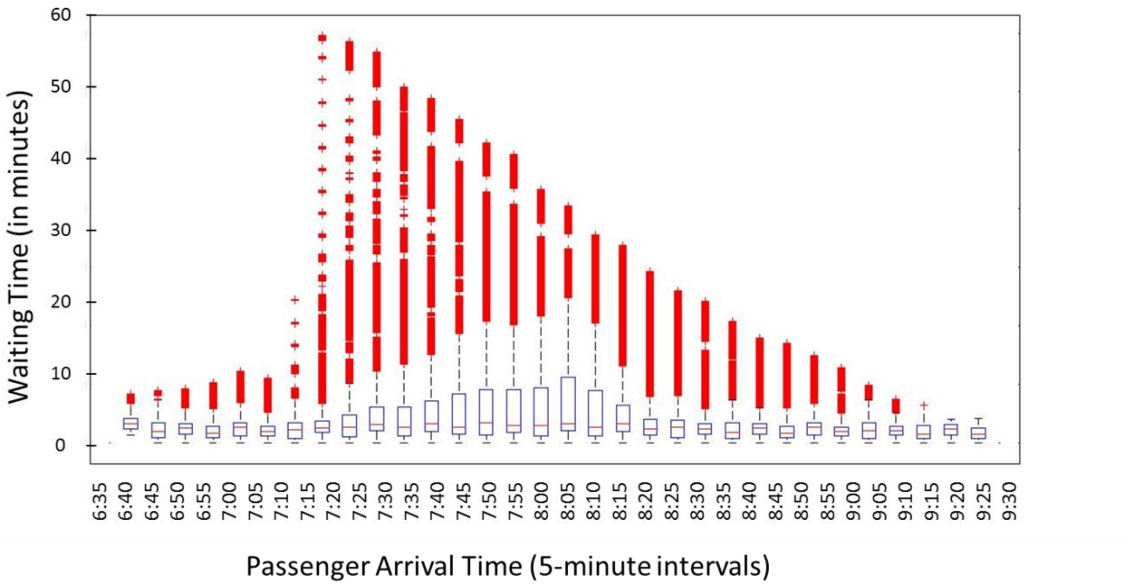


Figure 6.12. Box-and-whisker plot of passenger waiting time at Cubao Station (capacity expansion; 4 minute headway; 8 passengers per sq.m.; 10% ridership increase)

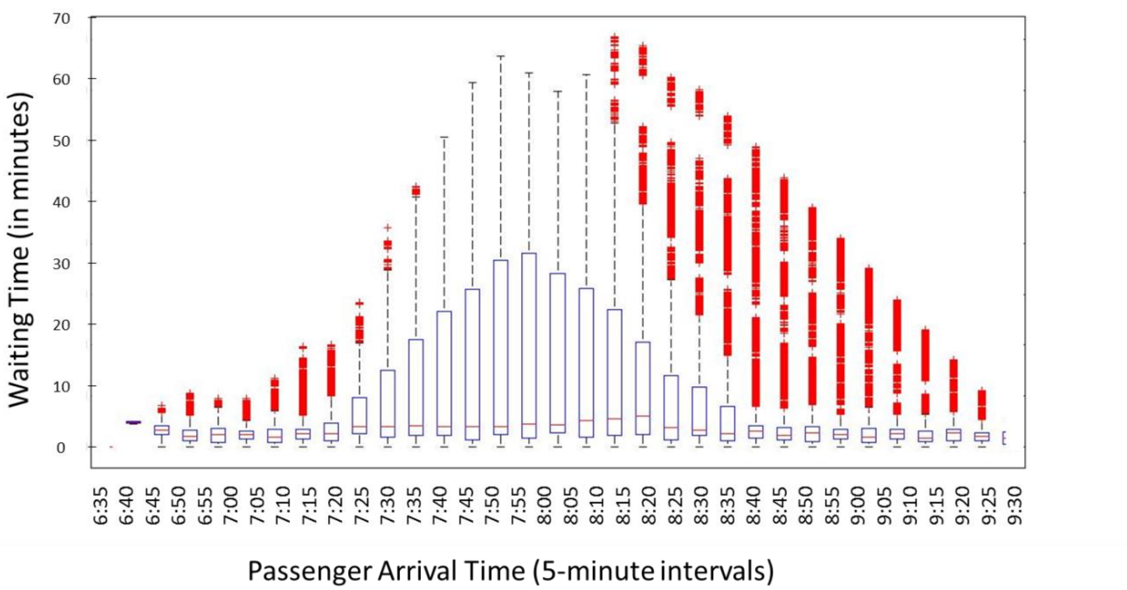


Figure 6.13. Box-and-whisker plot of passenger waiting time at Santolan-Annapolis Station (capacity expansion; 4 minute headway; 8 passengers per sq.m.; 10% ridership increase)

To simplify the presentation of the waiting time results for each scenario, the values for the entire morning peak period are aggregated and the box-and-whisker plots are constructed for each station. Figure 6.14 shows the box-and whisker plots for passenger waiting time during the morning peak period according to station and headway assuming that there is no ridership increase. It can be observed from the graph that the median of passenger waiting time is kept low in the case of a low headway, and that it increases as the headway is enlarged. Moreover, Cubao and Santolan Stations generally have longer waiting times than the first three stations because the trains may be full when it arrives at those stations.

All in all, the results imply that keeping the headway to be under 4 minutes with no ridership increase should drastically reduce waiting times.

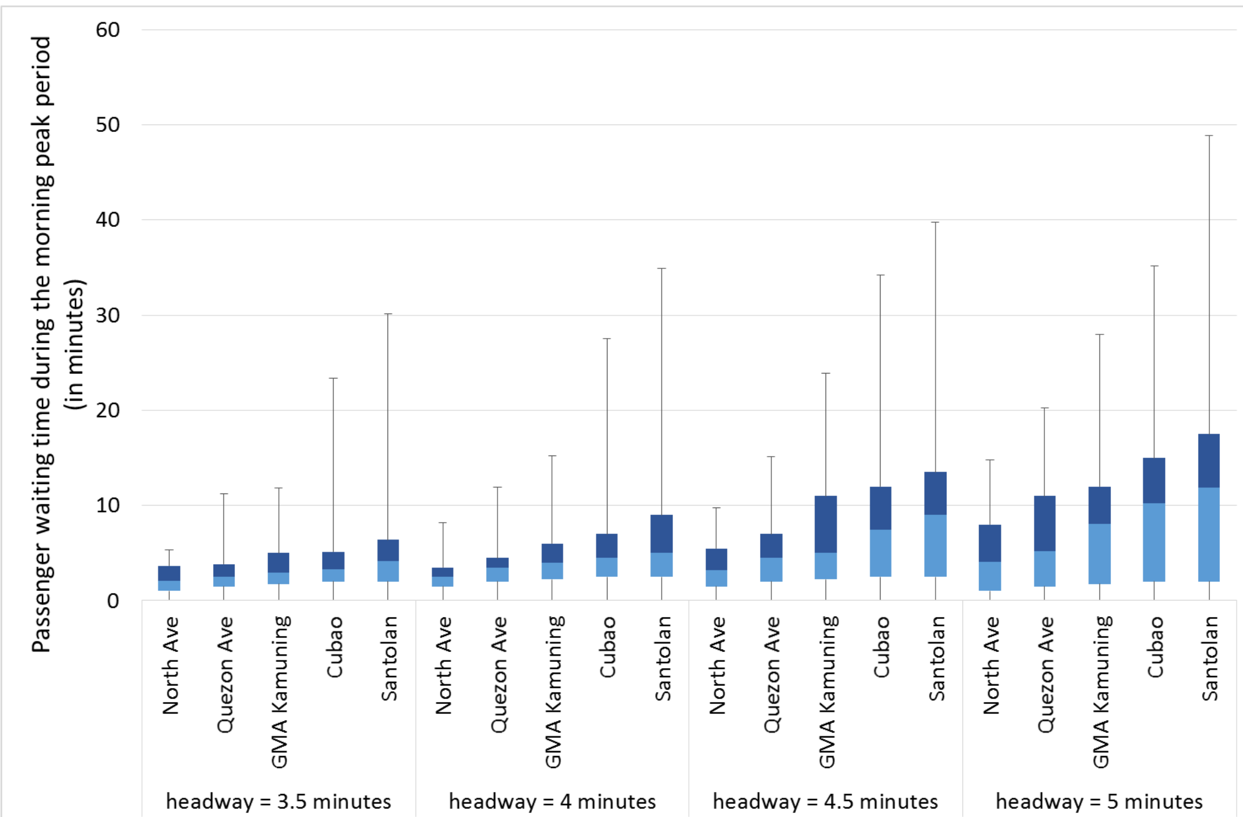


Figure 6.14. Box-and-whisker plot of passenger waiting time at selected stations for capacity expansion with different headways (passenger density = 8 passengers/sq.m.; 2014 demand)

Figure 6.15 presents the results in the case wherein there is a 10% uniform increase in passenger demand to test for its sensitivity to ridership changes. As expected, there is a slight increase in waiting time due to the increase in ridership. However, the increase is more pronounced for headways greater than 4.5 minutes make waiting time severe for some stations.

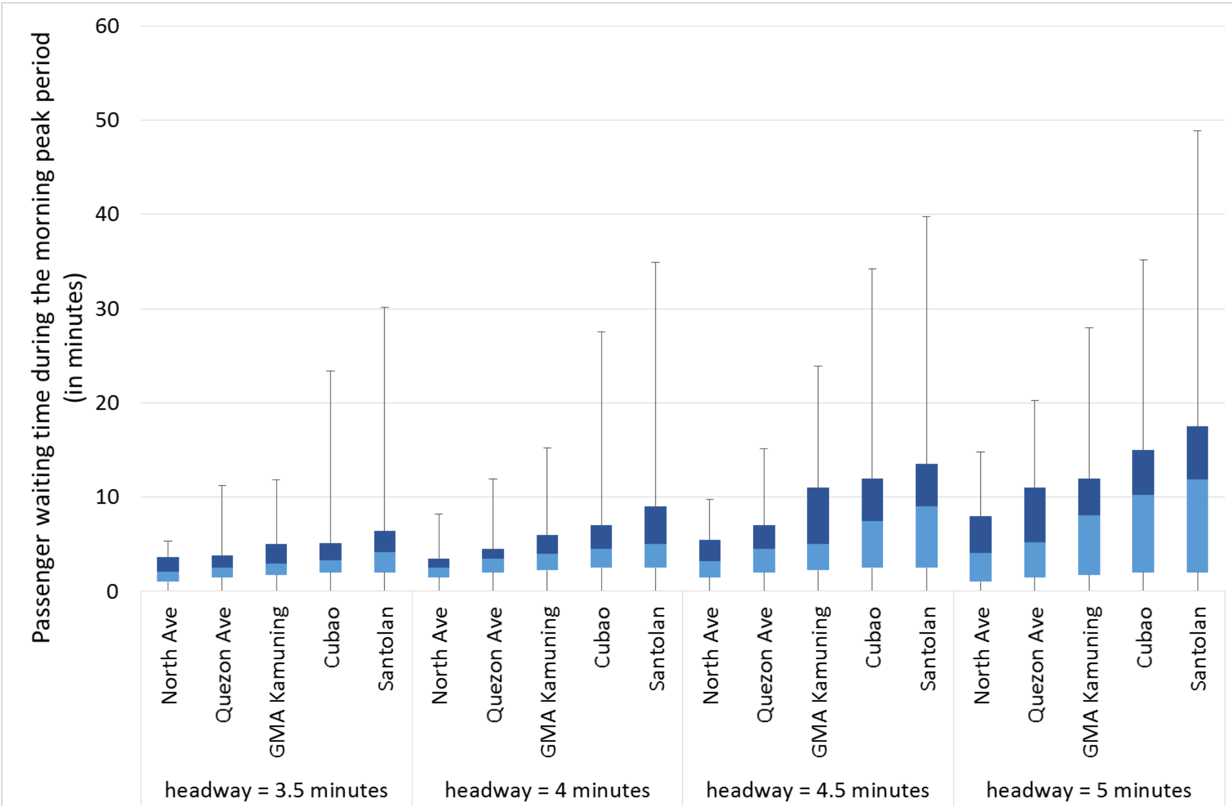


Figure 6.15. Box-and-whisker plot of passenger waiting time at selected stations for capacity expansion with different headways (passenger density = 8 passengers/sq.m.; 2014 demand+10%)

The simulation model only focused on the first five stations in the southbound direction because these are the stations that periodically experience long and variable waiting times. However, several respondents in the questionnaire survey (which is used to estimate passenger satisfaction) board at stations other than the first five stations. Due to boarding and alighting patterns from the sixth station onwards, it is unlikely that passengers boarding at these stations would experience prolonged waiting time (this was also confirmed in the video observation survey in Section 3.5.2). Thus, it is assumed that these passengers would experience waiting times equal to the headway, indicating that there is no delay.

The effect of passenger waiting time reduction as a result of capacity expansion on passenger satisfaction is shown in Figures 6.16 and 6.17. In general, the capacity expansion increases neutral and positive ratings to around 70% because of the drastic reduction in waiting time especially for North Avenue Station, which is the most used boarding station in the questionnaire survey dataset. Moreover, there are no significant differences between the scenarios according to headway due to the small differences in waiting time (just a few minutes) between the scenarios.

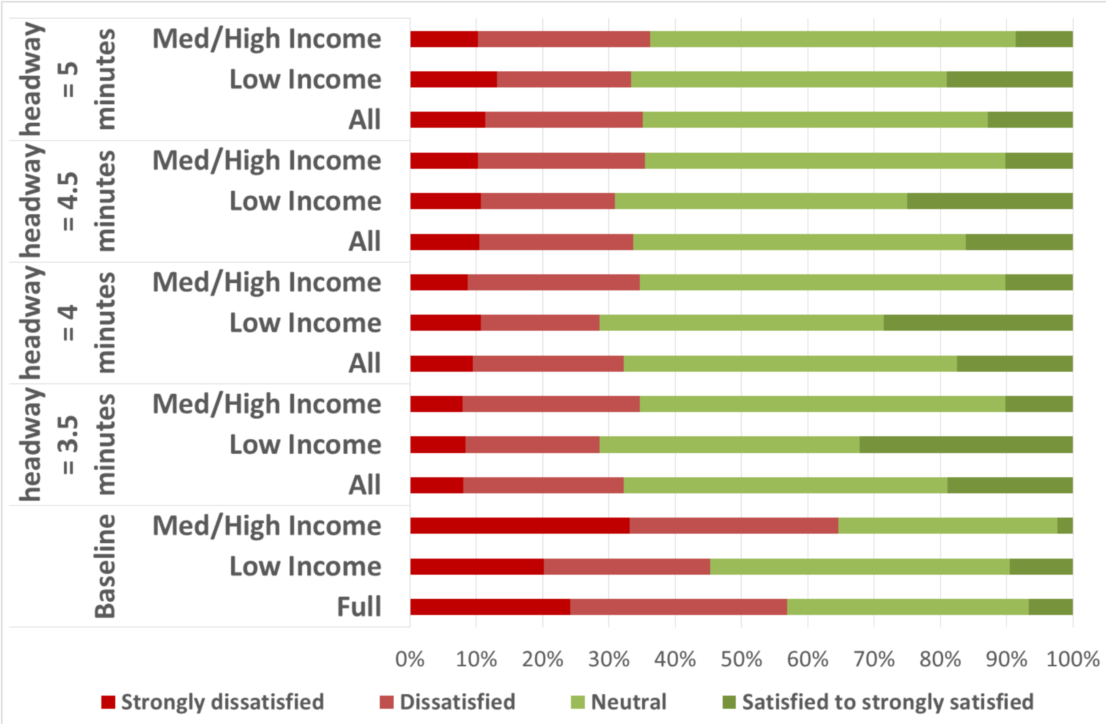


Figure 6.16. Aggregated passenger satisfaction index (capacity expansion; same ridership)

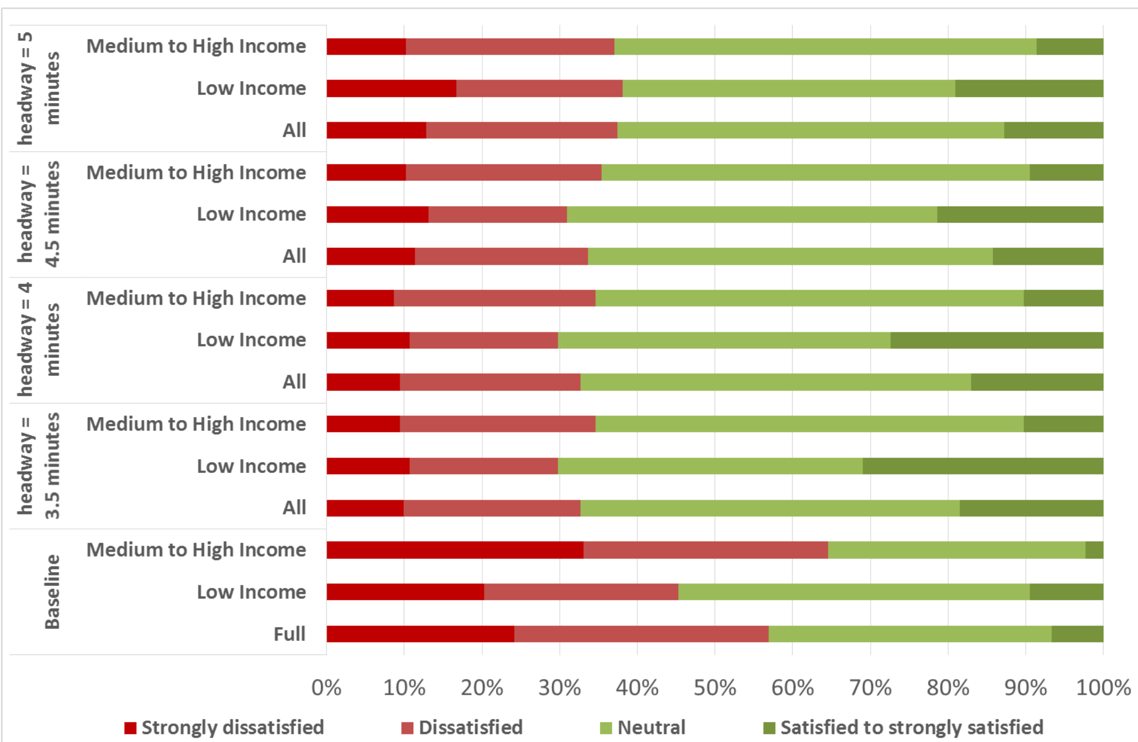


Figure 6.17. Aggregated passenger satisfaction index (capacity expansion; +10% ridership)

Furthermore, the passenger satisfaction levels between the case of no ridership increase and 10% ridership increase are almost the same. These similarities are due to the fact that passenger satisfaction levels are composed of variables other than waiting time.

6.2.4.2. Fare Increase

The effects of fare increase in ridership were discussed in Section 3.3.4. To recall, the fare increase ranged from 30% to 87% according to distance traveled (see Figure 6.18). Although the fare increase has already been implemented in reality, it is of interest to determine the effect of this policy change on waiting time, given that there has been reduction in passenger demand. Ultimately, the analysis would determine whether the increase in fare has been compensated by improvement in level of service and what the effect on passenger satisfaction is.

Ridership decreased by an average of 44% for all stations as a result of the fare increase but only 13.7% in North Avenue Station, which is the most critical station. Considering only the first five stations in the southbound direction, the before and after ridership numbers are 66,522 and 47,070, respectively. Figure 6.19 shows this trend.

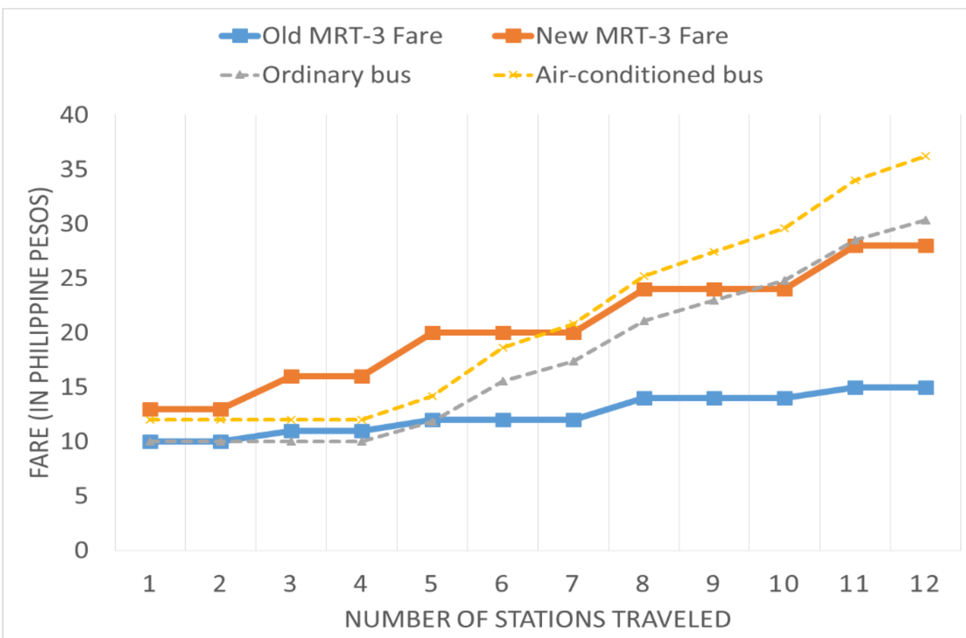


Figure 6.18. Old and new fare levels at the MRT-3

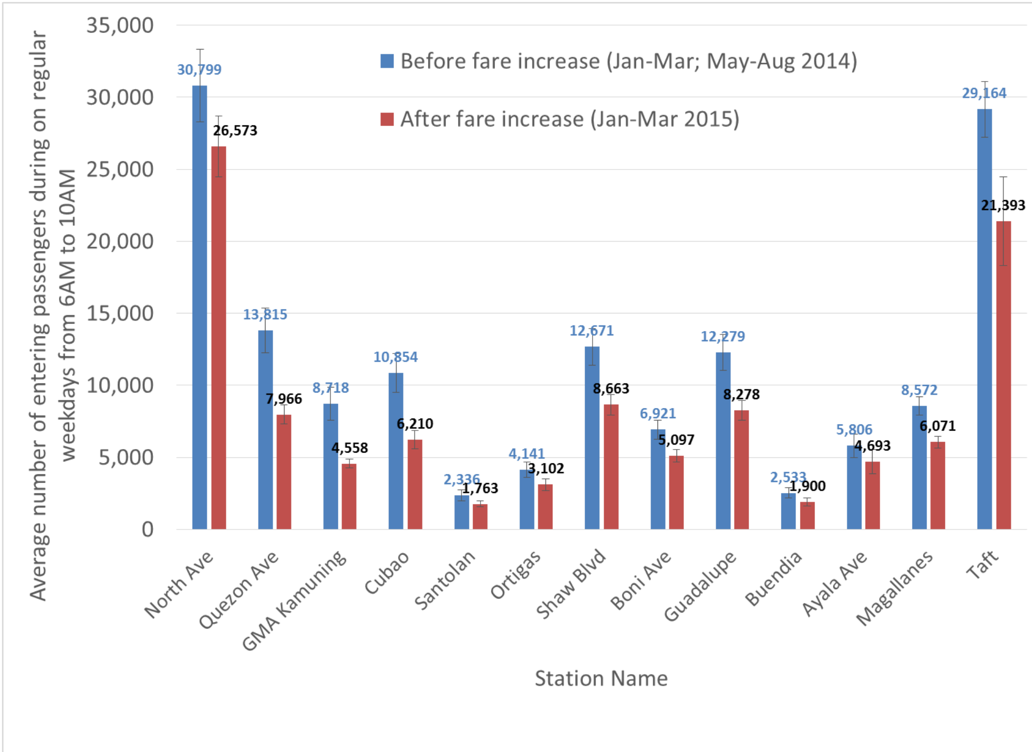


Figure 6.19. Morning peak passenger entries before and after fare increase (actual data)

Using the conditions outlined in Table 6.1 and the passenger demand after the fare increase, it was found that waiting times would reduce by 28% on average, as seen in Figure 6.21. Its effect on aggregated passenger satisfaction is shown in Figure 6.22.

6.2.4.3. Proportional Crowd Control Policy

As discussed in Section 3.4.1, the current crowd control policy in Metro Manila MRT-3 imposes a station entry limit of 500 passengers at a time, but this number seems that it was arbitrarily chosen by the operator. Its supposed effects of improving equity and reducing waiting time at the subsequent stations is not felt at Cubao or Santolan Station. The existing crowd control policy is ineffective in dissipating queues and unfairly prolongs the waiting time at the first station, given that it has higher demand, as well as at the fourth station because the train is usually full by the time it reaches, as seen in top part of Figure 6.20.

Thus to improve this, a new policy called ‘proportional crowd control policy’ is proposed such that the crowd control limit is proportional to the demand at each station and skipping trains are deployed at a certain demand threshold to reduce and equalize the maximum waiting time at each station. This is illustrated in the bottom part of Figure 6.20.

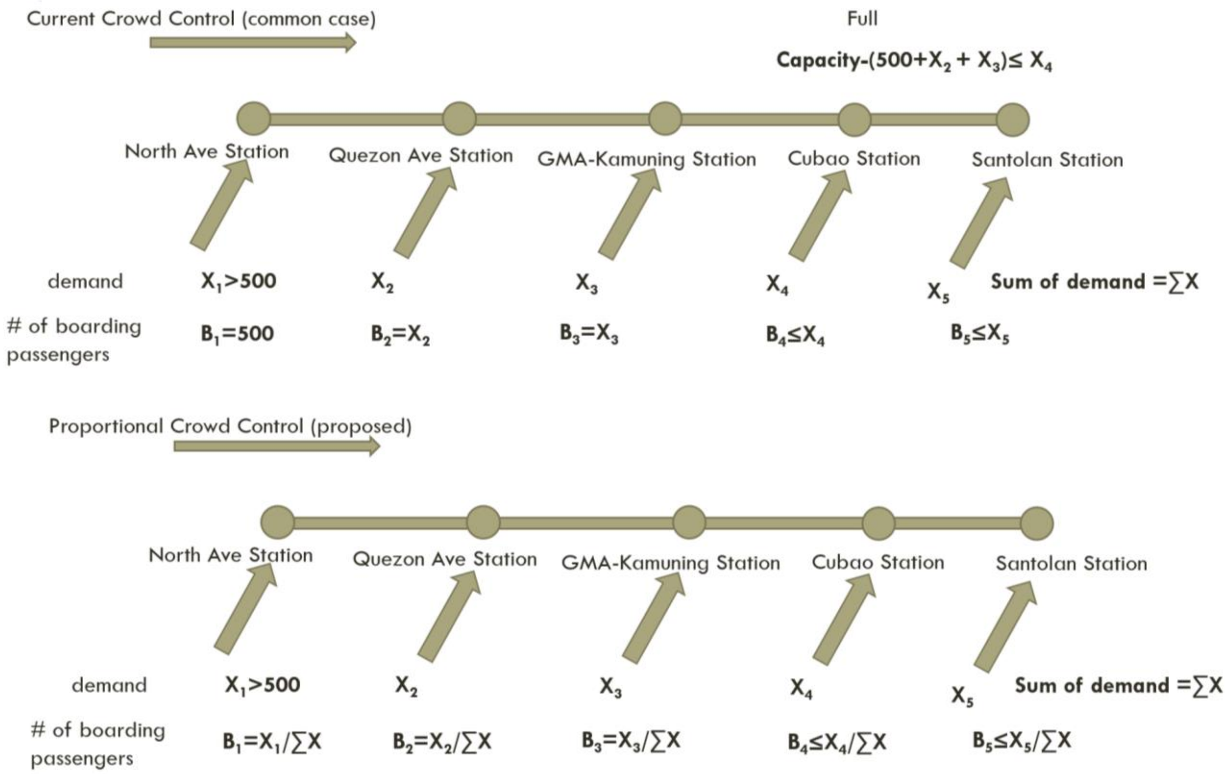


Figure 6.20. Comparison between the current crowd control policy and the proposed proportional crowd control policy

This proposed policy is tested using the waiting time simulation model with the parameters outlined in Table 6.1. Unlike the two other countermeasures, it assumes uniform passenger arrival pattern because the total demand at each headway interval needs to be known to implement this policy.

The results in Figure 6.21 show that this policy is effective at equalizing the maximum waiting time across stations and reduced waiting time at overburdened stations, but that increased the average for some stations. These ‘transfers’ are expected as the main goal of this policy is to addresses the equity problem. (Equity in passenger waiting time is discussed in more detail in Section 6.3.1.1)

Moreover, its effect on aggregated passenger satisfaction is presented in Figure 6.22.

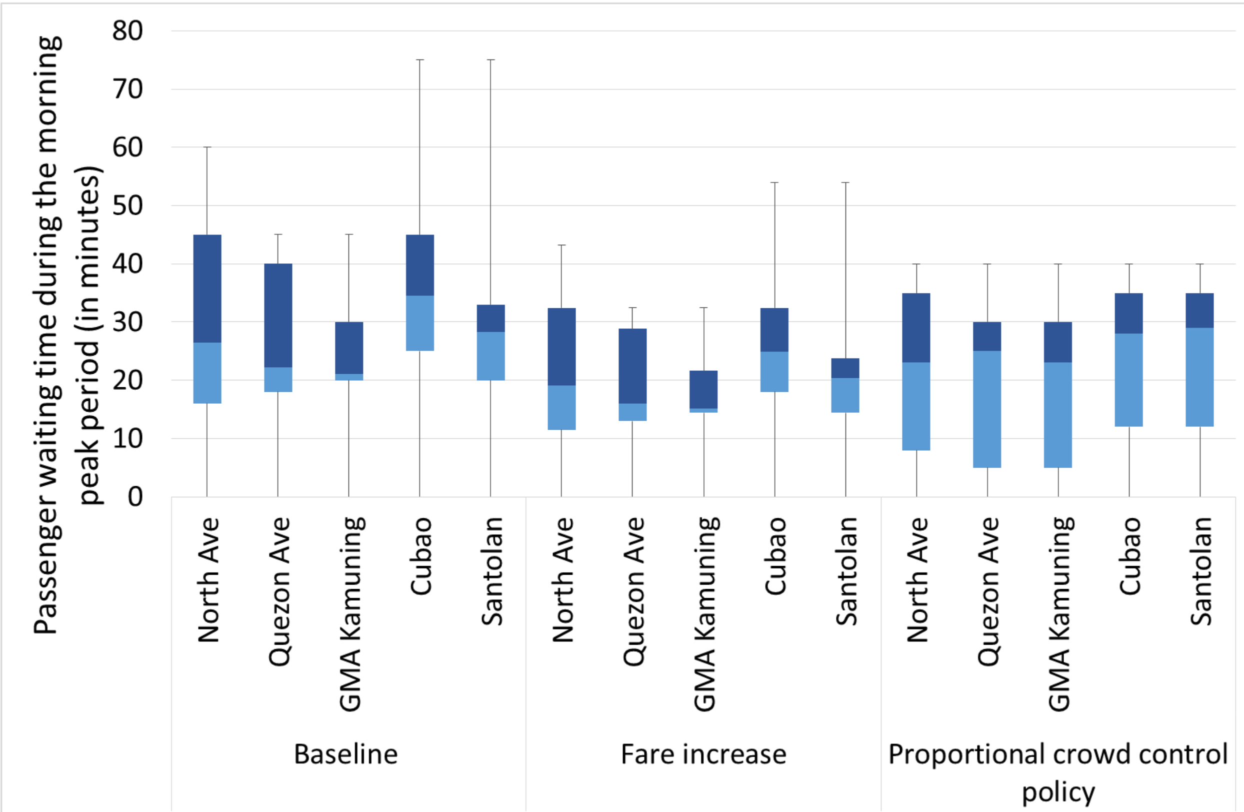


Figure 6.21. Effect of fare increase and proportional crowd control policy on waiting time

6.2.5. Sensitivity Analysis

Due to the absence of detailed models that would change in-vehicle time, perceived risk and perceived air quality, a sensitivity analysis on these attributes is conducted instead. This research study does not cover how these attribute changes would materialize.

Sensitivity of in-vehicle time is tested by reducing the feeder mode travel time by 20% as a ballpark figure. In reality, this could be accomplished by improving MRT-3 feeder modes, which are usually subject to road congestion and multiple transfers.

Moreover, the effect of reducing risk perception on satisfaction is tested. Risk perception is one of the important explanatory variables for passenger satisfaction, thus, countermeasures that improve it should be considered. As mentioned in Section 1.1, MRT-3 has dilapidated rail tracks that have caused some safety incidents, so rail track replacement is suggested as a countermeasure to increase safety and reduce objective risk. However, the relationship between observable variables and risk perception as well as objective safety data are not available and beyond the scope of this research. Furthermore, risk perception is a complex construct that is explained by many factors as explained in the psychometric paradigm by Slovic *et al* (1982, 1985; see Section 2.2.4 for a discussion) and is generally not in line with objective risk. Its impact on passenger satisfaction is shown in Figure 6.22.

Improving air quality perception is also tested in the sensitivity analysis. The mechanics of air quality perception has not been studied in detail. It was established in Section 5.5.2 that it has no apparent relationship with $PM_{2.5}$ particle count and waiting time, but it is connected to worry about health effects. As such, even if countermeasures such as replacing existing diesel buses by electric buses would reduce $PM_{2.5}$ particle count and other pollutants along EDSA, people may not perceive it unless the government runs an educational/informational campaign (e.g. in Tokyo). Given that the predictor variable in the passenger satisfaction model includes air quality perception and not actual $PM_{2.5}$ particle count, the relationship between the two as well as exposure time (in the form of passenger waiting time) needs to be taken into account. The effect of a one-point increase in air quality perception on passenger satisfaction is shown in Figure 6.22.

6.2.6. Overall Comparison

The effectiveness of the countermeasures is measured by how good they are in increasing the share of passengers who are either neutral or positive about their rating of MRT-3.

Moreover, the combination of all countermeasures is also tested (i.e. capacity expansion scenario (3.5 minute headway; no ridership increase case), fare increase, reduction in risk perception, and increase in air quality perception, except the proportional crowd control policy which is only relevant when there is delay).

A comparison between the countermeasures is given in Figure 6.22.

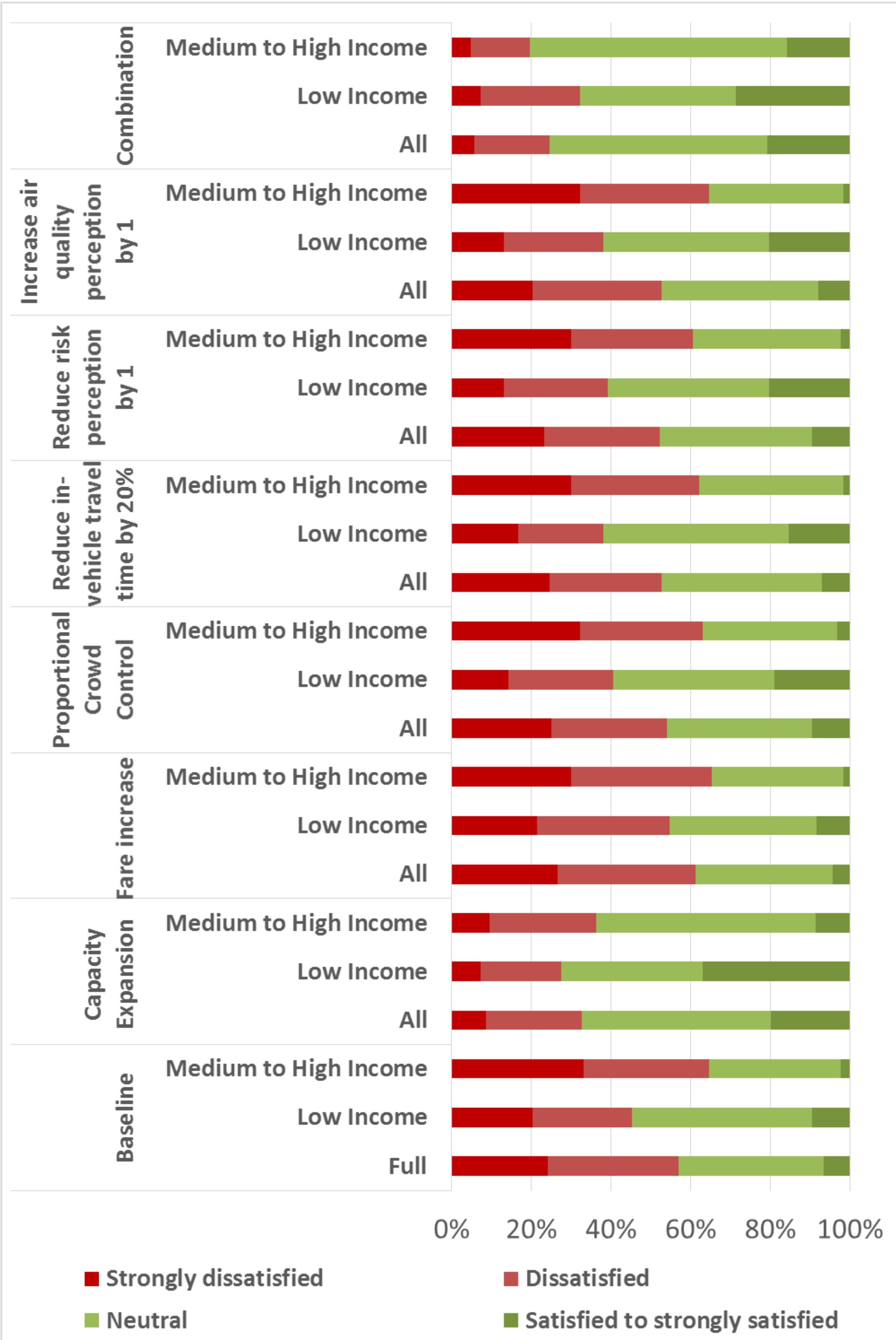


Figure 6.22. Comparison of aggregated passenger satisfaction indices among different countermeasures

In general, medium to high-income people have lower satisfaction levels than their low-income counterparts. It can be seen in the baseline case that most passengers have very low to low satisfaction levels, while low income passengers have low to moderate satisfaction, which could be explained by their lower values of in-vehicle and waiting times. There are also more people with higher income levels in the dataset, which drive overall satisfaction lower.

Among the proposed countermeasures, capacity expansion yields the highest proportion of moderately to highly satisfied passengers because it would lower waiting time to just 3.5 minutes, assuming the elimination of passenger overload delay resulting from insufficient capacity. Moreover, it can be observed that fare increase lowered the satisfaction levels of low-income people by one percentage point, but it slightly increased the proportion of satisfied medium- to high-income people. This suggests that for low-income people, the reduction in waiting time does not compensate for the increase in fare.

The effect of changing perception-related variables is examined, even though this may be probably difficult in reality because it is influenced not just by actual conditions but probably individual differences. For instance, it would be hard to improve air quality perception even by actual improvements in air quality, as it was established that commuters do not perceive actual PM2.5 exposure due to lack of visual and olfactory characteristics. Nonetheless, improving such perception-related variables by one point (out of 7) would only have a minimal effect on satisfaction levels, as seen in Figure 6.22. The effect of a one-point reduction in risk perception is almost the same as the effect of a one-point increase in air quality perception.

Moreover, reducing in-vehicle travel time by 20% also yields to small changes in satisfaction levels. However, reducing waiting time by eliminating passenger overload delay would yield the highest improvement in satisfaction, almost doubling the satisfaction levels for all groups. Low-income people also tend to have higher satisfaction levels given that they have lower values of time than higher-income people.

Combining the countermeasures would yield an overall increase in neutral or positive ratings from around 40% to 80%. The proportion of satisfied low-income passengers is lower due to the fare increase.

6.3. Overall Discussion

This section synthesizes the results from the previous chapters and conducts an overall discussion on passenger well-being as well as an equity analysis.

6.3.1. Equity

Two types of equity are explored in this subsection: equity of passenger overload delay (related to passenger waiting time in Chapter 3), and environmental equity (concerned with $PM_{2.5}$ exposure in Chapter 4).

6.3.1.1. Equity of Passenger Overload Delay

This section extends the analysis by considering passenger waiting time from the viewpoint of equity. It should be noted that this section is independent of the countermeasure analysis part, although it can be applied as an extra measure.

Following the definition by Lam *et al* (1999a), the term passenger overload delay is used to refer to the time penalty that passengers will wait for the next coming vehicle when they cannot board the first coming vehicle because of insufficient capacity of in-vehicle links (see Figure 6.23 for an illustration). In this case, other sources of delay are not considered (e.g. variation in headway, accidents) and the passengers do not have an option to transfer to alternative routes (i.e. no transit assignment problem). In other words, when all trains arrive on time, passenger overload is the only source of delay. Since passenger overload delay is a time penalty and the maximum expected waiting time for a line with sufficient capacity is equal to the headway, it is then reasonable to define passenger overload delay as the difference between the actual waiting time and the headway. Thus, delayed passengers are those who are refused on the first train, and thus have a waiting time greater than the headway. It follows that undelayed passengers are those with waiting times less than or equal to the headway.

However, in a situation where the service reliability is imperfect, train operations is an additional source of delay. A comparison is given below in Figure 6.23. In this study, perfect train service reliability is considered to focus on the equity of passenger overload delay.

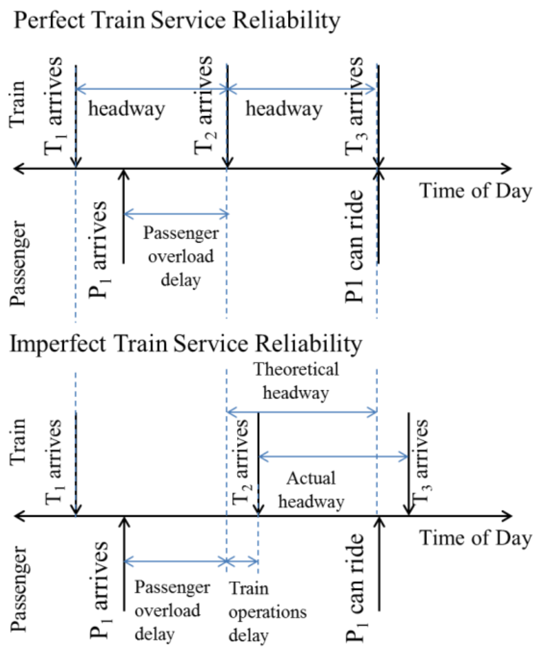


Figure 6.23. Definition of passenger overload delay

A passenger overload delay equity index that captures the concepts of equity and relative deprivation among passengers is proposed. When delayed passengers compare themselves with less delayed and undelayed passengers, they would feel relative deprivation. Conversely, when undelayed passengers compare themselves to delayed passengers, they would feel relative gratification. Using the headway as the reference point implies that the passenger was not able to board the first train. Let a 'time interval' be the period between just after the previous train left up to until the next train arrives. A passenger who arrives at a certain time interval expects to ride on the train that arrives at the end of the interval, and if he does so, he is undelayed.

The proposed delay equity index entails the comparison of waiting times among all passengers under a censored waiting time distribution rather than the original waiting time distribution. This means that all undelayed passengers are considered to be equal to the headway. It would also reflect the improvement in social welfare due to a decrease of the number of delayed passengers. This is similar to a distributional poverty gap measure called Takayama Index, which measures poverty under a censored income distribution wherein all non-poor people have income equal to the poverty line (Clark *et al*, 1981). To apply this in the context of passenger overload delay, the following equations are defined.

Head count ratio, H, refers to the portion of delayed passengers q among all rail passengers n during the morning peak period.

To formulate the social welfare-theoretic delay equity index, it is necessary to establish the relationship between the frequency distribution of waiting time y, $f(y)$, and the frequency distribution of the social (dis)utility $-w$, $g(-w)$. For any individual with waiting time y_i, there is an associated disutility level $d(y_i)$, which is the deprivation function for an individual due to waiting time.

$$d(y_i) = \frac{1}{\alpha}[\max(z, y_i)]^{\alpha} \tag{14}$$

Waiting time is used in the deprivation function instead of passenger overload delay because the use of the latter would imply that only the relative deprivation of delayed passengers among themselves is considered, and not against the undelayed passengers. It is reasonable to assume that delayed passengers would compare their situation with undelayed passengers as well. In effect, a censored waiting time distribution is used because the Poisson arrival is considered. Some degree of inequity is already inherent for a Poisson arrival process, thus, if a censored waiting time distribution is used, the contribution of the assumed randomness of the arrival process itself is reduced and the inequity would largely be attributed to insufficient capacity.

The social welfare function is increasing and additive, and is given as the sum of all deprivation functions. It represents the total disutility felt by society due to the waiting time.

$$-\mathrm{w}(y_p, z, \alpha) = \sum_i d(y_i)\,, \qquad \mathrm{i} = 1, \ldots, \mathrm{n} \tag{15}$$

$$= \left(\frac{1}{\alpha}\right) \sum_i {y_i}^{\alpha} + \left[\frac{n-q}{\alpha}\right] z^{\alpha}, \qquad \mathrm{i} = 1, \ldots, \mathrm{q} \tag{16}$$

The inequality aversion parameter is $\alpha \geq 1$ for concavity in waiting time, and it represents the importance given to passengers with higher delay. The above equation means that undelayed passengers are considered to have a waiting time equal to headway, given that the actual value of waiting time for undelayed passengers is entirely due to the randomness of arrival. Since a smaller value of y_i is desirable, as when $\alpha > 1$, more weight is placed on large waiting times in determining $-w(y_p, z, \alpha)$ and in the limit, as $\alpha \rightarrow \infty$, only the largest waiting time matters and $-w(y_p, z, \alpha)$ becomes maximin with respect to waiting time.

From here, an equally distributed equivalent waiting time, $y*$, for all passengers, is deined as the value of waiting time that if shared by all passengers yields the same level of social welfare as the censored waiting time distribution. The equally distributed equivalent waiting time, $y*_p$, is for delayed passengers only.

$$-w(y_p, z, \alpha) = \left(\frac{n}{\alpha}\right) y^{*\alpha} = \left(\frac{q}{\alpha}\right) {y_p}^{*\alpha} + \left[\frac{n-q}{\alpha}\right] z^{\alpha} \qquad (17)$$

A situation of no passenger delay would mean that all passengers in the censored waiting time distribution have a waiting time equal to the headway z (i.e. all passengers can ride on the first train assuming that they arrived at the start of the period). The equally distributed equivalent waiting time is always greater than or equal to z. The resulting delay equity index is then:

$$P = \frac{-w^0 - (-w)}{-w^0} = \frac{y^*}{z} - 1 \qquad (18)$$

where $-w^0$ is the social welfare level for a situation of no delay.

The significance of this delay equity index is that it is effectively the ratio between the delay (difference between the equally distributed equivalent waiting time and headway) and the headway. This can also be interpreted as the percentage increase in social welfare level (i.e. worsening in social disutility) from case of no passenger delay to the current situation. The delay equity index ranges from zero (i.e. the case when everyone is undelayed; equality) up to infinity. The index satisfies the monotonicity axiom, that is, the reduction of waiting time of a delayed passenger must improve equity. It also satisfies the transfer axiom, that is, a pure transfer of waiting time from a delayed passenger to another passenger with lower delay must improve equity if the difference between their delays is less than in the initial case, ceteris paribus.

The applicability of this index is illustrated using the deterministic case using 2012 data as an example.

Figure 6.24 shows that the delay is concentrated on the fourth station only, with the maximum waiting time being around 31 minutes. In contrast, all other stations do not experience waiting times higher than the headway. This means that even with perfect train service reliability, passengers in Cubao Station (4th station) still experience passenger overload delay due to capacity constraints. It should be noted that other sources of delay such as late arrival of trains) may worsen passenger waiting times and spread it to other stations.

The situation improves by employing the “skip train” operations countermeasure by spreading the delay to other stations and decreasing the maximum waiting time to around 17 minutes, as seen in Figure 6.25. Efforts to spread the delay by employing “skip train” operations results in lower delay for the third and fourth stations, but causes those at the first, second and third stations to experience delay as well.

These results are consistent with actual observations at the MRT-3 CCTV live streaming website (Metrostar Express) during the morning peak period (7-9AM) wherein many passengers in the first five stations heading towards the southbound direction were observed to wait for several trains before being able to board. The waiting time was observed to be most severe for the fourth station, which is similar to the results in this study.

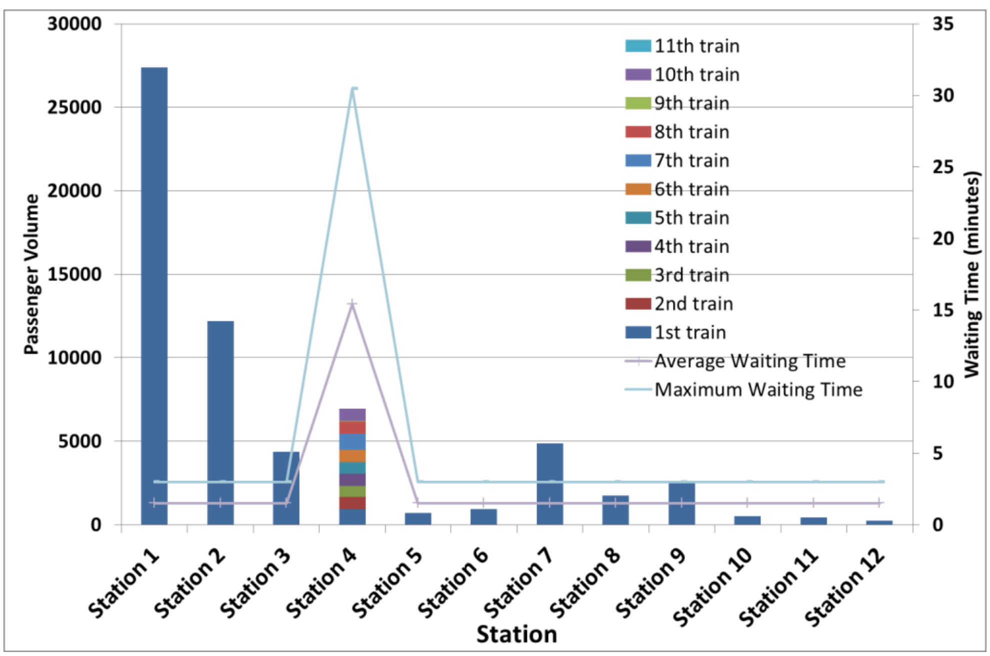


Figure 6.24. Waiting time for constant operations

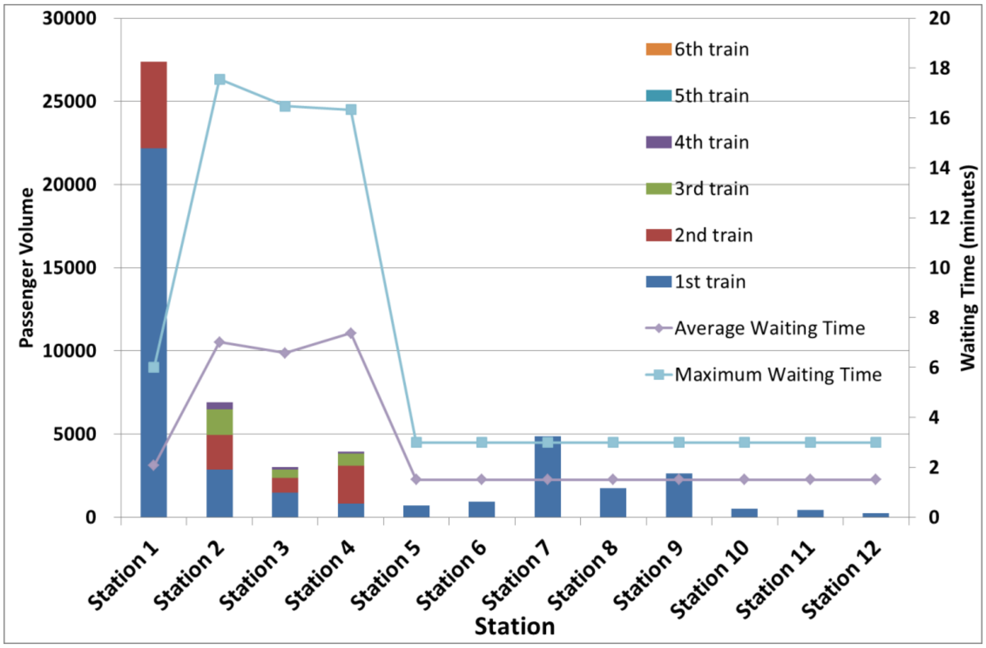


Figure 6.25. Waiting time for "skip train" operations

Table 6.8. Passenger overload delay equity in Metro Manila MRT-3

Parameter		Constant operations	"Skip train" operations
Total delay (minutes)		200004.32	405650.14
Average delay (minutes)		3.14	6.38
Maximum delay (minutes)		30.47	17.55
Standard deviation		6.59	4.05
Coefficient of variation		2.10	0.64
Gini coefficient		0.61	0.50
Proposed Delay Equity Index	(α=1)	0.50	0.56
	(α=1.5)	1.45	1.25
	(α=2)	4.03	2.56
	(α=3)	31.31	10.15
Social welfare level	(α=1)	-2.86E+05	-2.97E+05
	(α=1.5)	-5.39E+05	-4.95E+05
	(α=2)	-1.44E+06	-1.02E+06
	(α=3)	-1.85E+07	-6.38E+06
Delayed passengers		6,581	24,246
Undelayed passengers		57,040	39,375
Head count ratio		0.10	0.38

Several parameters, including total delay, maximum delay, head count ratio, Gini coefficient, social welfare level and the proposed passenger overload delay equity index, were employed to assess the equity of the distribution of delay among passengers for the morning peak period in the southbound direction. It can be observed from Table 6.8 that the Gini coefficient indicates an improvement of delay equity from constant operations to the “skip train” operations. It can be seen that according to Gini coefficient as well as for the proposed delay equity index, the constant operations scenario is less equitable than “skip train” operations. The same result is seen for the proposed delay equity index. However, when more weight is given for people with higher delay (as α increases), equity and social welfare levels are seen to worsen.

However, the total delay and number of delayed passengers are seen to increase, implying that there is a trade-off between equity and efficiency (i.e. minimization of total system delay). These results indicate that the existing operation strategies used in the MRT-3 are not enough in addressing passenger overload delay even with perfect service reliability assumption, indicating that it is the capacity constraint that is causing delay equity among passengers. The MRT-3 employs a scheduled skip train operations as well as crowd control procedures whenever necessary yet excessive waiting time is still observed (Metrostar Express). With delay at this level, it is possible that passengers at the stations that experience delay would be deprived of the opportunity to ride the rail, further aggravating equity problems.

6.3.1.2. Environmental Equity

Environmental equity, also called environmental justice, is the development, implementation, and enforcement of environmental policies and laws to ensure that no group or community is made to bear a disproportionate share of the harmful effects of pollution or environmental hazards because it lacks economic or political clout. It focuses on the fair distribution of environmental benefits and burdens.

Given these principles, it is clear that there is environmental inequity across travel modes, such that ordinary bus passengers (and arguably, jeepney users, motorcycle riders, cyclists and pedestrians) are exposed to disproportionally higher levels of $PM_{2.5}$ than users of MRT-3 and air-conditioned bus. Moreover, depending on the boarding station, the total exposure of a passenger can be disproportionally higher than their counterparts. While there were no stark differences in the $PM_{2.5}$ levels between stations, their waiting times have differences which affects environmental inequity.

Apart from commuters, drivers and ticket conductors of ordinary buses are the most exposed sector considering the length of time they spend on the road. Proper masks that would significantly diminish $PM_{2.5}$ exposure levels should be worn by concerned citizens, especially those who are sensitive to particulate pollution.

6.3.2. Passenger Well-being

In this sub-section the findings of Chapters 3, 4 and 5 as well as the earlier part of this chapter are discussed and evaluated against the research hypotheses presented in the introduction. It outlines the contribution of this research to knowledge about commuting and its effects on passenger well-being.

Using a variety of data collection methods, the extent of the problem in terms of level of service, air quality and perception was established. Before this study was made, the evidence on MRT-3's problems on congestion and air pollution was mostly anecdotal only, so data collection was necessary to quantify the problem in an objective manner.

6.3.2.1. Level of Service

In Chapter 3, the main goal was to establish the level of service and identify the factors that affect it. Evaluation of the level of service confirmed that the main problem at the MRT-3 is the prolonged waiting time at certain stations, which is composed of station access time from the end of the queue to the station turnstiles, and platform waiting time. Simply put, this waiting phenomenon arises due to the discrepancy between passenger demand and MRT-3 capacity.

Factors that affect this phenomenon were examined. For the demand side, the historical trends investigated in Section 3.3 imply a relationship between ridership and fare levels of MRT-3 and other modes, gas prices, minimum wage, population and season. As MRT-3 became more affordable due to its unchanging fares until 2014 amid inflation (meaning increase in other modes' fare levels, gas prices and minimum wage) and as the population increased, the ridership also increased and exceeded MRT-3's rated capacity. A substantial decrease in passenger demand was also observed immediately after the fare increase in January 2015. Moreover, it was shown in Section 6.5.2 using a waiting time simulation model that the actual fare increase in 2015 reduces waiting time to some extent due to the corresponding decrease in demand.

Passenger behavior influences waiting time as well as it was observed that passengers at the first station choose to wait for the next train even if the current train still has some space in order to sit, thus prolonging his/her waiting time by a few minutes. However, such behavior is not observed in middle stations where waiting for the next train is not a choice but a result of a lack of physical space in the train.

For the supply side of the problem, system capacity as a function of headway (or frequency) and vehicle capacity was examined. Supply side factors can be directly controlled by the operator to some extent. For the train frequency, it was revealed in the surveys that MRT-3 does not achieve its design capacity because it does not adhere to its published regular headway. This could be due in part to its lowered train speed implemented as a safety precaution after an accident in August 2014, which implies that the safety situation at the MRT-3 influences waiting time as well. This would suggest that addressing safety concerns would allow train speed to be increased and headway to be decreased as well. Another factor that increases the headway is the decreased number of running coaches as more coaches remain in the depot, which was pointed out by Bondoc (2015).

Furthermore, operations policies implemented by MRT-3 affect this phenomenon. Passenger waiting time was measured before and after the implementation of a new crowd control policy, which artificially limited the number of passengers entering the platform at some stations. Prior to the implementation of the said policy in 2013, it was found that platform waiting time is long and variable at the middle stations (third to fifth stations) in the peak direction because the trains are usually almost or already full when it arrives at those stations and there are usually only a few alighting passengers, if any. However, implementing the crowd control policy in 2014 led to passenger queuing on the roadside and stairways at the first station and at the fourth station as well even if official ridership data showed that demand decreased in that year. While this drastically reduced the number of people on the platform, passengers are forced to queue on sidewalks and stairways. Moreover, this did not alleviate the long and variable platform waiting time problem experienced by middle station passengers. Skip train operations policy, wherein an empty train is deployed to the middle stations upon the operator’s discretion, allows those passengers to board at some point but only after waiting for a considerable length of time.

Changing the operations policy could potentially address the waiting time problem. In Section 6.5.3, it was shown that implementing the proposed proportional crowd control policy would reduce the maximum waiting time experienced at some stations.

Moreover, it was observed that passenger density inside the train depends on passenger behavior to some extent. As observed in many other systems, passengers tend to avoid the middle part (Evans and Wener, 2007) of the vehicle and crowd the train doors, presumably to alight more easily. However, this prevents more passengers from boarding the train because, and effectively reduces vehicle capacity, but this may be a good thing considering the negative effects of crowding and high passenger density (Turner et al, 2005) and that passenger density at the MRT-3 is already high. Regardless, the most critical point to improving vehicle capacity is not by increasing passenger density but by increasing the number of train cars. It was illustrated in Section 6.5.1 using the waiting time simulation model that the government's proposal of adding an extra train car and keeping regular headway would drastically lower passenger waiting time even if a 10% increase in passenger demand is assumed. Queuing on the roadside and stairways is also a consequence of inadequate station space, which suggests poor infrastructure planning.

In-vehicle time was measured as well and was found to be generally more reliable than waiting time as delay due to dwell time is not an issue. A comparison study of in-vehicle travel time between modes in 2005 (results by Fillone, 2005) and 2015 found that the average speed using the MRT-3 has decreased in 2015, and is even lower when waiting time is considered. However, the average speed is still higher than that of ordinary and air-conditioned buses for both years, given that the buses are subjected to road congestion and have more frequent stops.

Aside from travel time using the MRT-3, total morning commute time is increased by feeder access and egress travel time including transfers. This is the case for most passengers as the MRT-3 only covers a relatively small area so most passengers need to use feeder modes to use the MRT-3. Such modes are often subjected to road congestion, which make travel time long and unpredictable. This also makes the overall commute more expensive considering that road-based modes are generally priced higher and because of the unintegrated fare structure that requires commuters to pay per mode used and according to distance traveled.

6.3.2.2. $PM_{2.5}$ Exposure while Commuting

The prolonged travel time problem at the MRT-3 extends to another problem that is a side effect of commuting at the MRT-3 – $PM_{2.5}$ exposure while waiting at the roadside and platform, and when inside the train. This study investigated the $PM_{2.5}$ pollution problem at the MRT-3 and how it compares to other modes.

$PM_{2.5}$ particle counts were measured at MRT-3 stations and inside the MRT-3, as well as inside ordinary and air-conditioned buses, and the results were presented in Chapter 4. The results of the intra-modal and intermodal comparison of $PM_{2.5}$ exposure lend more evidence that commuting using urban rail leads to exposure. Given that no 'absolutely safe' threshold has been set so far (WHO, 2013), the mere presence of $PM_{2.5}$ particle count causes concern. It was found that $PM_{2.5}$ levels at the roadside is higher than inside the train. Intra-modal comparison between selected MRT-3 stations revealed that there were no significant differences on the $PM_{2.5}$ particle counts of four out of five stations in the survey, with one station having significantly higher levels possibly due to its proximity to provincial bus terminals. Intermodal comparison of $PM_{2.5}$ particle counts inside the MRT-3, ordinary bus and air-conditioned bus found that the MRT-3 has the lowest particle count, followed by the air-conditioned bus and the ordinary bus. It is consistent with previous literature in which the highest concentrations were measured for non-motorized modes such as walking or riding a bicycle (i.e. without any protection of being inside a vehicle), followed by buses/minibuses and urban rail, then private cars (refer to Section 2.5). Unlike other studies, a distinction was made between air-conditioned and ordinary buses. The stark differences between the two modes for the same route imply that air conditioning reduces particle count. Moreover, roadside levels are almost similar to ordinary bus levels, which is expected because such buses have open doors and windows and no air conditioning.

$PM_{2.5}$ exposure is not just affected by the $PM_{2.5}$ particle counts but also by the length of exposure to particulate matter. Exposure time to MRT-3 commute-related $PM_{2.5}$ pollution is defined as the sum of waiting time at the roadside and platform and in-vehicle time while in the train. Given the extent of passenger waiting time and in-vehicle time at the MRT-3, passengers are potentially exposed $PM_{2.5}$ pollution at the roadside and platform and while on board the train for a considerable length of time.

As previously mentioned, intermodal comparison considering just the in-vehicle measurements of $PM_{2.5}$ results in MRT-3 having the lowest levels among the three modes. However, if exposure time is considered in the intermodal comparison, MRT-3 exposure is increased and is almost equivalent to that of air-conditioned bus, but not as bad as that of an ordinary bus. As such, it is imperative to reduce waiting time to reduce $PM_{2.5}$ exposure time at the roadside and platform to decrease overall $PM_{2.5}$ exposure for MRT-3 passengers.

It was found in literature that underground levels of the urban rail (on the platform and inside trains) have higher concentrations than roadside levels due to faulty ventilation (refer to Section 2.5). However, such results were not seen in this study; in fact, for Ayala Station (the only station with a basement level in this study) roadside measurements and second floor measurements were found to have higher particle counts. Moreover, there are low levels inside MRT-3 trains, probably because MRT-3 runs elevated for most of its alignment unlike the ones in literature which focused on underground systems.

6.3.2.3. Perceived Conditions

The actual conditions presented in the previous sub-sections indicate that the situation is largely negative, but do the passengers perceive them in that way? This was the question that was addressed in Chapter 5 using a questionnaire survey for regular morning peak MRT-3 commuters. Moreover, a model that investigates how individual perception and travel time lead to psychological effects of commuting was developed.

Perceived conditions are affected by actual conditions and moderated by individual characteristics. In other words, the same (objective) situation may be perceived differently depending on individual response. For instance, a passenger density of 10 passengers/sqm was rated as very crowded by someone, but regarded as only slightly crowded by someone else. The same discrepancies were observed for length of commute, predictability, risk perception, air quality perception, awareness, perceived benefits, perceived service quality, mental adaptation and commuting stress. A fundamental analysis was conducted to test the extent to which individual characteristics influence perception, and it was found that there are some differences according to socio-economic characteristics (gender, age, income), experience with using the MRT-3, and workplace characteristics (flextime policy and lateness penalty). Such individual characteristics as well as other factors such as personality, religion, upbringing and philosophy cause individuals to have different standards and aspirations in perceiving a certain condition.

Moreover, the relationship of perceived air quality while waiting at the MRT-3 to roadside/platform $PM_{2.5}$ particle counts and waiting time was tested, and it was found that there are no correlations among them. Stations with higher $PM_{2.5}$ counts or longer waiting times do not necessarily rate air quality as lower. This finding is consistent with previous studies which show that visual and olfactory characteristics of air have a significant impact on perceived air quality, so the absence of black exhaust fumes (like $PM_{2.5}$ which is invisible to the naked eye) may lead to better rating of air quality (Saksena, 2011). Thus, apart from individual differences, another explanation for the gap between actual and perceived conditions is lack of awareness. Information dissemination on $PM_{2.5}$ exposure may change perception and address this gap, but this is beyond the scope of this study. All in all, commuters should be more aware of the effects of their MRT-3 commute especially the physiological ones.

6.3.2.4. How the Daily MRT-3 Commute Affects Passenger Well-Being

MRT-3 commute affects passenger well-being in tangible and intangible ways that are not limited to monetary terms.

Productivity Loss

It was established that passengers' long and variable waiting time and overall morning commute time lead to negative consequences at work, including frequent tardiness and lost salary (for those with lateness penalty), and poor reputation at the workplace.

Moreover, commuters need to leave early to account for the long and variable commute time, and forego time that could have been spent for leisure or work. Traditionally, there is a tradeoff between long commute and housing quality, however this is a different case because even those who live within the city (close distance-wise but not travel time-wise) experience such negative circumstances.

Potential Health Effects and Safety Problems

While health effects are not explicitly investigated, there is a plethora of research linking $PM_{2.5}$ exposure and respiratory diseases (WHO, 2013), and commuting to stress. Crowding, waiting time, predictability and transfers and long commutes were found to cause stress-related health effects (Osuna, 1985; Novaco and Gonzalez, 2008; Evans *et al.*, 2002; Evans and Wener, 2006, 2007; Wener and Evans, 2011).

It was mentioned in the introduction that an independent audit found that the MRT-3 is suffering from safety problems and safety incidents such as cases of broken rail have increased in recent years. For instance, a derailment accident occurred in August 2014 but on a ground level station. A derailment accident at the elevated sections of MRT-3 could potentially be more catastrophic. Moreover, incidence of some crimes such as pickpocketing and harassment increases with crowding. In spite of this, passengers have varying levels of risk perception, with some still being optimistic about MRT-3 safety.

Commuting Stress

As stated in the previous sub-section, chronic stress may affect not only psychological mood and behavior, but also potentially causing negative physiological effects (Frederick and Loewenstein, 1999). It may also impact performance at work and organizational behavior (Koslowsky et al, 1995).

It was found in this study that total waiting time and some perceived conditions influence commuting stress, which is measured using self-report indicators on physical and mental exhaustion, and workplace productivity. The largest effect was found to be awareness, which requires commuters to have heightened mindfulness and street-smartness due to the crowded conditions, possibility of crime and the fast pace during the morning rush hour. Air quality perception and crowding also affects commuting stress, while mental adaptation was seen to moderate the effect of crowding on commuting stress. Meanwhile, feeder time, risk perception, perceived service quality and predictability were found to have insignificant effects on commuting stress.

Passenger Satisfaction

Passenger satisfaction was found to be influenced by actual conditions (fare, waiting time, in-vehicle travel time) and perceived conditions (risk and air quality), and controlled by mental adaptation. It was confirmed that waiting time is a significant contributor to dissatisfaction and mitigating it would most likely improve satisfaction and subsequently, well-being. This result is supported by a questionnaire survey conducted by De Langen, Alzate and Talens (2004) in 2002 at a time when MRT-3 ridership had not surpassed its design capacity and service operations were better (in short, passenger waiting time was not a problem), wherein it was found that passengers at that time were generally satisfied with the waiting time at stations as well as with the travel time compared to other modes (e.g., bus, car or taxi).

Waiting time was found to be valued around four times larger than in-vehicle travel time for all groups, implying a strong aversion to waiting. This estimate is slightly higher than previous studies (e.g. Mohring *et al.*, 1987; Mishalani *et al.*, 2006) which have found waiting time to be valued as 1.5 to 3 times higher than in-vehicle travel time, probably because the waiting time at the MRT-3 is typically longer and the waiting environment is generally unfavorable. Moreover, higher income passengers have around four times larger values of in-vehicle time and waiting time than their low-income counterparts, which is just as expected because people with higher income generally regard commuting time as having more monetary value. Higher income passengers may also have higher standards and aspirations than their low-income counterparts.

6.3.2.5. Effect of Adaptation

One notable finding in this research is that there are passengers who are not as stressed or dissatisfied as their counterparts who are in the same circumstances. Extensive literature has shown that adaptation helps people cope with negative experiences (Lyubomirsky, 2011) to improve their well-being. It is a psychological response to reduce the side effects of a negative experience.

Passenger satisfaction is a matter of comparing the commute to individual standards and aspirations. High satisfaction for poor service may also indicate low expectations, which could be an outcome of adaptation, as repeated commuting in such situation enhances habituation. Commuting stress, on the other hand, arises following a long, crowded, unpredictable commute and is manifested by exhaustion and productivity loss. Repeated exposure to the stressor may reduce this impact depending on the adaptation level of the individual.

Adaptation to their MRT-3 commute does not occur for all commuters, with some still not adapted to it even after using it for several years. Previous research (Lyubomirsky, 2011) has found that negative changes to one’s life get better with time, but some are not fully recovered especially to life-changing events such as getting a disability or chronic pain due to an illness. Arguably, daily commuting in negative circumstances is trivial compared to such experiences, but individual differences may account for this.

Experience with using MRT-3 was found to influence adaptation, such that the commuter becomes more accustomed to his daily MRT-3 commute as he repeats the activity more. It has been suggested in literature that well-being declines in the short run following a negative experience but that decrease diminishes as adaptation sets in (Lyubomirsky, 2011), so this may explain why people who have used it longer have higher adaptation. Age was also found to be a factor, with older people adapting more easily, probably because times have been harder for them in the past and may be used to hardship. Meanwhile, there were no differences on adaptation between gender, age, income and work characteristics.

Perceived benefits, perceived service quality and predictability were found to promote adaptation, while perceived crowding was found to hinder it. Perceived benefits represent commuters' gratitude for being able to use the MRT-3 in spite of its shortcomings, so people who perceive more benefits can more easily adapt to it. Moreover, having a higher rating on service quality implies that it the commuting situation may be acceptable to them, so it is easier to adapt to it. Higher predictability indicates habituation to the system, as they may have learned the system through daily experiences and hold an expectation that their waiting time may be long and that their commute will generally be negative, and may not be that affected by it anymore. Waiting time was not found to influence adaptation.

While adaptation reduces negative effects on well-being, it may also be a bad thing from the societal perspective. The government and the MRT-3 operator make take advantage of people's resilience and positive outlook and do not bother to improve the situation because "They'll get used to it," that is, there is an expectation that adaptation would set in anyway. If people are accustomed to it, accept it and resign themselves that things are simply like it is, and are even satisfied with this kind of situation, there would be no clamor for better services.

6.3.2.6. Comparison with Buses

It was put forward in the introduction that passengers use the MRT-3 in spite of the poor conditions because they do not have any other feasible alternatives. The findings of this research support this claim. While MRT-3 is in a poor condition in terms of travel time, pollution exposure and safety, buses along EDSA are in a worse state. Even though waiting time is long and variable at the MRT-3, the total travel time of MRT-3 is still lower than buses. Moreover, MRT-3 has lower $PM_{2.5}$ particle counts than ordinary buses and similar levels to air-conditioned buses even if waiting time is included.

In terms of safety, statistical evidence presented in the introduction shows that road-based modes have a higher probability of being involved in accidents. Risk perception of MRT-3 passengers is also consistent with this – there was a high level of agreement to the statement that MRT-3 is safer than other modes.

Moreover, in terms of perceived benefits, there was an even higher level of agreement that the MRT-3 is faster and cheaper than other modes. Road-based modes are generally priced higher than MRT-3 especially for longer trips, which adds to the attractiveness of MRT-3.

There are merits to using a bus, such as lower passenger density and more seats, so it may provide higher comfort. It is also more convenient and accessible because it also has stops in between MRT-3 stations and beyond the MRT-3 line, which would give incentive to people who intend to board or alight a considerable distance from MRT-3 stations or do not want to transfer. It may also be cheaper and faster for short trips if waiting time and its lower base fare are considered. However, MRT-3 passengers generally travel medium to long distances and value travel time, money and safety more so this could explain why they continue using the MRT-3. Thus, modal shift from MRT-3 to buses is not favorable at their current state.

Another way to look for a solution to the problem is to consider the bigger picture. As previously discussed, lack of choice is a driving force that increases passenger demand beyond the design capacity. Feasible and more attractive alternatives should be added to commuters' choice set to address this problem. This could be done by improving the conditions of other modes or introducing an alternative mode (e.g. BRT) to encourage modal shift from MRT-3, which could in turn improve the level of service at the MRT-3.

However, it should be noted that at the current state, increasing MRT-3 capacity to serve the existing demand rather than to reduce demand to balance with existing capacity is more favorable. Displaced passengers may have to completely abandon their trips altogether or to move to another mode (e.g. buses), which could lead to well-being loss.

6.4. Chapter Summary

This chapter develops a new evaluation framework for assessing the impact of countermeasures by considering the actual and perceived conditions and passenger satisfaction. It also conducts an overall discussion on equity and passenger-well-being.

First, the results from the previous chapters are used to identify prospective countermeasures while considering level of service, air quality and passenger perception. One of the critical problems identified in the previous chapters is passenger waiting time, so some countermeasures that would reduce it were focused on. These were capacity expansion, fare increase and proportional crowd control policy. In order to estimate the changes that these countermeasures would have on passenger waiting time, it was deemed necessary to create a waiting time simulation model. This model estimated the probability distributions of input variables using these primary and secondary data, and captured the effect of variability through Monte-Carlo simulation. It was found that capacity expansion by increasing the number of cars from three to four under a headway of 3.5 minutes while maintaining a passenger density of 8 passengers/sq.m. would drastically reduce passenger waiting time especially for the first three stations. This is also applicable to a 10% increase in demand. However, increasing the headway beyond 4 minutes would introduce significant delays especially in the middle stations. Fare increase and proportional crowd control policy, on the other hand, only improves the base case slightly.

With the exception of capacity expansion, the countermeasures that tried to improve the situation through ‘soft’ policies such as fare increase, only improved passenger satisfaction by a small percentage. Capacity expansion, on the other hand, has a significant impact on it, even if headway changes and slight ridership increase are considered. Combining all the countermeasures would increase neutral and positive ratings from around 40% to 80%. This highlights the importance of investing in hard infrastructure to increase the capacity as well as considering perceived conditions to improve passenger satisfaction.

Moreover, a passenger overload delay equity index was developed as an indicator of passenger waiting time.

7. Summary and Conclusions

This research endeavor has investigated the well-being of MRT-3 passengers by considering actual and perceived conditions. Its overall objectives of establishing the conditions at MRT-3 based on level of service, air quality and passenger perception, and of identifying and evaluating appropriate countermeasures were achieved through a variety of data collection methods, modeling and analyses.

7.1. Summary of Major Findings

The major findings of this comprehensive study are presented below.

1) Passenger Waiting Time, Headway and Operations Policies

The severity of passenger waiting time has changed during the course of research from 2012 to 2015.

When this PhD research was started in 2012, the main contention was that passengers at the middle stations spend a long and variable time waiting on the MRT-3 platform as a result of high passenger demand and inadequate capacity, leading to intra-modal and spatial inequity. This point was confirmed by a video observation survey in mid-2013. However, the situation changed in 2014 as the MRT-3 operator introduced a new crowd control policy in late 2013 wherein passenger entries are limited to a certain number. This has caused passengers at other stations to wait for a long and variable time as well, with most of it at the roadside rather than on the platform, as confirmed in an observation survey in late 2014. This prompted the division of waiting time into two components: station access time at the roadside, and platform waiting time.

Moreover, it was found that the operator's schedule adherence worsened in 2014, as the headway was found to be larger and more variable than in the previous year due to maintenance issues and lower running speed. All in all, this phenomenon is caused by a combination of passenger demand, irregular headway and operation policies in place.

2) Travel time using MRT-3 and its main competitors (ordinary bus and air-conditioned bus), which is equivalent to exposure time to $PM_{2.5}$ while commuting

A travel time survey conducted simultaneously with the $PM_{2.5}$ monitoring survey revealed that in spite of the long and variable waiting time at the MRT-3, its overall travel time for the same distance was lower than both ordinary bus and air-conditioned bus. While waiting time is minimal for both ordinary and air-conditioned buses due to their high frequency, a comparison of in-vehicle travel times reveal that both types of buses have long and variable in-vehicle travel times due to the road congestion and long stops along EDSA. In contrast, MRT-3 has a steady in-vehicle travel time due to its generally stable running speed (being fully segregated from road traffic) and short dwell times due to the lower vehicle capacity.

3) $PM_{2.5}$ exposure while waiting (intra-modal comparison) and while riding (intermodal comparison)

$PM_{2.5}$ particle count was measured at selected MRT-3 stations and inside the MRT-3, ordinary bus and air-conditioned bus to conduct intra-modal and intermodal comparisons.

For the intra-modal comparison between MRT-3 stations, it was found that the roadside, ticketing area and platform of most stations have statistically similar average $PM_{2.5}$ particle counts, with one station having statistically higher counts. Moreover, exposure is different according to waiting time at the boarding station, with passengers at the northern stations waiting longer and thus getting more exposed to $PM_{2.5}$ pollution. In this vein, lower waiting times would also lead to lower $PM_{2.5}$ exposure. Converting the particle counts to mass concentration and comparing to international standards on $PM_{2.5}$ pollution reveals that most values fall under the category of 'unhealthy'.

For the intermodal comparison between MRT-3, ordinary bus and air-conditioned bus, it was found that ordinary buses have the highest levels of $PM_{2.5}$ particle count ('unhealthy' to 'very unhealthy'), followed by air-conditioned buses ('unhealthy'), then by the MRT-3 ('moderate' to 'unhealthy'). The same rankings are obtained when in-vehicle time (exposure time) is considered. The $PM_{2.5}$ exposure of ordinary bus passengers is the highest among the three modes, given that it has the highest $PM_{2.5}$ levels as well as the longest travel time. Surprisingly, the level of $PM_{2.5}$ exposure inside an air-conditioned bus as compared to inside the MRT-3 is more severe, which could be attributed to poor ventilation and filtering inside the air-conditioned bus.

However, when waiting time is also considered, $PM_{2.5}$ exposure at the MRT-3 increases because there are higher levels of $PM_{2.5}$ particle count at the roadside, ticketing area and platform than inside the train and the exposure time is long. In this case, the exposure level at the MRT-3 is similar to that of an air-conditioned bus.

4) Variability and Predictability of Commute

Majority of passengers perceive their travel times and waiting times to vary by more than 20 minutes. However, several passengers also perceive their commute to be predictable even if they are long and variable, which indicates that they have learned the system (probably through experience and outside information) and have less rigid expectations.

Passengers generally associate unpredictability of their commute with negative constructs such as commuting stress, and predictability was found to promote adaptation. It seems that passengers are unaffected by waiting time variability as it was found to have an insignificant effect on passenger satisfaction.

5) Adaptation

Respondents were found to have exhausted their options to change their behavior physically (e.g. change in departure time) to improve their commute, so mental adaptation sets in as a response to adverse conditions during the commute and with the absence of other behavioral adaptation strategies. It moderates the relationship between level of service attributes and outcome variables (i.e. commuting stress and satisfaction).

SEM analysis revealed that mental adaptation moderates the relationship between service quality attributes and commuting stress, meaning that more adapted passengers perceive lower commuting stress despite of their negative valuation of their commute.

6) Passenger satisfaction is predicted by actual and perceived variables and controlled by adaptation

Estimation of a passenger satisfaction model using ordered logit regression analysis showed actual conditions (fare, waiting time, in-vehicle travel time) and perceived conditions (risk and air quality) predict passenger satisfaction with MRT-3, and this is controlled by mental adaptation. Surprisingly, variability of waiting time was not a significant factor, probably because passengers do not mind if their (see discussion above on predictability). While it is common for passenger satisfaction models to include the predictor variables on actual conditions, the statistical significance of variables on perceived conditions would constitute as new and unconventional. Moreover, mental adaptation acts as a control to passenger satisfaction as more adapted people tend to give higher satisfaction ratings even if they have a negative commute.

In addition, different income groups value the predictor variables differently, with low income people affected more by fare levels but less by travel time components. Waiting time is also seen to be valued more than in-vehicle travel time, which is consistent with other studies but is generally valued more (four times the in-vehicle time compared to 1.5-3 times the in-vehicle time in literature), and gives much incentive for the operator to reduce it.

7) Evaluation of Countermeasures

The passenger satisfaction function was used to estimate the portion of passengers who feel ‘strongly dissatisfied,’ ‘dissatisfied,’ ‘neutral,’ and ‘satisfied’ with the service provided by MRT-3. Using the ordered logit model discussed above and the corresponding proportional odds, the predicted probabilities for each satisfaction level were obtained and combined subject to a threshold of 55% to form the aggregated passenger satisfaction index.

Countermeasures that affect actual conditions were identified as capacity expansion, proportional crowd control policy, fare increase and reduction of in-vehicle feeder time. The first three affect passenger waiting time, and their effects on it were estimated using the waiting time simulation model that considers the dynamic aspect of waiting time and the stochasticity of passenger arrivals. Among these, the government’s proposed capacity expansion (i.e. increasing vehicle capacity by 25% under crush capacity and perfectly regular headways of 3.5 minutes) was shown to reduce *average* waiting time to equal headway for any passenger arrival time interval within the morning peak period. However, capacity expansion that have a headway higher than 4.5 minutes would cause passenger overload delay especially from the third station. Regardless of the scenario, capacity expansion would have a significant increase in neutral and positive satisfaction ratings.

Moreover, proportional crowd control policy and fare increase only reduce passenger waiting time by a small fraction, implying that improvement in hard infrastructure is critical in improving waiting time.

Countermeasures that change perceived variables are tested through a sensitivity analysis of increasing or reducing the rating by one point (out of 7). It was found that a one-point reduction in risk perception is almost equivalent to a one-point increase in air quality perception.

Combining the results of all the countermeasures show that the number of neutral or positive commuters would roughly double, with medium/high income respondents being more positively affected because they have higher values of travel time components and perceived conditions in general, and also due to low income people being more dissatisfied by fare increase.

8) Equity

Equity of passenger overload delay, which is the difference between actual passenger waiting time and undelayed waiting time, was discussed by creating an equity index inspired by poverty indices. It was found that skip train operations improves equity of passenger overload delay but increases the total delay across the system, indicating a tradeoff between equity and efficiency. Environmental equity was also discussed as an extension of

9) Passenger Well-being

Having constrained the definition of well-being to actual and perceived commuting impacts only, passengers were generally found to have low well-being as a result of their MRT-3 commute. It was found that many passengers suffer long and variable waiting time, frequent tardiness at work, but have various levels of commuting stress and passenger satisfaction depending on their adaptation level. Countermeasures that focus on reducing waiting time and improving perception can increase satisfaction and thus, enhance well-being.

7.2. Contributions and Recommendations

The execution of this comprehensive research on MRT-3 could not have been timelier. Media coverage and socio-political interest on the deteriorating level of service of MRT-3 and the resulting plight of the commuters have been increasing in the past several years. With the steady population growth and increase in mobility needs, the problems would only become worse if nothing is done to address them.

The findings of this research may be useful for the Philippine government and the MRT-3 operator to identify and implement appropriate policies and countermeasures that would improve the status quo. At the same time, it could help broaden their perspective on providing urban rail services to Metro Manila commuters, and not only focus on conventional indicators such as affordability. The 'lack of financial resources' argument is usually put forward when the issue of improving MRT-3 by investing in additional infrastructure arises; however, the negative effects of the poor conditions at the MRT-3 (e.g. prolonged waiting time, pollution exposure and commuting stress) would also equate to lower social welfare and productivity and monetary loss due to opportunity costs and additional health costs. As such, these negative impacts should be taken into consideration to justify the huge financial investment needed to improve the MRT-3.

Moreover, improving the MRT-3 should not only be done in a one-dimensional manner – this should also be done concurrently with the improvement of the whole urban transport system. For instance, improving the service quality and pollution exposure of other modes such as ordinary and air-conditioned buses could introduce new alternatives to MRT-3 passengers who feel that they have no choice but to use it due to its relative attractiveness.

The findings of this research is also useful for researchers and industry experts who wish to conduct additional research on topics including but not limited to MRT-3 and other urban rail lines in Metro Manila, transport policy, land use and urban planning, social equity and air quality.

Furthermore, the evaluation framework used here may also be applicable to other overly congested urban rail systems especially those in developing megacities as long as it is contextualized to the circumstances. Excessive queuing on the roadside and platform while being exposed to pollution is a problem that is not normally addressed in research and planning. Nonetheless, this may also occur to transit stations without sufficient capacity to contain its passenger demand or transit stops along the roadside.

7.3. Limitations of this Research

This research has several limitations and shortcomings. First, it largely focused on the conditions at the MRT-3 during the morning peak period on regular weekdays, but realistically, other time periods such as the afternoon and evening peak could bring additional insight to this research. The questionnaire survey was also conducted mostly online, thus targeting younger respondents who are more adept in using technology. Moreover, the observation surveys were done in a short period only and not continuously due to logistical concerns such as budget, manpower and permit acquisition.

Commuting stress in this research also relied on self-reported measures, but Novaco and Gonzalez (2008) note that stress has cognitive, affective, and behavioral disposition dimensions, as well as task performance, physiological reactivity, psychological adjustment, and personal health components, so multiple instruments should be utilized. This would entail measurement of physiological reactions to commuting, such as salivary cortisol (e.g. Evans and Wener, 1998) and blood pressure. Thus, commuting stress in this study is used in a narrower sense than the ideal one.

Countermeasures are limited to those that change waiting time because the limited resources and timeframe allowed only a waiting time simulation model to be made, which was a challenging endeavor in itself. Changing other factors (e.g. in-vehicle time, perception) would have entailed the creation of detailed models and that require additional data and resources that could not be realistically covered within the research period. To account for this, a sensitivity analysis on those factors was conducted instead.

Moreover, the waiting time simulation model considered both demand and train frequency to be exogenous in the model. It should be clarified that the creation of a passenger demand model is beyond the scope of this research; passenger demand was treated exogenously and taken as a given from historical data rather than estimated, and the extent to which factors affect demand are not tackled. Such model would entail taking into consideration the larger picture including Metro Manila's existing transport network, O-D demand, land-use patterns and demographics. Thus the results of the countermeasure evaluation did not consider the forecasted effect of a change in level-of-service attributes on the demand, which would in turn change the level of service received. Moreover, headway was treated as a given instead of modeling the vehicle fleet, turn-around period and other operational characteristics because this would require detailed information on the MRT-3 system characteristics.

While this study measured $PM_{2.5}$ particle counts and exposure time, addressing the causes of high pollution levels is not part of the research scope. Particulate matter pollution is a regional problem that has a variety of causes that cannot be adequately addressed on a small-scale and requires a wide, concerted effort. As a result, no $PM_{2.5}$ exposure model was created, which would have allowed testing of exposure-related countermeasures. Moreover, there are some limitations on the measurement method used – a single $PM_{2.5}$ particle counter was used to measure the relative concentration on different stations and modes over several days, but these values are used to conduct intra-modal and intermodal comparisons. Moreover, these morning peak period measurements are compared against US EPA guidelines, which are based on a 24-hour exposure.

In addition, it is important to note that the situation at the MRT-3 is dynamic throughout the research period, which is unavoidable in a real-world research study. Thus, the research framework and methodology had to be adaptive, and it was difficult to plan in the long run when there were many uncertainties. For instance, the fare increase was not considered in developing the surveys, but had to be accounted for somehow.

Lastly, the effect of MRT-3 commute on well-being could be conducted more comprehensively by including more aspects, such as health effects, work well-being, organizational behavior and overall well-being.

7.4. Future Work

Having mentioned the limitations of this research, it is important to look forward and identify some aspects and issues that can be considered to expand and improve this study in the future.

For the data collection, the number of data points for the observation survey and $PM_{2.5}$ monitoring survey, and the number of respondents for the questionnaire survey could be increased to allow a more robust analysis. Longitudinal data instead of cross-sectional data would also be more suitable for adaptation analysis. While cross-sectional data has been used in other adaptation studies as well, longitudinal data would allow a temporal comparison of adaptation levels to track how it changes over time and other variables. To extend this further, it may be interesting to establish a pre-event baseline (i.e. before commuting using the MRT-3, for example, for newcomers to a crowded city and how they become adapted to commuting in such conditions. This type of data would also allow a more thorough assessment of proposed countermeasures and their impacts on actual and perceived conditions. This includes modeling the train operations from the supply side as well instead of considering it as either perfectly reliable or stochastic.

The effect of actual fare increase as well as the upcoming capacity expansion on both actual and perceived conditions may also be pursued to improve waiting time simulation and refine the parameter estimates of the passenger satisfaction model. This could be done by conducting additional observation surveys and comparing them with baseline ones.

The $PM_{2.5}$ particle count measurement results should be supplemented by a mass concentration measurement survey and chemical composition analysis to better relate it to air quality thresholds set by WHO and the government. It would also be beneficial to conduct the intra-modal and intermodal comparison measurements simultaneously to truly be comparable. Moreover, the creation of a $PM_{2.5}$ exposure index that is related to potential health effects of $PM_{2.5}$ could be considered. Additional measurements using filtering method should be made to estimate a more appropriate conversion factor to transform $PM_{2.5}$ particle count to mass concentration. It may also be useful to simultaneously measure the background levels of $PM_{2.5}$ in Metro Manila to gain additional insight on how severe the problem is.

The creation of a demand model that considers the bigger picture including Metro Manila's existing transport network, O-D demand, land-use patterns and demographics, as well as the interactions between supply and demand could be very useful in evaluating countermeasures more accurately.

Commuting stress could also be measured by physiological tests rather than just using a self-reporting scale. The effect of commuting on overall well-being (not just commuting stress and passenger satisfaction) could be considered in the future. Moreover, the well-being of commuters using other modes could also be studied and an intermodal comparison between different modes could be made.

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