LINKING STATION AREA NODE- AND PLACE FUNCTIONS TO TRAFFIC FLOW

A case study of the Tokyu Den-En Toshi line in Tokyo, Japan

Master's Thesis report

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ABSTRACT

The land-use and transport feedback cycle states that activities and accessibility are coinciding in a way that they supplement each other's existence. Actively shaping the urban environment requires a tool for promoting smart growth, guiding economic development and shifting market demands and lifestyle preferences. Transit Oriented Development (TOD) is a strategy that accommodates increasing urban population with reduced impacts on the transport network and the environment. Although, the effects of these TOD's on traffic flows on the railway networks is less well documented. This research focusses on determining the effects of land-use and infrastructure developments in station areas on the traffic flow of the railway network. These effects are studied based on the case of the Tokyu Den-En Toshi line, an urban railway line in Tokyo, Japan. To better understand the dynamics between accessibility and activities in station areas the Node-Place (N-P) model was used. The effects of changing station area node and place functions on station use were determined based on a linear regression model. The distribution of link loads on the Den-En Toshi line resulting from the predicted station use was modelled using a growth factor method. Additionally, insights in the history of the Den-En Toshi line and practical experiences were gathered based on expert interview with Tokyu Corporation employees.

PREFACE

This is the final report of my Master's thesis research with the Transportation and Urban Engineering Research Group at Yokohama National University in Yokohama, Japan. When I was introduced to the Tokyu Den-En Toshi line in Tokyo Japan I was amazed by the radically different view that the Tokyu Corporation has on rail transport and land development; the railway business is not about "connecting points" but rather about the real estate opportunities that develop along a railway corridor (Cervero, 1998). The fact that the Tokyu Corporation not only paired land development and transit investments, but also applied this to an entire corridor is very ingenious. From that moment on I was motivated to find out how this was possible and how great their success actually was. The topic I therefore chose for my Master's thesis research is: Linking station area node- and place functions to traffic flow, a case study of the Den-En Toshi line in Tokyo, Japan. This report describes the research carried out during my stay in Yokohama and during the finalization at the University of Twente in Enschede.

When I initiated my graduation, I had only a single condition for my graduation project. That was for me to live in Tokyo. I would like to thank Karst for allowing me to choose this path and supporting me in this endeavour. Without the kind welcome and support from Nakamura-sensei this would not have been possible. For this I am very grateful. Furthermore I would like to thank Ties for guiding me through the day to day issues. I would also like to thank Paul Chorus, was kind enough to introduce me to the subject, Dr. Ota and Mr. Seki, who gave invaluable insights in the practices of Tokyu Corporation, and Inga, who assisted me in statistics and English grammar.

This experience would not have been half the fun without the presence of my Japanese friends, Yasu, Yurie, Naoyuki, Yeoung-Soo, and Vu. Thank you for letting me tag along and showing me everything Japan has to offer.

Above all, with the full support I received from my parents I was able to enjoy my time in Tokyo and create memories that will be with me for life.

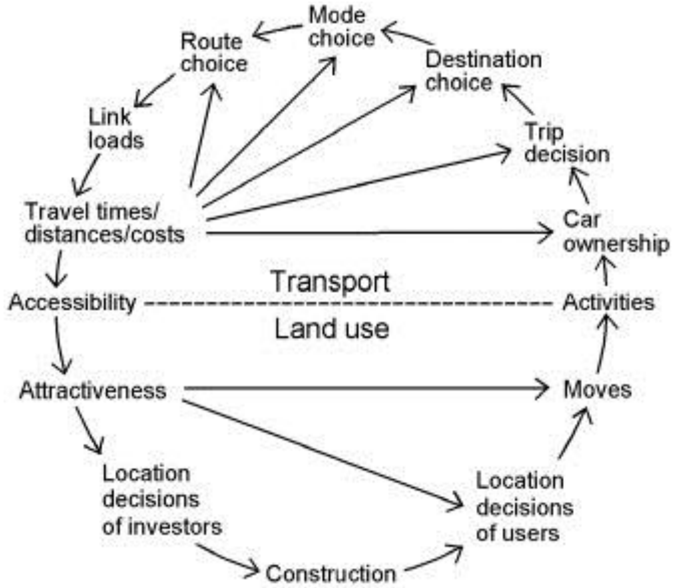
みんなでほんとうにありがとうございます！

SUMMARY

The goal of this research is to develop a tool to determine the effects of land-use and infrastructure developments in station areas on the traffic flow of a railway corridor. These effects are studied based on the case of the Tokyu Den-En Toshi line, an urban railway line in Tokyo, Japan.

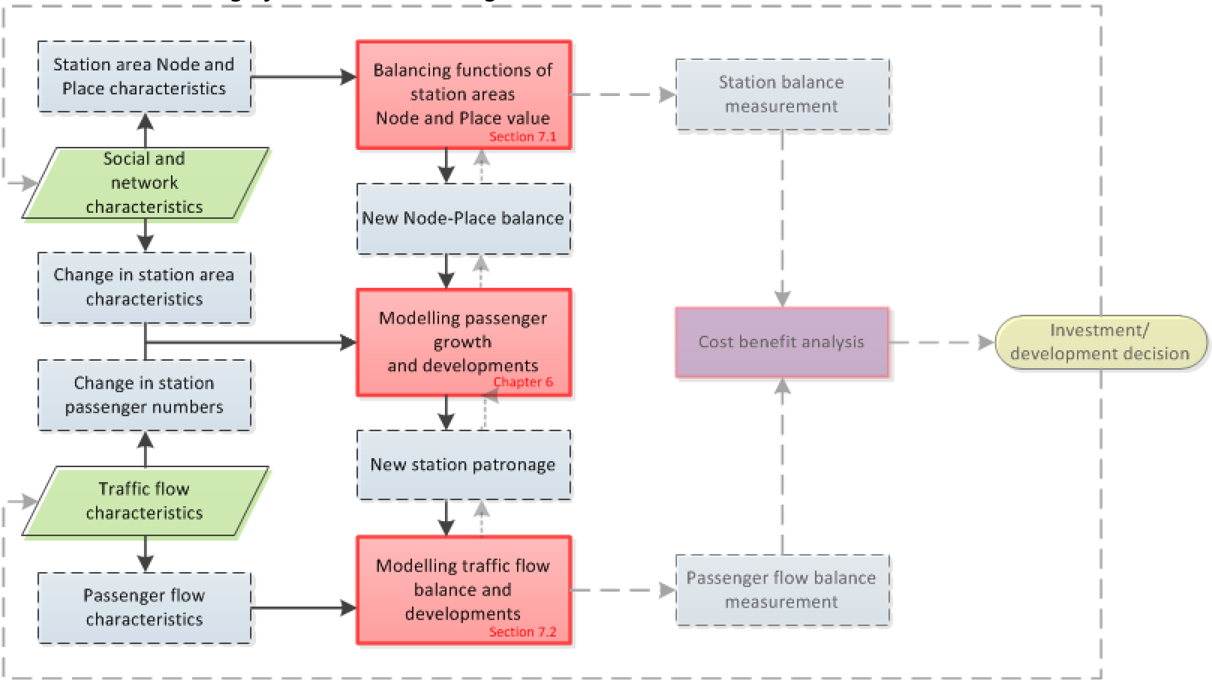
The theory of the land-use and transport feedback cycle states activities and accessibility are coinciding in a way that they supplement each other's existence. Actively shaping the urban environment requires a tool for promoting smart growth, guiding economic development and shifting market demands and lifestyle preferences as can be derived from the transport and land-use cycle. Transit Oriented Development (TOD) is a strategy to accommodate increasing urban population with reduced impacts on the transport network and the environment. TOD is defined as compact, mixed-use development near transit facilities with high-quality walking environments.

Land-use and transport feedback cycle



The research approach comprises of three modelling steps.
First, to identify the TOD development strategies in station areas the Node-Place (N-P) model was developed as an analytical framework to better understand the dynamics between accessibility and activities in station areas. Based on station area socio and network characteristics, TOD indicators were used to describe the station area node and place functions for the stations along the Den-En Toshi line.
Second, in order to link the effects of changes in node and place functions to station use, a linear regression model was developed. This regression model describes the change in station use as function of station area characteristics.
Third, the station users are distributed over the corridor in order to determine the resulting link loads. To obtain this distribution a growth factor method was used.
The link between balancing station area N-P functions and the resulting traffic flow had not been established and is valuable to transportation engineering. The resulting model approach linking station area N-P functions and traffic flow can be seen in the schematic of the research design.

Schematic rendering of the research design

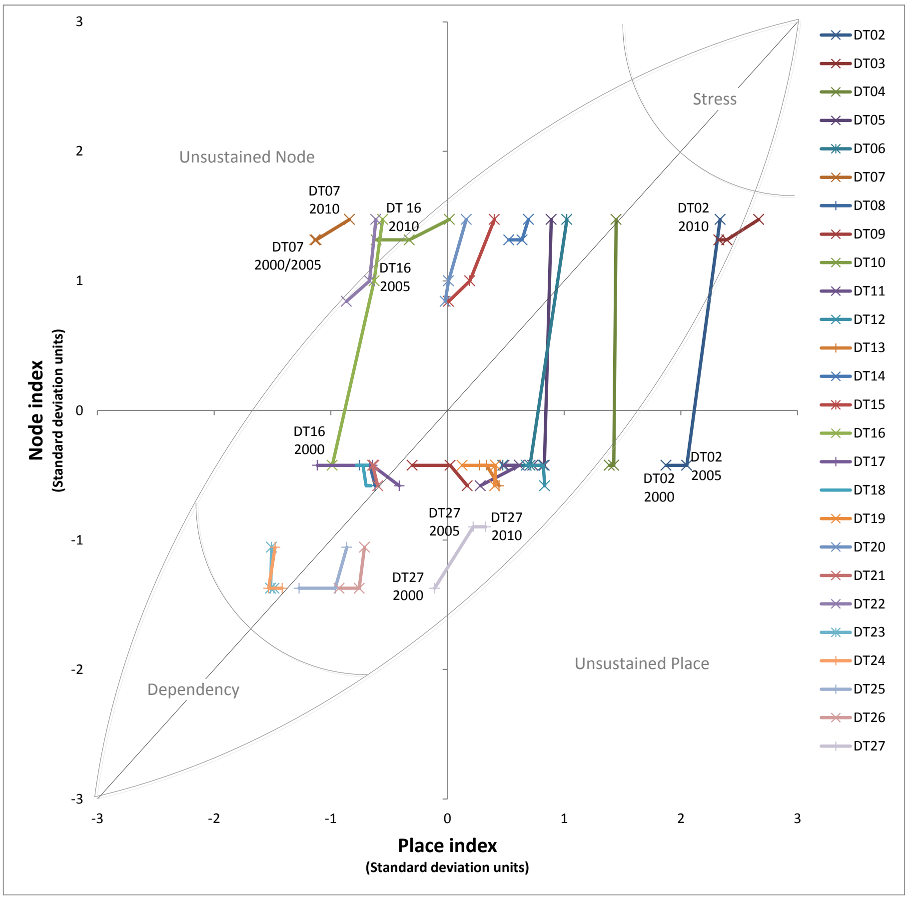


To complement the research additional insights in the history of the Den-En Toshi line and practical experiences were gathered based on expert interview with Tokyu Corporation employees. From these experiences it can be stated that in developing rail integrated communities timing was of the essence. It was the coinciding of the post war economic boom, with the continuing industrialization, the prevailing land scarcity in urban areas and the massive population migration from the countryside that paved the way for private railway companies such as Tokyu in the development of urban railways.

The research approach required the construction of a longitudinal dataset over a long study period greatly limited the available data sources. Remaining as reliable data sources were population census data to measure activities, time table data to measure accessibility and passenger data to measure station use. With the data obtained from these sources, the established TOD indicators were only partly covered. The established indicators were: Population, Workforce-clusters (three clusters), Multi-functionality, Station-type, Number of directions, Frequency, Travel time to centre and GDP.

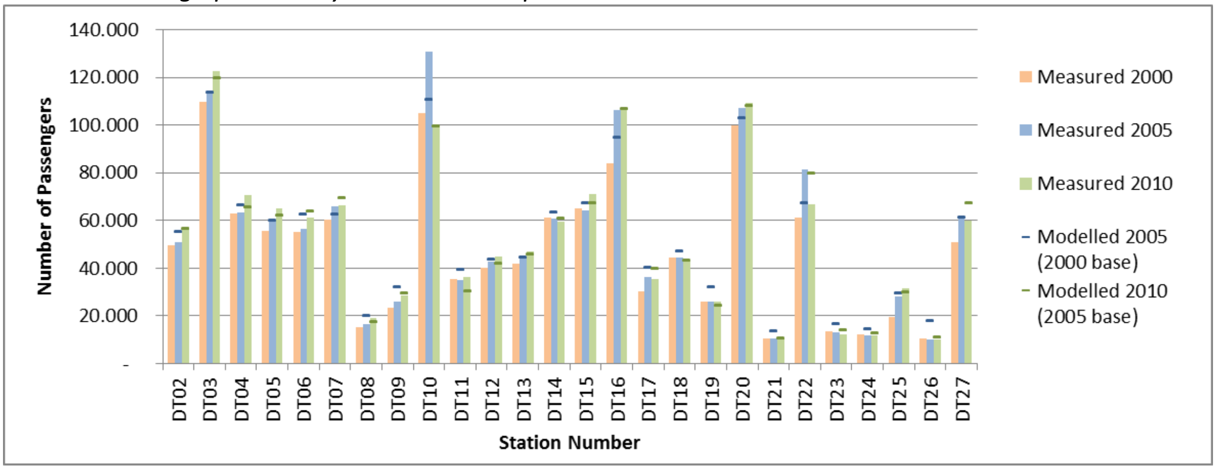
The implementation of the N-P model was based on the methodology as proposed by Chorus (2012). The most important indicator in shaping station areas were selected based on the regression analysis and implemented in the N-P model.
An N-P model based on Station Type in the node index and Workforce Cluster 1 in the place index did not provide desired result. Because the Station Type indicator is only categorical the node index can only take two values, resulting in an N-P diagram that is not insightful to identify possible development opportunities. Therefore, a second N-P model was established based on the Frequency and Population indicators. This model showed the desired distinction between station areas and was therefore adopted for this research.
Over the course of the study period, the stations along the Den-En Toshi line showed a fluctuation of the balance between station area node and place functions. This is shown in the following figure. According to theory of the land-use and transport feedback a balance is always found over time. It was concluded that the N-P model confirms that this also occurs in reality. It must however be noted, that environmental factors do play a large part in shaping station areas, making it impossible to accurately explain all of the fluctuations taking place.

Temporal trend in the N-P model



Three different approaches were established to link station area characteristics and station use.
First, using between subjects analysis, cross sections from the dataset were investigated. The best model fit with an R^2 of 0.687 was achieved by using the indicators Station Type and Workforce Cluster 1. This did not result in estimated values accurately enough to continue the use of this approach for the subsequent traffic flow forecasts.
Second, a within subject analysis was used to investigate time series per subject. In general, modelling time-series for each station using the same indicators as during the between subject analysis achieved better modelling results. Between the individual stations, there was variation in the accuracy of the time-series models. For future research it is recommended to perform a regression analysis with multi-level modelling techniques on the full panel dataset.
Third, an analysis investigating parameter change was discussed, where the change in the original parameter values between successive years was used. The main disadvantage of this approach is that the year to year change is much more susceptible to fluctuations in external influences. This showed in the modelling result for the year to year model estimation where an R^2 of only 0.272 was achieved. Therefore, a second model estimation was done based on the indicator change over a 5 year interval. This allowed the model focus to be placed more on the macro effects, resulting in an R^2 of 0.540. To predict station use for a future year, the change estimated based on the model was added to the value of the station use for the used base year. This approach has the advantage that when using these modelling results for making predictions on station use the modelling error only influences the modelled change, but does not affect the base value of the outcome variable. This resulted in a prediction 5 years ahead with an R^2 of 0.98, shown in the following figure. The obtained model was used to analyse the effect of station use on traffic flow.

Modelled change plus base year values compared to measured values



The effect of changes in station use on the traffic flow was determined by distributing the station users over the Den-En Toshi line. In general, there are two methods commonly used for trip distribution modelling: Growth factor methods and synthetic models (such as the gravity model). Limitations in the available data necessary for estimating a cost deterrence function and the large number of trips to external zones make the application of a gravity model suboptimal. Therefore, the growth factor method was selected. This method has one major drawback, which is the inability to cope with changes in the network. When applying this method in the full analysis this was taken into account by limiting the investigation to the effects of changes in activities.

The availability of trip end totals with the addition of information on direction of travel resulted in a very accurate estimation of the base matrix of the distribution, resulting in less than 0,4% error on the link loads obtained.

Studying the development of traffic flow balance on the Den-En Toshi line through the distribution of the link loads over the corridor led to the conclusion that it has become continuously more unbalanced since its completion in 1984. In general, no measure seems to have been taken to stabilise traffic flow and divide it better to suit the infrastructures capacity. It seems as if the focus was rather on generating as much traffic as possible. Only recent developments such as the Ōimachi line extension aim for a more efficient use of the available infrastructure

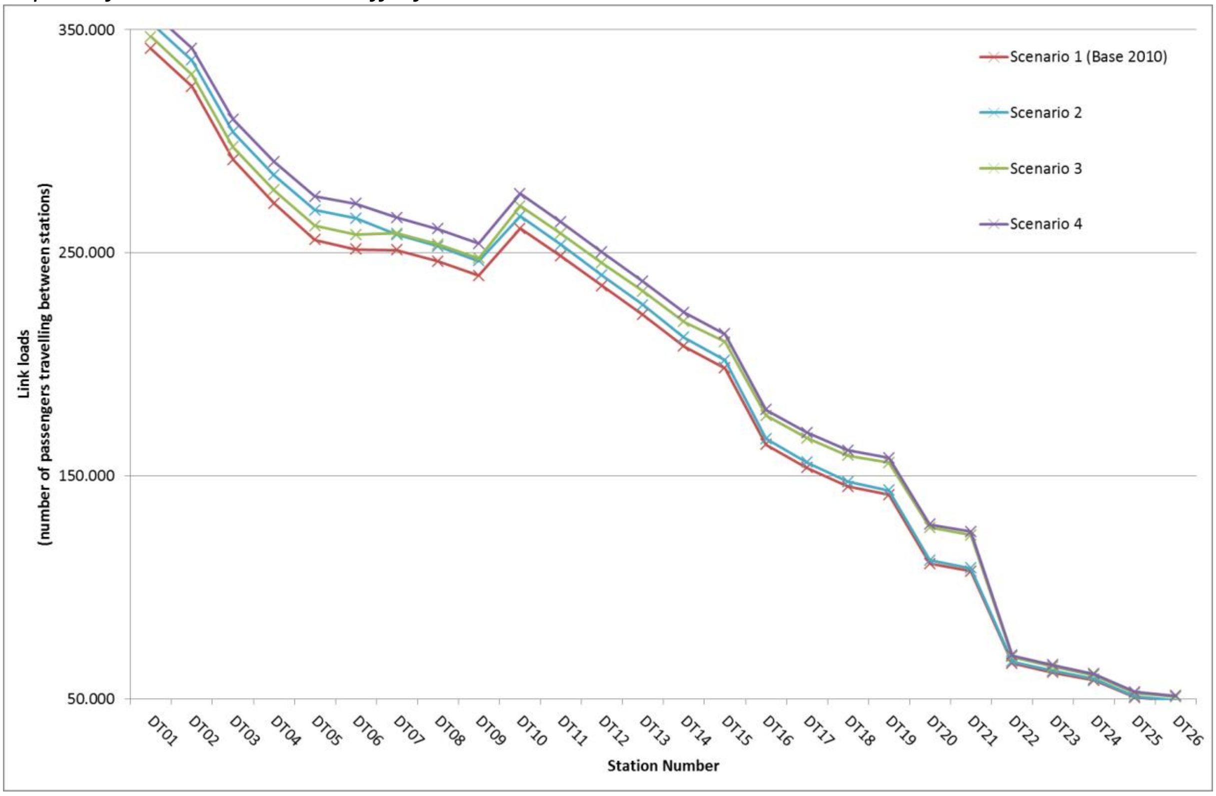
The full model linking station area dynamics and traffic flow was demonstrated using a case scenario. For the case scenario, the stations which showed the most unsustained balance in the N-P model were selected. These were Futako-Tamagawa (DT07) and Nagatsuta (DT22).The place index of these stations was increased in order to obtain a better N-P balance, resulting in a rise in population densities. The effect of the rising population densities on station use was predicted and the station users distributed over the Den-En Toshi line in four case scenarios: Scenario one; no change (Base year 2010), scenario two, balancing N-P functions for Futako-Tamagawa, scenario three, balancing N-P functions for Nagatsuta and case scenario 4, balancing N-p functions for both stations simultaneously.

In the following figure the four case scenarios can be observed. The second case scenario shows the effects of additional population density at Futako-Tamagawa (DT07) on traffic flow. Due to the large attraction of Shibuya (DT01) especially the link loads on the first section of the corridor increase. This of course results in an even more unbalanced traffic flow on the Den-En Toshi line.

In the third case scenario, when increasing the N-P balance of Nagatsuta (DT22), a station further away from central Tokyo, the effects on traffic flow show a different image. The largest increase in link loads took place on the section between Nagatsuta and Futako-Tamagawa (DT07). Although the link loads towards Shibuya (DT01) also increased, this still resulted in a slightly better traffic flow balance for the corridor overall.

The combination of improving the N-P balance for both Futako-Tamagawa and Nagatsuta resulted in an addition of both effects described earlier. This resulted in a slight overall decrease in traffic flow balance over the Den-En Toshi corridor.
Based on this analysis, it was concluded that improving the N-P balance for a single station might have a negative effect on traffic flow balance. Improving the N-P balance for a station further away from the major attraction centre did help improve traffic flow on the entire corridor.
Hypothetically, in order to stabilise traffic flow, an attraction centre similar to Shibuya (central Tokyo) should be created on the far end of the line. Another hypothetical possibility would be to decrease the attractiveness of central Tokyo.

Impact of case scenarios on traffic flow



CONTENTS

1 INTRODUCTION

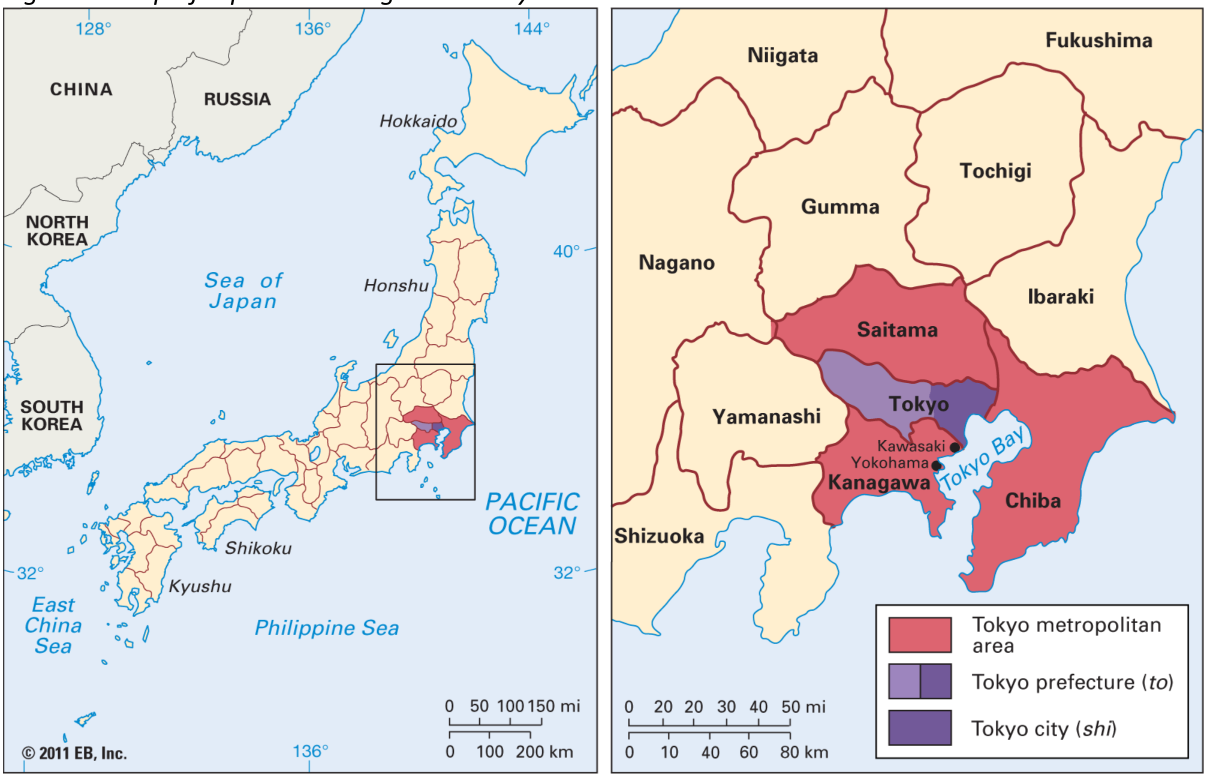
1.1 Railway development in Tokyo

Tokyo is a perfect example of how rail transport and new town development are successfully linked. It proposes an exceptional case because it was the private sector, driven by profit motives, which realized these rail-oriented satellite towns. Today the Tokyo Metropolitan Area has an extensive railway network, totalling more than 2500 km in length of which over half is privately owned and operated. As in other major world cities the period in which the railway network expanded the most was between 1915 and 1935, when almost 600 km of tracks was build. But after the Second World War Tokyo's railway network kept growing steadily due to the rapid industrialization in combination with the prevailing land scarcity in Japan. A strong urbanizing movement led to the development of new towns along railway corridors, where railway was the only means of reaching Tokyo's Central Business District. (Cervero, 1998)

1.1.1 The Greater Tokyo Area

There are several definitions of what areas encompass Tokyo. The centre of Tokyo is defined as the 23-ward area or Tokyo-shi, consisting of the 23 wards governing Tokyo, with 8.8 million residents in an area of 621 square kilometres. The prefecture of Tokyo or Tokyo-to is one of Japans 47 prefectures and is controlled by the Tokyo metropolitan Government (TMG). It covers an area of 2.187 square kilometres where approximately 13 million people reside. The Tokyo metropolitan area or Greater Tokyo Area (GTA) also includes the prefectures of Saitama, Chiba and Kanagawa (containing the city of Yokohama, Kawasaki and Chiba), spreading over an area of 13.557 square kilometres with over 36 million inhabitants, making the greater Tokyo area the largest metropolitan area in the world. (Chorus, 2012)

Figure 1: Map of Japan and the greater Tokyo area



Source: Encyclopaedia Britannica, 2011.

1.1.2 Railway network and ridership

In Japan 29% of all trips are made by public transport, a far higher share than in any other western country. In the GTA railway even accounts for 53% of all trips carrying almost 15 million passengers every day. To support these trips the GTA contains over 2500km of railway tracks, both privately publically or even jointly owned and operated. Over 30 different operators run on this network of interurban railways, subways, monorails and trams. East Japan Railway Company (JR East), who operates most of the interurban railways, carries almost half of all passengers in the GTA. The subway lines serving the central area are operated by Toei Metro, owned by the TMG, and the private Tokyo Metro, whose shares are owned by the TMG and national government. Another 8 major railway companies operate in different geographical regions of the GTA. The eastern region is operated by Keisei, north by Tobu, west by Seibu and Keiō, south-west by Tokyu and Odakyū and the southern region by Keikyū and Sōtetsu. (Chorus, 2012)

Figure 2: Railway operators in the Greater Tokyo Area

Source: http://commons.wikimedia.org , 2013

The geographical division of the railway operators is the result of a consolidation law that combined several smaller railway operators. It was applied in the late 1930s but was abolished several years later, leaving only several major operators divided by region. Private railway lines are prohibited by law from passing through central Tokyo, therefore all terminate at Yamanote loop that circles central

Tokyo. Only the publicly owned subways and the, until the 1980's publicly owned JR East lines operate within the Yamanote loop. Though, many railway operators cooperate by offering through services within the Yamanote loop, thus reducing the need for transfers but making the network more vulnerable to delays. Headways in central Tokyo average 2 minutes and on the suburban railways around 7 minutes during rush hour making the network highly occupied. Despite this the Tokyo railway system is extremely reliable and trains very punctual. It is also known as one of the safest railway systems in the world. During rush hour extreme crowding occurs where on some lines occupancy rate is exceeded by up to 220%. Despite off this excellent railway system commuters still spend 60 minutes on average for a one-way commute. (Cervero, 1998)

1.1.3 Government policies towards public transport

The world-class public transport system in Tokyo is the result of a combination of transportation and land-use policies. Because of the land constraints in Japan and the reliance on imported oil there are numerous policies and taxes for discouraging car usage in place. Taxes such as vehicle acquisition, annual registration and surcharge taxes, but also high fuel taxes and tolls on all highways. A remarkable policy is how the TMG has also implied a garaging requirement where registering a vehicle requires the owner to have an off-street parking space, as free public parking is not available. Infrastructure development policies have mainly concentrated on improving the railway network rather than the road network. Public transport encouraging policies are direct sponsoring of services, but also tax incentives. Commuters receive tax-free commuting allowances from their employers, whereas the commuters by car only receive 15% of the commuting allowance. The most important instruments in the government's aim to integrate public transport and urban development are tax incentives and financial support. With the introduction of a multipolar land arrangement law, growth is redirected from the CBD to satellite communities and dense developments around railway station areas are encouraged. (Cervero, 1998)

1.2 Private railway operators

In the GTA eight major privately owned railway companies operate (excluding JR East), most of which began in the early twentieth century. These companies all solely started out as railway companies and diversified their business over time, expanding to businesses like real estate development, retailing, bus operations and power generation. All of these businesses were entered in order to generate more traffic on their railways, by creating offices or apartments in station areas, offering shopping malls and entertainment and increasing station accessibility. The reason for this diversification were government policies regulating fares, keeping them low, requiring the railway companies to make profit elsewhere. Furthermore competition between railway companies is limited due to exclusive franchising for certain regions in the GTA, also including bus services, thus increasing profitability. (Cervero, 1998)

Though Tobu is the private company which owns the largest network, Tokyu Corporation is the most successful. *Table 1* shows the comparison between all major railway operators in the GTA based on the connection between railway network kilometres and passenger kilometres. The success of the Tokyu Corporation depended on their ability to integrate railway and real estate development. Today Tokyu carries over 1 billion passengers each year on a network of just over 100 directional kilometres (Tokyu, 2013).

Table 1: Characteristics of the major railway operators in Tokyo

	Rail network kilometres		Passenger kilometres	
	Km	**%**	**Million km**	**%**
JR East	1106,1	42,4	80,058	43,7
Tobu Railway	463,3	17,8	12,389	7
Tokyo Metro	195,1	7,5	18,518	14,6
Seibu Railway	176,6	6,8	8,753	4,7
Toei Metro	131,2	5	6,131	6,4
Odakyū Electric Railway	120,5	4,6	11,084	5,7
Tokyu Corporation	104,9	4	10,202	6,4
Keisei Electric Railway	102,4	3,9	3,583	2,5
Keihin Electric Express Railway (Keikyū)	87	3,3	6,223	3,7
Keio Electric Railway	84,7	3,3	7,471	3,9
Sagami Railway (Sotetsu)	35,9	1,4	2,586	1,4
Total	**2607,7**	**100**	**166,998**	**100**

Source: JR East, 2011

1.2.1 Economics

Though railway was originally the main business of the private railway companies it is not the most profitable. A financial rate of return averaging between 1.1 and 1.2 is not spectacular, but in comparison, other railway companies worldwide very seldom achieved profitability. The most profitable side business for private railway companies is real estate development, making up for over half of the profits of the Tokyu Corporation. Among Tokyo's private railway companies the ones who ventured into real estate businesses successfully also are the ones with the highest network usage. This gives the impression that the integration of railway- and real estate development is vital in establishing a profitable traffic flow.

Other profitable businesses of private railway companies are for example warehouse chains, such as Tokyu's own department stores. It is also common for most private railway companies to venture into bus services, but these have always incurred minor losses. The busses provide feeder services for the stations and land developments owned by the railway corporations, making these more profitable. Bus services are then subsidized with profits from other company ventures. Together all these ventures allow the railway companies to increase profit margins drastically, making them among the most successful businesses in Japan. (Cervero, 1998)

1.2.2 Property development

Integrating railway and new town development originated in Osaka in 1910 where the Hankyu Railway Company opened the Takarazuka line and after disappointing ridership started to develop housing around its stations to increase profitability. This approach was quickly adopted by other railway companies in Tokyo and the rest of Japan. Profited by the post war boom, Japanese railway companies started to pursue real estate development and exploiting value capture opportunities where land appreciation values skyrocketed near railway stations.

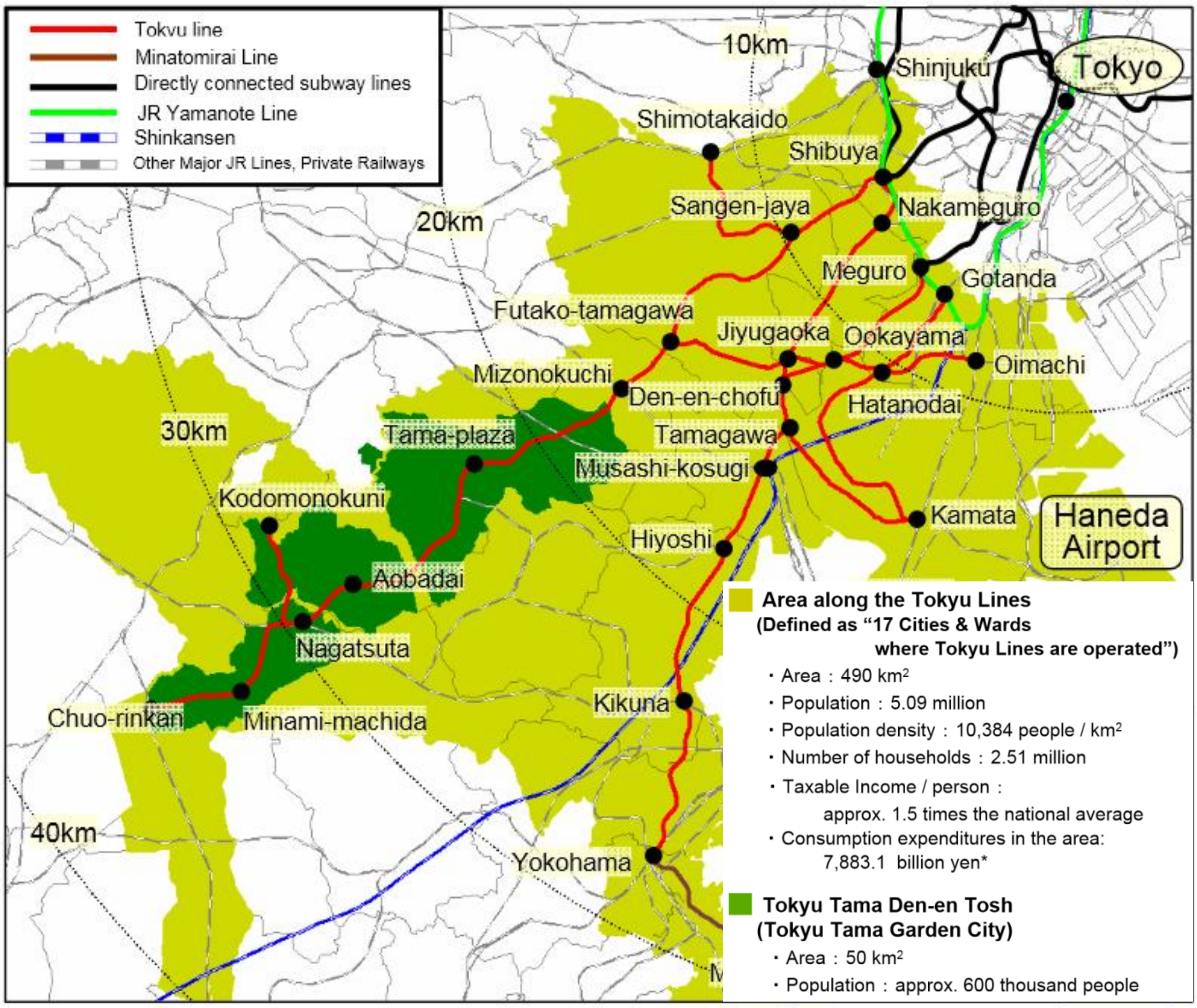
To purchase the land required for the development of a railway line and the adjacent real estate development the railway companies used an ingenious land consolidation strategy known as "land readjustment". In the land readjustment schemes, as performed by the Tokyu Corporation, landowners cooperate and combine their often irregularly shaped undeveloped land and in return get a slightly smaller but fully serviced plot in return. The plots are serviced with infrastructure such as roads, sewage, parks and other public facilities, which is paid for by selling some extra reserved land of the cooperative members. Thanks to these readjustment schemes railway companies are not required to make an enormous initial investment on acquiring land.

In the early 20th century the Tokyu Corporation also started to acquire vast patches of undeveloped land southwest of central Tokyo prior to the development of new railway lines. Their first major project was the development of Den-En-Chofu, a prestigious residential area on the Tokyu Toyoko line between Shibuya and Yokohama. Major office buildings in both Shibuya and Yokohama attract commuting passenger and several university campuses and retail and entertainment facilities along the line attract passengers outside rush hour. These land developments implemented by Tokyu has created a traffic flow that is bidirectional and generated traffic outside rush-hour periods.

1.2.3 Introducing the Tokyu Den-En-Toshi line

What is often viewed as one of the most successful land development projects a private railway company is the realisation of Tama Den-en Toshi. These are a series of new-towns located along a corridor to the southwest of Tokyo between the current stations of Tama –plaza and Machida, in 1950 one of the most undeveloped parts of the GTA. The initial master plan was conceived in 1956 and within 10 years the first rail sections were operational leading to the completion of the corridor in 1970s and 1980s. Today the Tokyu Den-En Toshi line has a length of 31.5 kilometres and a total of 27 stations, originating in the major hub of Shibuya via other major stations of Sangen-Jaya, Futako-Tamagawa, Mizonokuchi, Tama Plaza, Aobadai, Nagatsuta and terminating in Chūō-Rinkan.

Figure 3: Map of the Tokyu lines and Tama Den-En Toshi



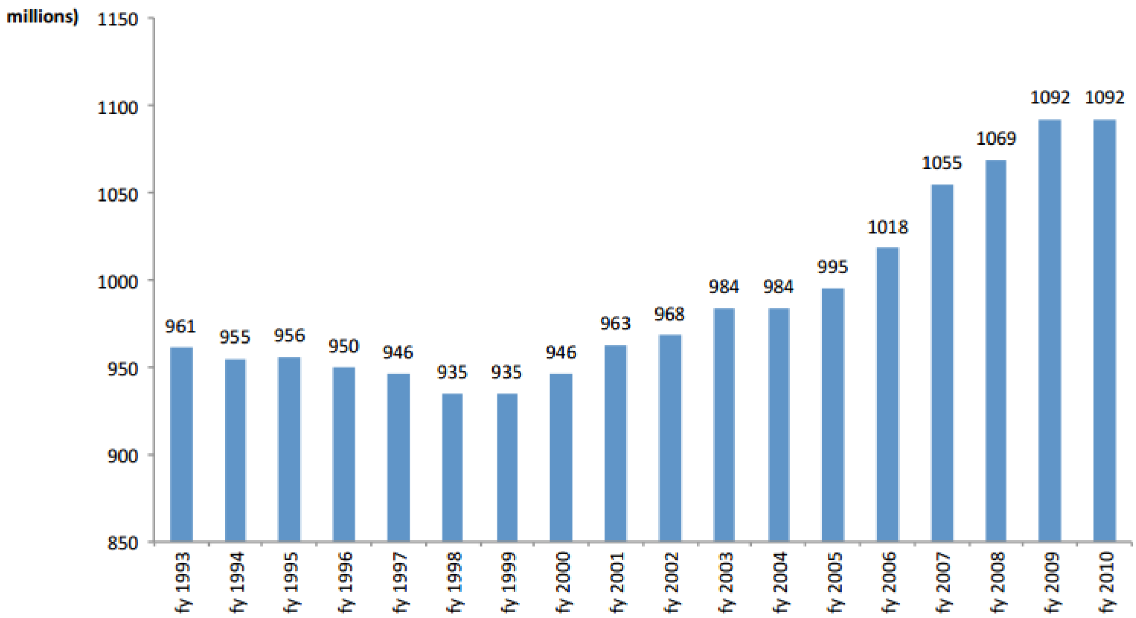
Source: Tokyu ,2013

1.3 Recent developments

The development of Tama Den-en Toshi and the station areas along Den-en Toshi line did not stop when the corridor was completed. The initial lack of employment opportunities in Tama Den-En Toshi and that of sufficient public facilities required the Tokyu Corporation to keep developing the bedroom community to a more transit oriented corridor. Constantly redevelopment of the existing urban space in and around station areas has led to a continuous growth of passengers on the Tokyu lines even over more recent years, as can be seen in *Figure 4*.

The declining trend during the nineties is the effect of the crisis Japan endured in the early nineties, showing that coherent development of land-use and infrastructure can only take place if there is growth or redevelopment to guide. The growth is the effect of several land developments such as newly constructed malls, housing and office towers along Tokyu's railway lines. Together with infrastructure improvements, for example line extensions and the implementation of mutual direct train services with other railway companies (Tokyu Corporation, 2013) facilitated this continuous growth.

Figure 4: Annual passenger numbers Tokyu Corporation 1989-2010



Source: Tokyu Corporation, 2011

2 THEORETICAL FRAMEWORK

To give some insight in how the Tokyu Den-En Toshi corridor was developed and what ideas are behind the success, a theoretical framework is discussed. In the theoretical framework a basis will be given for performing this research and fulfilling the research objective. The framework will consist of a theoretical understanding of the co-development of urban areas and railway infrastructure and the methods and strategies commonly used in current practice. Furthermore modelling traffic flow is shortly explained and a more in depth insight is given in the discussion between optimizing station area balance and traffic flow balance.

2.1 Co-development of urban areas and railway infrastructure

Levinson (2008) poses the question: Does development lead to the construction of new infrastructure to support it, or do extensions of the transport network enable and induce new development? For rail systems it is believed that density is the most important success factor as it generates more potential riders within a stations action radius. This does not imply that either dense land-use patterns generate rail investment or that the availability of railway infrastructure stimulates high density land developments in station areas but that it can be described as a process of co-development (King, 2011; Levinson, 2008). This concept of co-development can also be applied to Tokyo in general and the Den-En Toshi corridor in particular. Other major examples that describe historical co-development are London and New York public transport networks.

2.1.1 Historical examples

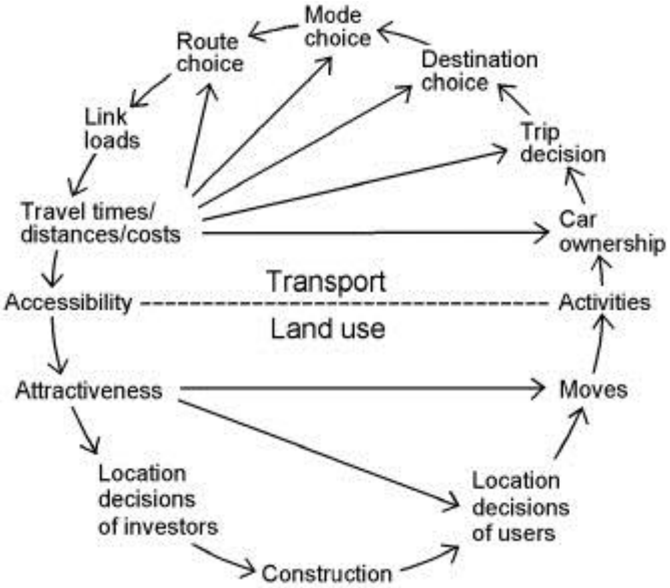
In 19th and early 20th century London the co-development of railway and land-use caused a decentralisation trend. The switch from slower modes to rail transport offered residents to have more space for the same price while residing within the same travel time radius to their workplaces. The reduced competition in the centre established the dominance of commercial activity in the core. In the periphery rail infrastructure attracts residential development which leads to more rail investments which again leads to more residential development in neighbouring areas (Levinson, 2008). Though developing rail outside existing urban areas poses a larger risk on investment it much cheaper due to the availability of undeveloped land and the use of the existing network in the centre. Value capture opportunities play an additional role as railway generates development potential.

The development of the New-York subway network in the early 20th century was fuelled by private railway companies competing over serving the rapidly growing population of Manhattan and its outer boroughs. Though a competitive factor was involved the network growth mostly took place in areas that were already being served by railway as opposed to undeveloped areas. This was mainly caused by the way railway was financed, where the infrastructure was publically financed and private railway operators had to make a profit on solely fare revenues (King, 2011). So a larger risk on investments led to developments in established areas rather than undeveloped areas.

2.1.2 Land-use and transport feedback cycle

Transportation infrastructure is designed and built to serve economic and social needs, and land development is dependent on economic and social opportunities provided by access to transportation (King, 2011). This is also illustrated by both the cases of the development of subway systems in London and New-York. The interaction between transportation infrastructure and land development is commonly expressed as a feedback cycle. On one side activities generate trips on a transport network and on the other side accessibility stimulates development. Any changes in either the transport network or land-use patterns will, following the cycle, generate a change in the other but with a delay. When modelling a transportation network or land-use patterns the limitations and magnitude of the delay or lag in the land-use and transport feedback cycle should be understood. (Wegener & Fürst, 2004)

Figure 5: Land-use and transport feedback cycle



Source: Wegener and Fürst (2004)

2.2 Transit oriented development

Travel demand in major cities has a large impact on the liveability, sustainability and economic performance of the region. Actively shaping the urban environment requires a tool for promoting smart growth, guiding economic development and shifting market demands and lifestyle preferences as can be derived from the transport and land-use cycle. Transit Oriented Development (TOD) is a strategy to accommodate increasing urban population with reduced impacts on the transport network and the environment. Cervero (2004) defines TOD as compact, mixed-use development near transit facilities with high-quality walking environments (not necessarily at the expense of automobile access). Providing a range of services within walking distance and regional accessibility by high quality public transport reduces the use of automobiles and the overall need to travel forming a lower impact on infrastructure and the urban environment.

Ewing and Cervero (2010) identified a broad set of factors in the built environment that influence travel behaviour and are characteristic for TODs. These factors are categorised as the 5 D's:

- **Density**; the number of residents and/or employees that are located within a unit of area, indicating the potential for trip origins and destinations.
- **Land-use diversity**; the degree of which different land uses are located within close proximity of each other, reducing the need to travel outside the area for common trip purposes.
- **Pedestrian oriented design**; a range of measures which describe how conductive an area is to walking, variously described by the quality of footpaths and road crossings, the connectivity of the road network , and the quality of the pedestrian environment.
- **Destination accessibility**; reflecting the proximity or ease of access to regional trip opportunities such as employment, which can be measured by distance or time.
- **Distance to transit**; how far an area is from the nearest public transport stop or station.

2.2.1 Modern applications of TOD

The concept of TOD has been applied in many major cities around the world showing the success of its application. In the Danish capital of Copenhagen planners were able to channel suburban development during the post-world war 2 boom along several railway corridors. Dense development of housing, retail and entertainment along the peripheral railway corridors was encouraged and low density developments outside railway catchment areas discouraged. Furthermore the CBD was expanded developing highly railway accessible office sites encouraging commuting from the peripheral corridors. These developments resulted in an economic growth that created many new jobs, while the pressure on the CBD was relieved and public transport use rose sharply (Knowles, 2012). As described in the introduction the development of the Tokyo railway network was one of the most successful applications of TOD (Calimente, 2009).

2.2.2 Effects of land-use and transport developments

Empirical studies of land-use and public transport interactions have mainly focussed on assessing impacts on urban features. These impacts are measured based on land-use, economic, social and environmental indicators (Pagliara & Papa, 2011). However, the impacts on the transportation system itself are less well documented.

2.3 Balancing station areas

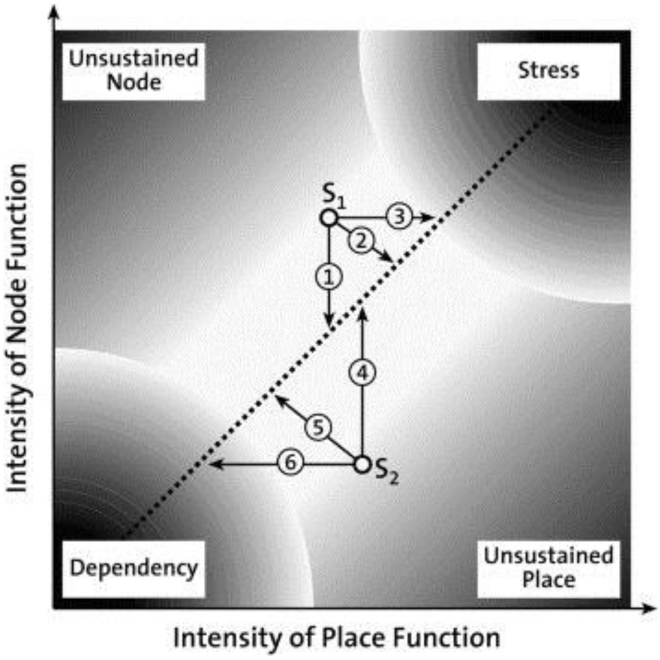
The evaluation of functionality of a railway station should not solely be based on mobility, but should also include nearby station surroundings (Reusser, Loukopoulos, Stauffacher, & Scholz, 2008). This belief is based on the observation that stations not only provide access to the railway system, but also hosts many services involving direct contact with customers. The TOD indicators, density, land-use diversity, distance to transit, pedestrian oriented design and destination accessibility should all be evaluated in such an evaluation framework.

2.3.1 The Node-Place model

Bertolini (1999) developed the Node-Place model as an analytical framework to better understand the dynamics of station area development and identifying potential development strategies for the Randstad region, the Netherlands. The Node-Place (N-P) model follows the theory of the "land-use and transport feedback cycle". Improving accessibility of a location will create conditions that stimulate the development of land-use at that location. And in its turn the diversification and intensification of the land-use in an area will subsequently create conditions that stimulate the development of the infrastructure. This process continues until equilibrium is reached or until external factors intervene in the process.

The Node index in the N-P model represents the station area and network accessibility. Accessibility refers to the number of opportunities available within a certain distance or travel time, whereas mobility refers to the ability to move between different activity-sites (Hanson & Giuliano, 2004). The Place index represents de density and diversity of activities within the station area.

Figure 6: The Node-Place model



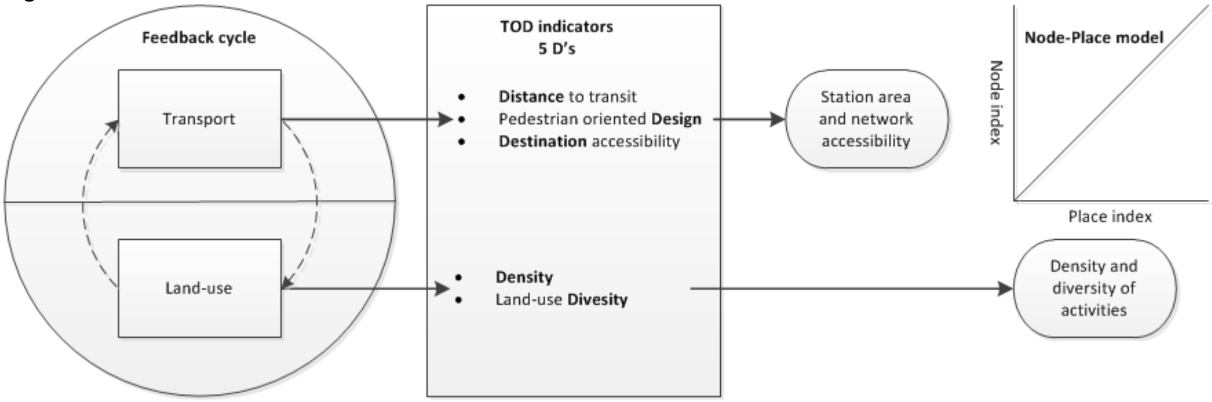
Source: Reusser et al. (2008)

Following from the land-use and transport cycle it is assumed that a balance exists between node and place functions. This balance is represented by the diagonal shown in *Figure 6*. This allows distinguishing between five regions of which balanced stations can be found in the centre region along the diagonal. Near the origin are stations that cannot sustain themselves requiring governmental support or are dependent on other stations in the network. Furthest away from the origin are stations that are under stress due to competition between its node- and place values over the available space. Unbalanced nodes are stations with high node values offering high travel potential but having underdeveloped place functions and unbalanced places have a highly developed place function but underdeveloped corresponding node value. The proposed balance between node- and place functions provides a criterion for assessing the sustainability of land-use and infrastructure developments. (Reusser et al., 2008)

2.3.2 Model indicators

The node-place index is determined by combining different key variables and comparing them by multi criteria analysis. As explained, the Node index represents station area and network accessibility and the place index density and diversity of activities. These properties can be described by the TOD indicators. *Figure 7* shows the connection between the land-use and transport feedback cycle and the Node-Place model. Node and place index are described by the five TOD indicators.

Figure 7: Node-Place model indicators



How these TOD indicators are measured is derived from previous research (Bertolini, 1999; Chorus, 2012; Reusser et al., 2008). Possible indicators to measure accessibility and determine the node index of a station area are the number of train connections, the type of train connections, the proximity to a centre or sub-centre and the number of bus lines from a station. Possible indicators to determine the place index of a station area are the population around the station, the number of workers and the degree of multi-functionality. The workers are divided in four clusters; 1 services and administration, 2 retail, hotel and catering, 3 industry and distribution, 4 education, health and culture. The degree of multi-functionality is a measure for the quantity and diversity of functions that can be found in a station area (Chorus, 2012; Chorus & Bertolini, 2011)

Reusser et al. (2008) refined the model for the Swiss case by adding several indicators based on expert knowledge with the precondition of data availability. They furthermore observed a non-linear relationship between node and place functions indicating that the balanced functions are not situated along the model diagonal. It is argued that this is caused by the fact that stations have a minimum node value, depending on the minimum number of trains per day specified. This allows the place value to vary within a wide range without the necessity to influence the node value in order to stay balanced. (Reusser et al., 2008)

2.3.3 Model use

The node-place model is already being used as an analytical tool in the discussion of the land-use development process. The model only determines the locations where under the right conditions (with an emphasis on conditions) the land-use and infrastructure developments are most likely to take place. The findings of Reusser et al. (2008) are already used by the Swiss National Railways (SBB) to fuel the discussion on possible development opportunities. For further insight in the development dynamics and explore the scope for intervention Bertolini (2008) also used the node-place model to compare station area development over time.

In the Dutch context the node-place model is already being implemented by the Ministry of Infrastructure and the Environment in order to identify improvement opportunities on the national highway and railway network. The node-place model was applied to all station areas in the Netherlands characterizing concentration of residential and employment functions and their accessibility in the network. Based on this characterization spatial development strategies were drafted, with a focus on stimulating multimodal transport and reinforcing the reliability of the railway network. (VROM-raad, 2009)

2.4 Balancing traffic flow in the network

From an urban planning point of view it is desired to balance station area node and place functions as described in the previous section. But form a transport engineering point of view it is desired to improve traffic flow and the use of the available infrastructure. This also means developing station area functions in a way that traffic flow on the network is optimized.

2.4.1 The corridor approach

For a successful integration of land-use and railway transport it often pointed out that a consistent network focus over a longer period of time is required. So, an approach is required that not only focuses on the integration of land-use and transport on a local station level but also on where mobility patterns are coordinated on a higher level such as the corridor or even network level (Bertolini, 2008; Cervero, 1998). There are several reasons why a corridor approach is most desirable. Within a railway corridor origin and destination locations can be developed in a coherent way. Coordination of the development of different station areas on a railway corridor reduces competition between different station areas on the same corridor and can even stimulate synergies. Furthermore a corridor approach allows for developments to be coordinated in such a way that that the railway infrastructure is used more efficiently by creating a bi-directional traffic flow and generating off-peak travel (Chorus, 2012).

Railway corridors can operate on different levels, the lowest level being local, then regional, national and at the highest level international. For studying the context of railway development in Tokyo the regional level would be most suitable. This is mainly allowed by the fact that Tokyo's railway companies operate within their own region focussing on developing their own network. Though network function is not overlooked by the collective of railway operators in Tokyo companies strive to use their own infrastructure as efficiently as possible (Chorus, 2012). Analysing developments and traffic flow on the regional corridor level allows for a manageable scope avoiding the complexity associated with the higher network level.

3 RESEARCH OUTLINE

The introduction of railway development in Tokyo, the Tokyu Corporation, their corporate vision and strategy and how they developed the extremely successful Tokyu Den-En Toshi corridor have given an insight in TOD in Tokyo. Together with the theoretical background as to how transport and land-use are linked and how the railway companies are able to profit from developing the synergy between land-use and transport, this gives a solid base for addressing some of the problems that occur and the knowledge that is required to solve these problems. In this chapter first the problem statement will give an indication of the knowledge gap as portrayed in the theoretical framework. Second, the research objective is stated by which means this research will contribute to this knowledge, and third the research questions are formulated that need answering in order to fulfil the research objective. Finally the placement of the research questions in the research design is shown schematically and relations further explained.

3.1 Problem statement

The concept of TOD has been studied intensively over the years and strategy and analysis tools have improved increasingly. For example the node-place model developed by Bertolini (1999) that helps policy makers identifying development potential of land-use and infrastructure in station areas or the analysis of the impact of TODs on transit ridership performed by Sung and Oh (2011). However what many studies lack is a broader view of the impacts of spatial and transport developments on traffic. It is limited to local impacts like passenger growth, but disregard traffic flow on a higher, corridor or network level.

The coherence of land-use and infrastructure developments and traffic flows on a railway corridor has not been studied to its full extend leaving some questions unanswered. Where TOD opportunities such as identified by the Node-Place model have been executed it is yet unclear as to how these changes impact traffic flow on a corridor level. The question remains unanswered whether the focus of developments should be on optimizing station areas or traffic flow on a railway corridor in order to use the available space and infrastructure as efficiently as possible. (Bertolini, 2008; Chorus, 2012)

The Tokyu Den-En Toshi corridor is a good example of the application of TOD. Both the initial development of the corridor and the continuous redevelopment of the existing urban environment in and around station areas are meant to utilize the available space and infrastructure as efficiently as possible. Corporate strategy of the Tokyu Corporation has proved to be highly effective when looking at passenger numbers and company profits (Tokyu Corporation, 2013). What the effects of these TOD's are on traffic flow on the Den-En Toshi line is unknown though. It is necessary to have an understanding of development impacts and be able to estimate these effects. These development impacts should be understood not only on a local level but also on a higher corridor level. This requires looking at the efficiency of infrastructure use and traffic flow.

The impacts of TOD's can be measured based on social, economic and environmental indicators, but for this research the focus will lie on economic impacts. In particular the focus lies on the impacts of TOD's profitability of a railway company, by analysing its efficiency from a traffic engineering point of view. On one hand a private railway company strives to increase station use as much as possible as it generates fare revenues and revenues in their respective side businesses. On the other hand, the cost of transporting those passengers has to be minimized. So a cost effective balance must be found between developing station areas by balancing node and place functions and optimizing the use of available infrastructure by generating a balanced traffic flow on a corridor level.

3.2 Research objective

So as previously described an integral approach in optimizing station areas and traffic flow on a corridor level is desired. Derived from the problem statement the objective of this study is to:

> ***Develop a model that describes the interaction between station area Node-Place functions and traffic flow in a case study of the Den-En Toshi line in Tokyo, Japan.***

The Tokyu Den-En Toshi corridor lends itself perfectly for this objective because it is one of the longest running TOD projects that has been executed on a corridor level. This makes a detailed analysis of historical data possible, which is required for such a study as the full extent of the impact of land-use and infrastructure developments can only be identified after several years. The development pattern of the Den-En Toshi corridor has the centre of Tokyo on one end but does not have a major attraction centre on the other. This allows for a comparison of the effectiveness of local strategies, whether the station area activities and accessibility are optimized and corridor strategies, whether the efficiency of traffic flow between stations is also improved.

3.3 Research questions

To fulfil the research objective the following questions require answering. To illustrate how the research questions fit in the research design and help achieving the ultimate research goal the research design is showed schematically in Figure 8. The research design is further elaborated in the subsequent section.

The first step in developing a forecast model to help optimizing profitability is to learn from current practice and their experience in how development impacts are determined. Also an insight in the business case of the Tokyu Den-En Toshi corridor will help to explain the effects of past developments and allow for a more accurate forecast of future developments. Therefore the first two research questions which help gaining insight in the practices of the Tokyu Corporation are:

1. *How did the Tokyu Corporation develop the initial business case of the Tokyu Den-En Toshi corridor and what were the major spatial and infrastructure projects over the last 30 years that helped to achieve the current success of the Tokyu Den-En Toshi line?*

2. *What methods are being used in practice by the Tokyu Corporation to model and predict the interaction between station area characteristics and traffic flow and how this interaction is influenced in order to optimize corridor profitability?*

Focussing on the interaction between station areas and traffic flow first the station area is considered. In order to develop a forecast model for passenger numbers as a function of station area characteristics the proper indicators to measure these characteristics are determined based on theory, previous research and data availability. This results in the following two research questions:

3. *Can the station area be defined by the walkable radius for the stations on the Tokyu Den-En Toshi line?*

4. *What indicators can be used to describe station area characteristics in density and diversity of activities and station- and network accessibility?*

In order to measure the effect of a combination of certain station area characteristics and in essence its success, social, economic and environmental indicators can be used. These can for example be social mobility, fare revenue, real estate profits or CO_2 and particulate matter emissions. For this research though it is chosen to utilise passenger numbers that make use of the station as the outcome variable and thus an economic indicator of its success. Based on the station area characteristics a forecast model can be developed for passenger numbers. This forecast model can then provide the link between the effects of optimizing activities and accessibility of station areas and the traffic flow on the corridor. In order to develop this passenger forecast model the fifth research question is as follows:

5. *Can the indicators describing station area characteristics explain the development in passenger numbers for the Den-En Toshi line stations?*

The Node-Place model is then applied in order to describe how well station area characteristics are balanced in term of Node and Place functions. This model assists in determining how well the density and diversity of activities are adjusted to the station- and network accessibility. By assessing this balance development opportunities can be identified and available station area infrastructure and land use can be optimally utilised.
Several studies have shown how the N-P model can be operationalized and experiences gained in practical applications for policy making can be applied in this research. Previous studies stated that the development of a station area's node and place functions did not always result in a better balance of station area functions. In order to implement the N-P model in the case of the station areas along the Tokyu Den-En Toshi line the following research questions can be formulated:

6. *Can developments in density and diversity of activities and station- and network accessibility of station areas along the Tokyu Den-En Toshi line over the past 30 years be explained by balancing station area node and place functions according to the Node-Place model or might there be other unexplained influences?*

Where the passenger forecast model establishes the link between station areas and passenger numbers it does not consider traffic flow on the corridor yet. Therefore it is of interest how passenger numbers are not only influenced on a local station level, but also how this local level influences traffic flow on a regional/ corridor level. It is stated that ideally a traffic flow would be fully balanced, resulting in a traffic flow where bi-directional and off-peak travel is established. How balanced the traffic flow is indicates something about the efficiency with which the available infrastructure is used and the efficiency of railway operations. In this research occupancy is utilized as the indicator for efficiency of railway operations on the Tokyu Den-En Toshi corridor. With the full model developed describing the relation between balancing station area functions and balancing traffic flow on a corridor past and future developments on the Tokyu Den-En Toshi corridor can be evaluated. The past and future changes in the balance of station areas can be compared to the changes in balance of the traffic flow on the corridor, posing the seventh research question:

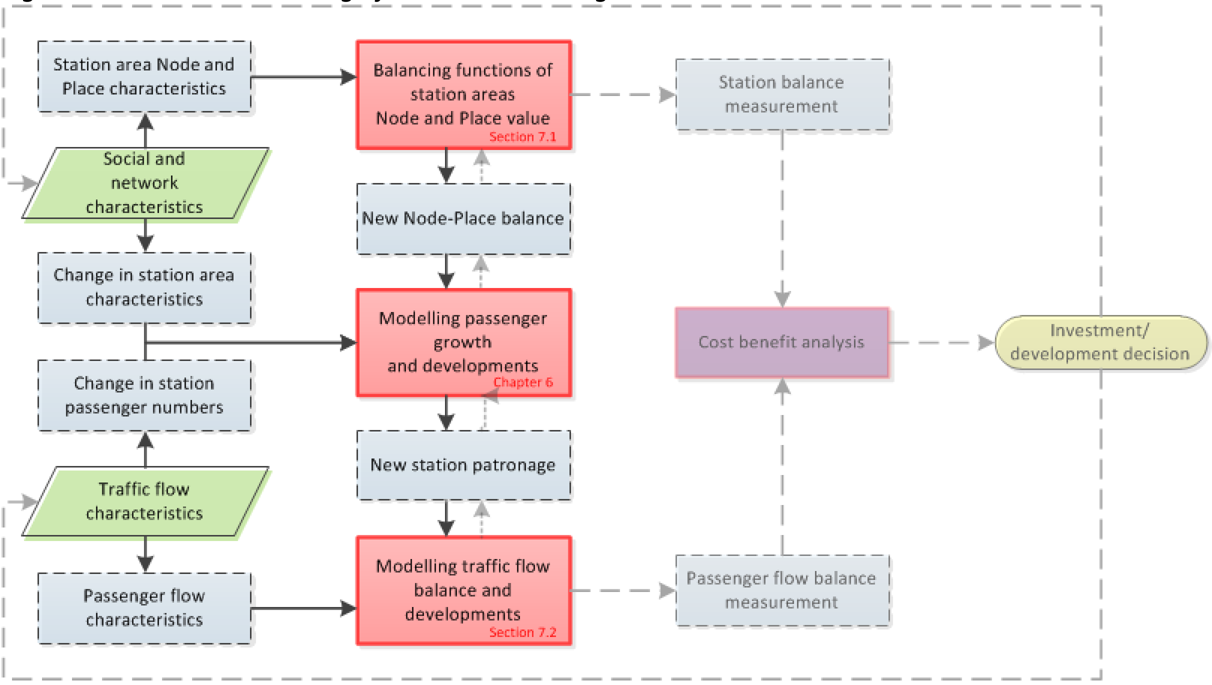
7. *Is the Tokyu Den-En-Toshi corridor a balanced railway corridor and have past developments contributed to establishing an efficient traffic flow?*

This research simply tries to provide a model for assessing development effects on a corridor level and does not attempt to evaluate the effectiveness of development strategies itself. It does not provide a complete Cost-Benefit analysis, but provides a basis on which possible development opportunities can be evaluated and decisions based (see *Figure 8*).

3.4 Research design

The design of the research is further elaborated clarifying how the research questions relate to each other and how they contribute to performing the research goal. Figure 8 shows the schematic of the research design. In the diagram is shown which input is required in green, how this is modelled in red, what it returns to evaluate and how this contributes to the decision making process. Within the model several processes can be distinguished together with their underlying relationships to the model input, output and other processes within the model itself. In the diagram several processes and relationships are depicted transparent showing their presence, but which are not addressed in the scope of this research. The complete diagram with the encompassing processes and underlying relations depicts the transport and land-use feedback cycle as described in the theoretical framework. Within the schematic references are added to make it possible to use the diagram as a guide navigating through this research.

Figure 8: Schematic rendering of the research design



3.4.1 Model input

The model requires a variety of input data to describe each of the processes present. The left side of the research design schematic represents the input required for the model. Station area social and network characteristics are measured based on TOD indicators as described in the theoretical framework. The traffic flow characteristics are measured based on the number of people that use the station areas and subsequently travel between stations.

The station area characteristics are used to explain station use with an aggregated forecast model. The same indicators for station area characteristics are used in assessing station area balance and identifying development opportunities. The weight of each of these indicators is derived from the forecast model. The traffic flow cannot be directly derived from the station use obtained from the forecast model and therefore requires more detailed disaggregated Origin-Destination relations.

3.4.2 Processes and relations

The middle section in the research design consists of the model itself. The model can be divided into three segments. The middle segment consists of the forecast model describing the change in station use as a function of changes in socio and network characteristics over a period of time. The top section assesses the success of the station area and helps to identify development opportunities. Changes in traffic flow characteristics are assessed separately in the bottom segment of the model.

In this research the emphasis is placed on the relationship between station area functions and how this affects the traffic flow on a corridor level. This process can be seen as the vertical relation between the model segments, seen from top to bottom (*Figure 8*). First development opportunities are identified and determined how they influence social and network characteristics. This change in characteristics is fed into the forecast model determining the effect on station use. And the change in station use in its turn results in a new traffic flow. Though this research only looks into how balancing station areas effects traffic flow on the corridor it can also be viewed the other way around. When there is a desire to further balance the traffic flow on a corridor the model can determine what changes are required in the station areas functions.

3.4.3 Model output

The proposed forecast model can be used to provide input for evaluating development strategies. On the one hand the model results in an indicator for the performance of a station area. It measures whether the accessibility and activities taking place in the station area are optimally adjusted to each other, obtaining the best station area performance. On the other hand the model results in an indicator for the performance of the traffic flow. It measures how the occupation is divided over the corridor, and shows whether the infrastructure is optimally utilised.
Both the influence station area and traffic flow performance can be assessed in terms of costs and benefits. Comparing costs and benefits of balancing station areas or balancing traffic flow results in a policy advice as to what spatial and infrastructure developments produce the desired results. Though this process is also depicted in the schematic, it is not discussed in this research. Finally the land use and transport feedback cycle is completed when proposed developments are executed and therefore cause a change in the social, network and traffic characteristics of the railway corridor and the station areas along it.

3.5 Preview

In the first chapter an introduction to railway development in Japan, and Tokyo in particular was given to provide a basic understanding of the political, economic and social processes that have shaped the Japanese railway business into what it is today. In more detail the research subject, the Tokyu Den-En Toshi corridor was introduced by giving an outline of its development and characteristics.

The second chapter laid out a theoretical framework describing previous research in this field. The relevancy and findings of previous research were discussed and with that a foundation laid for this research. The methods and data that are used in previous research on this topic were introduced and it was discussed how these data and methods can be utilised in this research.

This chapter discussed the relevancy of this research emerging form the theoretical framework, addressing the knowledge gap in currently available literature and the demand for decision tools by for example railway operators and policy makers. Based the problem statement the goal of this research was set. The research questions required to achieve the research goal were stated and the methodology to obtain these answers was described. Each of the following chapters is closed with the answering of the research questions relevant throughout that chapter.

The research starts out in chapter four with an insight in the practices of the Tokyu Corporation. These insights are gathered based on interviews with Tokyu Corporation employees, who are experts on the development of the Den-En Toshi line, real estate development in station areas, and the planning and operation of the railway line. It is discussed how these insights could benefit this research and how it influences the results and the conclusions that can be drawn from these results.

The fifth chapter provides the basis for all measurements. First the indicators used to measure station area characteristics are selected based on the theoretical framework and data availability. Second the scope of a station area is derived from trip characteristics along the Den-En Toshi line. And third each of the indicators used is described and individually examined.

Chapter 0 provides the insights in the statistical analysis performed on the acquired dataset. It briefly describes some more theory into regression modelling before continuing to the core of this research, building the regression model linking station area characteristics and station use. The model is then subsequently extended to optimization of station areas and to link station area characteristics and traffic flow in Chapter 7.

Finally the conclusions of each of the previous chapters and the answers to the research questions are summarized in chapter 0. And the chapter is then finalised with fulfilling the research goal and discussing the reservations of this research and recommendations for future endeavours.

4 AN INSIGHT IN PRACTICE

The Tokyu Den-En Toshi line was chosen as a case study because it is one of the most prominent cases where land and infrastructure development have been integrated. From the history and experiences dealing with this combined infrastructure and property development several lessons can be learned. This chapter provides an insight in the initial development of Tama Den-En Toshi and the course of its continued development throughout the last 30 years. Furthermore it is discussed how the Tokyu lines are managed and what forecasting methods are used in investment decisions. With the insights this chapter offers the first two research questions as posed in section 3.3 can be answered.
Additionally, an insight in the business case of the Tokyu Den-En Toshi corridor will help to explain the effects of the interaction between infrastructure and property developments and the success of the railway line. It provides a backdrop when interpreting the results from the modelling section of this research and can assist in providing a more accurate forecast model.

These insights gathered in this chapter are based on expert interviews with two Tokyu Corporation employees, conducted in January 2014. The first interview was held with Dr Masufumi Ota, head of the building division, for his expertise in property development and his knowledge of Tokyu's history. The second interview was held with Satoshi Seki of the planning section in the railway division to provide additional information about the operational and planning aspects of Tokyu's railway business. As a guideline a set of questions was set up prior to the interviews in Appendix 9.2.
This chapter starts out with a brief look at the initial development of Tama Den-En Toshi, the new town development along the Den-En Toshi line. Then subsequently the aspects in property development and railway infrastructure as carried out by Tokyu over the course of the last few decades. This is followed up by current approach and practices in operation and planning and specifically how the effects of planning decisions are forecasted. This chapter is finalized with the lessons learned from these insights in a brief conclusion.

4.1 The development of Tama Den-En Toshi

As described in the introduction after the Second World War the railway network grew steadily due to the combination of several major factors. Japan experienced the post war economic boom, which together with the continuing industrialization, the prevailing land scarcity in urban areas and the massive population migration from the countryside into the urban areas shaped the ideal conditions for rail oriented new town development (Calimente, 2009).

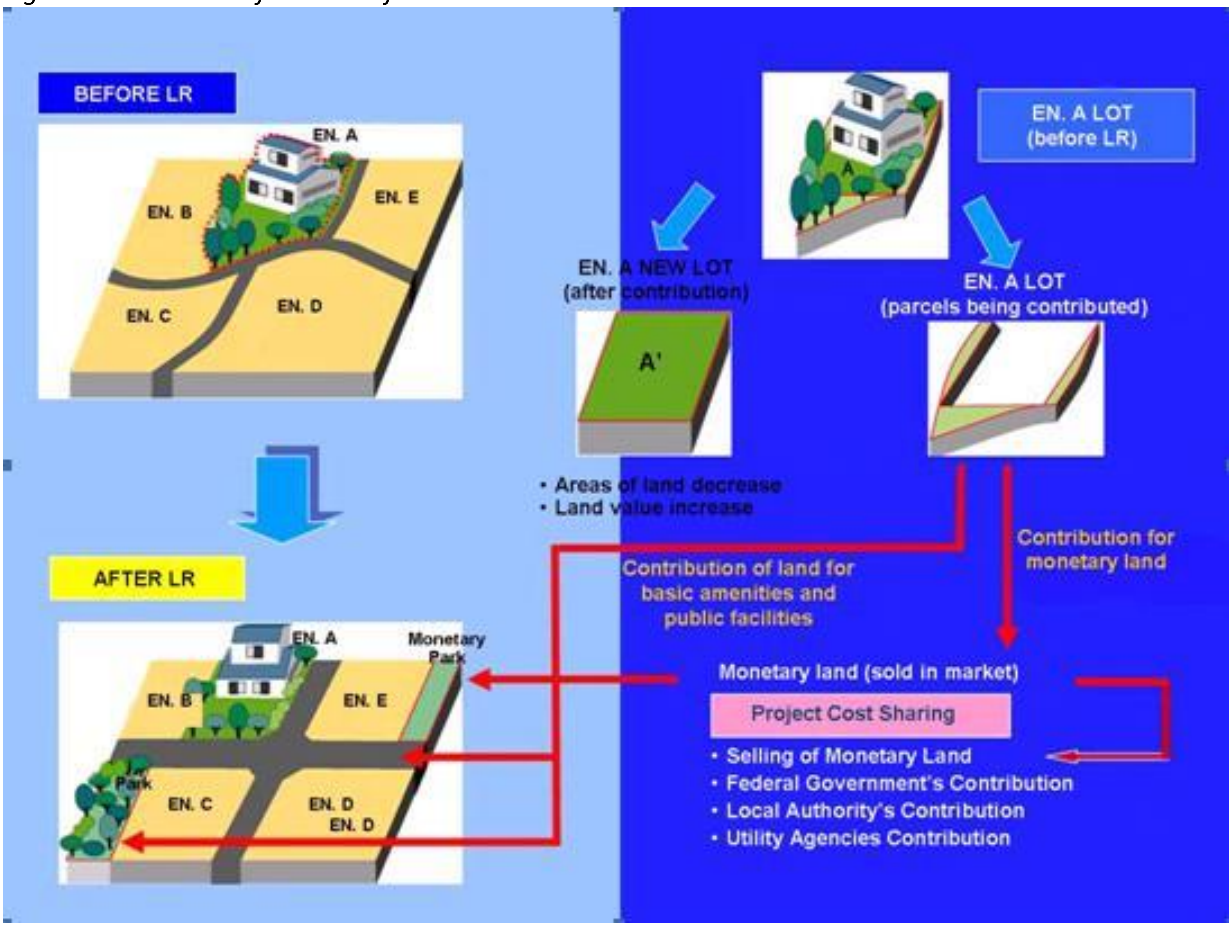
The private railway companies, including Tokyu, ventured into new town development as means of expanding their business and increasing their profit margins. The idea was to centralize residential area development in newly built suburbs around railway stations and with that generate the ridership for the railway line. From these bedroom-communities people would commute to the centre where the jobs are located via the railway line generating passengers. They tried to provide a high quality, high density living environment with excellent public transport access. This development strategy is described in the concept of the "garden city", first pioneered by Kobayashi of Hankyu Corporation in the Osaka area (Tokyu, 2013).
Similar strategies around TOD had previously been applied in the United Kingdom in London, but with less success. In London it was attempted to build self-contained communities where people would both work and live. This would eliminate the need for a car as means of commuting, leaving the railway to provide the necessary accessibility. Instead it turned out that people would work in one neighbourhood and reside in another, commuting between neighbourhoods by car because the radial orientation of the railways would make it inconvenient to travel between communities (Tokyu, 2013).

At the time of the new town developments the landowners around Tokyo were very poor and took the offers of the railway companies to develop their mainly agricultural land into residential areas through joint land development schemes. In comparison, this strategy did not work in London as the landowners there already possessed substantial wealth and did not see any added value in joint area development (Tokyu, 2013).

These joint development schemes are better known as land-readjustment projects. The purpose of land readjustment projects is to attain the comprehensive improvement of urban environment and the promotion of effective land use through reorganizing housing lots in coordination with the development of public facilities by means of areal reduction of housing lots and land re-plotting (JICA, 1991).

A land readjustment project has several special features, first that the project is carried out without affecting the rights of the landowners and holders of other rights. Secondly the landowners offer a tiny portion of their land to a project developer to be used for public purposes and for financing the project. The project executor performs the necessary works for public use and re-plots the land more conveniently towards public facilities and more suitable as building area (JICA, 1991). An example of a land readjustment project is visualised in *Figure 9*.

Figure 9: Schematic of land readjustment



Tokyu carried out the land readjustment to obtain the necessary land to construct a railway line. The parcels contributed by the landlords were used to construct the railway and railway related facilities on and also to provide space for and cover the costs of constructing amenities and public facilities.

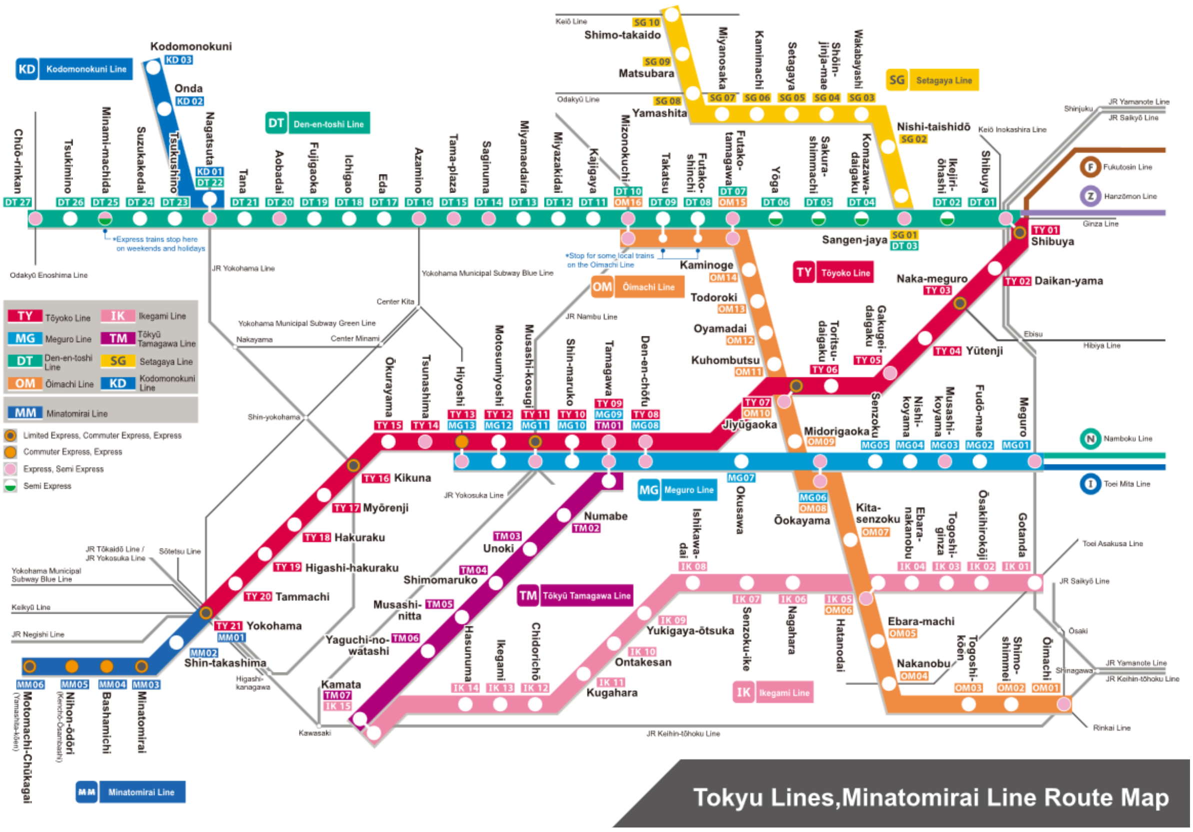
The situation in the area served by the Tokyu Corporation the executive body of the project was a land readjustment cooperative. Land readjustment organized by a land readjustment cooperative

requires agreement of at least two-thirds of land owners before a project can be executed. When a majority is attained city planning law dictates that all land owners have to cooperate. This was done with a cooperative style made famous by Tokyu for which the basis was close communication with the landlords taking great effort.
A strong point of the new town development as done by Tokyu was the high quality surface infrastructure that was provided. This made it very easy to access the stations along the railway lines. In addition an extensive network of feeder busses would further improve the station accessibility. Tokyu would supply the residents with shops and leisure activities in the station plazas.
This approach was much more successful on the Den-En Toshi line than the Toyoko line because they were not able to reserve sufficient space along the Toyoko line as it was constructed in a much more densely built up area.
It is interesting to note that the very first plans for Tama Den-En Toshi actually revolved around an expressway from Shibuya to Enoshima. But due to political interference Tōkyū was forced to change their plans and centre their new town around railway infrastructure instead.

4.2 The Den-En Toshi line through the decades

The development of Tama Den-En Toshi new town and the Den-En Toshi line can be divided in property and infrastructure. Spread along its 27 stations (*Figure 10*) several noteworthy property developments and development strategies were deployed. The accessibility of the Den-En Toshi line stations and station areas also underwent major changes over the years. Together with the projects currently underway and a glance towards future strategies the Den-En Toshi line through the years is described in greater detail. Additionally to the overview in *Figure 10* a general description of the Den-En Toshi line stations is included in Appendix 9.1.

Figure 10: Map of the Tokyu railway network



Source: Tokyu company website,2014

4.2.1 Property development

The development of the station areas along the Den-En Toshi line started out with the land-readjustment schemes. The land-readjustment schemes did not always turn out as planned, as can be seen for example near Azamino (DT16) station where there still remains a farmhouse right in front of the station building. But together with buying up large pieces of farmland where the line was to be developed the land readjustment schemes proved highly successful in the development of Tama Den-En Toshi.

In general the garden city concept included only residential and commercial development, in contrast to the concept of TOD. This is mainly because the implementation of these concepts is highly dependent on the property market. Real-estate developers are less keen on developing offices in an area where demand for office space is not very high.

For example when first developing the Tama-Plaza (DT15) station area (*Figure 10*) it was attempted to make it into an office location, but it proved extremely difficult to attract businesses. Some 20 years later in 1993 high rise office buildings were constructed in front of Yōga (DT06) station where Tokyu owned some land but previously only residential development had taken place. This attempt did prove successful and sparked the currently running redevelopment project at Futako-Tamagawa (DT07). Current market conditions generating a higher demand for offices in accessible locations outside the more expensive traditional centres allow for the redevelopment of Futako-Tamagawa (Tokyu, 2013).

The difference in success can be mainly ascribed to proximity, as Yōga (DT06) and Futako-Tamagawa (DT07) (*Figure 10*) lie relatively close to the traditional business centre. Other office development projects such as in Minami-Machida (DT25) relied more on the proximity of the expressway and therefore the accessibility from Yokohama by car.

By constructing for example shopping centres near stations people are attracted to the area. When the demand for an area rises, so does the price of the land which profited Tokyu Corporation in turn. Though Tokyu did do some housing development, the main focus was on commerce in and near the stations. Also other side businesses were ventured in such as elderly care, child care facilities sporting facilities and cable provider. Tokyu even ventured into education by establishing several schools and attracting Tokyo City University, of which part was founded by Tokyu itself, and having its locations scattered through the Tokyu area (Tokyu, 2013).

Other than office space and retailing facilities Tokyu did not venture in many other types of property development. Public facilities such as hospitals and libraries were mainly provided by local governments and private sector companies. Other private developers mainly stayed with residential development, as office development was not profitable at most locations along the Den-En Toshi line. Though, several manufacturing facilities and research institutes of major businesses such as IBM are present in the less densely populated areas at the end of the line at Eda (DT17) and Chūō-Rinkan (DT27).

One of Tokyu's major initial property developments targeted Tama-Plaza (DT15) station. At Tama-Plaza Tokyu owned a large section of the land and created a commercial centre in anticipation of the new Yokohama Municipal Subway Blue line being built. Tokyu tried to persuade the Yokohama municipal government to build the new subway to Tama-Plaza, but the Yokohama municipal government decided to divert the line to Azamino (DT16) instead. This caused Tokyu a substantial loss in a possible value capturing opportunity.

The desire of the municipal government was to continue the blue line to Shin-Yurigaoka on the Odakyū line. This subway would run very close to the municipal boundary between Yokohama and Kawasaki. From the point of view of the municipal government it would yield more result for Yokohama if the line was to be constructed further within the Yokohama city borders. Azamino station is only a local centre, but was made express stop for the connection. This example shows that political motivations can sometimes overshadow economic benefits.

Beside the addition of office space and high-rise apartment complexes around Futako-Tamagawa (DT07) the Shibuya (DT01) terminal and the surrounding station area is also receiving a complete overhaul. The station area around Shibuya is being completely redeveloped with the plans for constructing 6 new sky scrapers. The Shibuya area has started to age and lost part of its attraction, therefore redevelopment of the station area was required. Otherwise demand will drop and less people will travel to Shibuya. The undergrounding of the Tokyu Toyoko line terminal and it connection to the Tokyo Metro Fukutoshin line in 2013 (*Figure 12*) opened-up prime real-estate on the location of the former Tokyu Toyoko line terminal. A massive underground arcade was constructed connecting the Toyoko line to the existing Den-En Toshi line in a single underground station building. These developments allow for an even more densely built-up area around Shibuya station. In the future this will most likely generate an even higher influx of passengers than before.

4.2.2 Infrastructure

In 1985 the number of passengers travelling between Ikejiri-Ōhashi (DT02) to Shibuya (DT01) during rush hour was approximately 57.000, but that number has risen to 82.000 per hour today (Tokyu, 2013). This is a good indication of how busy the Den-En Toshi line became in the years after its completion. With the steady increase in passenger numbers so increased the capacity, as can be seen in *Table 2*.

The Shin-Tamagawa line, the newly built railway tunnel between Shibuya (DT01) and Futako-Tamagawa (DT07) was opened in 1977. Though trains already continued on the following section of the Den-En Toshi line starting from 1979, it was not yet officially a part of the Den-En Toshi line. Mutual direct service with the Tokyo Metro Hanzōmon line at Shibuya was commenced immediately after the completion of the Shin-Tamagawa line. The operation on the Den-En Toshi line started out with 15 trains of only 6-cars, but this number was rapidly increased. By 1984, when the last section to Chūō-Rinkan (DT27) was completed and the new line together with the Shin-Tamagawa line was renamed Den-En Toshi line, there were already operating 17 trains an hour with a maximum of 10 cars each.

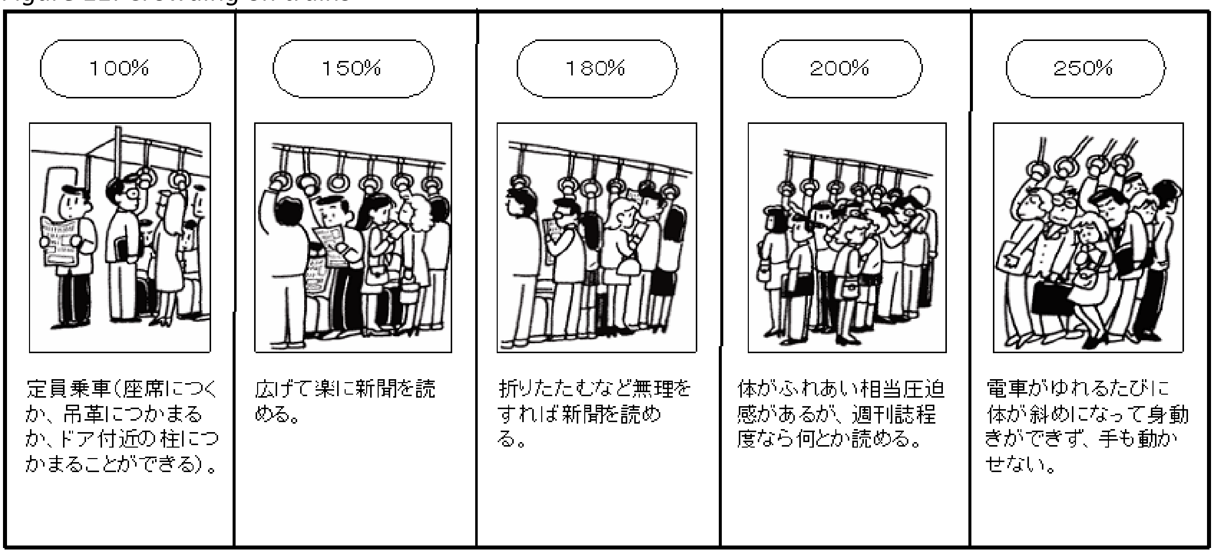
Table 2: Course of Den-En Toshi line transport capacity during busiest hour (morning)

Year/Month	Occasion	Headway	Nr. of carriages X Nr. of trains
1977 / 07	Shin-Tamagawa line opened	4 min. 00 sec.	⑥x15
1979 / 08	Den-En Toshi – Shin-Tamagawa line start of continued operation	4 min. 00 sec.	⑧x14, ⑥x1
1981 / 04	Capacity increase	3 min. 45 sec.	⑧x16
1983 / 01	Capacity increase	3 min. 30 sec.	⑩x10, ⑧x7
1984 / 04	Chūō-Rinkan section opened	3 min. 30 sec.	⑩x16, ⑧x1
1985 / 04	Capacity increase	3 min. 20 sec.	⑩x18
1986 / 10	Capacity increase	3 min. 10 sec.	⑩x19
1987 / 09	Capacity increase	3 min. 00 sec.	⑩x20
1989 / 01	Hanzōmon line extension	2 min. 30 sec.	⑩x24
1991 / 03	Introduction of ATC	2 min. 25 sec.	⑩x25
1992 / 11	Capacity increase	2 min. 15 sec.	⑩x27
1995 / 11	Capacity increase	2 min. 10 sec.	⑩x28
2003 / 03	Start mutual direct service Tobu	2 min. 10 sec.	⑩x28
2004 / 10	Capacity increase	2 min. 05 sec.	⑩x29
2007 / 04	Start of operation semi-express	2 min. 05 sec.	⑩x29

Source: Tokyu Den-En Toshi line brochure, received during interviews

When the underground section of the Den-En Toshi line between Futako-Tamagawa (DT07) and Shibuya (DT01) (Shin-Tamagawa) was constructed, space was reserved in the tunnels to increase the platform length from eight to ten cars. There was not foreseen at that time the line would become so crowded that the extension to ten car platforms would no longer suffice. The tunnel body restricted the possibility of extending the trains even further at a later time due to the high costs involved and the complexity of elevated highway constructed on top of the tunnel. So when the line started to become more crowded capacity could not be increased by simple adding cars to trains.
The Den-En Toshi line became notorious for its crowding during the morning peak, reaching in excess of 220% of capacity. This was characterized by the gloved station attendants trying to push passengers in like sardines as illustrated in *Figure 11*. To try to keep crowding at bay and increase the Level of Service (LOS) several other additions were done to the infrastructure to further increase the capacity of the tunnel. The most important being the placement of additional signalling to reduce the headways of trains from three minutes in 1987 to two minutes and 10 seconds in 1995 shaving off mere seconds with each improvement(Tokyu, 2013).
On the farther end of the line an overtaking track was added at Fujigaoka (DT19) (3 tracks) for express services to overtake local services. The express trains could also already pass at Kajigaya (DT11). At Saginuma (DT14) and Nagatsuta (DT22) the express trains stop to offer cross platform transfers with the local services. And at Azamino (DT16), Tama-Plaza (DT15), Mizonokuchi (DT10) and Futako-Tamagawa (DT07) the express trains stop but do not pass the local as there are no passing tracks. There are also no passing tracks or double platforms in the tunnel between Futako-Tamagawa (DT07) and Shibuya (DT01) or on the continuous Hanzōmon line. Though express services were improved over the years, focus on the Den-En Toshi line still lies on local services with only one express train for every two local trains running. In comparison to the Toyoko line, on which an equal amount of express and local trains run, this emphasises the different strategies that can be implemented (Tokyu, 2013).
In addition to the infrastructure upgrades Tokyu started adding six door cars instead of four door cars to their trains with all standing spaces. Station facilities were upgraded to cope with the astonishing amounts of passengers, by widening the platforms were possible and adding elevators and escalators. More recently at several stations platform doors were added to further increase safety of the passengers on the platforms and the LOS at the stations.

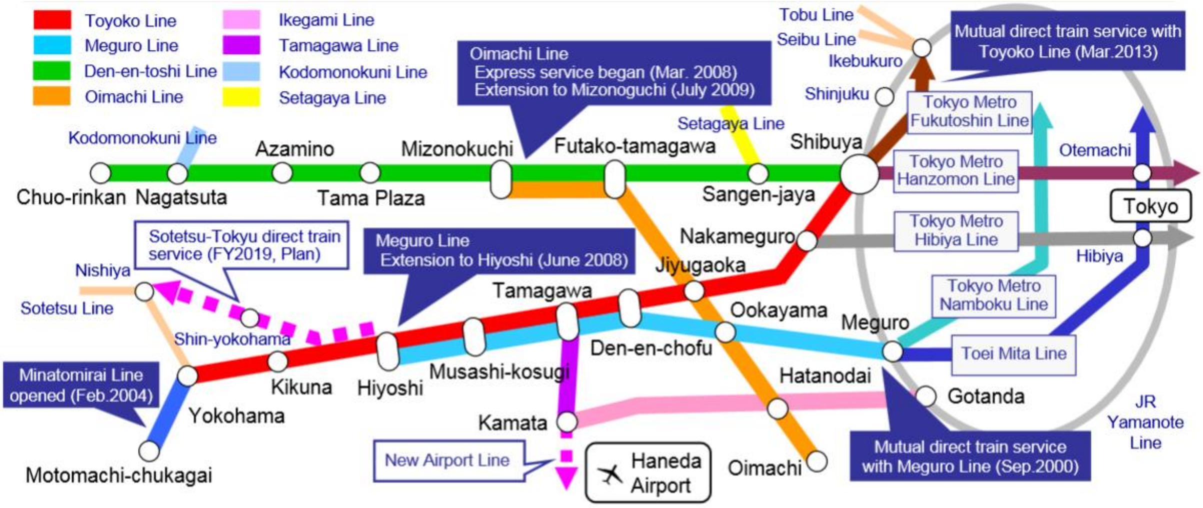
Figure 11: Crowding on trains



Source; MLIT, retrieved December 2014

Today the infrastructure is at its limit, causing congestion and delays almost every day. Many railway companies try to increase capacity to cope with growing demand. There are generally speaking two ways of increasing capacity. The first is double tracking the congested section, which is a costly solution as it requires large land purchases or tunnelling schemes. Second is to divert demand over the available company network. To relieve congestion on the Den-En Toshi line the Ōimachi line, which terminated at Futako-Tamagawa (DT07) only had a local function was upgraded and extended in order to serve as a bypass (*Figure 12*).
This required the service being offered being both quick and comfortable for which the Ōimachi line express service was created. But most importantly the Ōimachi line was extended from Futako-Tamagawa to Mizonokuchi (DT10), parallel to the Den-En Toshi line. This meant doubling the tracks of that section from two to four tracks. This reduced crowding on the Den-En Toshi line by offering passengers another route to travel to central Tokyo via the Ōimachi line. Now transfers can be made for example from the Ōimachi line at Ōokayama station to the Meguro line, which in its turn has through services with the Tokyo Metro Nanboku line and the Toei Metro Mita line. Furthermore at Ōimachi station passengers can easily transfer to the JR Keihin-Tohoku line which serves the eastern side of Tokyo. Though the number of passengers on the Den-En Toshi line dropped due to the upgrade and extension of the Ōimachi line, the total number of passengers of Tokyu Corporation increased (Tokyu, 2013).
The Ōimachi line extension and upgrade was a 100 billion yen investment (680 million euro) mainly because of the high costs of land purchase along the Den-En Toshi line to accommodate the double tracking. It took 15 years to plan, obtain the land and construct the extension, which seems very fast. But because Tokyu is a private company it highly depends on fare revenues and therefore must keep its customers satisfied. If passengers are dissatisfied they simply change operator or mode choice. This investment reduced the congestion rate from over 200% to 180%. To continue to decrease congestion Tokyu is in the early planning stages of extending the Ōimachi line further to Saginuma (DT14) or Tama-Plaza (DT15) in order to further increase the ease of access via the Ōimachi line. An extension beyond Tama-Plaza is not planned as the population of Tokyo is expected to decrease most likely causing it to yield too little benefit (Tokyu, 2013).

Figure 12: Improvements of the Tokyu railway network



Source; Tokyu fact sheet, retrieved December 2013 from http://www.tokyu.co.jp/

For the local accessibility of the stations along the Den-En Toshi line Tokyu operates bus services. Main feeder routes are operated by Tokyu and in some areas additional municipal bus services with a more social purpose are available. Tokyu provides these bus services as an integral approach to attract as many passengers as possible to use its facilities. Bus services are not profitable, but operational costs are supplemented with profit gained in other sections of the Tokyu Corporation.

A lot of local services are concentrated for example at Aobadai and other large bus terminals are available at Azamino (DT16) and Tama-Plaza (DT15). Additionally airport bus services to Haneda and Narita airports stop at Tama-Plaza to provide residents along the Tokyu lines with a higher accessibility to these important facilities.
Though bus services are already an integral part of the transportation system in the areas served by the Den-En Toshi line they can still be further improved (Tokyu, 2013). Bus fares are relatively high compared to the train, a flat fare of 200¥ for all bus services compared only 330¥ for the entire stretch form Chūō-Rinkan (DT27) to Shibuya (DT01) by rail. Further gains can be made by optimizing connectivity.by providing faster, smoother and barrier free connections.
The bicycle is less important as an access mode in the hilly area along the Den-En Toshi line, but also in Tokyu and Japan in general. There is not very extensive bicycle parking offered at the stations and is not free of charge. Both the railway company and the municipal governments concerned do not consider it essential to provide any of the road space and road side facilities, such as parking, for bicyclists.

4.2.3 The future of the Den-En Toshi line

For the future of the Den-En Toshi line several positive and negative changes are to be expected. Some of these aspects are shortly discussed to give an impression of the challenges facing Tokyu and how they are planned of being solved.

Over the last 20 years Tokyu mainly focussed on coping with the congestion on the Den-En Toshi line by increasing its capacity. Another possibility would be to reduce or divert the demand itself. Though the high demand causes inefficient use of infrastructure and equipment it is easily weighed out by the benefits of the higher number of people using the commercial facilities at the stations. The financial stats of Tokyu Corporation in *Table 3* clearly show why this strategy is adopted. In 2013 the operating revenue of the transportation division accounted for less than a fifth of the total revenue. The operating profit of the Transportation division accounts for about a third of the company's total profit. But almost half of total profit is made in the Real Estate division, showing the success of combining railway infrastructure with real estate projects. The ability of Tokyu to invest a share of the profit gained in the real estate division into infrastructure related projects creates a highly successful business strategy.

Table 3: Tokyu Corporation operating revenue and profit per business segment

Operating revenue (Unit : million yen)

	135th term	136th term	137th term	138th term	139th term	140th term	141st term	142nd term	143rd term	144th term
	2004/3	2005/3	2006/3	2007/3	2008/3	2009/3	2010/3	2011/3	2012/3	2013/3
Transportation(*1)	262,132	263,897	192,927	192,636	197,777	199,362	194,931	187,344	188,453	187,250
Real Estate(*2)	168,396	181,589	141,725	152,017	139,187	138,666	164,046	157,883	131,219	163,697
Life Service(*3)	384,643	384,452	678,239	660,271	649,428	621,293	557,957	515,494	490,712	527,670
Leisure and Services(*4)	86,203	60,000	189,512	183,284	182,747	176,057	153,329	155,707	151,583	-
Hotel and Resort(*5)	109,078	102,873	103,382	99,099	100,458	96,209	86,993	82,816	78,673	89,615
Construction(*6)	211,140	-	-	-	-	-	-	-	-	-
Business Support(*7)	90,800	113,157	154,245	170,284	189,790	155,984	149,376	126,038	126,945	175,669
Elimination, etc.	-88,991	-50,405	-71,478	-75,618	-86,437	-83,342	-76,503	-73,160	-73,378	-75,855
Total	1,223,403	1,055,564	1,388,554	1,381,975	1,372,952	1,304,231	1,230,132	1,152,125	1,094,209	1,068,046

Operating profit (Unit : million yen)

	135th term	136th term	137th term	138th term	139th term	140th term	141st term	142nd term	143rd term	144th term
	2004/3	2005/3	2006/3	2007/3	2008/3	2009/3	2010/3	2011/3	2012/3	2013/3
Transportation(*1)	20,358	39,460	38,929	25,699	33,907	25,806	23,229	28,481	18,319	18,048
Real Estate(*2)	20,577	23,343	21,808	26,020	24,945	23,587	22,851	16,923	22,429	26,803
Life Service(*3)	6,911	6,229	14,422	16,114	14,903	10,896	3,866	7,632	10,114	5,968
Leisure and Services(*4)	1,351	2,033	2,835	3,208	3,275	2,215	1,461	2,741	2,877	-
Hotel and Resort(*5)	3,563	2,747	3,906	3,714	3,618	682	-1,422	-1,443	-828	1,440
Construction(*6)	2,565	-	-	-	-	-	-	-	-	-
Business Support(*7)	2,725	2,568	2,404	4,966	6,035	2,018	2,611	2,628	2,515	3,052
Elimination, etc.	67	632	1,348	365	51	93	142	155	-395	428
Total	58,120	77,014	85,654	80,088	86,738	65,301	52,741	57,119	55,032	55,742

Source; Tokyu fact sheet, retrieved January 2015 from http://www.tokyu.co.jp/

Despite the profits outweighing the cost of inefficient operations, recently a separate division was created within Tokyu’s railway division that focusses on how to generate demand where the infrastructure and equipment allow for additional passengers. This led for example to the introduction of additional express trains on the weekends and special discount tickets.

In the near future a trend might become visible where Japanese people will start to attach more value to their private life that is discouraged by current working culture. This change may generate the possibility to decentralise offices and start to mix office and residential functions more, also further from the traditional centre. The relatively low land prices make people more mobile in choosing their residential location, which allows them to move closer to their work location. Futako-Tamagawa (DT07) is pioneering in this section, and redevelopment will soon also be directed to Tama-Plaza (DT15) where a lot of the buildings have aged and are ready for redevelopment. This could well result in the possibility to reduce and stabilise traffic flows on the Den-En Toshi line.

Aging of the population is starting to become a major concern in Japan and Tokyo. Tokyu begins to focus on how to retain its passenger numbers and also how it can capture this new group of elderly customers. A commuter pass is very commonly supplied by the employer. When people retire they lose these benefits which will likely cause a drop in the ridership. Tokyu aims to attract elderly passengers by upgrading station facilities barrier free and in the future make seat reservation for elderly possible. On the other hand Tokyu strives to make the Tama Den-En Toshi area more attractive for young families to retain a steady population number. For example at Tama-Plaza (DT15) apartment buildings for elderly people were built adjacent to the station. Elderly already living in the area occupying family residences were offered these convenient apartments, making the family residences available for a younger crowd to move to the suburban areas. Tokyu builds apartments, then buys the single family homes, renovates them and resell them to young families (Tokyu, 2013).
On the whole a slight decrease in population might benefit Tokyu as the number of trains in the rush hour could be reduced. This could benefit passengers as it allows for shorter journey times and Tokyu could reduce its operational cost. Ideal would be approximately 20 trains per hour, with service level changing little over the course of a day or on the weekends (Tokyu, 2013).

Since the completion of the Den-En Toshi line Tokyu has not and in the future will not expand its network any further. Instead focus lies on network improvement, for example by adding missing links and through services. As shown in *Figure 12* some of these improvements will be the connecting of the Tokyu and Sotetsu networks and the addition of a Haneda airport connection. Though the airport connection will only generate very few additional passengers the main benefit for would be the increase in value of the Tokyu area and especially adding international acclaim to Shibuya when it is directly connected to the airport.

4.3 Predicting land-use and transportation interaction in practice

To learn from current practice it was studied how planning decisions are made by Tokyu and what methods are being used to forecast the interactions between land-use and transportation.

For the evaluation of medium and long term planning Tokyu employs a traditional 4-step transportation model. The transportation model is used to make investment decisions in railway and property development, when it is necessary to analyse the effects of these decisions on traffic flow. It is also used to submit forecasts to the ministry of transportation regarding for example fare regulation or building permits and subsidizing. The development of the transport model is currently outsourced to a consultancy firm. In the past however Tokyu used a similar model for more than 20 years. Because this readily existing model cannot be disclosed, a separate forecast model was developed in this research.
As described in the theoretical framework this model consists of four modelling steps: Trip generation, trip distribution, modal split and route assignment. The trip generation and distribution steps in the model are based on the national population census. This census consists of population and workforce characteristics and distribution and is published every 5 years. For the major urban conglomerations in Japan a transportation survey is conducted, *the Person Trip Survey*, this in turn is used for the subsequent modelling steps.

Usage data on the railway lines is gathered by counting passengers entering and leaving the platforms on all of the stations within the Tokyu network. This counting is done for a single day each year. Based on these passenger counts all necessary analyses are performed. With these passenger counts for example congestion within carriages is evaluated and crowding levels are determined. This type of research mainly focusses on the most congested sections. On the Den-En Toshi line, this is for example the section from Ikejiri-Ōhashi (DT02) to Shibuya (DT01).
The IC-card (also referred to as smart card) data is only occasionally used for analysis because data obtained from electronic payment records is incomplete. Due to the through services offered with Tokyo Metro, passengers can for example enter a Tokyu station but exit at a Tokyo Metro station. Privacy issues and data security prevent the railway companies from exchanging IC-card data. Furthermore while unregistered transfers within the network are possible, it is not possible to determine routes.
IC-card data can for example be used to determine how many ticket gates are necessary at a station, or whether a certain type of discount ticket is used and how it is used by customers. These discount tickets include one day tickets and shopping purpose tickets with free travel between Shibuya (DT01) and Futako-Tamagawa (DT07).

4.4 Conclusion

Based on the interviews with Dr. Ota and Mr. Seki and the additional literature some general conclusions can be drawn. This furthermore answers the first two research questions (see section 3.3).

In applying TOD in Tokyo and developing rail integrated communities timing was of the essence. It was the coinciding of the post war economic boom, with the continuing industrialization, the prevailing land scarcity in urban areas and the massive population migration from the countryside that paved the way for private railway companies such as Tokyu in the development of urban railways.

As pointed out the first and foremost condition for the implementation of TOD is that there is actually growth to guide or a necessity to redevelop and further condense the existing urban area. During the post war economic boom, there was a high necessity for land development in Japan. These days however, the need for land development is much lower. This makes it less attractive to do large scale (re-)developments. Second, property development is market bound, implying the demand set forth by the market more or less dictates were the development takes place. It is much harder to create office space further outside the centre as there is simply no demand for it. Third, the entire land-use and transportation cycle is influenced or interfered with by political processes in turning out policy and legislation. Policy can have a positive influence, such as the legislation and tax laws in Japan benefitting the use of trains. However, it can also have a negative influence such as when the Yokohama municipal government decided to redirect the Blue line construction from Tama-Plaza (DT15) to Azamino (DT16) duping prior Tokyu investments at Tama-Plaza. From a theoretical point of view all these constraints make it more difficult to create an optimum situation.

In theory, it would be beneficial to establish high density mixed land use in station areas along the entire Den-En Toshi line, which would create highly efficient travel patterns. In reality though, it is difficult to generate the necessary attraction. Market conditions prevent from developing for example offices at the far end of the Den-En Toshi line in order to stabilise traffic flows.

In case of the Toyoko line (see *Figure 10*) this is different. Besides Shibuya at one end, Yokohama is another strong attraction centre on the other end of the line. This makes the Toyoko line extremely efficient compared to the Den-En Toshi line, but still the Minato-Mirai area in Yokohama is not a strong attractor as Shibuya.

In conclusion, Tokyu utilised economic, political and other circumstances to their advantage as much as possible by anticipating and responding to these processes. Nowaday, the economic growth is less evident and a stagnating population growth makes it more difficult to keep following these strategies. Proven concepts of development and redevelopment have to be adapted in order to remain successful.

In order to forecast changes in land-use and transportation Tokyu utilises a 4-step transportation model. Because this model cannot be made available for academic research a separate model was developed further in this report. Besides aggregated demand modelling with the 4-step model some smaller analysis were conducted on collected data (mainly passenger numbers). This can be considered as a fairly one-sided approach, as only the effects of land-use developments on transportation is modelled instead of emphasising the interaction working both ways. This can be largely explained by the fact that the benefits from property development, retail proceeds and transportation itself outweigh the costs associated with an unbalanced traffic flow.

5 MEASURING STATION AREA CHARACTERISTICS

As explained in the research outline, the emphasis of this research was on quantifying the relationship between station area characteristics and station use in a descriptive model. After having this relationship established, the model was expanded to measure the impact of optimizing station area Node-Place functions on traffic flow. For establishing station area node and place functions the same indicators were used, describing station area characteristics. Therefore, this part of the research consists of determining how station area characteristics can be measured and what is required to analyse the developments of station areas on the Den-En Toshi line. The stations along the Den-En Toshi line, with the associated station names, numbers and some general characteristics are included in Appendix 9.1 (additionally, a map can be found on page 22 in *Figure 10*), which can be used for further reference.

This chapter first describes how the indicators describing station area characteristics are selected. Second, it elaborates on the question how a station area can actually be defined. Meaning over what area the relationship between station areas and ridership should be studied. Then, the selected indicators for measuring the intensity and diversity of activities in station areas are explained by the data collected. Furthermore, the indicators for measuring the station area and network accessibility are described. Finally, the method for measuring station use an traffic flow are explained, together with a general economic indicator to better explain variation of station use over time.
Based on the indicators described in this chapter the descriptive model was developed in Chapter 0. With this descriptive model station use can be estimated, based on these station area characteristics measured. Furthermore, the station area characteristics were used in the Node-Place model, in Chapter 7. The station area and network accessibility indicators, as well as the intensity and diversity of activities indicators were combined to form the station area node and place functions.

5.1 Indicator study

Theory described that station area characteristics can be roughly divided in on the one hand intensity and diversity of activities and on the other as accessibility of the station area and the railway network. As outcome variable of these station area characteristics station use is also described. The choice of indicators used in the descriptive model to measure these station area characteristics has a large influence on the results. It also highly depends on the structural availability of the required data over a longer period of time. Therefore a simultaneously studies are done on which indicators can be used and what data is actually available to quantify the characteristics that these indicators represent.

5.1.1 Indicator selection

Previous studies yield a list of potential indicators to cover the TOD factors (Bertolini, 1999; Chorus, 2012; Reusser et al., 2008). The indicators used for this study were extracted from the literature discussed in the theoretical framework. No additional research was done to obtain a broader set of indicators, as it was assumed that they are sufficient to describe station area characteristics.

Due to the longitudinal nature of this study, the most important data requirement is its continuity over the entire study period. Furthermore, for practical and time consuming reasons a balance was found between the number of indicators and the increased model accuracy. The two data resources that qualified best for use in this research are general census and timetable data. Additionally, in order to describe general longitudinal trends, an economic indicator is necessary.
Based on the list of possible indicators and the type of data source, we used 10 indicators and a single outcome variable in this research. In *Table 4* the list of included indicators is displayed and which type of data is used to quantify these indicators. In *Table 5*, the excluded indicators are displayed with a short description of the reason of exclusion.

Table 4 List of chosen indicators

Indicator	Data source
Activity	
Population	Population census data (GIS)
The number of jobs per economic sector	Population census data (GIS)
Degree of functional mix	Population census data (GIS)
Accessibility	
Directions served by train	Timetable data
Frequency of train services	Timetable data
Number of stations or activities within a certain travel time or distance	Timetable data/ Population census data (GIS)
Type of train services	Timetable data
Station use and traffic flow	
Passenger numbers	Transportation census data
Gross Domestic Product	IMF economic census data

5.1.2 Indicator exclusion

To measure the accessibility of station area access and egress modes several indicators were proposed by previous research, but none were adopted in this study. In the Tokyo Metropolitan Area, walking is the most important mode of access and egress for station areas. However, conduciveness of the walking environment of station area surroundings is excluded from this study. This is due to the complexity of the methods objectively measuring these characteristics and the limited availability of the associated data.

Proposed indicators for the use of bicycle were disregard based on a lack of historical data on the availability of bicycle lanes and bicycle parking capacity. Car accessibility did not play a significant role in this research because its share is negligible as access or egress mode. It must be stated that in the hilly suburbs the car is more often used as access mode for dropping-off and picking-up passengers. This function cannot be described by the indicators proposed in previous research such as distance to the closest highway exit and parking capacity near the station area.

The number of directions of other public transport (bus & tram) has been used as an indicator in previous research, but was not applied here. One reason to not use this indicator was that there is no single source which can supply data on the number of bus lines/ directions. In the catchment area of the Den-En Toshi line, many different private and public bus operators are active, collecting the appropriate data does not fit within this research framework. The second reason was that many bus lines have a service frequency below once per hour. This has to do with a certain policy strategy of some of the private bus companies (Personal correspondence with Tokyu Corporation). Counting just the number of bus lines could therefore give a distorted image. For example, the more elaborate service frequency should be included in such an analysis as well.

Since the suggested data sources lack the ability to describe the station area accessibility, data of the Person Trip Survey (PTS, a survey on the travel behaviour of the citizens of the TMA that is held every 5 years) was considered. From the PTS data the number of trips and modes used to and from station areas can be derived. However, describing the station access and egress characteristics in this indirect way was disregarded because it does not show why it is conducive to this particular access or egress mode but only shows the trip characteristics. Furthermore, it cannot describe any change over time as only the PTS for 2008 was made available.

Table 5: List of excluded indicators

Indicator	Reason of exclusion
Activity	
Conference rooms and educational facilities	No historical data available
Distance from the station to the town centre	Not relevant for this study
Commercial services	Sufficiently explained by employee data
Urbanity of station surroundings	No clear operationalization available
Accessibility	
Conduciveness of station area for walking	No clear operationalization available
Number of directions of other public transport (bus)	Difficult to obtain, and expected to give distorted image
Daily frequency of other public transport	Difficult to obtain
Distance to the closest motorway access	No important access or egress mode
Car parking capacity	No important access or egress mode
Bicycle access (bicycle lanes)	No historical data available
Bicycle parking capacity	No historical data available
Passenger frequency	Used as a outcome variable in this study
Direction of commuters	Used as a outcome variable in this study
Staffing	All Stations identical
Quality of intermodal change	No clear operationalization available
Composition of station area users	No data available
Age and history of railway station	No clear operationalization available
Type of railway station (network function)	No clear operationalization available
Ticket availability	All stations identical

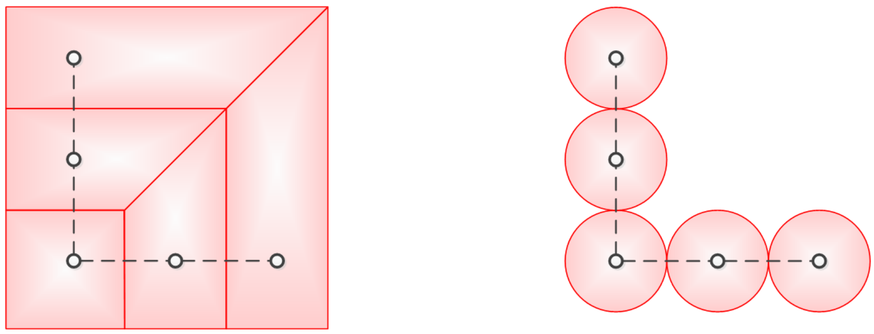
In addition, some indicators that have not been described in the indicator list can be extracted from the timetable data. Such as first and last train (total hours of operation), total number of trains on one day, weekend services and off-peak frequencies, both during day and evening times. These indicators are disregarded because they are predictor variables for a differentiation that was not done in this study. As will be described in the section on modelling passenger flow, no distinction was made between different days of the week or time of day.

In general, most of the indicators proposed in previous research were disregarded solely because of their lack of proper historically continuous data. Others were disregarded because of the unclear operationalization and the kind of data required, describing the proposed indicator. The remaining indicators cover three of the five TOD factors, leaving out “distance to transit” and “design”. Therefore, a partial set of predictor variables for the station accessibility was used in the model building, which has to be taken into account when interpreting the results.

5.2 Defining the station area

The analysis of activities within a station area first requires a definition of the station area itself. In transport studies, in order to determine movement patterns, the flow estimate is usually based on the socio economic characteristics of an area. For traffic flow on railway lines, this area of influence is defined as the catchment area of each station along the railway line and is based on the Voronoi diagram (see *Figure 13*A). This method only takes into account the network characteristics and disregards station specific characteristics. As this study is aiming to determine the relationship between activities and accessibility of station areas and the resulting traffic flow, it requires a different approach to determine the influence of a station. Therefore, the station area is defined in accordance with Bertolini (1999) as a surface included within a certain radius of influence around the station (see *Figure 13*B).

Figure 13:



Bertolini (1999) argued that the area of influence could be defined as a surface included within a walkable radius of 700 metres from the main pedestrian entrance to the public transportation node. This is based on the assumption that people are only willing to walk for a maximum duration of 10 minutes from the station to reach their desired destination. All activities that lie outside of this reach are negligible in the analysis of the immediate surroundings of the station. This assumes that the station area is sufficiently dense such that all the relevant activities can be reached on foot. To verify whether the majority of the trip origins and destinations lie within this walkable radius access and egress patterns in station areas along the Den-En Toshi line are analysed. For this analysis, Person Trip Survey data from 2008 was used.

For practical purposes, it was disregarded that the stations are not accessed and egressed directly along a radius, but always with a slight detour over the available road infrastructure. It is also assumed that the average distance covered on foot within 10 minutes is 700 metres. In practice, the number of trips made within the 700 metre walkable radius is slightly larger than the number of trips with a real length of 700 metres or less. It must however be noted that the assumed walking speed also influences which trips are captured within the defined radius.

5.2.1 Dataset

The type of data utilised in defining the station area is mobility panel data. In the major cities in Japan a mobility panel is held every 5 years, called the Person Trip Survey (PTS). During a single day, respondents register their travel behaviour and answer a set of general questions regarding their mobility. For this study the results of the 2008 PTS of both the Tokyo and Kanagawa prefectures are utilized. From these datasets the entries were selected in which the respondent used the train at one of the Den-En Toshi line stations.

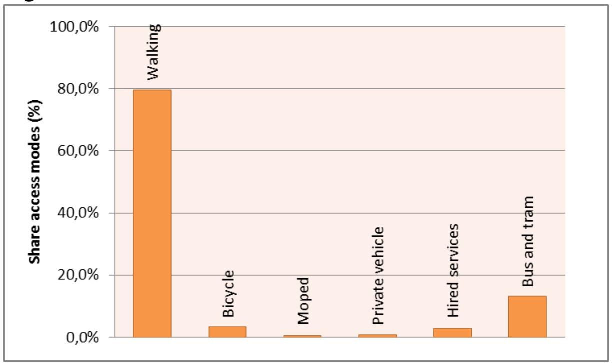
The entries concerning trip origin, destination, transfer locations, arrival- and departure times, trip purpose, mode and duration were retrieved from this dataset and used in the analysis of the station area definition. Entries with missing, unknown or false values in either the mode and duration characteristics were removed from the dataset. For example, if the mode was unknown, the action radius could not be calculated and the entry was unusable in this analysis. Over 17.000 registered trips on the Den-En Toshi line remained after processing, from a total of 19.000 entries.

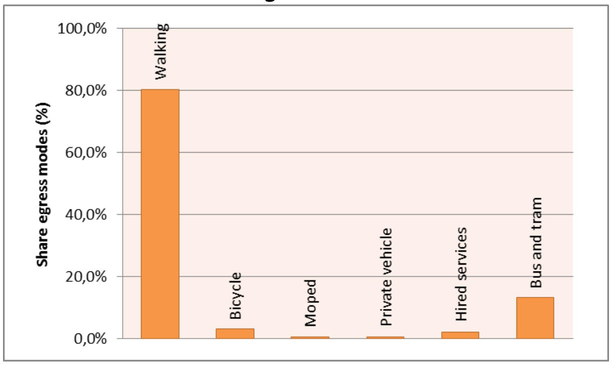
5.2.2 Analysing access and egress trip characteristics

Important for determining the station area is by what means and purpose the stations on the Den-En Toshi line are actually accessed and egressed. Only the mode with which the station is directly accessed or egressed was included in this analysis. This means that, when the total access or egress trip consisted of multiple modes with at least one other transfer, this was disregarded. From the dataset, it appeared that when the access or egress trip consisted of multiple trips, it concerned a bus trip to the station in combination with a walking trip to the bus stop in over 99% of the entries. It was assumed that the walking trip to and from the bus stop on average will neither increase nor decrease the action radius of the bus. It was therefore accepted to only investigate the mode directly connected to the station.

Of all the trips to and from the stations on the Den-En Toshi line, 80% of the trips were made on foot, as can be seen in *Figure 14*. With 13%, the second most important access and egress mode was the bus. Therefore, for the case study of the Den-En Toshi line, it can be stated that the majority of the access and egress trips were made on foot. Other modes such as bicycle, moped, car or taxi are relatively seldom and will arguably be of little influence in defining the station area. Furthermore, it shows that little distinction can be made between access and egress trips, because the trips are measured over a full day.

Figure 14: A. Distribution share access modes *B. Distribution share egress modes*





After concluding that walking is the main access and egress mode in the Den-En Toshi line station areas, the following step was to analyse the distance of these access- and egress trips. The PTS data only contains the duration of each trip, so in order to determine travel distances average travel speeds for each of the access and egress modes were assumed and travel distances derived. The speeds that were assumed for each mode can be found in *Table 6*, where also a summary is shown of the average mode shares and trip distances for access and egress trips combined.

Table 6: Trip distance per mode

Mode	Assumed speed (km/h)	Speed (m/min)	Trip share (%)	Average trip distance (m)
Walking	4,2	70	79,89%	623
Bicycle	10,0	167	3,17%	1.753
Moped	15,0	250	0,52%	2.300
Private vehicle	30,0	500	0,70%	5.486
Hired services	30,0	500	2,47%	4.625
Bus and tram	15,0	250	13,24%	3.749
Average				1.220

The average distance over which the stations on the Den-En Toshi line were accessed and egressed is 1220 metres. The average distance travelled by bus is 3,7 kilometres which with a mode share of 13% strongly influences the overall average distance travelled. The average distance for walking trips was 623 metres. It can be assumed that respondents using the bus as access or egress mode are not attracted to the station by the available activities in its vicinity but solely for its network value. For other modes with a large range the same can be concluded. For example Taxi, with an average range of about 5 kilometres and private vehicle too, are most likely attracted by activities outside the direct station surroundings. For bicycle, with an average distance 1700 metres and moped, 2300 metres, it can be argued that some of the trips are made within the direct vicinity of the station. However, because of their small shares they are of little influence and further analysis in this research focussed solely on walking as an access or egress mode.

The influence of trip purpose on trip distances within the station areas was also investigated. When average trip distances show a distinct differentiation between access and egress trips for different trip purposes it might be desirable to distinguish different station area types. For example, distinguishing between stations areas with a mainly residential or in contrast work functions and adjust the associated sizes of those station areas accordingly. The general distribution of trip purposes for all trips to and from Den-En Toshi line stations is shown in *Figure 15*.

Figure 15: Distribution trip purpose

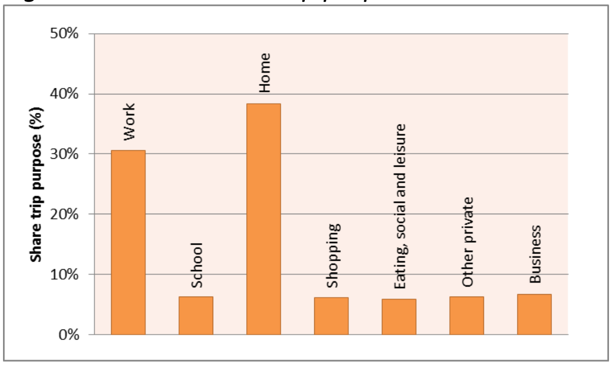


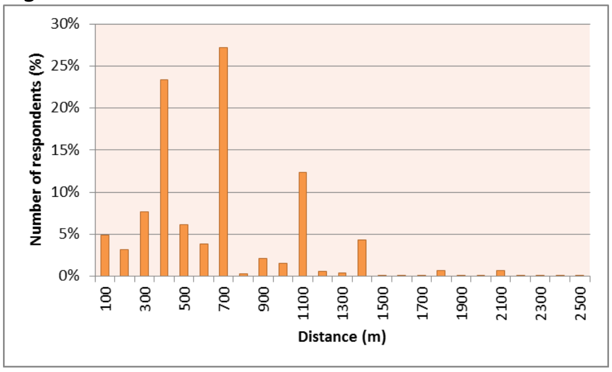
Table 7: Trip distancs for egress walking trips

Trip purpose	Average trip distance (m)
Work	612
School	803
Home	726
Shopping	320
Eating, social &leisure	516
Other private	451
Business	593

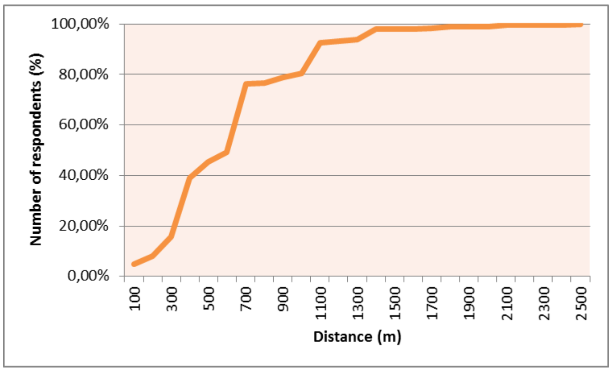
As only trip purpose, and by extension trip destination, is known but not the origin only for the egress side trip purpose was analysed. *Table 7* shows that there is a clear distinction between the distances travelled for each of the trip purposes. Especially for trips with a shopping purpose, it is striking that the distance travelled from the station is very low compared to other trip purposes. There is a difference in the distances travelled between the most important trip purposes, home and work. However it is not so extreme that station area definition should be changed according to the main station area function. The differences in trip purposes cancel each other out in the overall average distance travelled on foot of 623 metres.

The average distance travelled on foot was 623 metres, with a standard deviation of 400 metres. A look at the distribution itself as depicted in Figure 16A shows a more nuanced image. The course of the graph is the result of respondent bias; respondents are more likely to assume their trip takes 5, 10 or 15 minutes than anything more detailed in between. This resulted in large corresponding peaks at 350, 700 and 1050 metres. *Figure 16*B illustrates what share of the registered trips is made within a certain radius. Most of the trips, over 75% are made within 700 metres of the Den-En Toshi line stations, after which the graph smoothens. The next major increase in the share is at 1100 metres, resulting in covering a total of 92% of the access and egress trips made on foot.

Figure 16: A. Distribution distance walked



B. Cumulative distance walked



Choosing to define station area in a way that the vast majority of trips are included would assume a radius of 1100 metres based on these results. However, considering an action radius larger than 700 metres can compromise the overlap between station areas, as the average distance between stations on the Den-En Toshi line is only 1.2 kilometres. This would quickly result in an overestimation of the explanatory values of the station areas, moving away from the focus on activities within the station areas themselves. When a smaller radius than 700 metres is adopted, a large share of the trips in close proximity of the stations are lost and therefore a large share of the activities in station areas. According to the analysis of the PTS data, 80% of the access and egress trips are made on foot, of which 75% is made within a 700 metre radius of the stations. This results in a share of over 60% of all the trips utilizing the Den-En Toshi line stations that are made on foot within 700 metres of the station itself. Based on this, the assumption by Bertolini (1999) was confirmed and adopted for this study.

5.3 Measuring intensity and diversity of activities

As described in the previous section, the activities within a station area are measured using the population census. Census data can be retrieved from the Ministry of Internal Affairs and Communications Statistics Bureau. The census contains information on the population and the number of jobs, grouped in a number of job categories. These numbers are obtained from a geographic information system (GIS) where geographical information based on the location, descriptive attributes, and temporal characters of phenomena are integrated (Hanson & Giuliano, 2004). The dataset on the most detailed level, the neighbourhood or district (Chōme) level is published every 5 years. The data for the years 2000, 2005 and 2010 were retrieved from the Statistics Bureau website (http://www.e-stat.go.jp/) in December 2013.

Prior to the year 2000 the datasets on the district level are not available online, but can only be obtained from the paper archives of each of the corresponding cities. Of the required datasets of the years 1985, 1990 and 1995 only more aggregated data is available on a ward (Ku) level and only for the city of Tokyo. As it is very time consuming to access the city archives of the city of Tokyo, Kawasaki and Yokohama the dataset was not further extended.

It was attempted to obtain more specific data on historical land-use developments by interviewing involved people of the Tokyu Corporation itself. This did not yield any results, because information retrieved from the interviews with Tokyu Corporation employees was not specific enough to be quantified and used in the model estimations. This information would furthermore only cover the developments executed by Tokyu Corporation itself and not by any other third parties, which was the majority of regular land-use developments (Personal correspondence with Tokyu Corporation).

5.3.1 Data processing

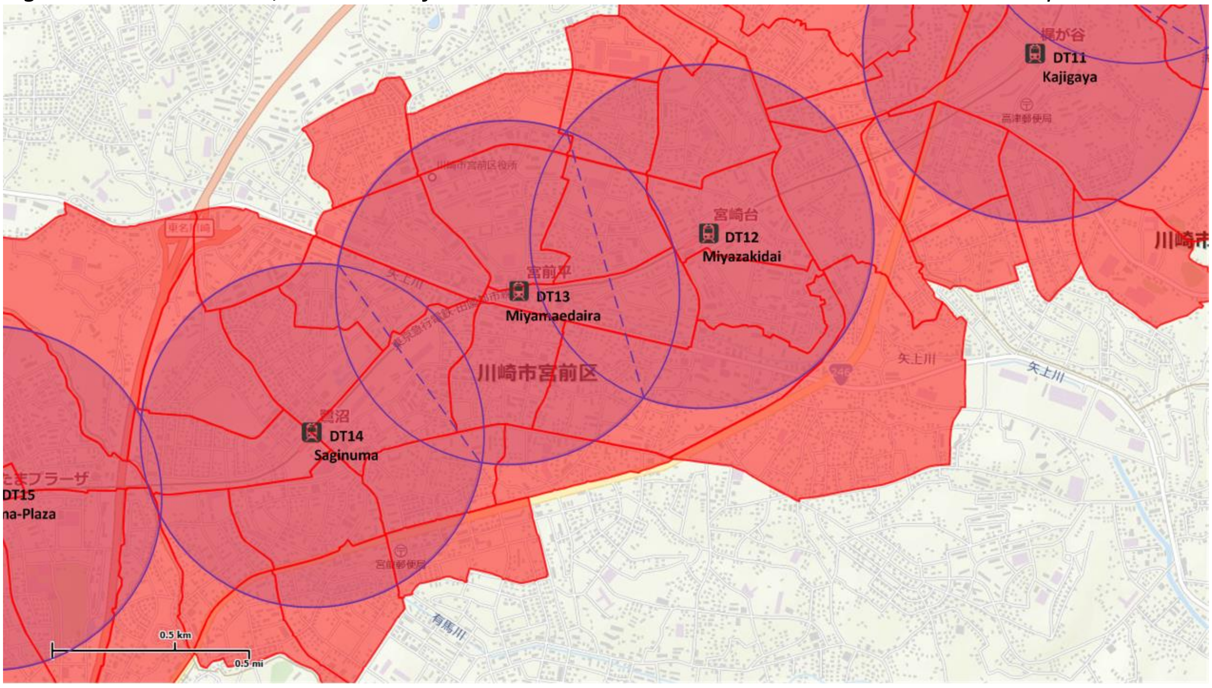
The first step in data processing required translating the census data from districts to station area, as defined in the previous section. The districts are very irregularly shaped and population and job numbers for each station area cannot be directly obtained, as can be seen in *Figure 17*. Chorus (2012) included all the districts of which the centre was located within the walkable radius. For this study, it was chosen to estimate the share of each district within the stations walkable radius in order to retain more detail.

A number of stations along the den-En Toshi line have an overlap in the walkable radius. Therefore, the population and workforce of the overlapping areas were divided according to the same principle as applied in the catchment area method. For every station with an overlap, population and workforce were not included in the attractiveness value of both stations, but were allocated to the nearest one. Otherwise a development within the overlapping area would cause an overestimation of the related growth in the predictive model for station use.
As some of the district key-codes and shape differ between the datasets, this is accounted for by redefining and recalculating the concerning districts. An overview of all Den-En Toshi line station areas can be found in Appendix 9.2.

The station areas are described for each year, but the census data supplies only one data point for every five years. In order to obtain data points for the years between those for which the datasets are available they were linearly interpolated. Another option would have been to use a single data point for five consecutive years, but the error yielded by this method was much larger compared to linearly interpolated data points. For the required data points that lay outside the available dataset, the data points of the immediately adjacent years were linearly extrapolated. This processing step yielded a workable dataset of the years 1998 to 2012.

It is very important to note that this method affects the results of the analysis. The assumption of continuous change can result in both an under- or overestimation of its effects on station usage and portray a false relationship. In the analysis, it might be desirable to estimate the impact of this assumption by comparing the model run with the continuous dataset with one where only the three true data points are utilized.

Figure 17: Station area, translation from districts to station area and station area overlap

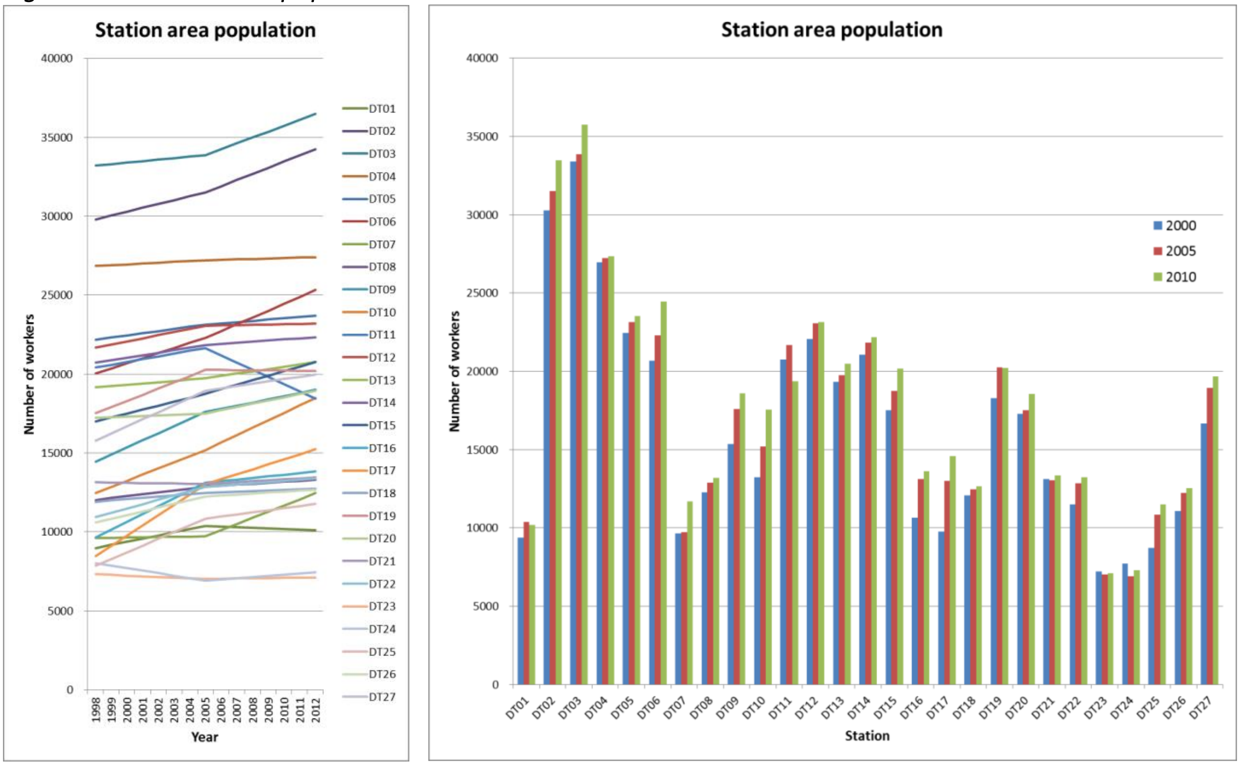


5.3.2 Population

For the station area population, the number of residents for each of the districts outlines the population density in the station areas. The number of residents for each of the station areas was calculated for the years 2000, 2005 and 2010. The result is shown in *Figure 18*.

There is an overall trend visible in this graph (*Figure 18*) showing that further away from the centre of the city the population densities are decreasing. Remarkable is the low population density around Shibuya station (DT01, see Appendix 9.1 for all station names and numbers and use *Figure 10* as network reference) where it should be around the same level as DT02 and DT03. An explanation could be that the high cost of living in the centre or possibly because of the space occupied by the station itself. Most likely, the data available for the districts around Shibuya station are not completely reliable. It was attempted to correct the data, but this remained unsuccessful. Therefore, the available data on Shibuya station was renounced and Shibuya station excluded from further analysis. As a consequence, some effects might remain unexplained. However, excluding this station from further analysis improved reliability of the model estimations and predictive value (i.e., generalizability) of this study.
For Futako-Tamagawa (DT07), the low number of residents could be explained by its geographical location directly adjacent to the Tama River, with part of the station platforms suspended above the rivers' flooding area. Overall, there is a general increase in the number of residents over the years for most stations. Only some of the smaller and less accessible stations at the end of the line (DT18, DT21, DT23 and DT24) show a more or less stable number of residents.

Figure 18: Station area population



5.3.3 Workforce clustering

In order to describe the intensity and diversity of activities in station areas as good as possible, optimal use must be made of the distinction in job categories made in the available census data. In a previous study of the Tokyo station area's (Chorus, 2012), the workforce was clustered in four different economic clusters, Services and administration, Retail, hotel and catering, Industry and distribution and Education, health and culture. For this research, a similar approach was chosen, where each job category represents a type of activity taking place in station areas.

The use of census data from three different years posed the problem that the defined job categories in each of the datasets differ from each other. Each of the sets holds more or less detail by utilizing larger, smaller or even completely different job categories, making it difficult to compare these datasets. The combining of job categories only allowed the use of three separate economic clusters without any overlap or differences. A detailed table of the job categories included in each of the economic clusters is available in Appendix 9.4. The three economic clusters used in this research are:

1. Transportation, information, communication, finance, real estate, research, education, welfare, public services and living related services.
2. Hotel, restaurant, café and retail
3. Agriculture, forestry, fishing, mining, construction, manufacturing and utility

The first cluster holds the most job categories: It includes office workers and service industry, which are the largest categories in the TMA. Due to overlap in the categories, it furthermore represents education, health and culture. This cluster indicates the number of office jobs available in the station area. The second cluster, with hotel, restaurant, retail and catering, is an indicator for the number of leisure activities available in the station area. The third category indicates the intensity of agriculture or heavy industry in the station area. These three clusters provide a sufficient explanation of the activities that take place with the different types of land use available in the station areas.

A visualization of the size of each of the economic clusters over the years is presented in *Figure 19*, *Figure 20* and *Figure 21* respectively. Deducing from these figures it can be stated that in general towards the sub-centre of Shibuya (DT01) the density rises for all the economic clusters in the station areas. The sole exception is Shibuya station itself. Similar to its population density, the number of jobs in the Shibuya area is grossly underestimated as can be expected from the situation in the direct station area. As described in section 5.3.2, the presumption to exclude the Shibuya station area from the analysis is also desired regarding the station area workforce.

For workforce cluster 1, a sharp decline in the number of workers in after 2005 can be found in the left graph of *Figure 19*. This effect could be explained by the global financial crises of 2008. The decline is stronger in the station areas nearer to the sub-centre as can be seen in the right graph of this figure.

For workforce cluster 2, a general decline over the last decade can be distinguished in the left graph of *Figure 20*. This can be explained by the decreasing number of restaurants due to population aging and a shift in the culture of eating out. The right graph of this figure again shows a steeper decline in the station areas in proximity of the sub-centre, most likely due to the interdependency of the restaurant and café business with the number of workers in the vicinity.

In *Figure 21*, the size of workforce cluster 3 depicts a massive decline in the number of workers in the heavy industries, especially nearer to the sub-centre. This is in accordance with the notion that high land values in the proximity of sub- and regional centres make it less likely for heavy industries to locate near one. Historically seen, the expansion of the TMA therefore would imply a movement of these activities outward into the suburban areas through the course of its growth.

Figure 19: Station area workforce; cluster 1

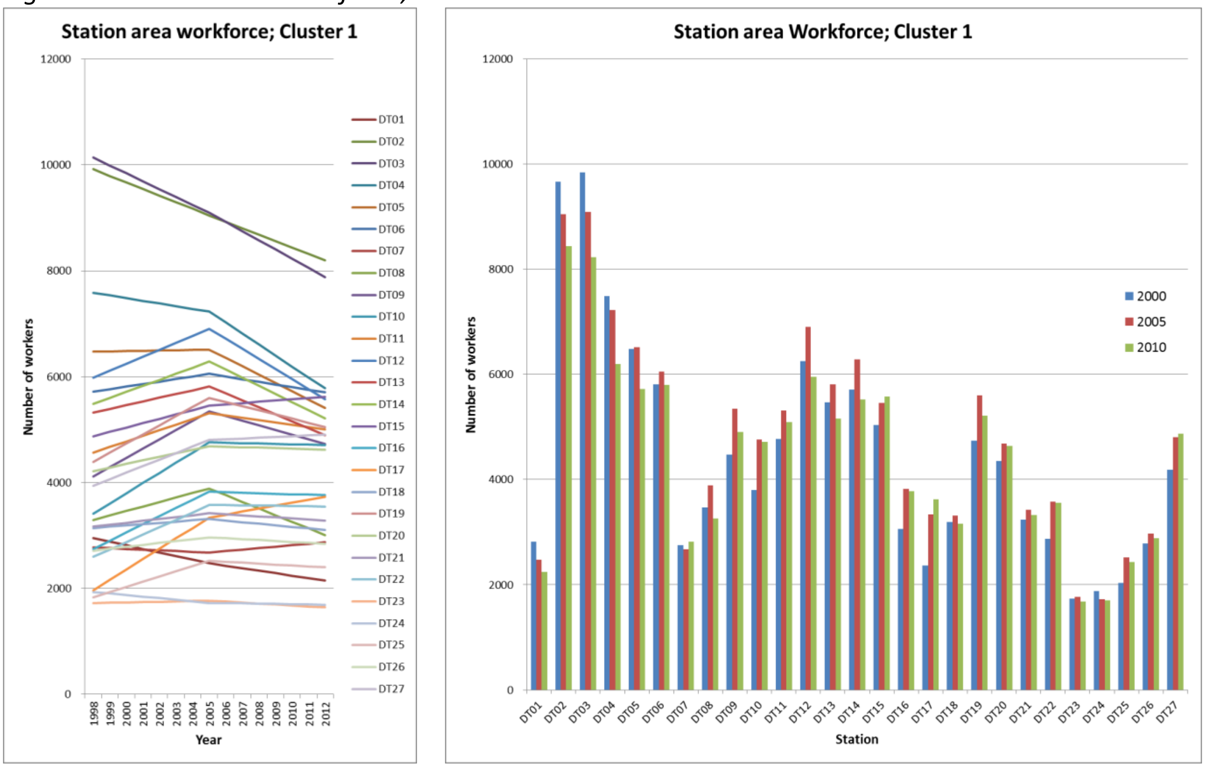
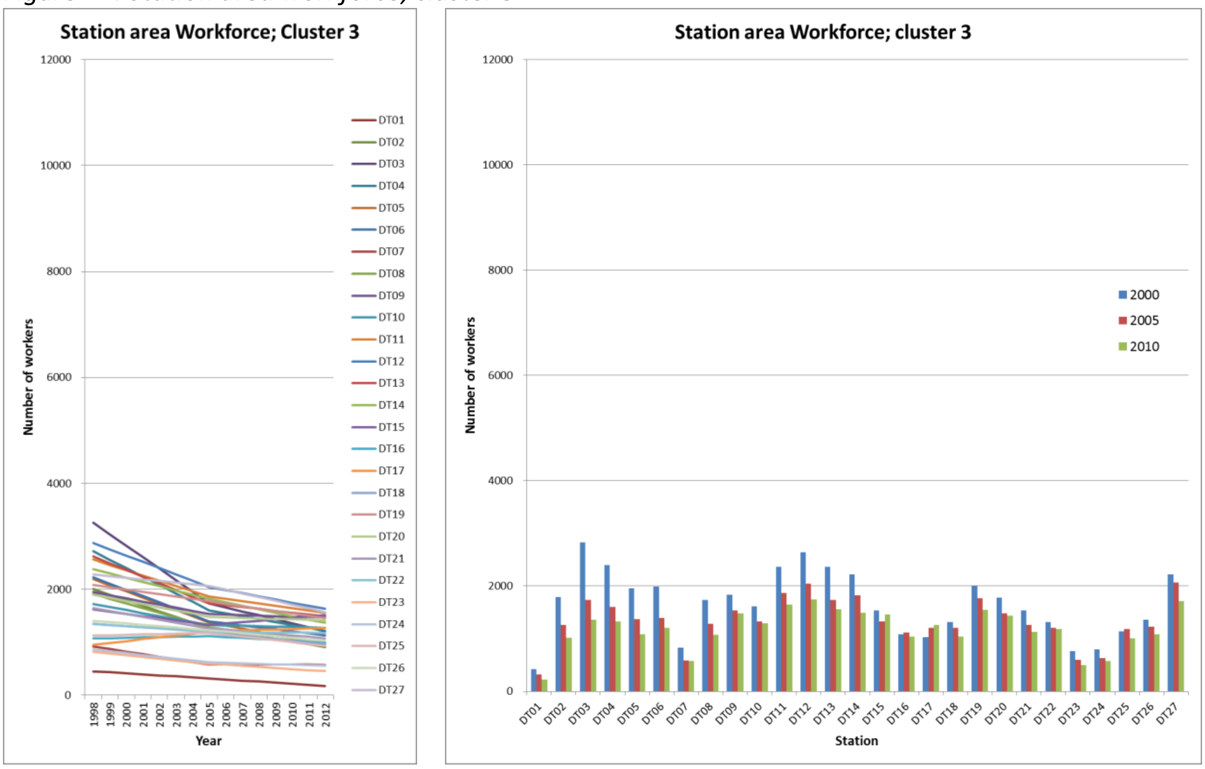


Figure 20: Station area workforce; cluster 2

Figure 21: Station area workforce; cluster 3



5.3.4 Functional mix

To measure not only the intensity, but also the diversity of activities, a measure of functional mix is included in the analysis of station area characteristics. The diversity of activities in a station area is one of the five Transit Oriented Development (TOD) indicators and can give an insight in the success of a station area. This measure of diversity furthermore says something about the function that a station area fulfils in the network. It measures whether a station area acts as residential neighbourhood, an economic centre, a place for retail, culture and leisure or a mix of all these functions. With the population (x_1) and the three defined workforce clusters (x_2, x_3, x_4) the degree of functional mix is calculated according to Equation 1.

Equation 1: Measure of functional mix

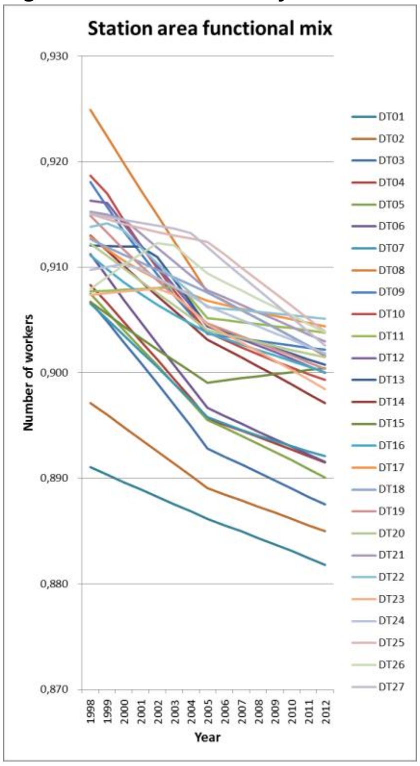
$$Degree\ of\ functional\ mix = 1 - \frac{\left(\left(\frac{a-b}{d}\right) - \left(\frac{a-c}{d}\right)\right)}{2} \quad with \begin{cases} a = max\{x_1, x_2, x_3, x_4\} \\ b = min\{x_1, x_2, x_3, x_4\} \\ c = Average\{x_1, x_2, x_3, x_4\} \\ d = Sum\{x_1, x_2, x_3, x_4\} \end{cases}$$

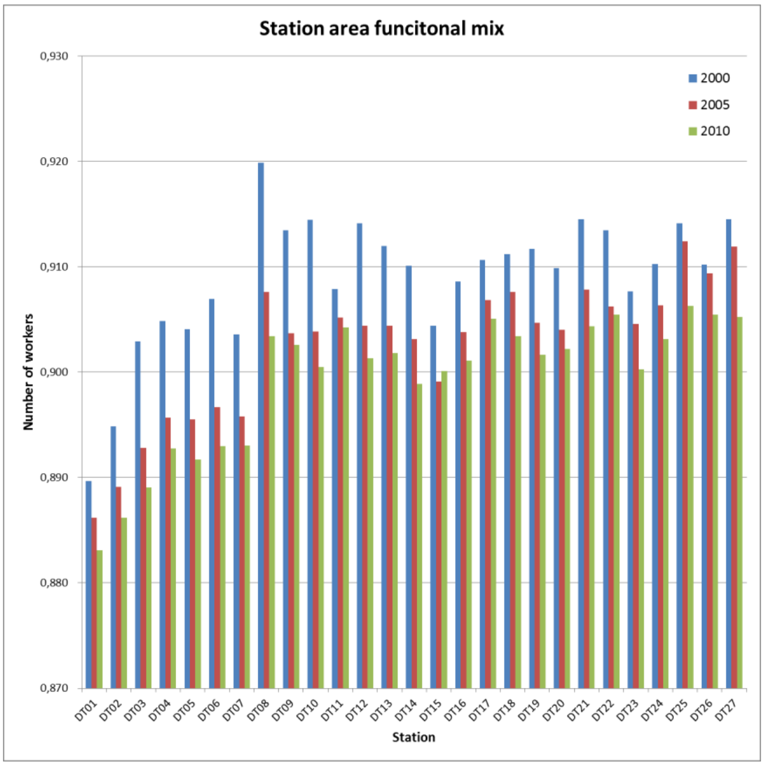
The formula states that when all functions measured are equal, the functional mix is maximal. When one or more of the functions described are not present, the functional mix is at its minimum. The number obtained does not give much insight in itself, but the relationship between different station areas and their respective functional mix does. As ratios are compared, it is unnecessary to rescale each of the functional indicators before calculating the degree of functional mix.

The design of the formula largely depends on the assumption that the perfect functional mix is obtained when each function measured is equal in size. This causes some distortion, because for example the desired functional mix in station areas in a densely developed region does not include any heavy industries. In dense urban areas preference goes to a mix of office and service, leisure and residential activities. This shows in *Figure 22*, where stations further from the sub-centre show a higher functional mix, most likely due to the larger presence of workers in cluster 3. The general decrease in functional mix over the last decade can also be largely attributed to the diminishing workforce of cluster 3.

Due to these reservations it, should be considered that this might not prove a good indicator for this model. The analysis should point this out when building the model and looking for power of the predictor variables concerned. An assessment can then be made based on the performance of this indicator whether or not to continue to include it in the descriptive model.

Figure 22: Station area functional mix





5.4 Measuring station area and network accessibility

Accessibility of station areas can be described by the TOD indicators Distance to transit and Destination accessibility. As described in the indicator study, the absence of consistent historical data on accessibility within the station area, such as bus lines and bus frequency, rules out the use of a distance to transit indicator. The Destination accessibility can be measured using historical timetable data of the Den-En Toshi line.

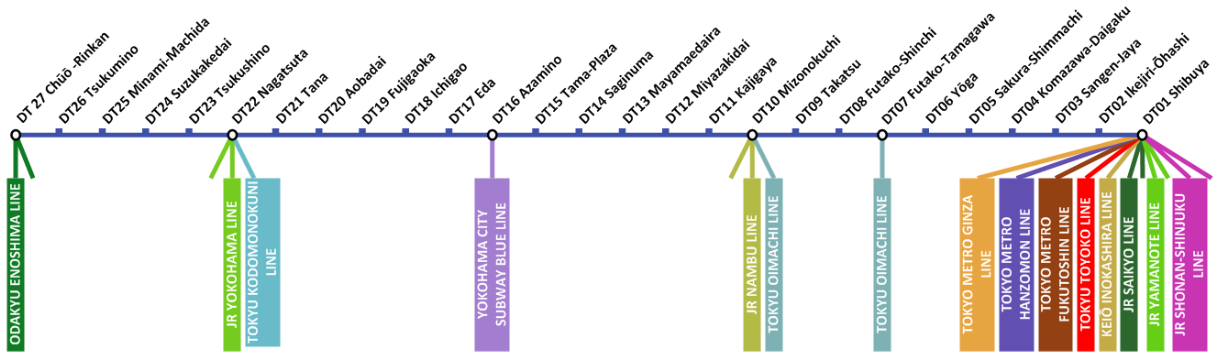
Starting from 1998, JR published the Tokyo Jikokuhyou (東京時刻表), including timetables for all the railway lines in the Tokyo metropolitan area. These were retrieved from the Tokyo Travel Agency library (日本交通公社旅の図書館). Prior to this year there was no central recording available for the timetables, but the Den-En Toshi line timetables starting from 1985 are partly available at the Yokohama municipal library and partly at the Tokyu museum library in Tokyu Corporation timetable publications. The Den-En Toshi line timetable does not change every year, in some cases remaining identical to previous years.

5.4.1 Number of directions

Number of directions served indicates the number of distinct directions that can be travelled towards originating from a station. A terminus station has one direction of travel, a through station two directions and a station where multiple lines intersect can have three or more directions. The number of directions served for each station is derived from historical dates when services commenced on each line concerned. A distinct direction is defined as the general direction of travelling. For example, a single line with two different terminus stations on one end is not considered as two distinct directions. In Appendix 9.1, describing the general characteristics of the Den-En Toshi line, the possible transfers at each station are included. The name of the connecting line, the number of directions and the year the service on the connecting line started are all tabulated.

Ahead of the completion of the Den-En Toshi line in 1984 (previously part of the Ōimachi line and the predecessors of the Shin-Tamagawa line, the Tamagawa and Kinuchi lines) Shibuya station (DT01) was already served by JR's Yamanote line, Tokyu's own Toyoko line, the Keio Inokashira line and the Tokyo Metro Ginza and Hanzōmon lines. In 1996 with the extension of the Saikyō line from Akabane via Shinjuku to Ōsaki over the Yamanote freight line and the interlacing with the Rinkai line starting from Ōsaki in 2002 add two more directions to Shibuya station. In 2001, service of the Shōnan-Shinjuku line commenced over the same Yamanote freight line section calling at Shibuya, adding a further two directions to the stations service. Finally, with the completion of the newly built Tokyo Metro Fukutoshin line in 2008, another direction was added to Shibuya station. The Narita Airport Express was not included due to its low frequency. Another reason was that this line runs in concurrence with already existing lines.

Figure 23: Den-En Toshi line connections



At the station of Sangen-Jaya (DT03), the Setagaya line is also disregarded as an additional direction. The Setagaya line is classified as a tramline, which would categorise it as an access and egress mode. Furthermore, the Setagaya line is not immediately connected at Sangen-Jaya station.
At Futako-Tamagawa (DT07) station, Tokyu's own Ōimachi lines connects to the Den-En Toshi line. The extension of the Ōimachi line from Futako-Tamagawa (DT07) to Mizonokuchi (DT10) in 2009 is also considered as separate line. It is assumed that for these two stations, the general direction of travel is different. Therefore, one direction is added to Mizonokuchi station and a second one to Futako-Tamagawa station. The Ōimachi line has no stops at the intermediate stations of Futako-Shinchi (DT08) and Takatsu (DT09). Mizonokuchi is also served by the JR Nambu line at the directly connected Musashi-Mizonokuchi station.
In 1993 Yokohama Municipal Subway opened the newly constructed terminal of the Blue line at Azamino station (DT16) adding a direction. Nagatsuta (DT22) station is also served by the JR Yokohama line and is the terminal for the Kodomonokuni line and the station of Chūō-Rinkan (DT27) is served by the Odakyū Enoshima line.

5.4.2 Frequency of operation

The frequency of services indicator is comprised from the number of trains that depart at each station within the busiest hour. The busiest hour was defined as the busiest hour of operation during morning rush hour, between 07:00AM and 09:00 AM on a weekday. For each station the maximum number of trains that would pass in one hour within this timeframe was taken as the indicator value. As described in the indicator study, the total number of trains per day is not taken into account by itself, but is assumed to be represented by the height of the frequency during the busiest hour.

After completion of the Den-En Toshi line in 1984, an increase in frequency can be seen over the following 10 years of operation in *Table 2* (section 4.2.2). As this table only shows the frequency between Futako-Tamagawa (DT07) and Shibuya (DT01), several other notions must be made. Frequency changes also took place with the addition of Azamino (DT16) as an Express stop after the opening of the Blue line in 1993. Furthermore, the increase in frequency at Tama-Plaza (Dt15), Azamino, Aobadai (DT20) and Nagatsuta (DT22) after extending more express services beyond Saginuma (DT14) station up to 2007. The final major frequency change stands out when in 2008 all local stations between Shibuya and Futako-Tamagawa were upgraded to Semi-Express stations. These Semi-Express trains run only during rush hours, when all express trains are converted to this type. This is the result of an attempt of Tokyu Corporation to decrease platform crowding at Shibuya station. When the speed difference between local an express trains was eliminated on this section, the frequency could be increased even further to maximum capacity.

5.4.3 Station type

The indicator for station type addresses whether the station is frequented only by local trains, or also express trains or any other services. For the Tokyu Den-En Toshi line, there are local, semi-express and express trains in operation. Semi-express trains have been introduced from 2007 onwards. For each station, the type of train service available was determined during the busiest hour between 07:00AM and 09:00AM, similar to the determination of the service frequency. This implies that any special weekend or holiday services are not evaluated in this comparison. The station types for each of the Den-En Toshi line stations (as is the current situation) has been included in Appendix 9.1, in the table containing the general line characteristics.
During the busiest hour, all express services are converted to semi-express services, leaving no distinction between express and semi-express stations. In order to prevent complications when using a categorical variable to estimate the forecast model, it was chosen to distinguish between two station-types: local and not local. This dummy variable was coded as 0 (local) and 1 (non-local).

5.4.4 Stations or activities within a certain travel time or distance

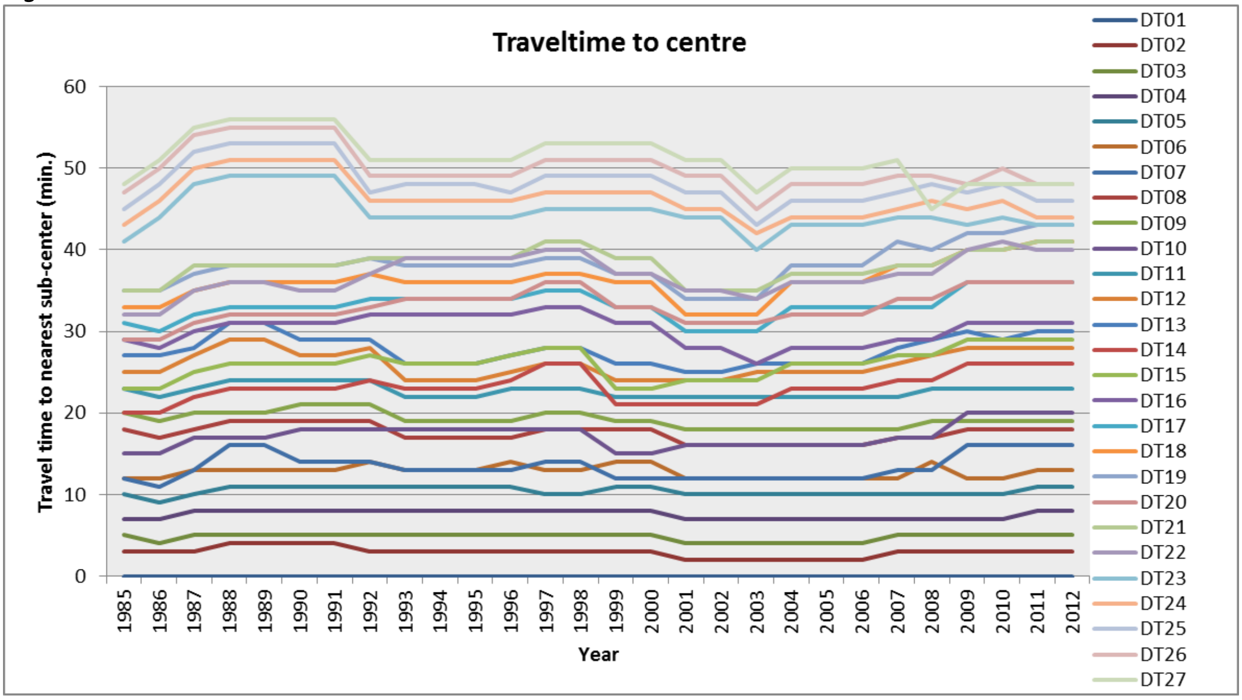
One important accessibility indicators is how many jobs/activities are available within a certain range of time, distance or cost (generalized cost of travel). There are several options to measure this, which vary degrees of accuracy and difficulty of implementation. Travel cost, or generalized cost of travel is disregarded due to data unavailability. Furthermore, travel time was preferred over travel distance, as it gives a more accurate description of the resistance to travel.

The least comprehensive would be to travel time to the CBD, or in this case the nearest sub-centre (the Shibuya area), in the general direction of travel. Other options are the number of stations within a certain travel time or weighing stations according to their importance in the network. For example, the number of jobs that can be reached within a certain travel time can be determined. The timetable data is only available as a paper reference or digital for 2014. Assessing network accessibility is therefore excessively comprehensive and deemed not feasible within the scope of this research. Therefore, travel time to centre was used for general purpose and job accessibility for 2014 only in a sensitivity analysis for the Node-Place model.

Travel time to centre

In order to keep the effort manageable station activities within a certain range was measured by travel time to the nearest major centre. Shibuya can be defined as a major centre in Tokyo and is therefore a reasonable measuring point. Shibuya (DT01) is one of the six major centres situated on the Yamanote loop line and the second busiest station in Tokyo. For each of the stations along the Den-En Toshi line the shortest travel time to Shibuya was measured. The shortest travel time was observed during the define morning rush hour period between 07:00AM and 09:00AM on a weekday. The possibility of transferring from the local to the semi-express or express trains was included.

Figure 24: Travel time to nearest centre



The travel time to the nearest centre is displayed in *Figure 24*. The graph displays the travel time to Shibuya (DT01) from each of the stations, for each year separately. No major trends stand out, remarking that over the course of its exploitation, travel times on the Den-En Toshi line have changed very little. This indicates that there is not much room for improvement. The line was maximally utilized from its initialization. It must be noted that frequencies did increase significantly, apparently without any deterioration of the travel time to the Shibuya area.

Job accessibility

Additionally to the network accessibility being described by the travel time to centre indicator, also job accessibility was determined. Because the digital timetable was only available for current travel times the job accessibility indicator was not included in the general analysis. Instead it was only used in the sensitivity analysis of the N-P model.

Job accessibility was determined based on generalised cost of travel. In this case the generalised cost is represented by the travel time between two stations. The travel times were determined using http://www.hyperdia.com/, a Japanese travel planning website. The travel times were retrieved for Tuesday December 2nd, 2014, between 08:00 and 09:00 AM. The shortest possible travel time was determined, including transfers from local to express services. From this data a travel time matrix was established.

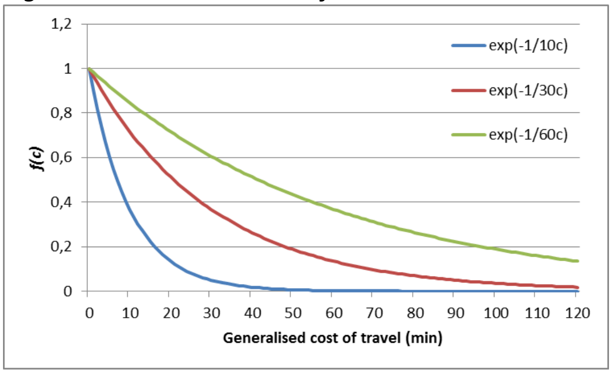
Job accessibility is measured as the number of jobs that can be reached within a certain travel time. This is for example, all jobs within 30 minutes travel. For this research it was chosen to use a cost-deterrence function, weighing the number of jobs with the travel time required to reach these jobs. A negative exponential was selected for the cost deterrence function, which is shown in Equation 2.

Equation 2: Cost deterrence function

$$f(c_{ij}) = exp(-\beta c_{ij})\ with \begin{cases} c_{ij} = generalised\ cost\ of\ travel\ from\ i\ to\ j\ (min) \\ \beta = \dfrac{1}{average\ travel\ time} \end{cases}$$

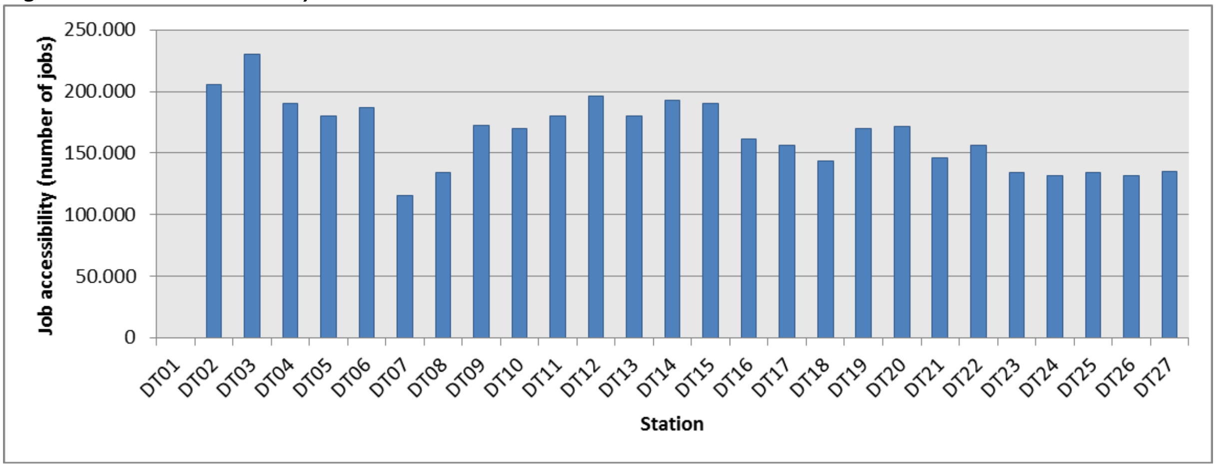
The course of the deterrence function is determined by β. *Figure 25* shows the effect of different β-values on the course of the deterrence function, relative to the generalised cost of travel. The value for β is specific to each area. A good estimate is one over the average travel time (de Dios Ortúzar & Willumsen, 2011). For a Dutch context this would be about 30 minutes. However, in Japan average travel time is over 60 minutes, which is also applied in this research. From the travel time matrix, the cost matrix is calculated for all possible connections.

Figure 25: Cost deterrence function



To determine job accessibility, the total number of jobs in *j* (all three workforce clusters combined) is multiplied by the cost of travelling from *i* to *j*. The job accessibility for *i* is then obtained by summing the weighted number of jobs over all *j*'s. The job accessibility is expressed as a number of jobs. Because the number of jobs for 2014 was not available, the closest available year (2010) was used. Shibuya (DT01) was left out of the calculation, as it would distort the image due to incorrect values for the number of available jobs. The job accessibility for the Den-En Toshi line is shown in *Figure 26*.

Figure 26: Job accessibility



The job accessibility shows a similar pattern as the distributions of the workforce clusters (*Figure 19*, *Figure 20* and *Figure 21*). However, the distribution is more flattened, showing lees distinction between stations. Because of the chosen distribution, based on the 60 minute average travel time, even the stations further away from the centre (DT01) show relatively large job accessibility. In the graph, the low job accessibility for both Futako-Tamagawa (DT07 and Futako-Shinchi (DT08) stand out. This is likely caused by the geographical location of these two stations on both banks of the Tama River, limiting the physical size of the station areas. Because the nearest stations have the largest impact on job accessibility, this also enhances the effect of reduced job accessibility for these two stations.

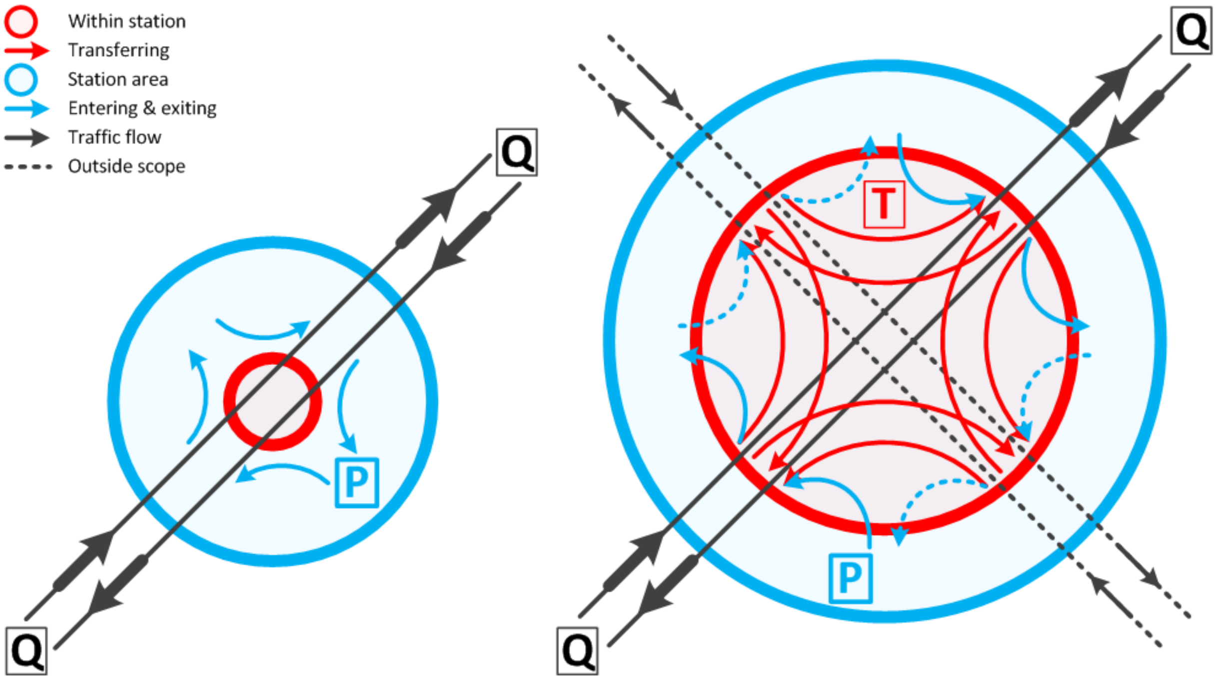
It has to be noted that this indicator has limited explanatory power. To obtain a complete image of job accessibility, it should be assessed on network level. Only being able to assess job accessibility for the stations along the Den-En Toshi corridor, a large area of influence is left out. Especially the influence of the jobs available in central Tokyo is underestimated. A large number of people using the Den-En Toshi line travel past Shibuya (DT01) further into central Tokyo.

5.5 Measuring station users

The success of a station area and the intensity of the infrastructure use were measured by utilizing passenger numbers that travel through the station areas and over de railway corridor. To describe the passenger movements from/to/in the Den-En Toshi line station areas and over the corridor, two datasets were retrieved. First, passenger data was retrieved from the Toshi Kotsu Nenpo (都市交通年報). This is a yearly report in which traffic data of the large metropolitan areas in Japan is summarised published by the Japanese Institute for Transport Policy Studies (ITPS). Based on counting data supplied by each railway company, yearly estimates were made for the passenger numbers of each railway station in the metropolitan areas. The Toshi Kotsu Nenpo was first published in 1984 and the most recent available version at the time was the 2011 edition (becoming available in 2013). Second, passenger data was obtained from Tokyu Corporation. This set consists of average daily passenger totals for each of the Den-En Toshi line stations from 2005 to 2012

The data obtained from the Toshi Kotsu Nenpo comprises of commuter versus non-commuter, upstream versus downstream and passing, departing and arriving passengers. For each station with more than one railway connection, the arriving and departing passenger were divided in whether they are transferring form other lines or just entering and exiting the station itself. *Figure 27* shows the relevant passenger movements that can be derived from this dataset. Both a standard through station as well as passenger movements for a station with intersecting railway lines are depicted. The red area represents the station itself and the passenger movements solely taking place within the station. These are the passengers that use the station solely for transferring to an intersecting line. The station area and the passenger movements out of and into the station are depicted in blue. Though depicted for clarity and marking their presence as dashed lines, the passenger numbers on the intersecting lines were irrelevant in the scope of this research and no data on these movements was used.

Figure 27: Passenger movements for both a through station and an intersecting station



5.5.1 Station area usage

The detail available in the passenger dataset allows for an opportunity to choose what to include when establishing the passenger forecast model. The forecast model is used to determine the relationship between the previously described station area characteristics and the number of passengers using the station area. This implies that the transferring passengers ([T], see *Figure 27*), who remain within the station itself when transferring should not be included in this part of the analysis. The passengers actually using the station area in *Figure 27* are depicted in blue and the total is represented by the blue [P]. As mentioned, the passengers coming from the intersecting lines that enter and exit the station area are not included and only shown as dashed lines. Since only a total number of passengers using the station area is required for this part of the analysis the direction of travel and the differentiation between commuter and non-commuter are disregarded and summed.

The dataset provided by Tokyu Corporation consists of average daily passenger totals for each of the Den-En Toshi line stations from 2005 to 2012, though not distinguishing between transferring and entering and exiting passengers. In order to compare the two datasets, the ITPS data was converted to total daily numbers. In this comparison, it was noticed that the numbers are identical, but that the years were shifted. For every publication of the Toshi Kotsu Nenpo, the Tokyu data was used of two years before the year of publishing. This was also confirmed based on several distinct features in the data, such as the opening of the Nagatsuta – Chūō-Rinkan section (DT22-DT27) of the Den-En Toshi line in 1984, the opening of the connecting Yokohama Municipal Subway Blue line at Azamino (DT16) in 1993 and the extension of the Tokyu Ōimachi line on the Futako-Tamagawa – Mizonokuchi section (DT07-DT10) in 2008. To correct for this error, the year count of the ITPS dataset was shifted by two years resulting in a passenger dataset running from 1982 until 2009.

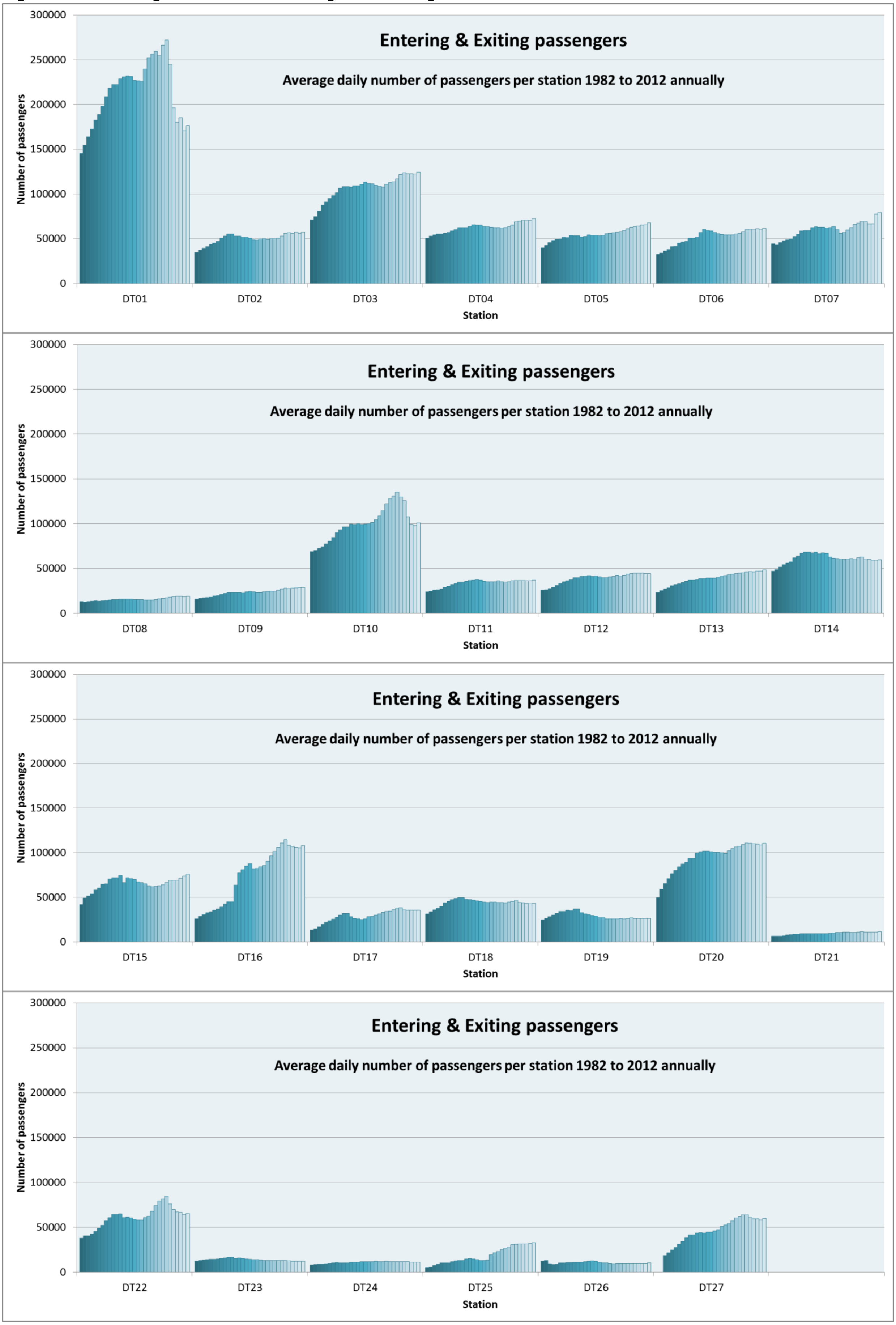
The ITPS data was supplemented with the Tokyu data to include the years 2010, 2011 and 2012 and retain as much of the workable timespan available for analysis. The Tokyu dataset comprised only of boarding and alighting passengers on the Den-En Toshi line, without distinguishing between transferring and non-transferring passengers at the intersecting stations. This distinction was estimated for the intersecting stations DT07, DT10, DT16, DT22 and DT27. The changing rate of the proportion between transferring and non-transferring passengers was calculated based on the two previous years and the missing passenger values for the subsequent years were calculated. At Futako-Tamagawa (DT07) and Mizonokuchi (DT10) stations, a strong decline and incline respectively could be distinguished in boarding and alighting passengers in 2009 (see *Figure 49*, DT07/DT10), as a result of the extension of the Ōimachi line in 2008. Therefore, the number of transferring passengers was fixed to be equal to the year 2009 and the transferring passenger numbers were calculated based on these years.

A visualization of the resulting data can be found in *Figure 28*, where the number of passengers through the station area is depicted for each of the Den-En Toshi line stations over the period of 1982 to 2012. For the intersection stations, the number of boarding and alighting passengers and the corresponding ratio of transferring and non-transferring passengers are highlighted in the graphs of *Figure 49* (see Appendix 9.5).

There are several general passenger trends that can be deduced from *Figure 28*. Towards the sub-centre of Shibuya (DT01), station areas are busier, as are stations with intersecting railway lines. An exception is Sangen-Jaya (DT03) where one of Tokyo's last remaining tramlines connects. Remarkably, busier are also Saginuma (DT14), which traditionally is a local centre, and Tama-Plaza (DT15), which was the focal point of Tokyu's development in the prospect of the planned Blue line connection that later was redirected to Azamino (DT16).

What is also visible for most station in their yearly trends is the presence of the 1990 Japan stock bubble burst resulting in the "lost decade" and even the 2008 world banking crises that show a stagnation of the passenger growth or even declining numbers.

Figure 28: Passenger numbers entering and exiting the station

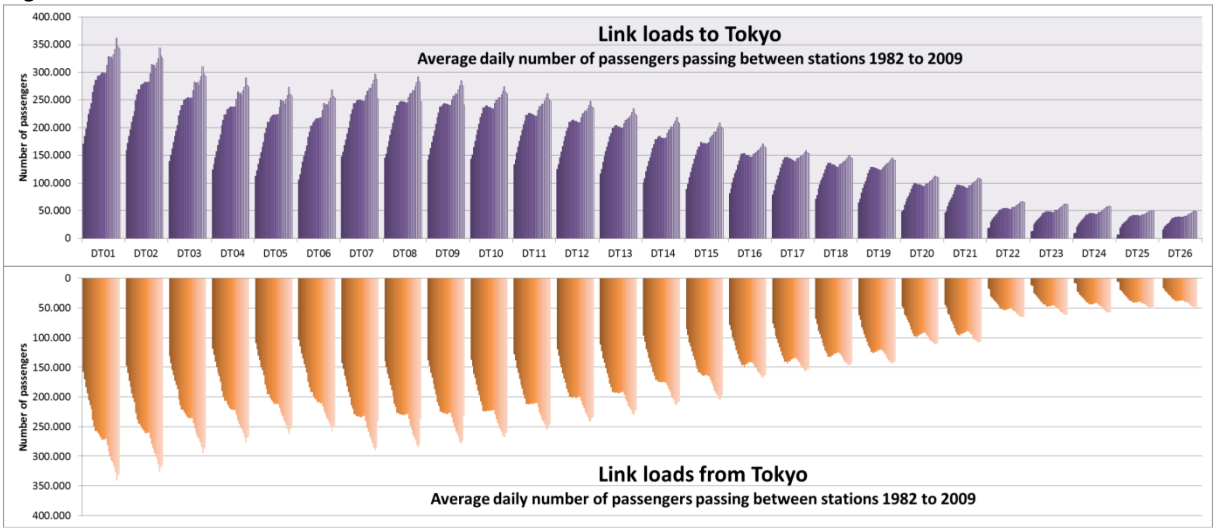


In the population number a general trend shows only a slight rise and in all of the workforce clusters a downward trend can be observed. In the face of a steady and continuous rise of passenger numbers, this suggests that an additional indicator is required to account for the unexplained variation in passenger numbers. As the state of the economy is often directly linked to the number of travellers and distance travelled this was a probable explanation for the difference in observed trends. Therefore, an economic indicator is included and described in section 5.5.3 in order to increase the models explanatory value.

5.5.2 Traffic flow

In the modelling section (section 7.2), the intensity and direction of traffic flow resulting from the changes in station use is also of interest. The traffic flow is characterized by the link loads, represented as the black arrows and [Q] in *Figure 27*. These numbers comprise of the passengers travelling between two stations resulting from the boarding and alighting passengers at each station, including both the transferring and entering and exiting passengers. No distinction was made between commuters and non-commuters. The direction of travel can be categorised in either moving towards Tokyo (Shibuya direction, to DT01) or moving away from Tokyo (Chūō-Rinkan direction, to DT27). Although the loads in both directions are very similar, they are not identical over the course of a day. The link loads between the Den-En Toshi line stations for the years 1982 to 2009 are depicted in *Figure 29*. There was no additional effort taken to obtain link loads for the years 2010 to 2012 from the additional Tokyu data as it does not contain enough detail to determine these values accurately.

Figure 29: Link loads between stations

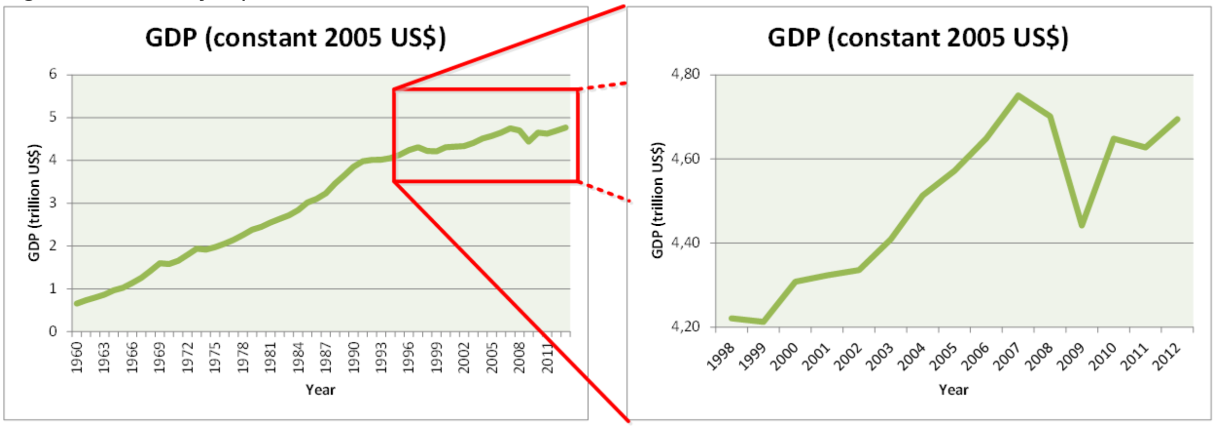


The graphs show a skewed distribution of the link loads over the entire length of the Den-En Toshi line. It seems as if the differences in link loads over the years became even greater. However between Shibuya (DT01) and Mizonokuchi (DT10) a large decrease in link loads can be observed between 2008 and 2009. This is most likely due to both the introduction of the Ōimachi line extension in 2008 and the global economic crisis. This seems to restore some of the imbalance in link loads over the line. Also noteworthy is that a large portion of the passengers travelling from the far end of the line seem to travel to Futako-Tamagawa (DT07).

5.5.3 Economic

Because the dataset created not only allows for cross-sectional research but the studying of changes over time it is important to include environmental influences in the modelling efforts. For example Wardman (2006) states that the demand for travel is highly dependent on the state of the economy, using the Gross Domestic Product (GDP) as an indicator. Therefore, this indicator is included in the time-series modelling efforts of this research to investigate whether it has a significant influence on the development of station area use over time. The data for the GDP indicator was obtained from the World Bank, where this data is freely available (http://data.worldbank.org/). *Figure 30* shows the GDP of Japan in constant 2005 US Dollar from 1960 to 2013. Additionally a magnification is given of the period between 1998 and 2013.

Figure 30: GDP of Japan



In the left figure, it can be seen that Japan has experienced a steady increase in the GDP with only very minor hitches up until the 1990's. In the early 90's a major economic crisis hits japan resulting in the so called "Lost decade". The effects of this crisis on station use can be easily distinguished in *Figure 28* in section 5.5.1. By the end of the 90's, the GDP starts to recover again and returns to a steady but less steep growth until the global financial crisis in 2008. As the data for measuring the density and diversity of activities only ranges from 1998 to 2012 it was not possible to study the effects of the "Lost decade" on station use. However the inclusion of the 2008 global financial crisis might be able provide the necessary insights into the effect of the GDP on station use.

5.6 Conclusion

This chapter described how the station area characteristics are measured in order to conduct an analysis of the performance of these station areas and how this relates to traffic flow. It has given a first insight into the characteristics of the Den-En Toshi line stations and how these developed over time. Concluding this chapter, research questions 3 and 4 posed in section 3.3 can be answered.

In section 5.2, the station area itself was defined using access and egress trips to and from the Den-En Toshi line stations. As the focus in this research was on the direct surroundings of the station itself, it was chosen to use a set action radius as the boundary of the station area. The action radius was determined by investigating the distance travelled of its access and egress trips. In the Den-En Toshi line station areas the major access and egress mode is walking, accounting for over 80% of all trips. Therefore, it was argued that an action radius can be derived from the walkable radius, similar to Bertolini (1999). As can be seen in the cumulative distribution curve in *Figure 16*, all walking trips are made within 1500 metres of the stations, and 75% of all walking trips already falls within 700 metres. For this case study, the station area was therefore defined by a 700 metre walkable radius.

In order to develop a forecast model for passenger numbers as a function of station area characteristics, the proper indicators to measure these characteristics were determined based on theory, previous research and data availability. The preliminary indicator study in section 5.1 showed that only limited data is consistently available over a longer period of time. The main data sources selected are: the population census that is released every 5 year, accounting for the intensity and diversity of activities within the station areas. Furthermore, timetable data was selected to account for the accessibility of the station areas, a yearly city wide transportation census to account for the station use and traffic flow and finally economic data to account for major environmental effects. These data resulted in the following indicators being used in this research:

- Population
- Workforce-cluster 1 (Transportation, information, communication, finance, real estate, research, education, welfare, public services and living related services)
- Workforce-cluster 2 (Hotel, restaurant, café and retail)
- Workforce-cluster 3 (Agriculture, forestry, fishing, mining, construction, manufacturing and utility)
- Multi-functionality
- Station type
- Number of directions
- Frequency
- Travel time to centre
- GDP
- Passengers

For this research, a dataset of these indicators, measuring the station area characteristics of 26 of the 27 Den-En Toshi line stations, was constructed for 15 consecutive years, spanning from 1998 to 2012. Based on the indicators described in this chapter the descriptive model was developed in Chapter 0. Furthermore, the station area characteristics were used in the Node-Place model, in Chapter 7.

6 LINKING STATION CHARACTERISTICS AND STATION USE

In chapter 0, the model input was defined, represented by the left side of the model design explained in *Figure 8* back in section 3.4. This chapter focusses on the middle part of the research design, the modelling section. The modelling section consists of three separate modelling steps, the main part represented by the forecast model (centred in the model design), and extension to the station area analysis and the traffic flow analysis which will be discussed in chapter 7.
This chapter is considered with the build-up of the passenger forecast model. First, a background on linear regression modelling is given in a theoretical layout and then the approach selected for this research is outlined. Second, the main analysis was performed in three stages, using three different modelling approaches: A cross-sectional approach, a time-series approach and an approach based on variable change. The results of each approach are discussed and based on the results subsequent modelling steps are taken in chapter 7. Some additional investigation was done to extend the forecast model, in order to build a basis for further research.

6.1 Forecasting passenger numbers

To investigate the interaction between station area characteristics and station users, linear regression modelling was used. The regression model explains the change in an outcome variable as a function of a set of predictor variables. In this model application, the change in the number of passengers using each of the stations along the Den-En Toshi line (the outcome variable) was explained by the change in station area accessibility and activity indicators (the predictor variables).
It is first discussed how the variance is measured for the variables considered in this research, how the dataset is built-up and what consequences this has on the modelling approach. The theory of regression modelling is stipulated along with the preconditions that go together with linear regression. Building upon this basic knowledge in linear regression, the regression model is extended to cope with hierarchal data. Based on the theory discussed, a modelling approach is constituted before continuing to the following section.

6.1.1 Measuring variance

There are two ways to measure a hypothesis, either by observing what naturally occurs or by observing change of the environment and the effect of this change on the variable of interest. This is the distinction between correlational/**cross-sectional** and time-series/**longitudinal** research. With these types of research usually also come two methods of data collection. The first method is measuring predictor variables using different subjects in a single point in time, which is called either a between-groups or **between-subjects** design. The second method is to measure the variables using the same subjects more than once, which is called a **within-subject** or repeated measures design. These two methods can also be combined and measure variance on multiple levels. In statistics and econometrics, multi-dimensional data is often referred to as **panel data**, involving for example measurements of multiple subjects over time.

The different experimental designs measure different types of variance. Differences in performance created by a specific experimental manipulation are known as **systematic variation**. **Unsystematic variation** is a result of random factors that exist between the experimental conditions. In a within-subject, or repeated measures design unsystematic variation can only be caused by the differences within the same subject at different points in time. In a between-subjects design the unsystematic variance is likely to be much larger due to the mutual variation between subjects. Therefore, when retaining the same set of subjects, repeated measures design have more power to detect effects than between-subjects designs (Field, 2009).

The variables trying to explain variance can have different levels of measurement. Variables can be **categorical** or **continuous**. A *categorical variable* is made up of categories, naming distinct entities. Its simplest from it names just two distinct types of things, which is known as a **binary variable** (for example, male or female). When two things that are that are equivalent in some sense are given the same name, but there are more than two possibilities, the variable is a **nominal variable** (for example, transportation mode: Car, train, bus). The only way nominal data can be used is to consider frequencies. When categories are ordered it is an **ordinal variable**. Ordinal data not only imply occurrence but also order of occurrence (for example, placement in competition: 1^{st}, 2^{nd} and 3^{rd}).
A *continuous variable* can take on any value on the used measurement scale. The first type of continuous variables is an **interval variable**. Data are interval when equal intervals on the scale represent equal differences in the property being measured (for example, a rating on the five point Likert-scale). When the ratios of values along a scale of a continuous variable are also meaningful and the scale has a true and meaningful zero point it is a **ratio variable** (for example, travel time). Continuous variables can also be discrete, where a **discrete variable** can only take certain values on the measurement scale (for example, age).

6.1.2 Theory of regression modelling

Knowing how variance is measured, the relationship between two variables can be discussed. A relationship between two variables can be measured using correlation analysis. In correlation research, the co-occurrence of variables is observed. The causal variable is not manipulated and its effect measured. Therefore it cannot be determined which variable causes a change in the other, only that they co-occur in a certain way (Field, 2009). This principle can be extended by predicting the value of one variable from the co-occurrence of another.

Regression analysis is a way of predicting an **outcome variable (Y)** from one or more **predictor variables (X)**. The outcome variable can be described by a model based on the predictor variables plus the error of the model ($Outcome_i = model + error_i$). In linear regression, the outcome variable Y is predicted using the equation of a straight line. The model for this straight line is fitted to the collected data for which the sum of squared differences between the line and the actual data points, the residuals, are minimised. For regression with multiple predictor variables the principle remains the same and the general regression equation becomes:

Equation 3: Linear regression equation

$$Y_i = b_0 + b_1X_{i1} + b_2X_{i2} + \cdots + b_nX_{in} + \varepsilon_i$$

In this equation b_0 and b_1 are **regression coefficients** and ε_i represents the **residual terms**. When regression analysis is performed, an equation can be produced that best describes the sample of observed values. Besides the model fit on the sample, it is also relevant to what extent the model can be generalized to a wider population. In order to use a regression model for these data, some assumptions ha to be met.

First and foremost it is assumed that the modelled relationship between outcome and predictor variables can be described as a **linear relationship**. There will be no additional research done to the shape of the relationship. For this research it suffices to assume a linear relationship.
All predictor variables must be quantitative or categorical (with only two categories), and the outcome variable must be continuous, being at least interval, and unbounded. Unbounded means there should be no constraints on the variability of the outcome, that all the values of the outcome variable are **independent**.

There should be no perfect **collinearity** between two or more predictor variables, meaning they should not correlate too much. Collinearity between predictors could cause untrustworthy *b*'s due to large standard errors, which limits the size of $\mathbf{R^2}$ (the **coefficient of determination**, representing the percentage of variation in the outcome that can be explained by the model) and makes it more difficult to assess the importance of each predictor.
The variance of the residual terms should be constant at each level of the predictor variable. This is the assumption of **homoscedasticity**. Furthermore, the errors or residuals of the model estimation should be **independent and normally distributed**. When comparing two residual terms, these should be uncorrelated.
The consequences of these assumptions are further explored in Section 6.1.3 and the practical application for modelling station use based on social and network characteristics of station areas are discussed in Section 6.2.3.

When using panel data, the assumption of independence is violated because the measurements of a subject measured over multiple moments in time will be correlated. When performing regression modelling on panel data, techniques have to be utilised that can handle such a hierarchal structure of the data. This can either be done with multi-level modelling or by simplifying the panel dataset.

6.1.3 Analysis approach

Part of the objective of this research was to try to only resort to basic modelling principles which are easy to execute and more importantly better to control and evaluate. Although multi-level modelling offers the most suited technique, in this research therefore only basic regression modelling is applied. It is recommended to continue and expand this research using multi-level modelling techniques and compare the gains of these models with basic linear regression. Additional information on the application of multi-level modelling is added in Appendix 9.5, but is not elaborated any further here.

To overcome the assumption of independence one of the levels from the structure of the panel dataset was removed. This can either be done by leaving out the time component, creating a cross-sectional model, or by studying each subject separately, creating a time-series model. For the purpose of this research the cross-sectional model hold the most relevance, as this is required to be able to compare station areas in section 7.1. Therefore it first a between subject analysis is performed and several cross-sectional models are built. To obtain some more insight into the possibilities of multi-level modelling subsequently a within subject analysis is performed and time-series models estimated for each of the stations separately. This gives an impression of the model improvements that can be gained from multi-level modelling.
Additionally the assumption of independence can be overcome by not to looking at the values of the variables themselves, but only at the change in the variables between two consecutive years. While the value of the outcome variable of two consecutive years is correlated, the change between those years can be assumed independent. This method does lose a large portion of its explanatory value because only part of the variable characteristics is observed. However it can prove an interesting insight in whether or not the change in the outcome variable is dependent on the height of the predictor variables.

In the following three sections subsequently the between-subject analysis, the within-subject analysis and the analysis of variable change are covered. From each section, the relevant conclusions are summarised before the findings are applied in the further modelling of interactions between station areas and traffic flow.

6.2 Between subject analysis

The between-subject analysis compares the different stations to each other at a single point in time, a cross-section of the observations made. Three cross-sectional models are estimated, for the years 2000, 2005 and 2010. For these years, the data of the social characteristics of the station areas is complete, as is discussed in section 5.3.1. Estimating models of three different cross-sections in the dataset has the additional advantage that the power of cross-sectional model over time and their ability to use as forecast models can be investigated.

In this section, first the implications of the assumptions in linear regression modelling for these cross-sectional models are discussed. Second, the data set is explored by looking at the correlations between the outcome and predictor variables from which the modelling variables are selected. Then, a description is given of which model estimations are made. The results of the modelling efforts are elaborately discussed in terms of model fit and assumptions. The practical interpretation of the model is given and implications for this research are shortly summarised before moving on to the following section, the within-subject analysis.

6.2.1 Making assumptions

As described in Chapter 0, the outcome variable is continuous. The predictor variables are at least interval except for station type which is categorical and previously adapted to have only two categories. The outcome variable is not unbound, because the station use defined by the average number of passengers entering and exiting the station per day can only take a non-zero form. Measurements range from 20.000 and upwards. This is considered enough tolerance to assume that the modelled values will not pass zero. Therefore, the outcome variable is considered unbound.

The predictor variables should vary, that is their variance cannot be zero. For the between subject analysis this means that GDP is excluded as indicator as it is the same for all stations within a certain year. There is less variation in the predictor variables when reducing the sample to a single year, but still each variable shows at least some variation.

There are many rules of thumb on what sample size is required to obtain a reliable regression model. For this research it is assumed that 10 to 15 cases are required for each predictor used in the regression model (Field, 2009), but more elaborate guidelines also exist. For this part of the analysis carried out between subjects, several models for different years are separately estimated. For each model run made a dataset of 26 cases or stations is available, allowing for accurate model estimations with 2 predictors. For each predictor additionally added the model accuracy is assumed to decrease drastically. The 27th station (DT01 Shibuya) was previously removed due to data issues. There were no outliers removed from the dataset.

Collinearity of the predictor variables is explored in the following section. And the assumptions of independent and normally distributed errors as well as the assumption of homoscedasticity will be evaluated based on the modelling results.

6.2.2 Exploring correlations

To discover which parameters to enter into the model first correlations were explored. The correlations between the predictor variables and the outcome variable and amongst the predictor variables themselves were examined. The correlations describe the size and sign (positive/negative) of the relationship between parameters. These can be compared to the theory and can assist accounting for the assumptions that are made in regression modelling. Important is the preliminary look it gives on multi collinearity between the predictor variables.

Instead of the usual Pearson's correlation coefficient the correlation analysis was performed using Kendall's tau correlation. This is chosen because of several characteristics of the dataset which are processed better by Kendall's tau (Field, 2009). First, most of the variables are non-parametric variables; second the dataset for each year has only a limited amount of observations and third because the "Number of directions" and "Frequency" variables have a large number of tied ranks. In order to establish whether the correlations are significant satisfying the appropriate assumptions is critical. The significance value for each correlation value states the likelihood that the same or a more extreme statistic is found. When the effect is statistically significant the observed correlation coefficient is very unlikely to happen if there would be no effect in the population.

The bivariate correlation table for all the predictor and output variables for the year 2010 is given in *Table 8*. The correlation tables for the years 2000 and 2005 are included in Appendix 9.7. Both the standardized correlation coefficient and the significance of the correlation coefficient are displayed. Between the same variables correlation is 1, implying a perfect relationship. Field (2009) states an effect is large above 0.5, but within this research it is preferred to establish stronger effects. A correlation coefficient below 0.3 is considered to have a small effect, between 0.3 and 0.7 a medium effect and above 0.7 a large effect. Direct causality should not be derived from correlations. This is because other unmeasured variables could influence the results (Third variable problem) and it is not stated which variable is influencing which (Direction of causality).The correlations can be used to investigate covariance between two variables.

Table 8: Kendall's tau correlation table; Year 2010

		Population	Workforce-cluster 1	Workforce-cluster 2	Workforce-cluster 3	Multi-functionality	Station type	Number of directions	Frequency	Travel time to centre	Passengers
Population	**Corr.**	1,000	,926**	,883**	,489**	-,470**	,380*	-,107	,456**	-,505**	,348*
	Sig.		,000	,000	,000	,001	,022	,511	,004	,000	,013
Workforce-cluster 1	**Corr.**	,926**	1,000	,858**	,452**	-,495**	,380*	-,098	,486**	-,511**	,335*
	Sig.	,000		,000	,001	,000	,022	,547	,002	,000	,016
Workforce-cluster 2	**Corr.**	,883**	,858**	1,000	,545**	-,396**	,346*	-,080	,380*	-,437**	,305*
	Sig.	,000	,000		,000	,005	,038	,622	,016	,002	,029
Workforce-cluster 3	**Corr.**	,489**	,452**	,545**	1,000	,043	,030	-,018	,049	-,065	,132
	Sig.	,000	,001	,000		,757	,858	,913	,756	,643	,343
Multi-functionality	**Corr.**	-,470**	-,495**	-,396**	,043	1,000	-,480**	,040	-,560**	,616**	-,346*
	Sig.	,001	,000	,005	,757		,004	,805	,000	,000	,013
Station type	**Corr.**	,380*	,380*	,346*	,030	-,480**	1,000	,345	,789**	-,386*	,721**
	Sig.	,022	,022	,038	,858	,004		,076	,000	,021	,000
Number of directions	**Corr.**	-,107	-,098	-,080	-,018	,040	,345	1,000	,245	-,121	,302
	Sig.	,511	,547	,622	,913	,805	,076		,183	,459	,062
Frequency	**Corr.**	,456**	,486**	,380*	,049	-,560**	,789**	,245	1,000	-,591**	,689**
	Sig.	,004	,002	,016	,756	,000	,000	,183		,000	,000
Travel time to centre	**Corr.**	-,505**	-,511**	-,437**	-,065	,616**	-,386*	-,121	-,591**	1,000	-,331*
	Sig.	,000	,000	,002	,643	,000	,021	,459	,000		,018
Passengers	**Corr.**	,348*	,335*	,305*	,132	-,346*	,721**	,302	,689**	-,331*	1,000
	Sig.	,013	,016	,029	,343	,013	,000	,062	,000	,018	

**. Correlation is significant at the 0.01 level (2-tailed).

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

There are a number of things standing out when examining *Table 8*. The first are the high values of the correlation coefficients, indicating collinearity between the variables population and the three workforce clusters. This shows that for this dataset with a limited number of observations there is very little variation to be explained between the densities of the population and the different workforce clusters. In general, a higher population density also results in a higher density in each of the workforce clusters. Especially high correlation between population and workforce cluster 1 density is present in the 2010 data. This might be a result of the fact workforce cluster 1 is a combination of two clusters that were unable to separate due to data issues, as explained in section 5.3.3. Workforce cluster 1 does not only represent office work, but also entails jobs with a more public function, such as schools and hospitals which are more likely to be found in residential areas. It can therefore represent both the office and population density. It could be argued that all density variables can be combined to a single variable. Though, in Sections 6.3 it shows that within the subjects these parameters do account for different variances. The variance in the outcome variable is best explained by either the population density or the density of workforce cluster 1. In the between-subject analysis one of these density parameters is selected and will represent a more general measure for the density of activities than for the specific activity that takes place in the station area.

The second thing that stands out is the direction of the relationship between the predictor variable multi-functionality and the outcome variable passengers. There is a significant negative relationship between these two variables. This suggests that an increase in multi-functionality of the station area would cause a decrease in the number of passengers using that station. Theoretically this should not be the case, as TOD theory states that multi-functionality has a positive effect on the success of a station area. The first indication of possible difficulties with the way the variable multi-functionality is constructed was noted in section 5.3.4. An explanation for the behaviour of this variable with this dataset is most likely due to the inclusion of workforce cluster 3. Cluster 3 consists of industry and agriculture, which generally only allows for a lower density build-up area instead of higher densities with the other workforce clusters. This results in a situation where a smaller workforce for cluster 3 causes a decrease in the measure of multi-functionality. On the other hand, it also results in an increase in overall density and with that also an increase in passenger numbers. For further research it should be more closely investigated why this measure of multi-functionality cannot describe the relationship between the degree of mixed land-use and the success of the station area accurately and how it should be measured otherwise. Due to these difficulties and possible misrepresentation the variable multi-functionality is excluded from the analysis in this research.
The third thing that can be noticed is the high correlation and possible collinearity between the travel time to the nearest centre and population and workforce cluster densities. This suggests that a higher density of the built-up area is associated with a closer proximity to the centre. This could be expected as a typical result of land-use and transport interactions. The variable travel time to centre cannot be used in the regression analysis together with one of the density variable, as they explain the same variation within the outcome variable. Therefore, they will be separately investigated.

When examining the correlation coefficients for 2000 and 2005 in Appendix 9.7 (*Table 16* and *Table 17*) mostly similar conclusions can be drawn as for the 2010 results. Only a single density variable can be used in the regression model and the variable multi-functionality is disregarded. Though the sizes of the relationships between the predictor variables and the outcome variable vary slightly compared to the 2010 values there are no striking differences. Workforce cluster 3 shows a shows stronger relations with other activity indicators in previous years, but this is not of importance as it has only very little explanatory value of the outcome variable. Other than that the indicator number of directions has more explanatory power of the outcome variable.

In conclusion, the accessibility indicators; station type, frequency and number of directions show the strongest relationships with the outcome variable passengers, as do the density indicators population and workforce cluster 1. Focus will be put on these variables in the regression analysis. Both the density variables and the accessibility variables have a strong correlation among each other and should not be used in the same regression model together.

6.2.3 Applying linear regression

With the basic understanding of the relationships that are present between the different predictor variables and the outcome variable regression models can now be built. For the model building it is chosen to base the indicator choice on the discussed theory and the correlation analysis, and not to perform explanatory model building. For the model runs with multiple variables the forced entry method is applied and predictors are forced into the model simultaneously without a set hierarchy. Ideally at least both one node- and one place indicator are used in the model run. This way the station area analysis can be based on the results obtained from the regression model.

From the correlation analysis three predictor variables were found with high correlation to the outcome variable; Frequency, Station type and Number of directions. These three variables were used as basis for the different model predictions made. So there are three basis models, 1a, 2a and

3a, which are run for each separate year (2000, 2005 & 2010). To increase the predictive power of the models a second variable is added in the subsequent model runs. The predictor variables that are added in the model are Population, Workforce cluster 1 or Travel time to centre. Each of the subsequent model runs (b, c & d) consist of one of the three basis variables and a second variable. By building the models this way the increase in the models predictive power when adding a second variable can be easily observed in the change statistics.
The basis variables are all variables measuring accessibility, but still as a second variable Travel time to centre is included. This was done because Travel time to centre showed a high correlation with the outcome variable and still a low correlation with the other predictor variables for accessibility as described in the previous section. It can thus be used as a replacement variable for density of activities. It must be noted that interpretation of these combinations of variables should be done with care. The results of each of the in total 9 model runs per year are shown in *Table 9*.
Other variable combinations have been tried but showed much lower explanatory value and were not included in the description of the analysis.

6.2.4 Assessing model fit and assumptions

First a closer look is taken at the squared multiple correlation coefficients, R^2. This is the measure of how much of the variability in the outcome can be explained by the predictor variables. For each model prediction the values are colour coded, with green being a model with a very good fit and red with a poor fit. The best fit is achieved by any variation of model 2 and the lowest by model 3. Furthermore, the explanatory value for the year 2000 is generally lower than that of other years. This might be the result of other latent variables changing between different cross-sections, such as the state of the economy or other variation that cannot be explained by the predictor variables used. Accounting for 62.4% (2000), 72.2% (2005) and 68.7% (2010) of the variation in the passenger numbers model 2c provides the best fit over the three consecutive cross sections, based on station type and the size of workforce cluster 1. The change statistics show that by adding the second variable WF cluster 1 to the model with the variable station type, only causes a significant improvement ($p<.01$) for R^2 in 2000 and 2005, but not for 2010 ($p=0{,}021$). In 2010 the extension of the Ōimachi line running parallel most likely causes such a drop in the number of passengers, such that the variable Station Type becomes a less suited predictor.

To cross-validate the model, assessing the accuracy of the model across different samples, the adjusted R^2 is examined. R^2 indicates the loss of predictive power, or shrinkage. Another option to cross-validate the results is to split the dataset, but it was chosen not to do so as the dataset is already relatively small. Cross-validation would require further reducing the dataset on which the model estimations are based. For the fitted models the decrease in the adjusted R^2 or shrinkage of the models predictive power generally lies between 2-4%. This is relatively high, but it should be noted that this study only uses a very limited sample. When generalizing these models beyond this sample, to for example the entire network around Tokyo, or Japan, or any other railway system in general more shrinkage should be expected (Field, 2009).
To test whether the residual terms are uncorrelated the Durbin-Watson statistic is used. The test statistic can vary between 0 and 4, with a value 2 signifying no correlation between residuals, above 2 indicating a negative correlation and below a positive correlation. For a model based on two predictors, with a sample size of 25 the critical value of the test statistic is 1,30 (Field, 2009). The values for the Durbin-Watson test all vary a little around 2, indicating little to no correlation between the residuals and therefore satisfying the assumption of independent errors.

Table 9: Model summary

Year	Model	Predictors	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	Change Statistics: Sig. F Change	Durbin-Watson
2000	**1a**	**Frequency**	,743	,552	,534	19820	,552	,000	
	1b	+ Population	,779	,607	,573	18961	,055	,086	2,346
	1c	+ WF cluster 1	,780	,608	,574	18940	,056	,083	2,312
	1d	+ TT to centre	,749	,561	,523	20045	,009	,503	2,049
	2a	**Station type**	,694	,481	,460	21334	,481	,000	
	2b	+ Population	,787	,620	,587	18662	,138	,008	2,216
	2c	+ WF cluster 1	,790	,624	,591	18554	,143	,007	2,170
	2d	+ TT to centre	,765	,585	,549	19496	,104	,025	1,985
	3a	**Nr. of directions**	,496	,246	,214	25733	,246	,010	
	3b	+ Population	,713	,509	,466	21211	,263	,002	2,085
	3c	+ WF cluster 1	,714	,509	,467	21202	,264	,002	2,052
	3d	+ TT to centre	,698	,488	,443	21664	,242	,003	1,895
2005	**1a**	**Frequency**	,810	,657	,642	20063	,657	,000	
	1b	+ Population	,827	,684	,656	19668	,027	,173	2,218
	1c	+ WF cluster 1	,824	,678	,651	19833	,022	,224	2,149
	1d	+ TT to centre	,812	,659	,629	20426	,002	,698	1,980
	2a	**Station type**	,785	,616	,600	21231	,616	,000	
	2b	+ Population	,846	,716	,691	18648	,100	,009	1,953
	2c	+ WF cluster 1	,850	,722	,698	18443	,106	,007	1,926
	2d	+ TT to centre	,863	,744	,722	17694	,129	,002	1,869
	3a	**Nr. of directions**	,609	,371	,344	27163	,371	,001	
	3b	+ Population	,738	,545	,505	23598	,174	,007	2,161
	3c	+ WF cluster 1	,744	,553	,514	23384	,182	,006	2,187
	3d	+ TT to centre	,729	,531	,491	23945	,161	,010	1,875
2010	**1a**	**Frequency**	,811	,658	,643	18922	,658	,000	
	1b	+ Population	,819	,671	,642	18950	,013	,345	2,334
	1c	+ WF cluster 1	,819	,671	,642	18952	,013	,346	2,362
	1d	+ TT to centre	,814	,663	,634	19165	,006	,535	2,134
	2a	**Station type**	,816	,666	,652	18680	,666	,000	
	2b	+ Population	,827	,685	,657	18548	,018	,258	2,081
	2c	+ WF cluster 1	,829	,687	,660	18475	,021	,228	2,149
	2d	+ TT to centre	,820	,672	,644	18914	,006	,529	1,960
	3a	**Nr. of directions**	,392	,154	,119	29745	,154	,047	
	3b	+ Population	,679	,460	,413	24264	,307	,001	2,187
	3c	+ WF cluster 1	,673	,453	,406	24427	,299	,002	2,252
	3d	+ TT to centre	,584	,341	,284	26809	,187	,018	1,860

Next, the model parameters were studied, which are the estimated *b*-values for the regression equation as previously shown in Equation 3. For each of the model estimations of model 2 the *b*-values for the model constant and the entered predictors as well as their standardized *b*-values are given in *Table 10*. The model parameters for the model estimations of model 1 are available in Appendix 9.7, *Table 18*, and model 3 is further excluded from the analysis due to low explanatory values. Focus is placed on model 2c, which showed the highest value for R^2.
For the most recent year (2010), the parameter Station type (b=45662) shows a positive relationship. If the station type is increased by one unit, 45662 additional passengers will use the station, given that all other parameters are kept constant. This number should not be interpreted too literally as it is only represents a composite measure of accessibility. Local stations have approximately 45.000 less passengers a day than (semi-)express stations on the Den-En Toshi line. The parameter Workforce cluster 1 (b=3,057) indicates an increase in the workforce cluster of one unit will 3,057 more passengers will use the station. Interpreting the value this seems odd, meaning a single employee would add an average of 3 trips a day through that station, assuming train is the only available mode. Of course this would not happen in reality and this is the result of the fact that this parameter also accounts for the variation in shopping and public facilities as well as population.
The associated standard deviation for the station type seems acceptable, as is confirmed by the *t*-statistic and the significance value ($p<0,05$) indicating that the *b*-value differs significantly from zero. The standard deviation for the workforce cluster seems too steep, its *t*-statistic and significance value show that it is not a significant predictor for passenger numbers in this model. When looking at the same models for the years 2000 and 2005 both station type and workforce are significant predictors for passenger numbers.
The standardised *b*-values give some more insight in the importance of each of the predictors in the model. The major share of the variance in the outcome is predicted by station type (*standardised β* = 0,735) while only a small share is explained by the size of the workforce cluster (*standardised β* = 0,166). For the previous years the share is doubled in size and a significant model in the predictor. The drop in predictive power of the model and the difference in the standardized predictor b-values most likely occurred due to the shift in passengers from Futako-Tamagawa (DT07) to Mizonokuchi (DT10) which the model seems unable to explain using the given indicators.
The confidence interval can give some more insight of the value of *b* in the population as opposed to this sample. The confidence interval for station type is relatively large varying roughly between 30.000 and 60.000. For a bad model an interval crossing zero can be expected, which is not the case for the predictor variables. From these values it can be concluded that the model is relatively unstable and is most likely poorly generalizable over a different dataset. Meaning that taking any other sample of stations would result in estimated constant and predictor values varying greatly compared to this model.
In section 6.2.2, predictors that did not correlate too much were selected for the model building. Continuing checking assumptions, it is assessed whether the model still satisfies the assumption of no multicollinearity, for which the variance inflation factor (or VIF statistic) is consulted. The VIF indicates whether a predictor has a strong linear relationship with any other predictors, but in comparison to scanning correlation matrices it can also detect more subtle forms of multicollinearity. Multicollinearity could become a problem at VIF values are greater than 10 and a tolerance below 0,2 which is not true for any of the predictors. The average VIF also does not deviate too much from 1 confirming that thanks to the proper selection of predictor variables collinearity is not a problem in the model estimations.
The assumption of homoscedasticity in model 2c is met for 2000 and 2005. Though it is a little worrying for 2010, it is no cause for more concern than was already raised by previous indicators of model fit. The associated scatterplots can be found in Appendix 9.7 in *Figure 50*.
Previously the independence of errors was already confirmed, leaving the assumption of normally distributed errors. This assumption is also met, as with the homoscedasticity, for 2000 and 2005 and is a little off for 2010. The associated histograms can be found in Appendix 9.7 in *Figure 51*.

Table 10: Model parameters; Model 2

			Unstandardized Coefficients		Standardized Coefficients		95,0% Confidence Interval for B		Collinearity Statistics	
Year	Model	Parameters	B	Std. Error	Beta	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
2000	2a	(Constant)	35807,947	4894,448		,000	25706,303	45909,592		
		Station type	44528,481	9432,816	,694	,000	25060,105	63996,857	1,000	1,000
	2b	(Constant)	10467,716	9750,564		,294	-9702,863	30638,296		
		Station type	42037,887	8295,865	,655	,000	24876,583	59199,190	,989	1,011
		Population	1,576	,545	,374	,008	,449	2,703	,989	1,011
	2c	(Constant)	13466,153	8676,930		,134	-4483,443	31415,750		
		Station type	41784,454	8255,999	,651	,000	24705,618	58863,290	,987	1,013
		WF cluster 1	5,109	1,729	,380	,007	1,532	8,686	,987	1,013
	2d	(Constant)	55469,814	9346,461		,000	36135,187	74804,441		
		Station type	38632,899	8964,319	,602	,000	20088,792	57177,005	,925	1,081
		TT to centre	-660,027	275,493	-,335	,025	-1229,929	-90,126	,925	1,081
2005	2a	(Constant)	33805,176	5149,167		,000	23177,819	44432,534		
		Station type	54250,046	8751,900	,785	,000	36187,012	72313,080	1,000	1,000
	2b	(Constant)	6995,455	10444,561		,510	-14610,767	28601,676		
		Station type	53279,152	7694,662	,771	,000	37361,532	69196,773	,998	1,002
		Population	1,546	,543	,317	,009	,423	2,668	,998	1,002
	2c	(Constant)	7402,983	9959,786		,465	-13200,404	28006,369		
		Station type	52764,969	7619,297	,763	,000	37003,252	68526,686	,996	1,004
		WF cluster 1	5,557	1,873	,327	,007	1,683	9,432	,996	1,004
	2d	(Constant)	57075,603	8079,984		,000	40360,884	73790,323		
		Station type	52530,033	7311,473	,760	,000	37405,099	67654,968	,995	1,005
		TT to centre	-854,422	251,372	-,359	,002	-1374,424	-334,420	,995	1,005
2010	2a	(Constant)	27388,308	5180,834		,000	16695,591	38081,024		
		Station type	50718,692	7326,806	,816	,000	35596,907	65840,477	1,000	1,000
	2b	(Constant)	17019,906	10321,402		,113	-4331,540	38371,351		
		Station type	46059,730	8312,213	,741	,000	28864,608	63254,852	,766	1,305
		Population	,695	,600	,155	,258	-,546	1,935	,766	1,305
	2c	(Constant)	16011,148	10517,210		,142	-5745,357	37767,654		
		Station type	45662,125	8317,200	,735	,000	28456,686	62867,563	,759	1,317
		WF cluster 1	3,057	2,468	,166	,228	-2,048	8,163	,759	1,317
	2d	(Constant)	34198,716	11869,486		,008	9644,814	58752,619		
		Station type	48085,726	8484,193	,774	,000	30534,836	65636,616	,765	1,308
		TT to centre	-191,221	298,954	-,087	,529	-809,654	427,212	,765	1,308

Additionally, to gain some insight in the robustness of the cross-sectional model estimations over different time periods, the estimated parameters were used to model passenger numbers for both previous and consecutive cross-sections. This should not be considered validation, but just gives an impression of the usefulness of cross-sectional model estimations for making predictions. As the parameter values of consecutive years do not satisfy the assumption of independence they cannot be used for validation of previous years. *Table 11* shows the R^2 values for some of the original model estimations and then the values of R^2 when the estimated parameters of a previous year are used to estimate passenger numbers for consecutive years.

For the models estimations 1b, 1c, 2b and 2c of each of the cross-sections both the R^2 of the original model estimation (in bold) as well as the application of this model on the other two cross-section datasets are given in *Table 11*. It shows that the model estimations lose very little explanatory value for the first consecutive year, mostly less than 1%. Model 2c, which previously showed the highest explanatory value, also retains its robustness. Previous tests did point out inconsistencies in the *b*-values of the model estimations; these could vary over samples due to a large confidence interval. This could explain why a model for a different year with different estimated parameters could yield a very similar R^2.

Table 11: Model fit

			R Square		
Model	**Predictors:**	**Year**	**Data 2000**	**Data 2005**	**Data 2010**
1b	Frequency Population	*2000*	***0,607***	*0,676*	*0,667*
		2005	*0,601*	***0,684***	*0,671*
		2010	*0,600*	*0,684*	***0,671***
1c	Frequency WFcluster1	*2000*	***0,608***	*0,672*	*0,670*
		2005	*0,601*	***0,678***	*0,670*
		2010	*0,606*	*0,677*	***0,671***
2b	Station type Population	*2000*	***0,620***	*0,709*	*0,662*
		2005	*0,614*	***0,716***	*0,675*
		2010	*0,575*	*0,694*	***0,685***
2c	Station type WFcluster1	*2000*	***0,624***	*0,720*	*0,678*
		2005	*0,622*	***0,722***	*0,683*
		2010	*0,599*	*0,709*	***0,687***

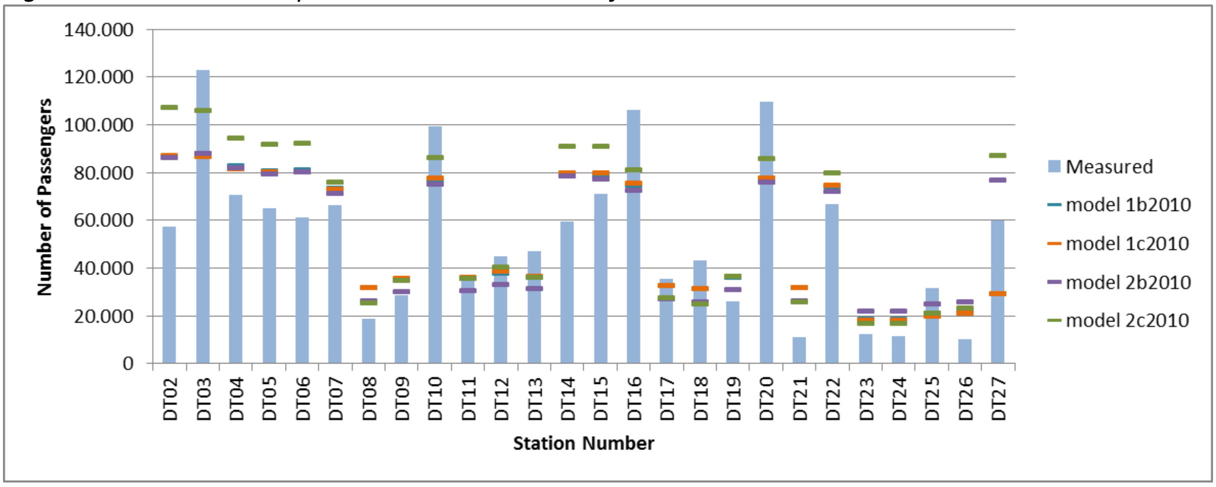
6.2.5 Conclusions between subject analysis

The simplification of the obtained dataset made it possible to utilize it in a cross-sectional analysis and perform a between subject analysis with basic regression techniques. First the correlations of predictor- and outcome variables were investigated, on which the predictor selection for the model building was based. The size of the sample allowed for an accurate model prediction with a maximum of 2 predictor variables. Several models were estimated for various predictor combinations and for three different cross-sections taken from the dataset.

The best model fit was obtained by the predictor variables Station Type and Workforce Cluster 1 (model 2c), over the three cross- sections. A visualisation of the measured and modelled values for the cross section of 2010 can be found in *Figure 31*, which obtained an R^2 of 0,687. This is a relative good model fit, but as can be seen in the figure it still largely overestimates the smallest stations and underestimates largest stations. This is the 30% of unexplained variation, as the predictors used just cannot account for enough of the variation present between the different stations. Part is also caused by the measurement error.

Studying the model parameters it can be concluded that though this model provides a good fit it is relatively unstable. The b-values have a large standard error and vary greatly across the sample. The assumptions of a linear regression were met for model predictions of model 2c for the 2000 and 2005 cross-sections, but not for 2010. Any of the other model predictions did not meet at least one of the assumptions previously made, and are therefore assessed as less accurate.

Figure 31: Modelled compared to measured values for 2010



However the interpretation of the meaning of these modelling results requires more thorough attention. The predictor variable Station Type represents all measure of network accessibility of the station areas. The predictor variable Workforce Cluster 1 represents all of the activities taking place in the station areas, living, working and otherwise. Therefore it has to be stated that the interpretation of the modelling results cannot be taken too literally.

For the means of this research the model fit is not sufficient because the error in passenger estimations is over 30%. This would result in prediction values that deviate too much from measured passenger numbers that following modelling steps discussed in chapter 7 become too inaccurate. As explained at the start of this chapter, some additional research is done to investigate how the model fit can be further improved with different modelling techniques.

6.3 Within subject analysis

To illustrate the advantage of multilevel modelling and give an impression of the added value in the model estimations, the panel data is split into time series data for each station separately. Using the same indicators new models are fitted to the time series data, a within-subject analysis, to determine what increase in predicting capability can be achieved.

Although the within-subject analysis has been conducted for each of the 26 stations, only four were selected to be discussed in this report. These stations were selected either because they show a unique development within the time series or because they show particular good or poor improvements in model fit. These subjects are most interesting to investigate and determine how the regression models are handling.

The first station is Yōga (DT06), because it shows an increase in frequency due to the introduction of the semi-express service. The second station is Futako-Tamagawa (DT07) which is the focal point of Tokyu's mixed land-use redevelopments and receives an additional direction with the extension of the Ōimachi line. The third station is Mizonokuchi (DT10) which shows an exceptionally poor model fit, most likely mainly due to the extension of the Ōimachi line. The fourth station is Azamino (DT16), which shows a very high predictive power and an exceptionally good model fit.

6.3.1 Comparing cross-sectional and time series regression models

To be able to compare model fit of the previously established cross-sectional models and time series models the model fit per station for each of the cross-sectional models was calculated. In *Table 12* on the left side the model fit of the 2010 cross-sectional models is given for each of the selected stations. The results show that both DT06 and DT07 have a reasonable fit and even an excellent fit for DT16, but a poor fit for DT10.

On the right side of *Table 12* the results for the time series models of each of the selected stations are given. The model fit is also visualised in *Figure 32*, showing the measured and modelled values for both the cross-sectional as the time series model estimations for each of the stations. For these models, the same indicators were used and entered into the model estimation the same way as described in 6.2.3. This means that both the intercept and slope of the regression lines were allowed to vary. For both DT06 and DT07 increases in predictive power is present, but only for model 1b power is increased noteworthy. Furthermore striking is the increase that was still achieved on the already very good model fit for DT16. And of course the massive increase in predictive power of model 1c for DT10. When taking a look at the values for Population and Workforce Cluster for DT10 (Mizonokuchi) back in *Figure 18* and *Figure 19* from section 5.3, it can be seen that there is a continuous rise in Population but a hold in the rise of Workforce Cluster 1. It is likely that the direction of impact for DT10 is reasonably different from the other stations, resulting in an extremely low model fit for the cross-sectional model. However, with the same predictors used, a reasonable model fit can be achieved when adjusting the regression slope and intercept in a time-series model.

Table 12: Model fit. Left; Cross-sectional models. Right; Time series models

	R Square							
Station	**1b2010**	**1c2010**	**2b2010**	**2c2010**	**1b***	**1c***	**2b***	**2c***
DT06	,687	,672	,716	,705	,788	,674	,796	,706
DT07	,623	,571	,721	,458	,721	,600	,721	,458
DT10	,023	,004	,001	,209	,153	,612	,001	,209
DT16	,891	,894	,861	,867	,921	,943	,924	,930

As it turned out that the models 2b and 2c did not increase predictive power, only the model parameters of the models 1b and 1c are further studied. No extensive verifying modelling assumptions was done, as this section is only meant to illustrate the gains that can be achieved by using more specific modelling techniques (e.g. a multi-level approach).

All intercepts of model 1b were positive, but varied to some extent (20.000-60.000). The b-values for the predictor variable Population can be considered relatively stable. It differs most for DT06, a station area which has a relative large share in Workforce Cluster 1, but only a small Population. The b-values for the predictor variable frequency are less likely. Both for DT07 and DT10, frequency shows a negative relationship with the outcome variable, which theoretically should be positive. Meaning it is likely that Frequency describes some different variation in the model than caused by the change in accessibility of the station area.
The coefficients of model 1c are similar, with only small differences. The modelling constant is negative for DT07. Furtermore, DT 10 shows a much larger value for the modelling constant than the values for other stations. A large modelling constant for DT10 can be explained by the large passenger base for this station. The variation on top of this base is poorly explained by the predictors. Similar to the modelling constants for model 1b, the frequency shows a negative b-value, expectedly for similar reasons. The negative modelling constant for DT07 itself should not be a problem, as the model itself still explains the variation present. When this model would be applied in a location with low frequencies this outcome would be more problematic. *Table 12* shows that the predictive power of model 1c for DT10 greatly improved, but the model does not reflect reality very well. The change in passenger numbers cannot be sufficiently explained by the predictor variables and would therefore need additional indicators.
Compared to the parameter values for the 2010 cross sectional models in *Table 18* (Appendix 9.7), the model parameters for model 1b show an improvement. This outcome was expected. Therefore, it can be presumed that the predictors or data are not completely reliable.

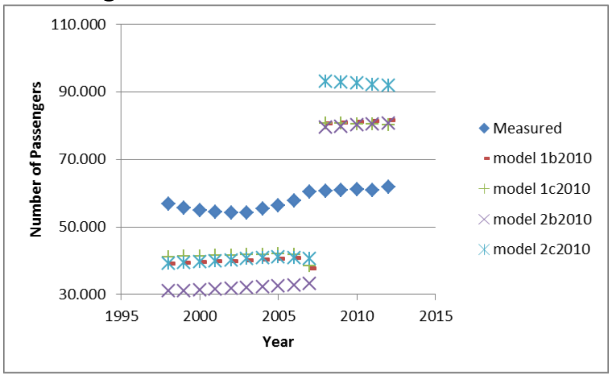
Table 13: Model parameters. Left; Model 1b. Right; Model 1c

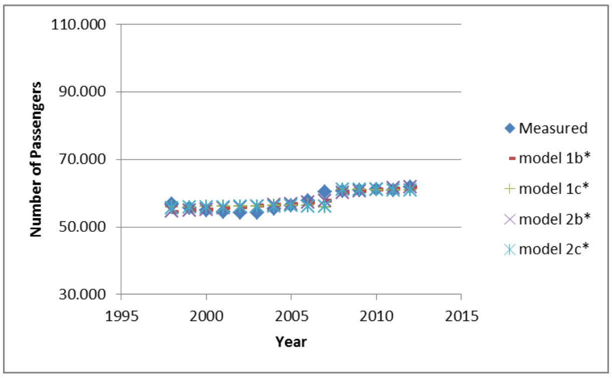
		Unstandardized Coefficients	Standardized Coefficients
Station	Model 1b	B	Beta
DT06	(Constant)	30724,483	
	Frequency	148,747	,302
	Population	1,067	,620
DT07	(Constant)	25802,149	
	Frequency	-801,699	-,062
	Population	5,931	,904
DT10	(Constant)	608209,620	
	Frequency	-20522,160	-,773
	Population	4,433	,634
DT16	(Constant)	22273,678	
	Frequency	859,531	,408
	Population	4,605	,566

		Unstandardized Coefficients	Standardized Coefficients
Station	Model 1c	B	Beta
DT06	(Constant)	40358,851	
	Frequency	415,921	,846
	WFcluster1	1,541	,059
DT07	(Constant)	-218597,965	
	Frequency	6898,109	,533
	WFcluster1	34,559	,300
DT10	(Constant)	578219,687	
	Frequency	-21266,267	-,801
	WFcluster1	26,993	,945
DT16	(Constant)	16035,367	
	Frequency	844,855	,401
	WFcluster1	18,070	,591

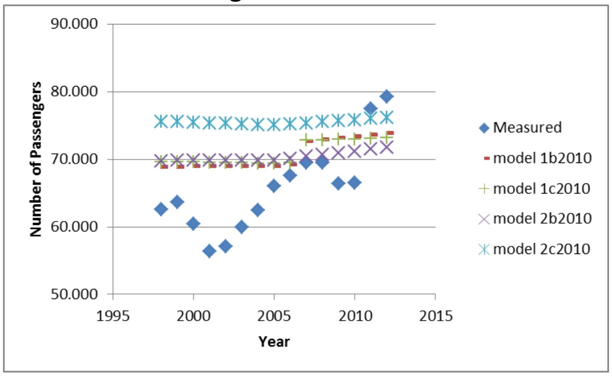
Figure 32: Modelled versus measured values. Left; cross-sectional models. Right ; time series models

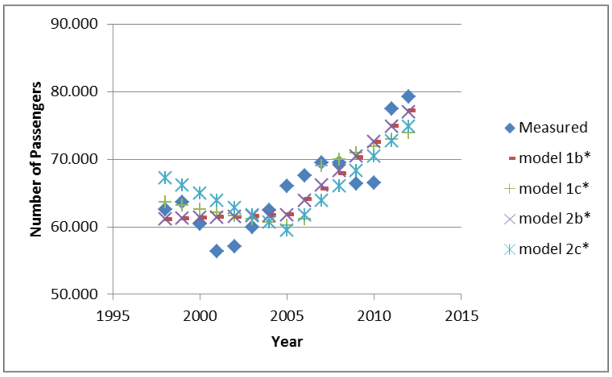
DT06 Yōga



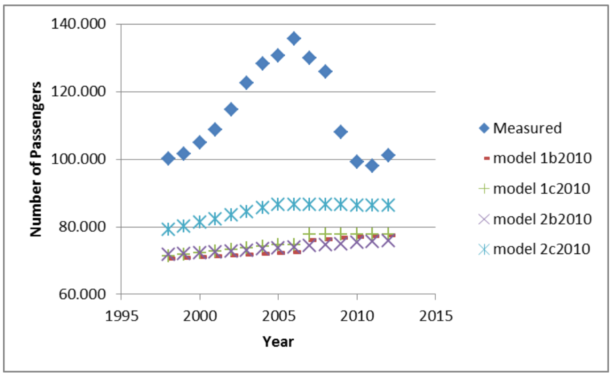


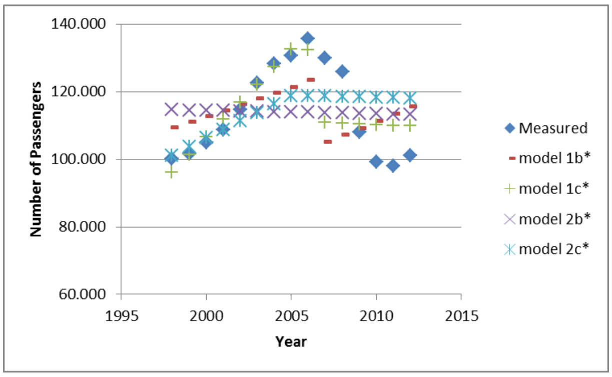
DT07 Futako-Tamagawa



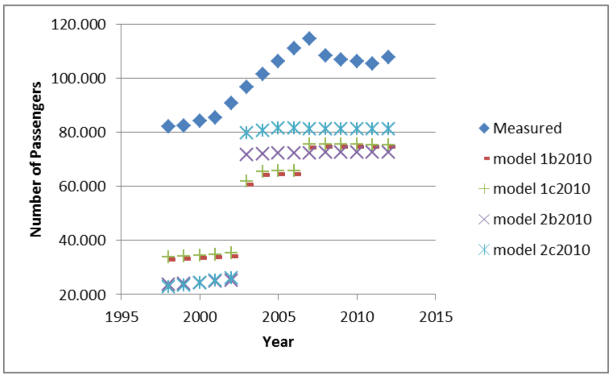


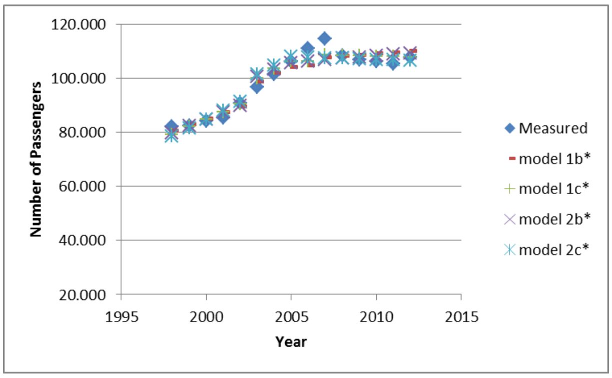
DT10 Mizonokuchi





DT16 Azamino





6.3.2 Conclusion within subject analysis

Concluding from the remarks in the above section and *Figure 32*, the model estimations for the time series models show a somewhat more accurate approximation of the measured values of the outcome variable.

For DT 06, it could be observed in the left graph (*Figure 32*) that the change in station type or frequency in the left figure is expected to cause a large rise in station use, but in reality this was only observed very slightly. The models with variable slopes and intercepts show a much better visual approximation, though they still cannot explain all of the fluctuation in the outcome variable.

For DT07, the order of magnitude already showed a good approximation for the cross-sectional model results, but accuracy was gained when a varying slope and intercept was modelled. Although the model seems to have improved, the parameter values show a distorted image, with a negative value for the Frequency predictor. The available predictor variables seem unable to fully explain the variation observed resulting in irrational parameter values. Most likely the problem would be solved with the addition of an indicator, such as Number of Directions, that explains the gap caused when the Ōimachi line was extended. Additionally, this could be caused by measurement error.

For DT10, most of the remarks similar to DT07 can be made, but the models seem to be even less capable of accurately predicting the observed variation. Only model 1c at least partly approaches the measured values, but still shows a large deviation from 2005 onwards. Part of the drop in station use could be accounted for with the addition of the Number of Directions parameter. It stands out that the WF Cluster 1 value remains constant after 2005, showing that the parameter scale with real measurement points only every 5 years might be too large while trying to account for more detail.

The time series models for DT16 show a much larger improvement in accuracy than could be expected from the observed model fit values. It stands out that all four models resulted in similar courses of the outcome values. Both the Frequency parameter in models 1b and 1c and the Station Type parameter in models 2a and 2b show very little to no change within the time series. The Population and WF Cluster 1 parameters explain the variation in station use very well with only one single parameter. Only a small outlier cannot be accurately described and might be explained by external factors such as the state of the economy or by a measurement error.

In general, it can be stated that there is always a risk in regression analysis that the model predictions come up with unrealistic parameter values. When interpreting modelling results such as the above it must be ascertained that what is modelled is in truth represented by the variables used, or that a non-existing relationship has been modelled. In conceiving a model, it should therefore always be considered what the effects are of the selected modelling approach on the outcome. That is, a hierarchal model would better fit the structure of the dataset in this research. Also, the method of estimation, in this case Maximum-Likelihood, has a certain effect on the model outcome. Furthermore, the effect on model outcome of the reliability of the predictor variables and the measurement error in these variables should always be considered.

With the predictor variables currently used a better model fit can be achieved when fitting the slope and intercept of the model for each subject separately. Whether this will result in an overall improvement of the model has to be investigated in further research. Being able to utilise the full dataset in a model-estimation would also allow for additional indicators to be included. This could improve the model accuracy even further. In conclusion, future research should consider performing a regression analysis with multi-level modelling techniques on the full panel dataset.

6.4 Analysing year to year change in station area characteristics

As explained previously in section 6.1.3 the panel dataset can be simplified by either looking at a cross-section or a time series separately. Additionally, the dataset can be adapted by only looking at the change of parameter values between successive years. This also overcomes the problem of repeated measures over time, because the change itself could be assumed random and independent. This allows for the application of simple regression analysis techniques to all observations. Looking at the change in values instead of the total values can give an insight into how change in one indicator influences another, but disregards the total size of the parameter. This is both the greatest strength and weakness of this approach.

In order to make a prediction for future passenger numbers, the modelled change was added to the passenger number for the base year. The modelling error therefore only occurs in the change estimate and not in the base of the value. The resulting error was therefore much smaller than when the full parameter value is estimated, as happens in the between subject and time series analysis.

By only investigating the change in characteristics, the effects of station size are disregarded. This makes the used values very susceptible to fluctuations, because these are not regarded relative to the parameter size, but solely in itself. Year to year fluctuations due to external factors therefore have a strong influence on the model results.

Furthermore, the regression coefficients (b-values) resulting from this analysis cannot be directly implemented in the station area analysis performed in the following chapter (section 7.1).

6.4.1 Modelling random intercepts with fixed slopes

Before carrying out the analysis first several things have to be considered. In the previously performed time-series analysis, no attention was paid to the term over which changes in parameter values have an effect on the outcome variable. That is, for example when the frequency of service is increased with four trains an hour the effect would realistically not be present immediately. There is a delay between the moment a change takes place and the moment the effect can be observed. However, without implying causality in any direction, it would also be possible that the frequency increased as a result of a growing station use. Assuming that effects take place in either direction, no effort was taken in shifting the timescale of predictor variables to better suit the change in the outcome variable. Additional research should investigate if there is any model accuracy to be gained.

An exploratory analysis was performed on the changes in parameter values between each time-step. As concluded in the previous section, some changes are the result of political, economic and environmental fluctuations and are poorly represented by the variables measured. A lot of these effects attenuate over time making it hard to produce accurate short term model predictions, but show more promising results when predicting over longer periods of time. Therefore, additionally to the delta analysis on yearly changes, the same analysis was performed between 5 year time periods.

For this exploratory analysis, stepwise regression was performed, first utilising the full dataset with a sample size of 364 measurement points from 26 cases over 14 time steps. The stepwise regression resulted in three model increments finalising with a model prediction with an R square of 0.272, based on the difference in Number of Directions (dND), the difference in Population (dPOP) and the difference in GDP (dGDP). The corresponding model parameters are shown in *Table 14*. The large dataset makes it possible to accurately estimate the model parameters, but the overall explanatory value is very low.

Second, a dataset was comprised of the differences between 2000/2005 and 2005/2010 from 26 cases resulting in a sample size of 52 measurements. The same stepwise regression was applied, also resulting in three model increments finalising with an R square of 0.540, based on the difference in Number of Directions (ddND), the difference in Population (ddPOP) and the difference in Travel Time (ddTT). This shows a moderate model fit and reasonable model predictors.

Table 14: Model parameters Delta models7

Model	Parameters	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	Sig.	95,0% Confidence Interval for B Lower Bound	Upper Bound
Yearly	(Constant)	42,227	132,717		,751	-218,770	303,225
	dND	-18162,146	1840,812	-,450	,000	-21782,242	-14542,050
R^2=0.272	dPOP	2,178	,499	,197	,000	1,196	3,159
	dGDP	3,086E-9	,000	,150	,001	,000	,000
5 yearly	(Constant)	1456,243	1092,595		,189	-740,568	3653,053
	ddND	-35598,510	5872,950	-,625	,000	-47406,868	-23790,152
R^2=0.540	ddPOP	2,571	,829	,314	,003	,904	4,238
	ddTT	-856,376	358,122	-,242	,021	-1576,428	-136,323

The yearly model showed a very low predictive value. This suggests that year to year changes cannot be modelled directly. There are three possible causes for this low predictive value. First, it could be due a difference between the moment changes take place and the moment they impact the outcome variable as explained previously. A more likely cause is that the year to year changes are subject to latent fluctuations in political, economic and environmental factors, which are not directly measured by the indicators used. Finally, it could be that the interpolation of the activity density variables (see Section 5.3.1) distorts the results and causes a low explanatory model value. This is would not apply to the 5 yearly model, because this model uses only the measured data points for the density of activities.

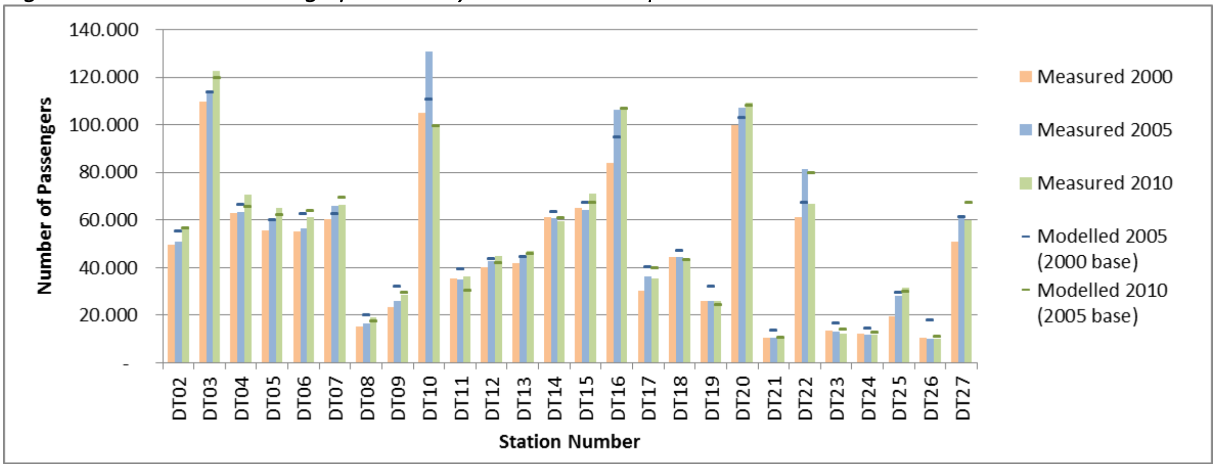
The 5 year model showed much more promising results, leading to the conclusion that this modelling approach is better suited for exploring macro effects. Large confidence intervals for the b-values indicate an instable model, as does an adjusted R square of 0.512. A sample size of 52 should be enough to result in an accurate model with three predictor variables based on the assumption of a sample size of 10-15 cases per predictor. However, if the effect being sought out is only a medium or even small effect, a larger sample size would be needed in order to make an accurate prediction. Other than that, the residual terms were uncorrelated and there was no significant multi-collinearity between the predictor variables.

The b-value for the change in Number of Directions (ddND) shows a strong negative relationship. This is different from the findings of the between-subject analysis and might result from the drop in passenger numbers between Mizonokuchi (DT10) and Futako-Tamagawa (DT07). In the current data set, describing parameter change, this is the only case where the number of directions for a station changes. In this case, it is more accurate to state that the predictor Number of Directions (defined in Section 5.4.1) describes the change in number of parallel directions. This might also be a reason why the indicator Number of Directions showed generally lower correlation values in the between subject analysis and lower explanatory values for the model estimations including this indicator (see *Table 9* section 6.2.4). In a future study it is recommended that a separate indicator for number of directions and number of parallel directions should be included. The standardised b-value Number of Directions shows a high correlation with the station use, and should therefore be used in the continuation of this research bearing in mind it describes the change in number of parallel directions.

The other two indicators show very plausible results. Showing a positive b-value for the change in population, keeping in mind this also represents a change in other activities in the station area. The change in travel time shows a negative relationship with the change in station use which is supported by the theory of the disutility of travel (de Dios Ortúzar & Willumsen, 2011).

To illustrate the gained accuracy of the model results compared to the between subject analysis, the observed values are compared to the estimated values. With the obtained model future predictions are made 5 years ahead, both from 2000 to 2005 and from 2005 to 2010. The predicted change is added to the base-year value for station-use for both 2000 and 2005 and shown in comparison to the measured values for the prediction years in *Figure 33*. When looking back at *Figure 31* (Section 6.2.4), it can be stated that, when the modelling error only affects the change in the outcome variable, the end result is more convincing. Both the estimations for the 2005 and 2010 values show an R-square of approximately 0.98 (98% explanatory value) for the compound parameter values, based on the base-year value for station use and the estimated change.
There are still some inconsistencies, especially DT10, DT16 and DT22 show relatively large deviations. It is interesting to note that the sharp rise in station use for DT10 between 2000 and 2005 was estimated poorly while the sharp drop between 2005 and 2010 was estimated very accurately. The high accuracy again could be explained by the inclusion of the parameter Number of Directions (Number of Parallel Directions). All the other deviations for these three stations could be caused by fluctuations in external factors or measurement errors. For example, this could be caused by fluctuations in the state of the economy. In this case these fluctuations were not distinct enough to accurately estimate the effect of the GDP indicator.

Figure 33: Modelled change plus base year values compared to measured values



6.4.2 Conclusions analysing year to year change

Based on the random intercepts analysis, the following can be concluded. First and foremost, year to year variation in parameter values shows too much fluctuation due to external factors and can therefore not be accurately modelled. For a time interval of 5 years, these fluctuations cancel out and have a smaller impact on model results. Due to the larger time interval used, focus was shifted to macro effects, but this would still be applicable in the continuation of this research.

Second, it was shown that outliers caused the estimated model to be slightly unstable. Especially, the change in Number of Directions (better defined as change in Number of Parallel Directions) is solely based on the measurements of Futako-Tamagawa (DT07) and Mizonokuchi (DT10) between 2005 and 2010. The sample size for the 5 year interval was too small to accurately generate a model with three predictor variables for the change in station use.

Third, the predicted values compounded from the parameter base value and the estimate parameter change did show incredibly accurate results. As the modelling error only affects the value of change and not the entire parameter itself, the modelled passenger number were very accurate.

Finally the parameter values obtained in this analysis cannot be directly applied in the station area analysis. As will be explained in the following section, weights for full indicators are required to determine the factors that shape station areas. This would require additional analysis for the weighing of parameters or a different approach to the one proposed in the research design (Section 3.4).

Concluding that if solely passenger numbers are to be predicted based on limited data, this method proves to be very promising. For the purpose of this research, however, there are some limitations which are discussed in section 7.1 and 7.2.

6.5 Conclusions passenger forecast modelling

This chapter discussed the link between station area characteristics (as defined in chapter 0), and the number of passengers using each station along the Den-En Toshi line. The link was established based on regression modelling techniques and with the obtained results research question 5, posed in section 3.3 can be answered. The relation of findings in this chapter to previous and following chapters can also be found in the research design schematic presented in *Figure 8* (Section 3.4).

In section 6.1, some theory regarding regression modelling was discussed. Based on this theory, three different approaches were established to link station area characteristics and station use.
First, using between subjects analysis, cross sections from the dataset were investigated. The best model fit with an R^2 of 0.687 was achieved by using the indicators Station Type and Workforce Cluster 1. This did not result in estimated values accurately enough to continue the use of this approach for the subsequent traffic flow forecasts in section 7.2. The modelling efforts resulted in the coefficient values (β-values) that can be used as relative indicator weights. This was required for the implementation of the Node-Place model in the station area analysis (Section 7.1). The model results of the between subjects analysis were used in this analysis.
Second, a within subject analysis was used to investigate time series per subject. In general, modelling time-series for each station using the same indicators as during the between subject analysis achieved much better modelling results. Between the individual stations, there was variation in the accuracy of the time-series models. Improved model accuracy for all stations was discussed (DT06, DT07, DT10 and DT16). Mainly, the results from Mizonokuchi (DT10) indicated that the model still cannot deal with extraordinary situations such as the extensions of the Ōimachi line parallel to the Den-En Toshi line. From these results, it was concluded that a better model fit can be achieved when fitting the slope and intercept of the model for each subject separately. Therefore it is recommended for future research to perform a regression analysis with multi-level modelling techniques on the full panel dataset.
Third, an analysis investigating parameter change was discussed, where the change in the original parameter values between successive years was used. The main disadvantage of this approach is that the year to year change is much more susceptible to fluctuations in external influences. This showed in the modelling result for the year to year model estimation where an R^2 of only 0.272 was achieved. Therefore, a second model estimation was done based on the indicator change over a 5 year interval. This allowed the model focus to be placed more on the macro effects, resulting in an R^2 of 0.540. To predict station use for a future year, the change estimated based on the model was added to the value of the station use for the used base year. This approach has the advantage that when using these modelling results for making predictions on station use the modelling error only influences the modelled change, but does not affect the base value of the outcome variable. This resulted in a prediction 5 years ahead with an R^2 of 0.98. Therefore, it can be concluded that using the indicators describing station area characteristics provide a sufficient model fit in forecasting passenger numbers for the Den-En Toshi line stations. The obtained model will be used to continue this research in section 7.2, analysing the effect of station use on traffic flow. Some additional options will be looked into in section 7.1 to see whether these modelling results can also be used to determine indicator weight in the station area analysis using the Node-Place model.

7 LINKING STATION AREAS AND TRAFFIC FLOW

The previous chapter established the link between station area characteristics and station use in several passenger forecast models. This chapter uses the results to determine how the balance of different station area characteristics affects the traffic flow on the corridor. *Figure 8* in chapter 3.4 shows that the top and bottom section of the model are added to the in chapter 0 established middle section of the model.

First, the balance of station area functions, accessibility and activities, is discussed continuing the introduction given in section 2.3. It is explained, what balance of station area functions is and how it is measured using the Node-Place model (N-P model). Subsequently, the N-P model is constructed for this case study of the Den-En Toshi line. With the established N-P model, the balance of Den-En Toshi line station functions throughout the study period is evaluated. The theory is compared to the findings within this case study.

Second, the balance of the traffic flow, the intensity and the direction of travel along the Den-En Toshi corridor were investigated. It is explained, what traffic flow balance is and how it measured. The distribution of station users over the corridor is discussed and the traffic flow of the Den-En Toshi line over the study period evaluated.

Finally, a case scenario was established to investigate the link between station area functions and traffic flow. The effect of balancing station area functions on traffic flow was studied.

All findings are summarised in a short conclusion.

7.1 Analysing station areas

The N-P model was introduced in section 2.3 as a policy tool for developing station areas. Based on the theory of the land-use and transport feedback cycle the model assumes that the activities and accessibility of station areas are balanced out over time to a certain optimum. By comparing station areas, this allows identifying the stations where the activities and accessibility are not adjusted to one another.

The NP model assumes that there is an optimal balance between node and place values. When a change in a station area takes place, over time the balance between node and place values is restored. If this balance is assumed, it can be concluded that the average node and average place value of the entire population is the ideal balance. A sample of the population should therefore show normally distributed node and place values. This makes it possible to compare station areas to the desired balance. Of course, the distribution will be skewed to some extent due to external influences such as politics, but these are very difficult to take into account. Furthermore, it must be noted that this study is only a case study, meaning that, the sample investigated is not necessarily a good representation for all stations in Tokyo.

The Variables used for the N-P model were selected in Chapter 0. The indicators making up the place value are representing density and diversity of activities. These indicators were: Population, Workforce-cluster 1, Workforce-cluster 2, Workforce-cluster 3 and Multi-functionality. The indicators making up the node value are representing station area and network accessibility. These indicators were: Station-type, Number of directions, Frequency and Travel time to centre. It must be noted again, that Shibuya station (DT01) was previously removed from the analysis due to incorrect data.

The application of the N-P model was adopted from Bertolini (1999) with additions to the methodology by Reusser et al. (2008) and Chorus (2012). The authors of the first two studies entered all the present indicators into the NP model. However, Chorus (2012) first selected the important indicators on shaping station areas based on correlation analysis, before entering these into the N-P model. Based on regression analysis with station use as the sole performance indicator, performed in chapter 0, an indicator selection was done.

7.1.1 Methodology

To be able to compare indicators with different units and process them in the N-P model several steps were taken.

Implementing the N-P model can be done by simply assuming that all of the indicators obtained (described in chapter 0) influence the node and place index and should therefore all be included. Chorus (2012) selected only the most influential indicators based on correlation analysis. A similar approach is used in this research. The indicators selected modelling the link between station area characteristics and station use in section 6.2 are used in constructing the node and place indices. The regression analysis used is basically an extension of correlation analysis, meaning the approach on selection index variables does not deviate from the approach selected by Chorus (2012).

Comparing node and place functions, the N-P model assumes normality of the univariate distribution of each indicator. To check whether the distribution of each indicator resembles normality, the symmetry and kurtosis of each variable were investigated. In this case study, the sample was very small, which resulted in skewed and peaked univariate distributions. Transforming the variables, for example by log transformation, did not improve the univariate distribution and is therefore not applied on any of the variables (Field, 2009). To continue this case study, the N-P model was implemented while disregarding this assumption, which should be kept in mind when interpreting results.

When the node or index is build-up out of multiple indicators, the diversity in parameter units needs to be overcome. In this case the parameters are rescaled. Bertolini (1999) rescaled all the variables between 0 and 1 and basically assumed that every indicator is weighed identically. While each indicator in truth does not have the same impact on the node or place index, the indicators can be weighted before adding them up. In chapter 0, the impact of each indicator measuring station area characteristics on the performance indicator station use (passenger numbers) was determined using regression modelling techniques. These weights (the regression coefficients) could be directly implemented on the indicators included in the N-P model.

The additional advantage of weighing the variables when constructing the node and place index is that a direct link between station use and the node- and place indices is established. The values of station use can therefore be immediately read from the resulting N-P diagram.

Comparing Node and Place index requires one final transformation. Both indices are expressed in the standard score (or standard deviation units), the number of standard deviations an observation is above the mean of the respective indices. Positive scores on either the node or place index scales represent an observation above the mean of all the index values and a negative one below the mean. This a necessary processing step in order to compare station area balance in node and place index relative to the other sampled stations.

7.1.2 Result of the Node-place model

The indicator selection for the visualization of the N-P model is based on the previous study on the importance of the available indicators in shaping station areas. From the between subject analysis on the effect of station area characteristics on station use the same indicators were selected to establish the node and place index. The best model fit was achieved by model 2c, based on Station Type and Workforce Cluster 1, resulting N-P diagram displayed in *Figure 34*. Each station is represented by a different colour/shape and has 15 measurement points throughout the graph.

Additional advantage of obtaining the indicators from the regression analysis on station use is that station use can be directly displayed in the same diagram. The red lines displayed represent the modelled values of station use with the respective node and place index values. The station use estimated with the between subject model is not a very accurate estimation of reality and will not be used to predict change in station use.

Figure 34: Node-Place model, Station Type versus Workforce Cluster1

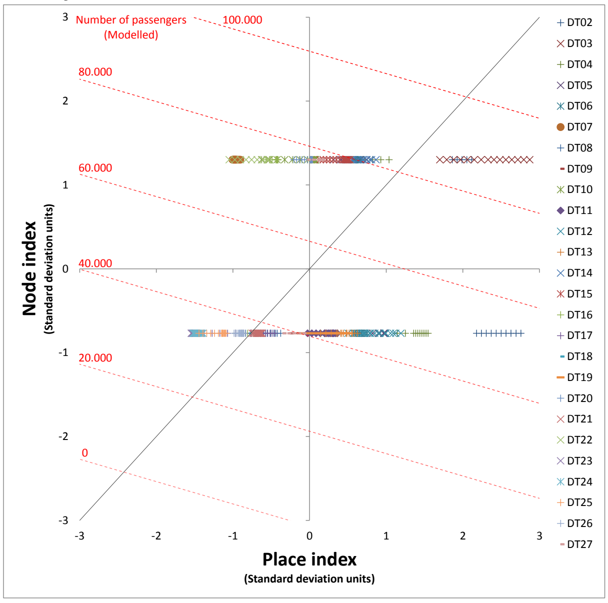
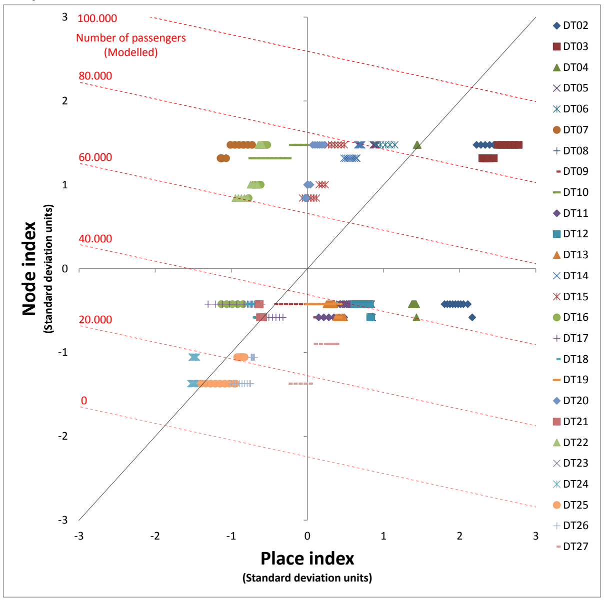


Figure 35: Node-Place model, Frequency versus Population



The N-P diagram does not reveal any immediate insights. The selected indicators provide a poor visual distinction between stations. The node index is solely based on Station Type, which is a categorical variable representing either local or express stations. When the node index of a station is adjusted to provide a better N-P balance, it can either be upgraded from local to express or downgraded from express to a local station. This limitation in the use of the N-P diagram is undesired, therefore different options to visualise N-P model are investigated.

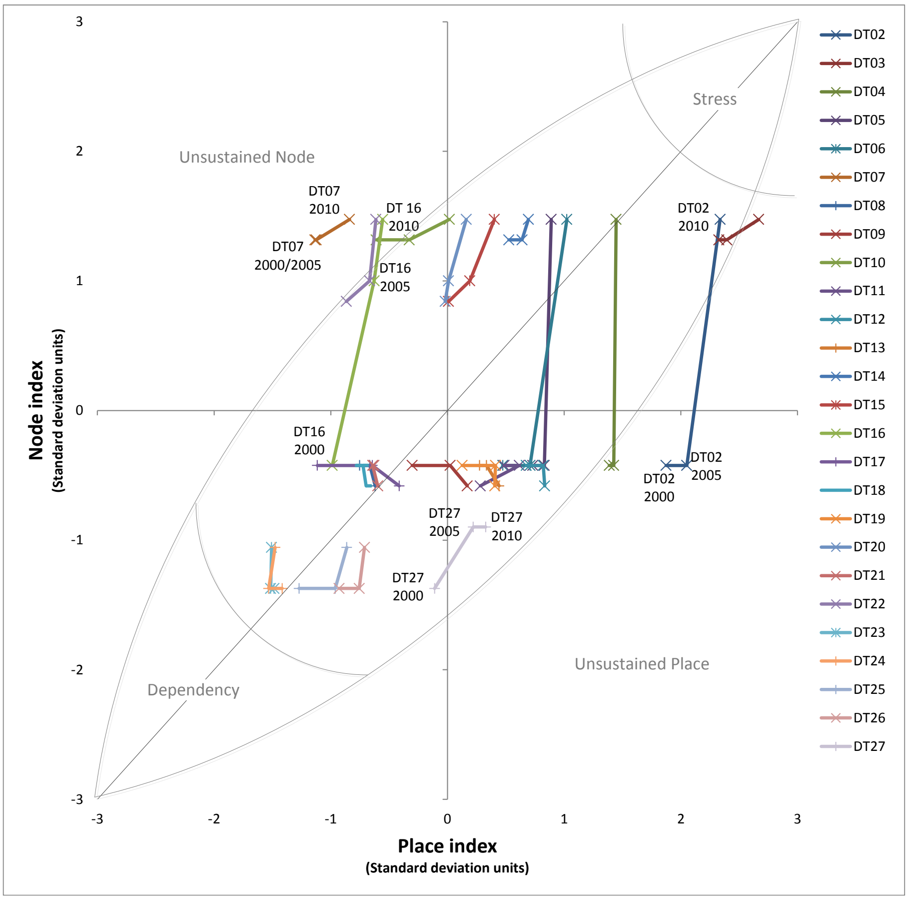
When constructing the node or place index from a single indicator, it is desirable that the indicator used is at least measured at interval level. This excludes the use of model estimations including the Station Type indicator. *Table 9* in section 6.2.3 shows that several other model estimations were made using different model indicators. When model estimations based on Station Type were excluded, the best model fit was achieved by model 1b. This model was based on the Frequency as node indicator and Population as the place indicator. The model showed an R^2 of 0.671 for the 2010 cross section. Implementing the indicators from model 1b into the N-P model resulted in the diagram shown in *Figure 35*. This N-P diagram shows a better distribution of all the stations over both the node and place index. However, the variation in the node index is still limited, because only a single accessibility indicator (Frequency) was used in constructing the node index. This diagram allows for a sufficient analysis of the balance of station area node and place index and is therefore adopted for further use in this research.

7.1.3 Analysing past developments Den-En Toshi line

The established N-P model can be utilised to evaluate the station area balance of the Den-En Toshi line stations over the time span of the research scope. It can be checked whether the station characteristics develop in such a way that node and place functions balance out over time as the theory of the land-use and transport cycle explains.

The N-P model established in the previous section, based on Frequency as the node indicator and Population as the place indicator. It was slightly adapted to be better able investigating the temporal trends by only showing the data points for the years 2000, 2005 and 2010. *Figure 36* is used to determine the N-P balance over time on the Den-En Toshi line. The five sections in the N-P diagram, unsustained node, unsustained place, stressed, dependent and balanced station areas are also displayed.

Figure 36: Temporal trend in the N-P model



The grey helplines in *Figure 36* are shown as indication, as there is no hard distinction between sustained and unsustained N-P balance. The N-P model for the Den-En Toshi line shows a corridor along which all stations are relatively well balanced. The relative differences between the stations do not deviate excessively from the mean. In general, most stations show a rising or slightly rising trend in the place index over the study period, except for several local stations along the centre and at the end of the corridor. The node index shows some small variations for most stations, while the rise in frequency for DT02, DT04, DT05 and DT06 due to the change from local to express stations can be clearly distinguished in the node index. Also the rise in node index for DT16 can be attributed to the upgrade from local to express station.

There are some stations that are, or at some point within the timespan were classified as unsustained nodes or unsustained places within the N-P diagram. More unsustained nodes are Futako-Tamagawa (DT07), Mizonokuchi (DT10), Azamino (DT16) and Nagatsuta (DT22). These are all express stations with transfer possibilities further outside Tokyo. According to the N-P diagram, these are all stations with high accessibility where the density of activities is too low.
More unsustained places are/were the stations nearest to the centre, DT02, DT03 and DT04. At these stations very high densities of activities are present.
The diagram shows no stations that are fully dependent or under high stress. Several stations at the end of the line do approach more dependency, but are still classified as self-sufficient in this N-P diagram. Tokyo and in particular the Tokyu lines, are renowned for the fact that almost every single station is profitable, which can also be concluded from the N-P model. Ikejiri-Ōhashi (DT02) and Sangen-Jaya (DT03) are under some stress, meaning that it becomes increasingly difficult to intensify the density of activities even further.
It must be noted that Shibuya (DT01) was removed from the analysis and is not present in the N-P diagram, while it was removed due to faulty data. A previous study on station areas in Tokyo (Chorus, 2012) concluded that Shibuya is an extremely stressed station, which is very plausible as it is one of the busiest train stations in the world.

During the study period, for some stations the balance between node and place functions was improved, while others deteriorated. Striking is the change in node index at Azamino (DT16) that caused it to become a more unsustained node. Azamino has a low density of activities because it used to be a small local station until the Yokohama Municipal Subway Blue line was connected at Azamino in 1993. As Tokyu anticipated the Blue line to be connected at Tama-Plaza, large scale real-estate development was carried out at Tama-Plaza instead. For over 5 years after the connection was made, Tokyu only serviced the station with local trains before it was upgraded. The positive effect of the real-estate development at Tama-Plaza (DT15) can still be seen in its place index.
With the upgrade of Ikejiri-Ōhashi (DT02) from local to express stop in 2008, a much more fitting node index is achieved for the corresponding density of activities. However Ikejiri-Ōhashi and Sangen-Jaya (DT03) are now approaching stress. Infrastructure facilities are utilised to its absolute maximum while building densities are very high.

7.1.4 Sensitivity analysis

A sensitivity analysis was performed in order to give an indication of how the interpretation of the Node-Place model would change if a different approach was used. It was chosen to select the most important indicators based on regression analysis, resulting in the N-P model described in the previous section. Three additional approaches were investigated. First, the N-P model was implemented using the full indicator set of all the accessibility and activity indicators available. Second, the N-P model was implemented with the full indicator set, while also including the data of Shibuya (DT01). This gave an indication of the effect of faulty data, but also gave an impression how Shibuya might be situated in the N-P diagram. Third, the N-P model was implemented using Job Accessibility as node indicator and Population as place indicator. To be able to compare these three approaches only the data for 2010 was used. This was done because Job Accessibility was only determined for 2010.

Figure 37: Node-Place model, full indicator set

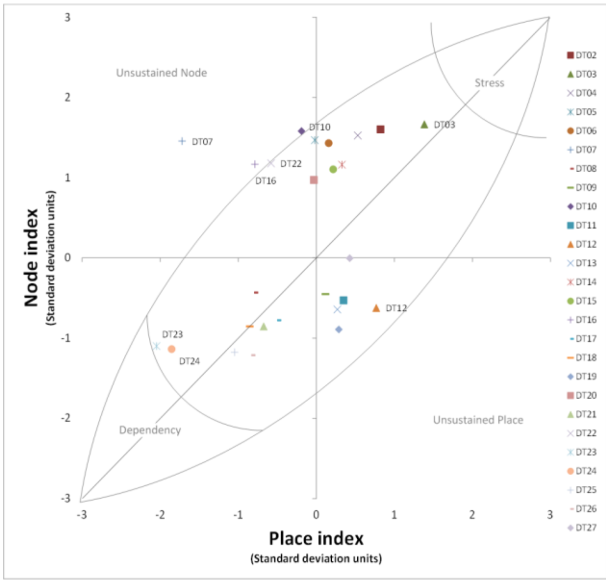
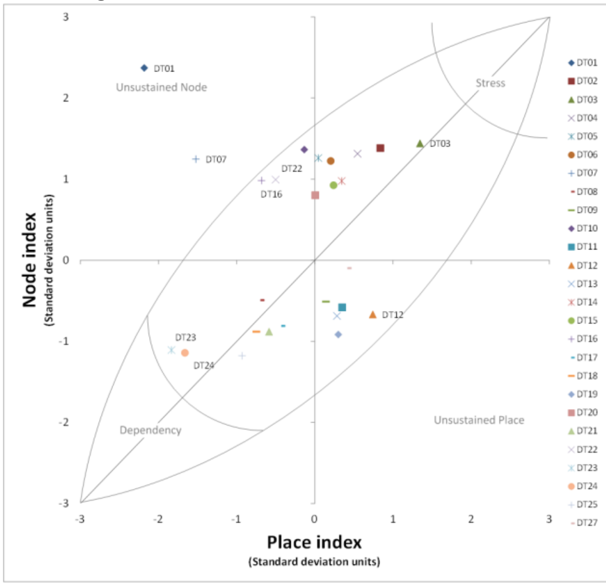


Figure 38: Node-Place model, full indicator set including DT01



Node-Place model with the full indicator set

For the N-P model application with the full indicator set the Node index was comprised of: Station-type, Number of directions, Frequency and Travel time to centre. The place index consisted of: Population, Workforce-cluster 1, Workforce-cluster 2, Workforce-cluster 3 and Multi-functionality. Each indicator was rescaled between zero and one, before they were summed up into the node and place index. No indicator weighing was applied. The node and place index were normalised to be able to compare standard deviation units. The resulting N-P model for the full indicator set is shown in *Figure 37*. The grey helplines in the figure are shown as indication of node place balance, as there is no hard distinction between a sustained and unsustained N-P balance.

The N-P model in *Figure 37* shows only a slightly different image than the selected approach in *Figure 36*. The stations that were previously marked as more unsustained nodes (DT07, DT10, DT16 and DT22) are also identified as less sustained by the N-P model using the full indicator set. Less sustained places are here DT12 and DT11, also similar to the 2010 situation in *Figure 36*. The exact location in the N-P diagram and therefore extent of unbalance vary a little. Besides

Node-Place model with the full indicator set, including Shibuya (DT01)

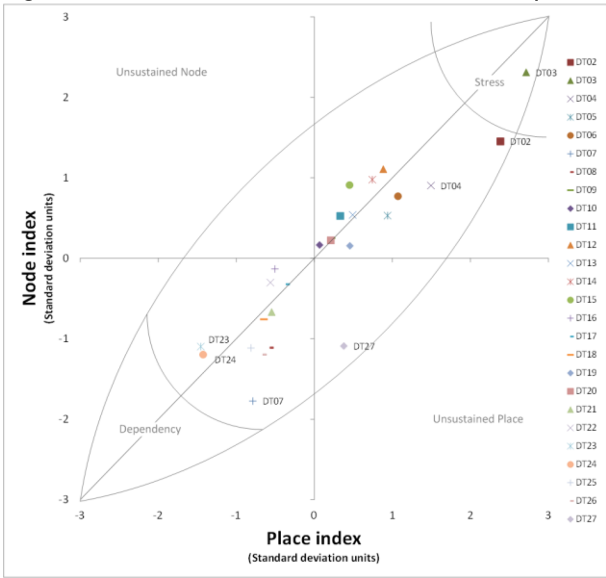
For the N-P model application including the faulty data for Shibuya (DT01), the same approach was used as for the previous N-P model application. It is shown in *Figure 38*, that the inclusion of Shibuya has only a slight effect. The highest node values (DT07, DT10, DT16 and DT22) show a slight drop relative to the node values in *Figure 37*. Shibuya has a significantly larger node index than the other stations. However, the place value for Shibuya is completely misrepresented. With correct values for the workforce and population indicators for the Shibuya station area, the station would be situated differently in the N-P diagram. In reality Shibuya has the highest concentration of jobs and would more likely be situated in the upper left corner of the N-P diagram, signifying a stressed station area.

Node-Place model, Job Accessibility versus Population

In transportation research accessibility is often described by the number of jobs that can be reached within a certain time. This job accessibility is a compound indicator consisting of travel time and the number of available jobs. To investigate what the result would be of using such a Job accessibility indicator, a separate N-P model was constructed. The node index was comprised of the Job Accessibility indicator. How this indicator was obtained from the dataset is explained in Section 5.4.4. Because Job Accessibility already uses information on the station area workforce, it was chosen to comprise the place index solely of the Population indicator.

The resulting N-P model is shown in *Figure 39*. It is striking that almost all stations are situated along the diagonal, signifying an optimal balance. Less balanced are Ikejiri-Ōhashi (DT02), Sangen-Jaya (DT03), Futako-Tamagawa (DT07) and Chūō-Rinkan (DT27). It is likely, that the image brought forward is the result of the limitations of the Job Accessibility indicator. Because with the available data only job accessibility for the corridor could be determined, the full value of network accessibility is disregarded. Especially the stations nearer to central Tokyo should have much higher Job Accessibility values. The concentration along the diagonal might be due to the inclusion of the workforce in the calculation of an accessibility indicator. For future research, it is therefore advised against using such a compound indicator in the N-P model.

Figure 39: Node-Place model, Job Accessibility versus Population



7.1.5 Conclusions Node-Place model

Resulting from the station area analysis performed with the Node-place model, following conclusions can be drawn. The implementation of the N-P model was based on the methodology as proposed by Chorus (2012). The most important indicator in shaping station areas were selected based on the regression analysis. The indicators having the most profound effect on station use were assumed to be the most influential in shaping station areas and therefore implemented in the N-P model.

An N-P model based on Station Type in the node index and Workforce Cluster 1 in the place index did not provide desired result. Because the Station Type indicator is only categorical the node index can only take two values, resulting in an N-P diagram that is not insightful to identify possible development opportunities. Therefore, a second N-P model was established based on the Frequency and Population indicators. This model showed the desired distinction between station areas and was therefore adopted for this research.

The use of indicators selected through regression modelling allowed the direct linking of node and place indices to the station use. Although the model estimations used were not accurate enough to base station use predictions on, they do give a good impression of the effect node and place functions have on station use.

There is a possibility to weigh the indicators when the node or place index is compiled out of multiple indicators. Previous research assumed that each indicator to have the same relative impact, which is not realistic. The weighing of indicators was not performed here because only a single indicator was used to construct the node and place indices. For future research, it is highly recommended that this is to be done in case multiple indicators are used in constructing the node and place indices.

The modelled relationship between station area characteristics and station use was assumed linear. However, from the N-P model can be concluded that the relationship might be better characterised by an exponential function. The model assumes changing the node or place values to extremes will still influence the station use in a similar way as with more acceptable values, which is unlikely to occur in reality. This should be considered for future research.

Over the course of the study period, the stations along the Den-En Toshi line showed a fluctuation of the balance between station area node and place functions. According to theory of the land-use and transport feedback a balance is always found over time. It can finally be concluded that the N-P model confirms that this also occurs in reality. It must however be noted, that environmental factors do play a large part in shaping station areas, making it impossible to accurately explain all of the fluctuations taking place.

From the sensitivity analysis can be concluded that by selecting only the most relevant indicators a good N-P model can be established. Adding more indicators only slightly changed the results. The inclusion of the data for Shibuya (DT01) gave a good impression of the size of the node index for this station, but the resulting place index should be disregarded due to the faulty data. Including a compound accessibility indicator, including place indicators in its calculation, is not recommended. This could result in a distortion image displayed in the N-P diagram.

7.2 Analysing traffic flow

The relationship between station area characteristics and station use has been established, but the effect on the direction and intensity of traffic flow has yet to be determined.
This section starts out with a short discussion on how the optimization of the traffic flow on a corridor level can be quantified. It is therefore considered what is measured based on the available data as described in section 5.5.2.
It is then explained how direction and intensity of traffic flow are estimated based on results obtained from the forecast model. Furthermore, it is described what methods are available to estimate the distribution, what their advantages and drawbacks are and how this is applied to the modelling results from the previous chapter.

7.2.1 Measuring intensity and direction of traffic flow

It is stated in the theoretical framework that, opposed to generating as much station users as possible for each station individually, the traffic flow should be optimized at a corridor level. Ideally, the available infrastructure is utilised to its maximum. This would be achieved by a traffic flow with an intensity equalling the maximum in both directions, at all times during all hour of operation and over the entire network. Because the data available for this research limited the scope of this measurement to exclude time of day and focus more on equal intensities over the network and in all directions. The available data did not allow the direct estimation of the efficiency of the network. However, within the scope of this research it suffices to investigate the average daily link load in both directions on the Den-En Toshi line.

In the previous sections, a model was developed for estimating the number of trips generated and attracted by each station (could be seen as combined trip generation and attraction model). The trips generated now need to be distributed over the line in order to investigate the link loads. In this research, only one mode was considered, the train, and only a single route, the Den-En Toshi line. Determining the distribution of trips over this railway corridor can be thought of as simultaneous executing the trip distribution, modal split and trip assignment steps from the traditional 4-step model. There are several ways to distribute trips of which the most commonly applied are growth factor methods or synthetic models such as the gravity model (de Dios Ortúzar & Willumsen, 2011). A distribution model estimates the number of trips between each of the zones, which can be displayed in a trip matrix.
The growth factor method utilises information on the changes in origin and/or destination totals to adjust the trip matrix of a base-year to the design year. This can either be done by applying a uniform growth factor over all the zones or, if possible, correct for the expected trip numbers originating and terminating in each zone.
Synthetic models, of which the gravity model is the best known, estimate trips based on trip ends and the disutility of travel as distance/time/cost increase. They do not directly use an observed trip pattern, but distribute the trips based on a deterrence function that describes the generalised cost of travel.

The main advantages of growth factor methods are their simplicity and when applying the growth factors the distribution of the trips in the observed base matrix is very well preserved. This is also its greatest weakness, as it limits the ability of the distribution to cope with changes in the network that influence the distribution itself. This limits the use of growth factor methods somewhat to short term planning purposes. Another disadvantage is the requirement of a base year matrix and the fact that the accuracy of the result is directly dependent on the accuracy of the base matrix.
Synthetic models can approach the effect of changes in the network described in the deterrence function. This allows it to be used to evaluate scenarios where changes in the network take place, and thus more suitable for long term planning. The accuracy is completely dependent on how well the chosen parameters in the deterrence function are able to describe the network changes.

Synthetic models are very convenient for internal to internal trips (within the study area), but when a significant proportion of the trips has at least one end outside study area (e.g. an external zone) the suitability of a model that depends on distance, travel time or generalised cost of travel decreases.

Both types of models have their restrictions. For estimating a gravity model, parameters have to be entered into the deterrence function. However, incomplete or no data at all is available to estimate this function. For example, travel time is only available to the centre (DT01), while the gravity model requires the travel resistance between each possible Origin-Destination (O-D) pair. Furthermore, a large part of the trips originates or terminates in an external zone. This can be seen in the passenger number graphs for all transfer stations (Appendix 9.6) in *Figure 49*, which depicts the ratio between passengers transferring and non-transferring passengers in the station use. These large numbers of transferring passengers, especially those at transferring at Shibuya (DT01) make it infeasible to use a cost deterrence function to model these trips.

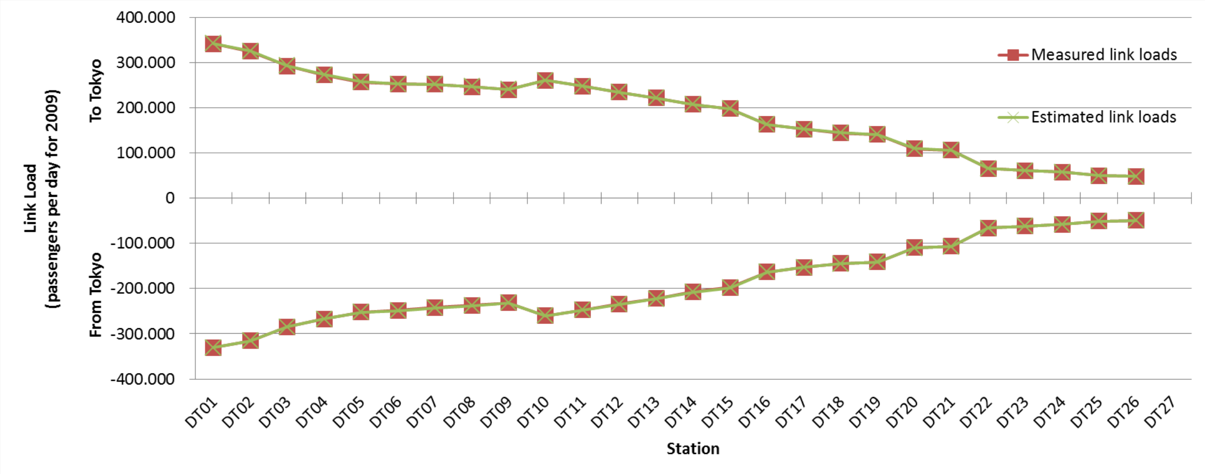
To estimate a growth factor model, a base trip matrix is required, but this was not available. The passenger data did hold additional information on travel direction instead of solely trip ends totals. This made it possible to easily and very accurately obtain a trip matrix starting out from an empty base matrix. To estimate a trip matrix for any given year from the available passenger data, some assumptions were made. It was assumed that every O-D pair is present in the matrix, which allows the first iteration to start out with a matrix filled with one's. Following from this is the assumption that each O-D pair has the same disutility of travel. In a network study, this would be an unviable assumption, but it can be justified for this case study for two reasons. First, the average travel time for trips in Tokyo is over 60 min, while the full travelling the full length of the Den-En Toshi line itself takes a little over 50 minutes. Second, for the Den-En Toshi line the general trip pattern is to Shibuya and continuing into Tokyo, as this is by far the largest attractor on the corridor (*Figure 49*).

These assumptions result in distributing the trips end totals over the O-D pairs proportionally to the size of the station use. Within the trip matrix each zone represents a station, and stations where there is a possibility to transfer receive an additional external zone in order to separately distribute the transferring station users over the corridor. In the matrix intra-zonal trips (for example DT10 to DT10 and also DT10 to Transfers at DT10) are set to zero, because logically, no trips are registered in the data that are made within a single station.

By applying the Furness method, the individual cell values for each O-D pair were scaled up to match the trip end totals. The standard Furness method scales up row and column totals in the trip matrix using the trip end totals for originating and terminating trips in each zone. The available passenger data allows distinguishing between passengers travelling towards Tokyo or travelling away from Tokyo within the trip end totals extending the Furness method. This basically allows the matrix to be divided in two sections along the diagonal, resulting in especially accurate trip distribution along the line ends.

From the passenger data, a trip matrix was produced for 2009 (the latest year with elaborate passenger data). Starting out, the Furness method matching the origin totals and with a total of 5 iterations a trip matrix was obtained (Appendix 9.8). From the resulting matrix, the link loads were extracted and displayed as the green line in *Figure 40*. Compared to the link loads directly obtained from the passenger data this shows a very good result. The maximum deviation from the measured link loads remains under 1000 passengers on an estimated 250.000 (less than 0.4% error). To validate whether the obtained matrix is stable, the same Furness method was applied while starting out from the destination totals instead of the origin. The same level of accuracy was obtained, and noteworthy is that the deviations of the individual cell values are very small signifying a stable and reliable base matrix.

Figure 40: Validation base matrix 2009



7.2.2 Modelling traffic growth and corridor balance

The stability of a trip matrix over time, estimated with information on origin, destination and direction of travel, was further explored. Taking any base matrix an approximation is made for a future year by scaling-up the origin and destination totals to the future year. Because the modelling results estimating the station use (section 6.2) only give in a total number of station users it is investigated whether an accurate trip matrix can be obtained when only using this number to scale-up future trip end totals.

The total number of station users is distributed proportionally over the trip end totals as in the used base year matrix. Similarly, the distribution over the direction of travel was done proportionally to the distribution in the base year. This resulted in new origin and destination totals for each station in each direction. The base matrix was then adjusted to the new totals by Furness method resulting in a trip matrix for the design year and from the trip matrix future link loads were calculated.

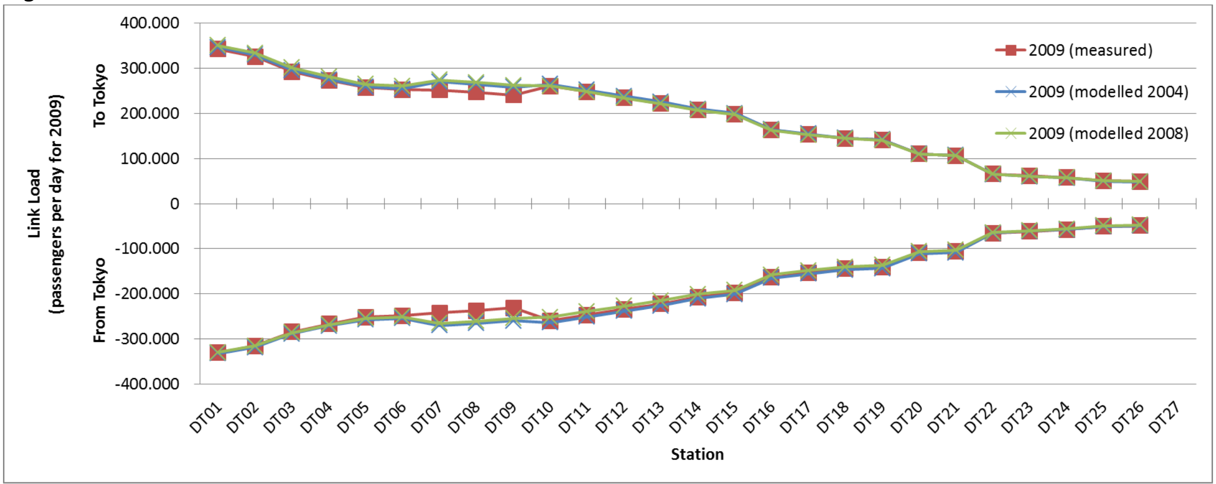
This estimation of a design year trip matrix was done based on different base years. *Figure 41* shows the measured link loads for 2009 in comparison to the link loads estimated for 2009 from the base years 2008 and 2004. In the estimations, the distribution of the base years, 2004 and 2008, were scaled-up using the station use of the design year, 2009.

The link loads resulting from the estimation show a relatively good fit to the measured link loads. It stands out that for the link loads between Futako-Tamagawa and Mizonokuchi (DT07 to DT10) the estimations are fairly off. The inability to cope with changes in the network is the largest weakness of growth factor methods, and this is clearly a result of that. The addition of the Ōimachi line extension between 2008 and 2009 obviously caused a shift in passengers transferring form the Den-En Toshi line to the Ōimachi line already at Mizonokuchi instead of Futako-Tamagawa which is unaccounted for in the trip distribution. This causes an overestimation in the link loads between these stations in the direction towards Tokyo and a similar underestimation in the link loads away from Tokyo. The deviation between measured and estimated link loads is somewhere between 20.000 and 25.000 passengers per day on a total over a total of around 250.000, an error of up to 12%.

Though errors in the link load estimations are much smaller on other sections of the line, especially at the far end of the line, they can still rum up to 8.000 passengers per day, a 3% error. There is not necessarily a loss of accuracy between the estimation 1 year prior to the design year and the estimation 5 years prior. Fluctuations in errors differ greatly over time, direction of travel and location along the line making it hard to make some concrete observations. It is possible that already the year to year fluctuations in the passenger numbers (on the normative day) cause a distortion in the estimations. Other than the Ōimachi line extension, no major changes have taken place in the network that could cause the peculiar outcome of the link load estimations.

The latest available passenger measurement took place after the addition of the Ōimachi line, therefore future link load estimations with 2009 as a base year should deliver more accurate results. With a base-year maximally 5 years prior to the design year, a 3% error in link load estimations is acceptable for the purposes of this research. Therefore, it was continued to make distribution estimations using the method discussed previously.

Figure 41: Measured versus modelled distribution

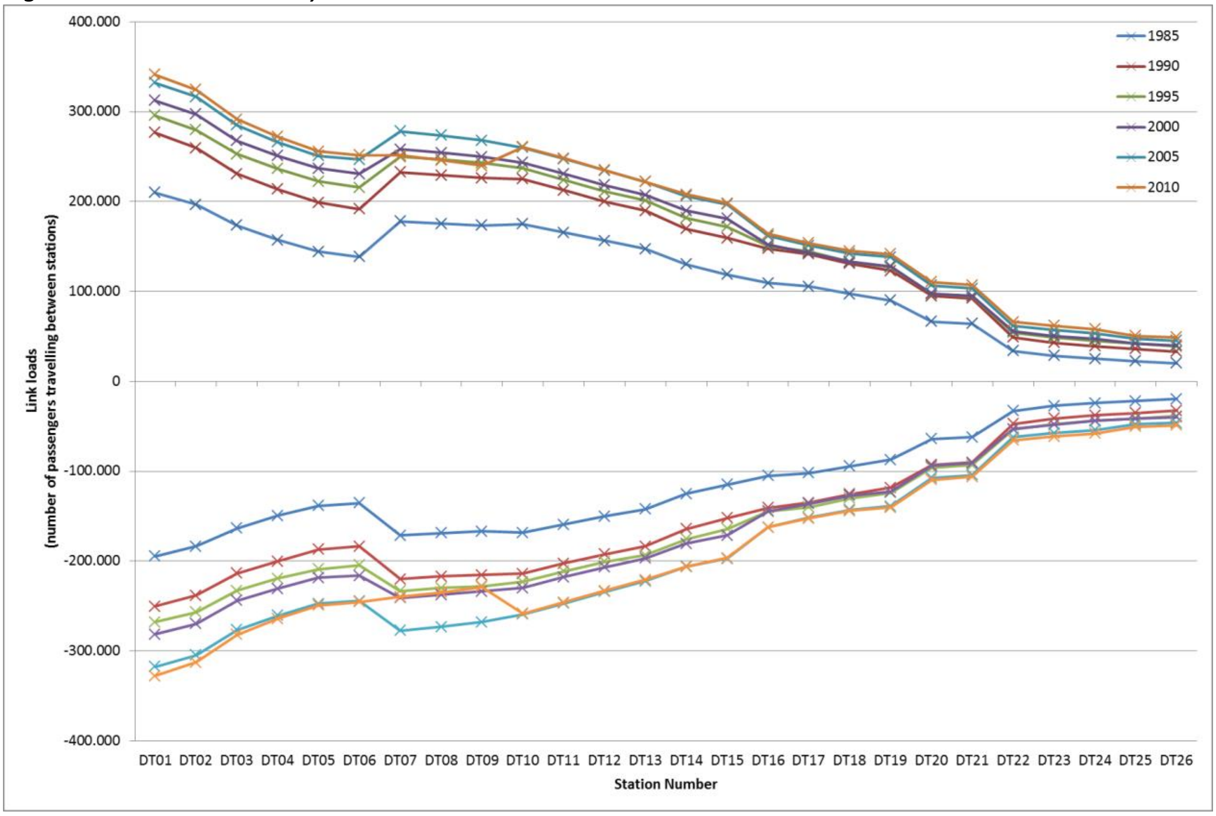


7.2.3 Analysing the development of traffic flow on the Den-En Toshi line

The historical development of the traffic flow balance on the Den-En Toshi line was studied. The development of the link loads along the Den-En Toshi line was investigated qualitatively in order to give an impression of the extent to which the infrastructure was utilised efficiently. Based on this, it was concluded whether developments have led to a balanced traffic flow over the Den-En Toshi corridor. In *Figure 42*, the measured link loads on the Den-En Toshi line are shown, measured every 5 year starting in 1985 to 2010.

After completion of the Den-En Toshi line in 1984, the link loads on the line grew rapidly, but stagnating in the early 1990's when a major financial crisis hit Japan. After only a slight recovery and continuation of growth experienced on the line, it reached its peak in 2007 (not displayed in the figure). Then, the link load growth stagnated once more due to the global financial crisis of 2008. Over the entire period, the Den-En Toshi line continuously experienced increasing link loads right up to 2008.
Striking in this graph is the strong drop in link loads on the section Mizonokuchi (DT10) and Futako-Tamagawa (DT07) between 2005 and 2010. This is likely the result of the parallel running Ōimachi line extension in 2008. Only slightly visible is the influence of the Setagaya tramline connection at Sangen-Jaya which causes the increase in link load between Sangen-Jaya (DT03) and Shibuya (DT01) to be even greater than on the remaining section. At Azamino (DT16), the connection of the Yokohama Municipal Subway Blue line in 1993 can be distinguished. From that moment on higher link loads start from Azamino towards Tokyo. On the section between Azamino (DT16) and Nagatsuta (DT22), there is a long period without significant change in link loads, picking up link load increases after 2000. Passengers using this section could be more influenced by the effects of the crises that prevailed during the 1990's. Striking is that the final section from Nagatsuta (DT22) to Chūō-Rinkan (DT27) shows a slight but continues growth over the entire time span measured. This could be the case, because the line serves a more local purpose in this section. In general, effects of network characteristics can be distinguished in the observed link loads on the Den-En Toshi line.

Figure 42: Link load history Den-En Toshi line



On the Den-En Toshi corridor, the general direction of travel is towards Shibuya (DT01) and further into central Tokyo. This is where the most job opportunities are and therefore where most people living outside central Tokyo will travel towards. When the line was completed this was already visible in how the link loads are distributed over the line. Over time, the skew in the link load distribution has only increased because the link loads near Tokyo grew much faster compared to the end of the line. This resulted in the Den-En Toshi line getting more unbalanced over time, resulting in increasingly inefficient operation.

The Ōimachi line extension removed some of the peak link loads between Mizonokuchi (DT10) and Futako-Tamagawa (DT07), but it seems to have less influence on link loads between Futako-Tamagawa and Shibuya (DT01). Tokyu intended for the Ōimachi line extension to relieve some of the load on the section from Futako-Tamagawa to Shibuya, which might have resulted in a smaller increase in link load on this section between 2005 and 2010.

Tokyu focused its development plans on Tama-Plaza (DT15) in the early 90's and later Azamino (DT16) to be local residential centres. It can be seen that the high residential concentrations caused an even greater increase of people commuting from Azamino to Shibuya (DT01) and beyond for job opportunities.

Except for the more recent network adjustment with the Ōimachi line extension, it seems that there have been no active policies to stabilise the traffic flow as much as possible and keep link loads evenly distributed over the corridor. All improvements and additions in the network and the developments in land-use densities around station areas seem to have focussed solely on generating as much passenger influx to the main centre as possible. This was done regardless of the losses in efficiency that occurred due to this strategy.

Distributing the link loads more evenly over the corridor and improving the balance can be achieved in several ways. A first possibility would be the generation of passenger travelling on sections with low use by using the line more locally and creating business centres outside of central Tokyo. For example, this can be achieved by focussing on the development of Nagatsuta as a business centre, making it a very strong local attractor and generating passengers on a less used section of the Den-En Toshi line. This however is not a realistic scenario as the market demands proximity of to central Tokyo for office locations. A second option would be the adaptation of the infrastructure or network to redistribute the link loads. Where the Setagaya-line connects to the Den-En Toshi line at Sangen-Jaya (DT03), link loads increase to intolerable levels. This could for example be overcome by extending the Setagaya-line to Shibuya or any other hub in central Tokyo, relieving some of the passenger load from the Den-En Toshi line. This would be a very similar approach to the Ōimachi line extension. The extreme density of the built-up area on this section would make it very unlikely that enough space can be reserved to make such a network adaptation happen.

In conclusion, it can be stated that not until more recently, there was little or no effort undertaken to create a balanced traffic flow where link loads are evenly distributed over the entire corridor. The Ōimachi line extension and the steering towards a better use of the available infrastructure is only a more recent trend. The possible measures required to create a balanced traffic flow are often restricted in their application. For example, creating attraction on less used sections is still mainly dictated by market conditions, which determines the location where these activities are demanded. Furthermore, the adaptation of the infrastructure or network is highly restricted, because of the densely built-up urban area around the sections where the bottlenecks are located. This makes it very difficult for a railway company such as Tokyu to focus on efficiency of operations. Therefore, the chosen strategy will tend towards maximizing revenues to cover the cost of inefficiencies in operations.

7.2.4 Conclusions analysing traffic flow

As an effect of changes in station area characteristics, the change in station use can be predicted. The effect of this change in station use on the traffic flow was determined distributing the station users over the Den-En Toshi line. Based on the analysis of traffic flow distribution, several conclusions can be drawn.

In general, there are two commonly used methods used for trip distribution modelling, a growth factor method and a synthetic model (such as the gravity model). Limitations in the available data necessary for estimating a cost deterrence function and the large number of trips to external zones make the application of a gravity model suboptimal. Therefore, the growth factor method was selected. This method has one major drawback, which is the inability to cope with changes in the network. When applying this method in the full analysis this was taken into account by limiting the investigation to the effects of changes in activities.

The availability of trip end totals with the addition of information on direction of travel resulted in a very accurate estimation of the distribution matrix resulting in less than 0,4% error on the link loads obtained from the distribution matrix.

Forecasting link loads confirmed the models inability to cope with network change. Due to a major network change in 2008, the extension of the Ōimachi line, the link load estimations based on the distribution matrix obtained before this time shows reduced accuracy. Using a distribution matrix from measurements obtained after the network change overcomes this problem. This does mean, that each time a network change takes place, a new distribution matrix must be estimated based on measurements obtained after the event. For this research the latest base matrix, based on passenger measurements form 2009 was used.

Studying the development of traffic flow balance on the Den-En Toshi line through the distribution of the link loads over the corridor led to the conclusion that it has become continuously more unbalanced since its completion in 1984. In general, no measure seems to have been taken to stabilise traffic flow and divide it better to suit the infrastructures capacity. It seems as if the focus was rather on generating as much traffic as possible. Only recent developments such as the Ōimachi line extension aim for a more efficient use of the available infrastructure.

7.3 Studying case scenarios

The N-P model covers the top section of the model in the research design schematic, *Figure 8* in section 3.4. The traffic flow analysis covers the bottom section of that same research design schematic. In order to run through the model schematic top to bottom to illustrate the effects of balancing station area characteristics on traffic flow, a case scenario was devised. These case scenarios state a hypothetical development identified from the N-P model after which the effects of these developments were calculated.

For the case scenarios two stations were selected, based on the most unsustained nodes as identified in the N-P diagram in *Figure 36*. The most unsustained nodes were Futako-Tamagawa (DT07) and Nagatsuta (DT22). Choosing one station close to the city centre and one further away allows for a comparison of the impact on traffic flow. In total four case scenarios were discussed, shown in *Table 15*. The first scenario is the base scenario, where nothing changes. The effects of the other scenarios are compared to this base scenario. The second scenario describes the effect if only Futako-Tamagawa (DT07) is balanced and the third scenario only Nagatsuta (DT22). The fourth scenario describes the effect of balancing N-P functions of both stations simultaneously.

Table 15: Case scenarios

	DT07 (2010)	**DT07 (Balanced)**
DT22 (2010)	Scenario 1 (base)	Scenario 2
DT22 (Balanced)	Scenario 3	Scenario 4

First, a new N-P balance was derived from the N-P model established in section 7.1. The desired node and place balance for the selected station was devised in two scenarios. A scenario which shifted the station into the balanced section of the N-P diagram and a scenario that assumed an ideal N-P balance. From the N-P diagram the values for the desired change was derived.

Second the derived values were used to calculate the change in station use as an effect of this shift in N-P balance. The new values for the station use are in its turn distributed over the corridor using the distribution model derived in section 7.2. The impact of improving the N-P balance of either station separately is studied first. Then the combined effect of improving N-P balance for both stations is studied. The resulting effects on traffic flow are displayed and discussed with regard to theory and practical implications.

Finally the conclusions drawn from the case scenario are summarised.

7.3.1 Deriving a new Node-Place balance

In the N-P diagram in *Figure 43* Futako-Tamagawa (DT07) and Nagatsuta (DT22) are highlighted. According to the N-P model, this station is an unsustained node, meaning that the great accessibility of the station would allow for a much denser development of the activities in the station area. These are as of 2010 the biggest outliers in the N-P diagram, with a lot of potential to increase the place index. It can be argued that, in order to retain station area balance, the node index could also be reduced. This would require a reduction in frequency, which is very unlikely to happen in practice. Furthermore, the distribution model cannot cope sufficiently with changes in infrastructure (section 7.2.1) so the focus remains on adjusting the place index.

The case scenario for Futako-Tamagawa (DT07) and Nagatsuta (DT22) are marked in *Figure 43*, where the place index was adjusted to achieve a better node and place balance. The place index was increased until the ideal N-P balance was matched. Because Futako-Tamagawa and Nagatsuta have the same node value, the N-P balance is the same. The increase in place index resulted in a desired growth measure for the population density of both station areas.

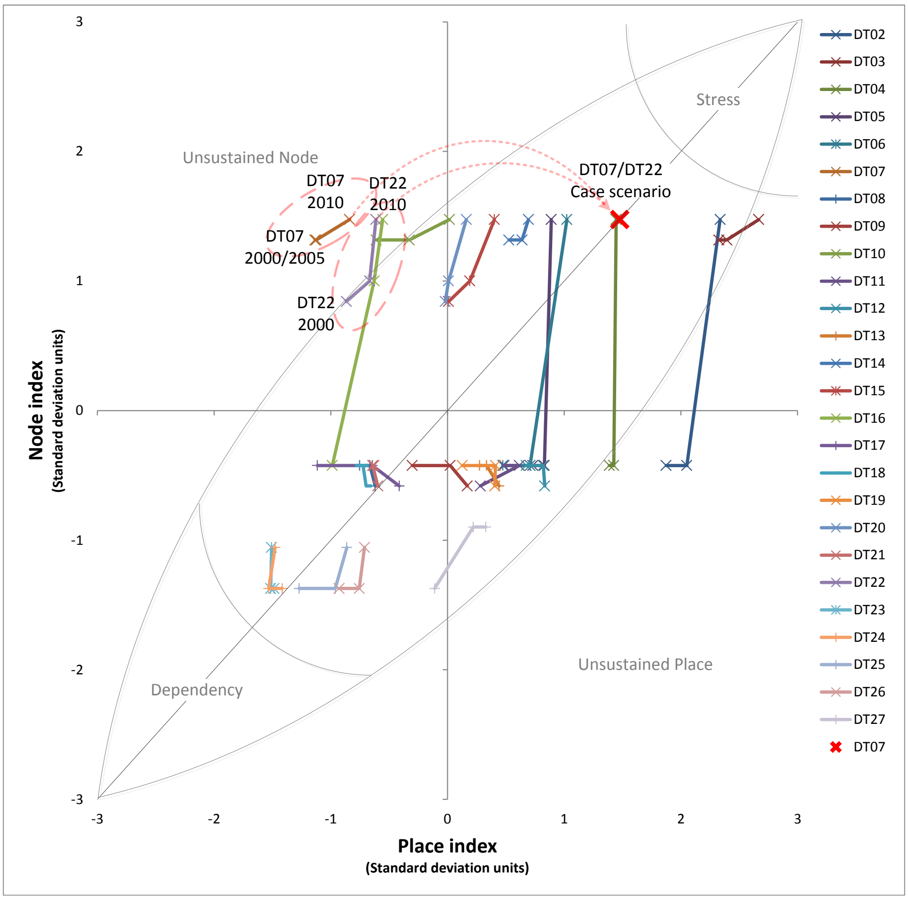
Tokyu has identified the same potential and is currently greatly investing in the restructuring of the surroundings of Futako-Tamagawa. Therefore, this is a very realistic case scenario. However, the increase in population around Nagatsuta is less realistic.

In 2010, Futako-Tamagawa (DT07) had a total population of 11.672 people within a radius of 700 metre around the station. The case scenario proposes a place index equal to the stations node index (1,475) which results in a population of 27.556. This number would seem a realistic target value for future developments. In comparison, the neighbouring station of Yōga (DT06) counted a population of 24.453 and the similarly accessible station of Mizonokuchi (DT10) a population of 17.547. The only limitation to possible development of the population density is the geographical situation around Futako-Tamagawa (DT07), which is situated right on the banks of the Tama River.

In 2010, Nagatsuta (DT22) had a total population of 13.222 people, living within the station area. Increasing the place index to match the ideal N-P balance also resulted in a population of 27.556 people. Nagatsuta already had a larger population than Futako-Tamagawa (DT07). Comparing the target value to neighbouring stations the target value might seem less realistic, but it is still possible. The station of Aobadai (DT20) for example, has a population of 18.748. Further from central Tokyo population densities drop drastically though.

The impact of the new place index values on station use is calculated in the following section, continuing with assessing the impact of this change on traffic flow on the Den-En Toshi line.

Figure 43: N-P diagram case scenario Futako-Tamagawa (DT07)



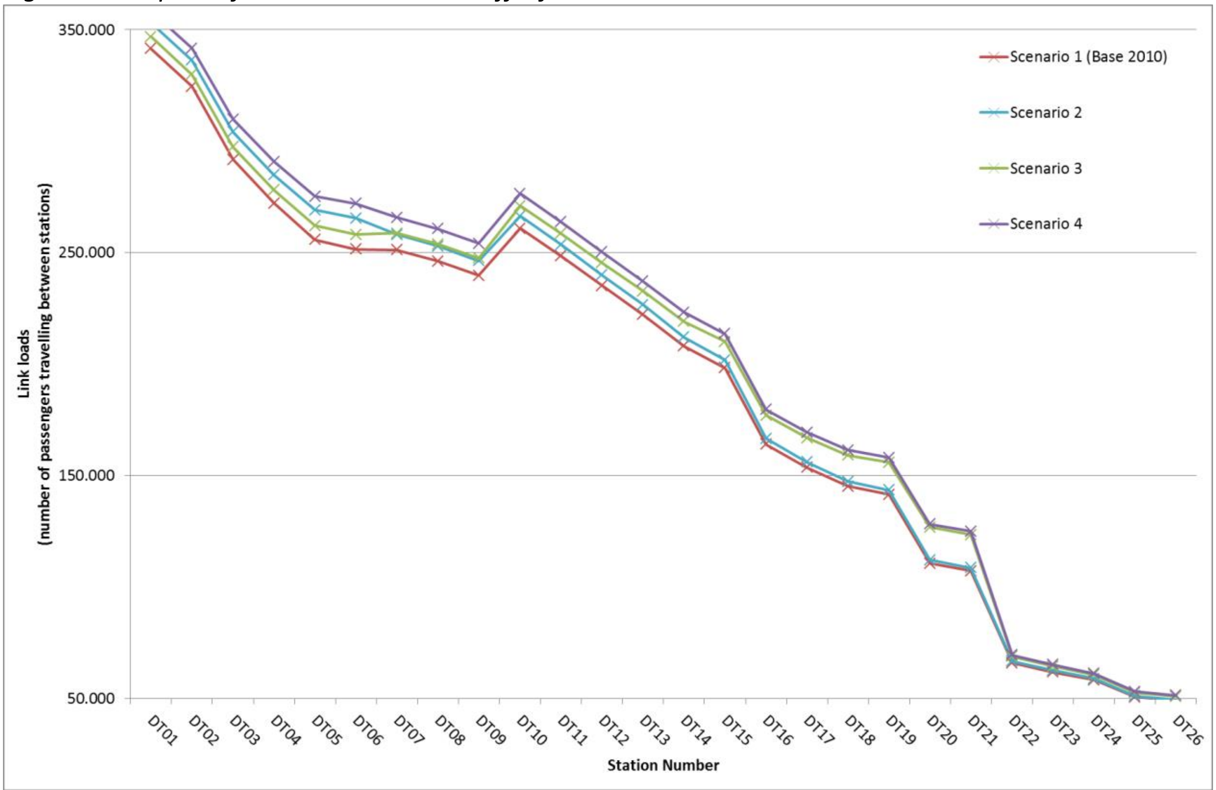
7.3.2 Assessing impact on station use and traffic flow

The N-P model identified possible development opportunities at Futako-Tamagawa (DT07) and Nagatsuta (DT22). From the N-P model a scenario was established for both stations, where a desired increase in the population density, which is represented by the place index, was derived. The effect on station use of the change in population density for these scenarios was calculated using the regression model established in section 6.4.

In 2010, Futako-Tamagawa was used by 66.516 passengers on average entering and exiting the station each day. The increase in population to 27.556 resulted in an increase of 42.293 passengers daily according to the change model. This results in a total of 108.809 passengers using the station.
In 2010, Nagatsuta (DT22) was used by 66.619 passengers on an average day. The increase in population form 13.222 to 27.556 resulted in an increase of 38.308 passengers. This results in a total of 104.824 passengers using the station daily.

The additional passengers generated by the change in station characteristics were then distributed over the corridor. This was performed using the distribution model established in section 7.2. When entering the new station totals for Futako-Tamagawa (DT07) into the distribution model, the station use for all other stations were fixed. Also, the number of transferring passengers at Futako-Tamagawa did not change, because the change in place index did not influence these passengers. The same was done for Nagatsuta (DT22), and for both stations combined. The changes in distribution resulting from the adaptations done in each scenario are displayed in *Figure 44*. In order to show a more detailed image only the link loads towards Tokyo are displayed.

Figure 44: Impact of case scenarios on traffic flow



The resulting changes in link load distribution are easily distinguished. Case scenario two shows a strong increase in link load distributions from Futako-Tamagawa (DT07) to Shibuya (DT01). Towards the further end of the line the effect is much smaller and decreases further with increasing distance. On the section beyond Azamino (DT16), the effect is almost negligible. With such an incredibly strong attractor such as Shibuya (DT01) on only one end of the corridor, every development in population density along the corridor will lead to higher traffic volumes towards Shibuya. When increasing the station area balance for Futako-Tamagawa, this resulted in an even further deterioration traffic flow balance.
Case scenario three shows a strong increase in link load distribution from Nagatsuta (DT22) to Futako-Tamagawa (DT07). Beyond Futako-Tamagawa, further towards Shibuya (DT01), the effects become much smaller. Also noteworthy is that the increase in passenger numbers at Nagatsuta has only very little effect on the final section towards Chūō-Rinkan (DT27). Although the attraction power of Shibuya is still visible, it is much less compared to the influence it has on the direction of travel for passengers from Futako-Tamagawa. When increasing the station area balance for Nagatsuta, this resulted in a slight overall improvement in traffic flow balance.
In scenario four, the combined effects of balancing N-P functions for Futako-Tamagawa (DT07) and Nagatsuta (DT22), shows an addition of scenario two and three. The traffic flow on the corridor as a whole becomes even more unbalanced.

7.3.3 Conclusions case scenarios

With these case scenarios, the entire research model as displayed in *Figure 8* from section 3.4 was completed and run through, top to bottom. First the Node-Place model was applied to analyse station area characteristics and identify development opportunities. This identified Futako-Tamagawa (DT07) and Nagatsuta (DT22) as stations with development opportunities, due to the less sustained N-P balance. Then, the effects of the identified improvements for Futako-Tamagawa and Nagatsuta on station use were calculated using the established regression model on change in station use. Finally, the additional passengers generated by the change of station area characteristics were distributed over the Den-En Toshi corridor in four case scenarios: Scenario one; no change (Base year 2010), scenario two, balancing N-P functions for Futako-Tamagawa, scenario three, balancing N-P functions for Nagatsuta and case scenario 4, balancing N-p functions for both stations simultaneously.
It can be observed that for the second case scenario where population density around Futako-Tamagawa is increased results in a much better balance of station area characteristics according to the N-P model. When studying the effects of additional population density on traffic flow is shows that due to the large attraction of Shibuya (DT01) especially the link loads on the first section of the corridor increase. This of course results in an even more unbalanced traffic flow on the Den-En Toshi line. Improving the balance in station area functions of a single station can thus have a negative effect on the traffic flow balance on the corridor as a whole.
In the third case scenario, when increasing the N-P balance of Nagatsuta (DT22), a station further away from central Tokyo, the effects on traffic flow show a very different image. The largest increase in link loads took place on the section between Nagatsuta and Futako-Tamagawa (DT07). Although the link loads towards Shibuya (DT01) also increased, this still resulted in a slightly better traffic flow balance for the corridor overall.
The combination of improving the N-P balance for both Futako-Tamagawa and Nagatsuta resulted in an addition of both effects described earlier. This resulted in a slight overall decrease in traffic flow balance over the Den-En Toshi corridor.
In conclusion, improving the N-P balance for a single station might have a negative effect on traffic flow balance. Improving the N-P balance for a station further away from the major attraction centre did help improve traffic flow on the entire corridor.

7.4 Conclusions linking station areas and traffic flow

This chapter discussed the linking station area balance described by the Node-Place model and traffic flow balance over the Den-En Toshi line. Previously, the link between station area characteristics and station use was established based on regression modelling techniques in chapter 0. This chapter expanded this model as can be seen in the research design schematic presented in *Figure 8*, section 3.4. With the obtained results research question 6 and research question 7, posed in section 3.3 can be answered.

The N-P model was constructed using the Frequency indicator for the node index and the Population indicator for the place index. These indicators were selected from the between subject models in section 6.2 as the most important indicators shaping station area functions. The resulting N-P model was used to analyse the development of the N-P balance of station areas along the Den-En Toshi line over the 15 year study period of this research, from 1998 to 2012. From this can be observed that the most unbalanced stations grew to a more sustained balance of node and place functions. To a lesser extent, there are also stations that grew further away from a sustained balance, for example due to continuous densification of jobs and residences. The developments resulting in an improvement of balance of an unsustained station balance can be explained by the N-P model. This leads to the conclusion that the theory behind the N-P model is plausible.

In order to distribute the station users over the Den-En Toshi line and calculate the resulting link loads, a distribution model was established. Using the growth factor method a distribution matrix was calculated based on the trip measured trip end totals and improved with additional information on direction of travel. From this an accurate base matrix was obtained for use in further analysis. As a result of using the growth factor method, the distribution model cannot cope with network changes. Any further analysis was therefore restricted to estimating the effect of densities in station areas on traffic flow. From the distribution matrix link loads were obtained which were used to analyse the traffic flow balance. The Den-En Toshi corridor showed a very unbalanced traffic flow which continuously deteriorated over the last 30 years. It appeared that up until the extension of the Ōimachi line in 2008, no efforts were done to use the available infrastructure more efficiently.

For the case scenario, the stations which showed the most unsustained balance in the N-P model were selected. These were Futako-Tamagawa (DT07) and Nagatsuta (DT22).The place index of these stations was increased in order to obtain a better N-P balance, resulting in a rise in population densities. The effect of the rising population densities on station use was predicted and the station users distributed over the Den-En Toshi line in four case scenarios. Based on this analysis, it could be concluded that improving the N-P balance for a single station might have a negative effect on traffic flow balance. Improving the N-P balance for a station further away from the major attraction centre did help improve traffic flow on the entire corridor.

8 CONCLUSION & DISCUSSION

To conclude this research, the research objective is evaluated based on the conclusions drawn from the analyses and discussion on the problems encountered and how these can be avoided in future research.

The objective of developing a model that describes the interaction between station areas and traffic flow of a railway corridor and help improve profitability is duly completed. However, some side notes on achieving the research objective have to be made. The modelling aspects were eventually not unified in a single model. The interaction between station areas and traffic flow of a railway corridor was captured as desired. Whether or not the established model can improve profitability cannot directly be stated, but will result from practical implications of the model.

To achieve the research objective throughout this research report, the accompanying research questions were answered. In the following conclusions each of these research questions is addressed separately. Finally, this chapter is concluded with a discussion of the problems encountered and recommendations for future research.

8.1 Conclusions

The conclusions drawn in present study are divided in several topics. First, the conclusions drawn from measuring station area characteristics are discussed and then on how these characteristics were linked to station use. Furthermore, the conclusions drawn from expanding this link from station area function balance to the resulting traffic flow are addressed. Finally, the conclusions are closed with the insights gained from the experiences in practice.

8.1.1 On measuring station area characteristics

The station area was defined based on an analysis of access and egress trips to and from the Den-En Toshi line stations. The action radius of the station was determined by investigating the distance travelled of its access and egress trips. In the Den-En Toshi line station areas the major access and egress mode is walking, accounting for over 80% of all trips. Therefore, it was argued that an action radius can be derived from the walkable radius. All walking trips are made within 1500 metres of the stations and 75% of all walking trips within 700 metres. Together with the consideration of the spacing between stations being 1200 metres on average, it was concluded that for this case study the station area can be defined by a 700 metre walkable radius.

The chosen research approach requiring the construction of a longitudinal dataset over a long study period greatly limited the available data sources. Remaining as reliable data sources were population census data to measure activities, time table data to measure accessibility and passenger data to measure station use. With the data obtained from these sources, the established TOD indicators were only partly covered. The established indicators were: Population, Workforce-cluster 1 (Transportation, information, communication, finance, real estate, research, education, welfare, public services and living related services), Workforce-cluster 2 (Hotel, restaurant, café and retail), Workforce-cluster 3 (Agriculture, forestry, fishing, mining, construction, manufacturing and utility), Multi-functionality, Station type, Number of directions, Frequency, Travel time to centre and GDP.

8.1.2 On linking station area characteristics and station use

The link between station area characteristics and the number of passengers using each station along the Den-En Toshi line was established using linear regression modelling techniques. Three different approaches were used linking station area characteristics and station use.

First, the between subjects analysis, investigating cross sections from the dataset was discussed. The best model fit with an R^2 of 0.687 was achieved by using the indicators Station Type and Workforce

Cluster 1. This did not result in estimated values accurately enough to continue the use of this approach for the subsequent traffic flow forecasts. The modelling results were used to select the most influential indicators for the station area analysis in the Node-Place model.
Second, within subject analysis was conducted to measure time-series per subject. In general, modelling time-series for each station using the same indicators as during the between subject analysis achieved better fitting models. With these results it can be concluded that a better model fit can be achieved when fitting the slope and intercept of the model for each subject separately. Therefore, it is recommended for future research, to perform a regression analysis with multi-level modelling techniques on the full panel dataset.
Third an analysis investigating parameter change was discussed, where the change in the original parameter values between successive years was used. The main disadvantage of this approach is that the year to year change is much more susceptible to fluctuations in external influences. This showed in the modelling result for the year to year model estimation where an R^2 of only 0.272 was achieved. Therefore a second model estimation was done based on the indicator change over a 5 year interval. This allowed the model focus to be placed more on the macro effects, resulting in an R^2 of 0.540. To predict station use for a future year the change estimated based on the model is added to the value of the station use for the used base year. This approach has the advantage that when using these modelling results for making predictions on station use the modelling error only influences the modelled change, but does not affect the base value of the outcome variable. This resulted in a prediction 5 years ahead with an R^2 of 0.98. Therefore it can be concluded that using the indicators describing station area characteristics provide a sufficient model fit in forecasting passenger numbers for the Den-En Toshi line stations.

8.1.3 On linking stations areas and traffic flow

The N-P model was constructed using the Frequency indicator for the node index and the Population indicator for the place index. These indicators were selected from the between subject models as the most important indicators shaping station area functions. The resulting N-P model was used to analyse the development of the N-P balance of station areas along the Den-En Toshi line over the 15 year study period of this research, from 1998 to 2012. It could be observed that the most unbalanced stations grew to a more sustained balance of node and place functions. To a lesser extent there were also stations that grew further away from a sustained balance, for example due to continuous densification of jobs and residences. The developments resulting in an improvement of balance of an unsustained station balance can be explained by the N-P model. This leads to the conclusion that the theory behind the N-P model is plausible.

In order to distribute the station users over the Den-En Toshi line and calculate the resulting link loads, a distribution model was established. Using the growth factor method, a distribution matrix was calculated based on the trip measured trip end totals and improved with additional information on direction of travel. This provides an accurate base matrix that could also be used in further analysis. As a result of using the growth factor method the distribution model cannot cope with network changes. Any further analysis is therefore restricted to estimating the effect of densities in station areas on traffic flow. From the distribution matrix link loads were obtained which were used to analyse the traffic flow balance. The Den-En Toshi corridor showed a very unbalanced traffic flow which continuously deteriorated over the last 30 years. It appeared that up until the extension of the Ōimachi line in 2008 no efforts were done to use the available infrastructure more efficiently.
Improving the N-P balance for a single station might have a negative effect on traffic flow balance. Improving the N-P balance for a station further away from the major attraction centre did help improve traffic flow on the entire corridor. Hypothetically, in order to stabilise traffic flow, an attraction centre similar to Shibuya (central Tokyo) should be created on the far end of the line. Another hypothetical possibility would be to decrease the attractiveness of central Tokyo.

8.1.4 On practices

In applying TOD in Tokyo and developing rail integrated communities timing was of the essence. It was the coinciding of the post war economic boom, with the continuing industrialization, the prevailing land scarcity in urban areas and the massive population migration from the countryside that paved the way for private railway companies such as Tokyu in the development of urban railways.

After conceiving the Den-En Toshi line Tokyu quickly assumed the focus on generating as much users as possible. The emphasis was therefore placed on providing bedroom communities where all the necessary amenities are present. Job opportunities remained in central Tokyo which resulted in a steady influx of commuters. This strategy has the benefit that people are required to use the railways daily and over long distances, assuring solid fare revenues. Probably even more important is that an incredibly large number of users pass through the Tokyu owned stations, where the amenities provided by Tokyu yield the most important benefits.

The main focus of Tokyu's land development was placed on the provision of these amenities in the direct surroundings of its stations, but they also veered into other side businesses. The main residential and office developments along the Den-En Toshi line were privately initiated, based on market demand.

With the completion of the Den-En Toshi line Tokyu's strategy required to handle the continuously more increasing peak in users during morning and evening rush hours. This highly inefficient use of operations was, and still is, greatly outweighed by the benefits gained.

The infrastructure of the Den-En Toshi line and the surrounding network changed very little over its 30 plus years of operation. Small adjustments were continuously made to fit more and more trains onto the existing infrastructure. At some point however, the true capacity was reached, restricted by the railway tunnel though the most densely populated section of the Den-En Toshi line, reaching Shibuya. Only recently investments were made with the Ōimachi line extension and the improved use of the Meguro line to relieve some of the pressure of the Den-En Toshi line and start to use the available network more efficiently.

The theory stating that profitability is increased by making optimal use of the available infrastructure is thus not applied in practice. It showed that a strong unbalance is present on the Den-En Toshi line, which only grew until recent years.

In order to forecast changes in land-use and transportation Tokyu utilises a 4-step transportation model. This model cannot be made available for academic research an own model was developed further in this report. Besides aggregated demand modelling with the 4-step model some smaller analysis are done on collected data, mainly passenger numbers. This can be considered a fairly one sided approach, as only the effects of land-use developments on transportation is modelled instead of emphasising the interaction working both ways. This can be largely explained by the fact that the benefits from property development, retail proceeds and transportation itself outweigh the costs associated with an inefficient traffic flow.

8.2 Discussion

During this research impediments lead to choices that are less than ideal. In this discussion these choices are evaluated more elaborately. The problems are identified, the causes stipulated and most importantly an approach to overcome these impediments in future research is given. Furthermore additional recommendations are made on how to improve the quality of the research even further. Five topics are discussed separately to keep the discussion structured.

8.2.1 On data

During this research data was collected from a variety of sources with various levels of accuracy and completeness. The fact that detailed land-use data was only available for three periods with a 5 year intermission most likely had a significant oppressing effect on the results of year to year effect analysis. Whether the application of more elaborate techniques to deal with missing data will yield better results has to be investigated in future research. For example, multi-level models are better capable of handling this problem and should also be considered for future research for this reason.

The construction of several indicators or the misinterpretation of the characteristics, they represent led to the exclusion of several of these indicators. In defining the workforce cluster indicators all heavy industries and agriculture have been grouped in Workforce Cluster 3. Where WF Cluster 1 and 2 represent land-use that is more favourable in dense built-up areas WF Cluster 3 is in fact the opposite. A large concentration of heavy industries logically has a negative effect on land-use densities and should therefore be treated as such.
This also led to the exclusion of the Multi-functionality indicator. The inclusion of WF Cluster 3 had the effect that stations where some industry and agriculture were still situated received a higher multi-functionality value. Therefore, it is advised that the entire structure of this indicator should be revised. In this revision, more attention should be paid to what type of Multi-Functionality is more favourable in station areas to achieve the desired TOD results.
The definition of the indicator Number of Direction let to a low explanatory value in the between subject and within subject analyses and a misrepresentation of network characteristics in the indicator change analysis. The construction of the Ōimachi line extension was the instigator of these difficulties because though the number of directions for Futako-Tamagawa (DT07) and Mizonokuchi (DT10) did physically change, the extension actually represented competition for the Den-En Toshi line. Where other stations that received additional directions, such as Azamino (DT16) where the Yokohama Municipal Subway Blue line was connected, were complemented, this was not the case for the Ōimachi line. Removing the indicator from the analysis was not an option because especially in the indicator regression analysis on indicator change it resulted in a large explanatory value. In continuing research based on this indicator, the distinction should be made between the complementing number of directions and the competing number of directions.

The definition of the station area heavily influences the outcome of the modelling results and the strength of the described relationship. Though a more elaborate investigation was performed in this research to define the station area than in previous studies, is should be considered whether this definition can be adopted for different study areas. The travel pattern in Tokyo is unique in the world in the way people use the public transport system. Over 80% of all commutes are made by train and because of the immense rail network density the proximity allows for walking to be the main transport mode in station areas. This would definitely not be immediately applicable to the Netherlands, where the bicycle plays a major role.

The chosen research approach, studying effects over time requires for a longitudinal dataset and associated modelling techniques. Obtaining data over a continuous period of time proved to be very difficult and limited the use of the available data sources. But for modelling land-use effects it was again demonstrated that data over such a time span is a minimal requirement. For a longitudinal study of land-use effects a study period of 10 years minimally is required, but an extension up to 20 or in the best case scenario30 years is recommended. This would allow for a much better capture the long term effects.

8.2.2 On regression modelling

For this research, an elaborate longitudinal dataset was constructed. The regression techniques applied were limited to basic regression, which required simplification of the available dataset. This was done by either taking cross sections, looking a time series of subjects separately and by only looking at the change in indicator values. The full potential of the obtained dataset was not utilised due to time constraints. In order to do linear regression analysis on longitudinal data, multi-level modelling should be applied.

It is assumed that the relation between station area characteristics and station use can be described by a linear relationship. But in reality it would be more plausible that the effects are represented by for example an exponential relationship, with effects of a single variable quickly diminishing after a certain indicator value is reached. The complexity of the modelling task rises significantly if linearity is not assumed. Because the modelling techniques associated with non-linear regression are more advanced and also because the shape of the relationship has to be established. This would only be advised after investigating the gains of using multi-level linear modelling.

In general, it is very important that the model estimations should always be evaluated in the sense of what the indicators used in the model actually represent in reality. Secondary to that, the parameter values based on these indicators should remain realistically. The best warning considering regression modelling still reads “garbage in, garbage out”.

8.2.3 On Station areas

The use of the Node-Place to identify development opportunities and better coordinate the accessibility of and the activities in station areas showed promising results. Though the assumptions made and the way it was implemented did give some considerations.
First and foremost, the inclusion of indicators in the node and place index was decided upon based on regression modelling. This in itself can be argued to be a correct application, but it resulted in the restriction of the number of indicators that were included in the N-P model. With better regression modelling results justifiably using a multitude of indicators this also reflects in the extensiveness of the N-P model. It has to be seen whether this actually delivers better results in analysing the balance of station area functions.
Furthermore the assumption that station area performance can be measured based on station use is an assumption that goes very well with the traffic engineering approach of this research. But when considering the economic or social aspects of station area land-use this might not be the most desired approach
Basing the node and place index on a regression model for station use basically allowed for the values of the node and place index to be read in number of passengers. This approach is very desirable in studying traffic engineering because it creates an immediate insight into how adjusting accessibility and activities to one another can influence station use.
The possibility to include weighting of indicators before constructing the node and place indices has been discussed to some extent. In this research it was not applied because only single indicators provided the base for the node and place indices. Multiplying a single indicator with a weighting factor does not have any impact if values are subsequently normalised. The application of this concept should be genuinely considered for further research.

In the N-P model it is assumed that the station characteristics are normally distributed and the N-P model theory states that stations with characteristics further removed from the norm are performing sub-optimal. This theory heavily relies on the assumption that these functions naturally balance out to an ideal. But as can be concluded from practical insights, political, economic and environmental context is a highly decisive factor in shaping these station areas and the station use itself. This consideration makes it difficult to accurately pinpoint the performance of a station area and the factors influencing it.

8.2.4 On traffic flow

The distribution model established in this research had severe implications on the model application. The use of a growth factor method to determine the distribution of trips over the Den-En Toshi line caused the model to be unable to cope with network changes. This basically excludes any analysis where the accessibility of a station area, the node value, is changed. Furthermore because this method does not estimate the distribution directly but assumes it based on a previously measured distribution it cannot be used with a large scope. The decisive factor in the consideration to choose a growth factor method over a synthetic model was once more the data availability. It must be said that for applying a distribution over a single corridor instead of an entire network it most likely would have seriously impaired the modelling results of a synthetic model. In that sense the application of a growth factor method was also justified.

8.2.5 On practices

Experiences on practice on the Den-En Toshi line lead to some noteworthy insights. The history of the Den-En Toshi line learns that conceiving such an exemplar of Transit Oriented Development owes its entire existence to a more or less coincidental concurrence of events. The conclusion states that the ideal circumstances were created due to the large economic growth that could be guided, the massive population migration into the cities, the prevailing land scarcity that required densification and last but not least the legal framework that was established, not favouring the use of the private vehicle.

9 Appendix

9.1 General descriptive characteristics Tokyu Den-En Toshi line

Station No.	Name	Japanese	Distance (km)	Station type	Transfers	Directions (Nr.)	Opening (year)	Ward (区), City (市)	Prefecture (県)
DT01	Shibuya	渋谷	0	Express	Tōkyū Tōyoko Line	1	1926	Shibuya	Tokyo
					JR Yamanote Line	2	1885		
					JR Saikyō Line	1	1996		
					JR Shōnan-Shinjuku Line	2	2001		
					Keiō Inokashira Line	1	1933		
					Tokyo Metro Hanzōmon Line (through service)	1	1978		
					Tokyo Metro Ginza Line	1	1927		
					Tokyo Metro Fukutoshin Line	1	2008		
DT02	Ikejiri-Ōhashi	池尻大橋	1,9	Semi-Exp				Meguro, Setagaya	
DT03	Sangen-Jaya	三軒茶屋	3,3	Semi-Exp	Tōkyū Setagaya Line (tram)	1		Setagaya	
DT04	Komazawa-Daigaku	駒沢大学	4,8	Semi-Exp					
DT05	Sakura-Shinmachi	桜新町	6,3	Semi-Exp					
DT06	Yōga	用賀	7,6	Semi-Exp					
DT07	Futako-Tamagawa	二子玉川	9,4	Express	Tōkyū Ōimachi Line	2	1927		

Section continuous on the next page

Station No.	Name	Japanese	Distance (km)	Station type	Transfers	Directions (Nr.)	Opening (year)	Ward (区), City (市)	Prefecture (県)
DT08	Futako-Shinchi	二子新地	10,1	Local				Takatsu-ku, Kawasaki	Kanagawa
DT09	Takatsu	高津	10,7	Local					
DT10	Mizonokuchi	溝の口	11,4	Express	Nambu Line (Musashi-Mizonokuchi)	2	1927		
					Tōkyū Ōimachi Line	1	2009		
DT11	Kajigaya	梶が谷	12,2	Local					
DT12	Miyazakidai	宮崎台	13,7	Local				Miyamae-ku, Kawasaki	
DT13	Miyamaedaira	宮前平	14,7	Local					
DT14	Saginuma	鷺沼	15,7	Express					
DT15	Tama-Plaza	たまプラーザ	17,1	Express				Aoba-ku, Yokohama	
DT16	Azamino	あざみ野	18,2	Express	Yokohama Municipal Subway Blue Line	1	1993		
DT17	Eda	江田	19,3	Local					
DT18	Ichigao	市が尾	20,6	Local					
DT19	Fujigaoka	藤が丘	22,1	Local					
DT20	Aobadai	青葉台	23,1	Express					
DT21	Tana	田奈	24,5	Local					
DT22	Nagatsuta	長津田	25,6	Express	Kodomonokuni Line	1	1967	Midori-ku, Yokohama	
					JR Yokohama Line	2	1908		
DT23	Tsukushino	つくし野	26,8	Local				Machida	Tokyo
DT24	Suzukakedai	すずかけ台	28	Local					
DT25	Minami-Machida	南町田	29,2	Local					
DT26	Tsukimino	つきみ野	30,3	Local				Yamato	Kanagawa
DT27	Chūō-Rinkan	中央林間	31,5	Express	Odakyū Enoshima Line	2	1929		

9.2 Interview with the Tokyu Corporation

Introduction

This interview is part of the Master's thesis research of Joran Sanders with Transportation and Urban Engineering Research Group at Yokohama National University in Yokohama, Japan. The goal of this thesis is to develop a model to determine the effects of spatial and infrastructure developments on the passenger flow of a railway corridor and to help optimizing between balancing station areas and balancing passenger flow on a corridor level. This relationship is studied based on the case of the Tokyu Den-En Toshi railway corridor in Tokyo, Japan.
The research is performed from a transportation engineer's point of view on the co-development of land use and infrastructure. The emphasises in this research is on the relationship between balancing supply and demand functions in station areas and how this affects the balance of the passenger flow on a corridor level. The proposed model can be used to provide input for analysing corridor profitability.
This interview supplies the background information that is required in order to fully understand the case of the Den-En Toshi corridor and the business strategy of the Tokyu Corporation. Though an understanding of the initial development is required, the focus of the interview will be on how the Tokyu Corporation evaluates railway operation. How the analysis and prediction of passenger flow and corridor profitability affect development strategies, currently and in the past.

Interview questions

The interview is divided into two parts; the first part focuses on the initial development of the Den-En Toshi corridor and its continuing re-development after completion. The second part focuses on analyzing and predicting passenger flow and evaluating development strategies. For each of these parts a research question is stated which can be answered with the questions in this interview. With the interview questions some context is provided as to why it is posed and how it helps answering the research questions.

Part 1: Initial development of the Den-en Toshi corridor and continuous re-developments

The first part of the interview will focus on the initial development of the Tama Den-En Toshi project, the Den-En Toshi line and the continuous (re-)development of station areas and their accessibility. The main question for this part of the interview is the following:

> *How did the Tokyu Corporation develop the business case of the Tokyu Den-En Toshi corridor and what were the major factors that contributed to the continuing success of the Tokyu Den-En Toshi line over the last 30 years?*

So first it should be understood why Tama Den-En Toshi new town was developed and what the major social, economic and legislative factors were that influenced its development. Furthermore a more detailed understanding is required of the co-development of the new town and the railway.

1. What was the initial goal for the development of Tama Den-En Toshi new town?
2. What were the most important social, economic and legislative factors in the development of Tama Den-En Toshi new town and the Den-En Toshi railway line?

Particularly interesting is the co-development of railway infrastructure and property development. An important factor in succeeding to create this Transit Oriented Development was the use of land readjustment schemes.

3. In what ways was the development of the Den-En Toshi railway line integrated in the construction of Tama Den-En Toshi new town? How were property development and railway construction co-developed?
4. What was the role of the land readjustment schemes in the realisation of the Den-En Toshi line?

After completion of the line the station areas were continuously redeveloped and accessibility improved. Describing changes over the years that were of influence on continuing developments.

5. What were the major real estate developments of Tokyu Corporation along the Den-En Toshi line in the land-use categories of housing, office, leisure and retail?
6. What other major private initiative developments have had an impact on the success of the Den-En Toshi line?

7. How did the government regulation of developments throughout the years change and what were the long term effects of government policy?
8. How was the infrastructure of the Den-En Toshi line further developed over time? So how did the accessibility change over the years, and what improvements on the infrastructure side were made to increase accessibility and level of service *(for example; track capacity, number of trains, types of services, speed of service or train capacity)*?
9. What other improvements were made with positive effects on accessibility *(for example; bus access, bicycle access, pedestrian access, fares, comfort or information services)*?

Part 2: Predicting passenger flow and evaluating strategy

The second part of the interview will focus on corporate strategy of the Tokyu Corporation and how the effects of development projects on passenger flow are predicted and evaluated. The main question for this part of the interview is the following:

> *What methods are being used in practice by the Tokyu Corporation to model and predict the impacts of spatial and infrastructure developments on station areas and passenger flow and their effect on corridor profitability?*

Strategy can roughly be divided into short term and long term strategies. Short term strategy focuses on adjusting the supply to the current demand. Adjusting supply to demand by analyzing and predicting passenger flow, evaluating efficiency of operations and adapt accordingly to maximize profitability. Long term strategy also focuses on changing and stimulating demand in order to better fit the available supply or even supply potential. In the long term property development plays a major role, or more specifically Transit Oriented Development.

So in order to gain insight in the strategy applied by the Tokyu Corporation on the Den-En Toshi line it must be understood how the efficiency of operations is evaluated.

1. What methods or models are used to analyse and predict passenger flow in the short term?
2. How is the short term efficiency of the transport system evaluated?
3. How do the methods or models used to analyse and predict passenger flow on the long term differ from the short term?

Furthermore it is of interest how profitability of operation translates to strategy and what role it plays in forming corporate strategy. Also the other way around it is of interest to gain insight in how the effects of corporate strategy on the efficiency and profitability of railway operations are evaluated.

4. What other aspects than the efficiency and profitability of railway operations, are input for developing long term strategy?
5. What role does optimizing the efficiency of railway operations play in forming strategy?
6. How are the effects of company strategies on passenger flow and profitability of railway operations evaluated?
7. How do the past and current strategies of the Tokyu Corporation towards property and infrastructure development compare?

As previously asked in the part focusing on the development of the Den-En Toshi line it is interesting to know what methods the Tokyu Corporation currently applies to balance supply and demand. Specifically on the Tokyu Den-En Toshi line, both in the short and the long term.

8. What methods are used to adjust short term supply to suit the demand better and optimize efficiency of operations?
9. What methods are used for generating or redistributing demand in order to optimize the profitability of operations?

This is the end of the interview. I would really like to thank you for your cooperation and the opportunity to gain an insight in the world of private railways and its workings. Your knowledge will form a solid base on which I can continue my research. Thank you very much.

9.3 Den-En Toshi line station areas and districts

Figure 45: Den-En Toshi line section Shibuya - Yōga

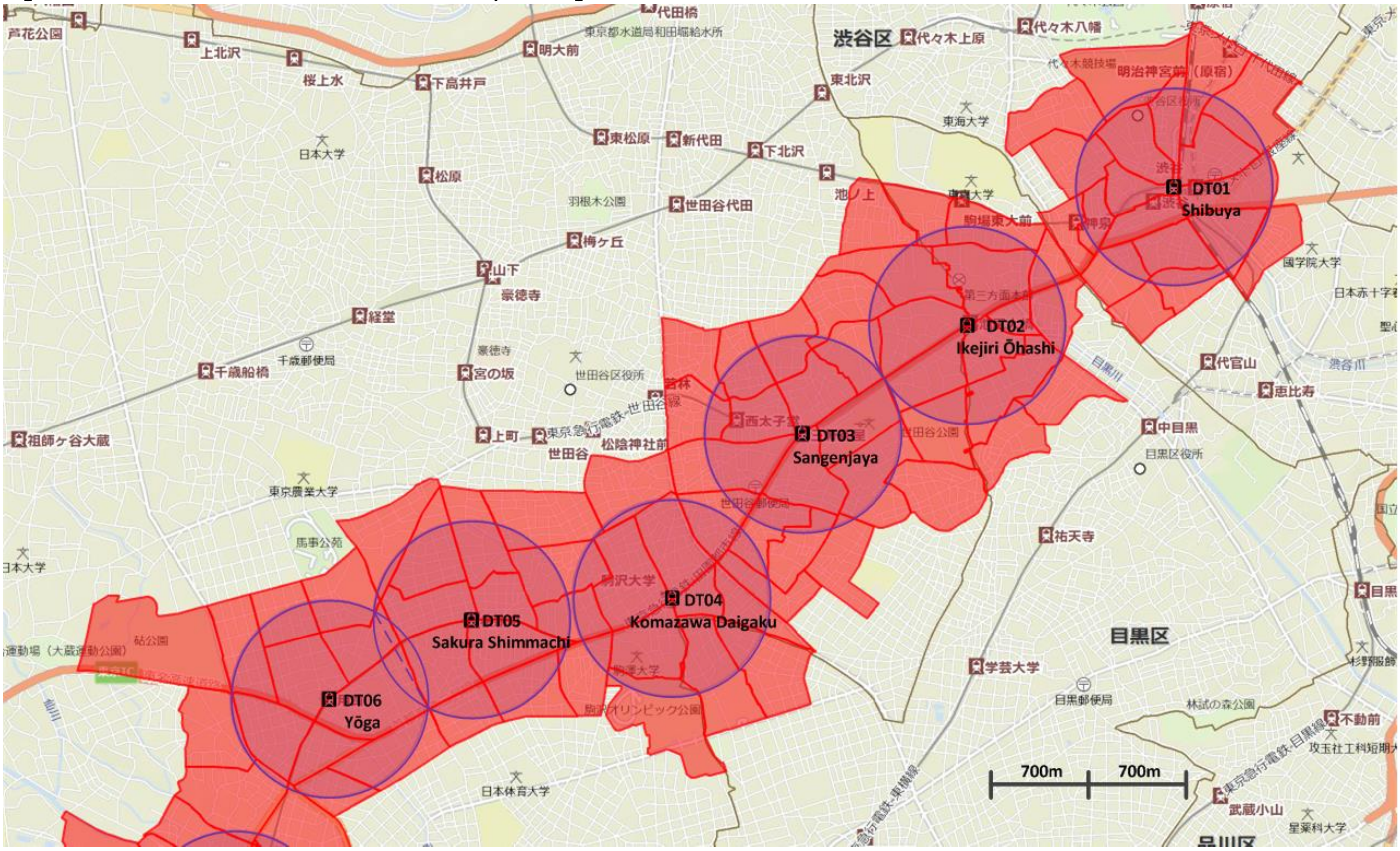


Figure 46: Den-En Toshi line section Futako-Tamagawa - Tama Plaza

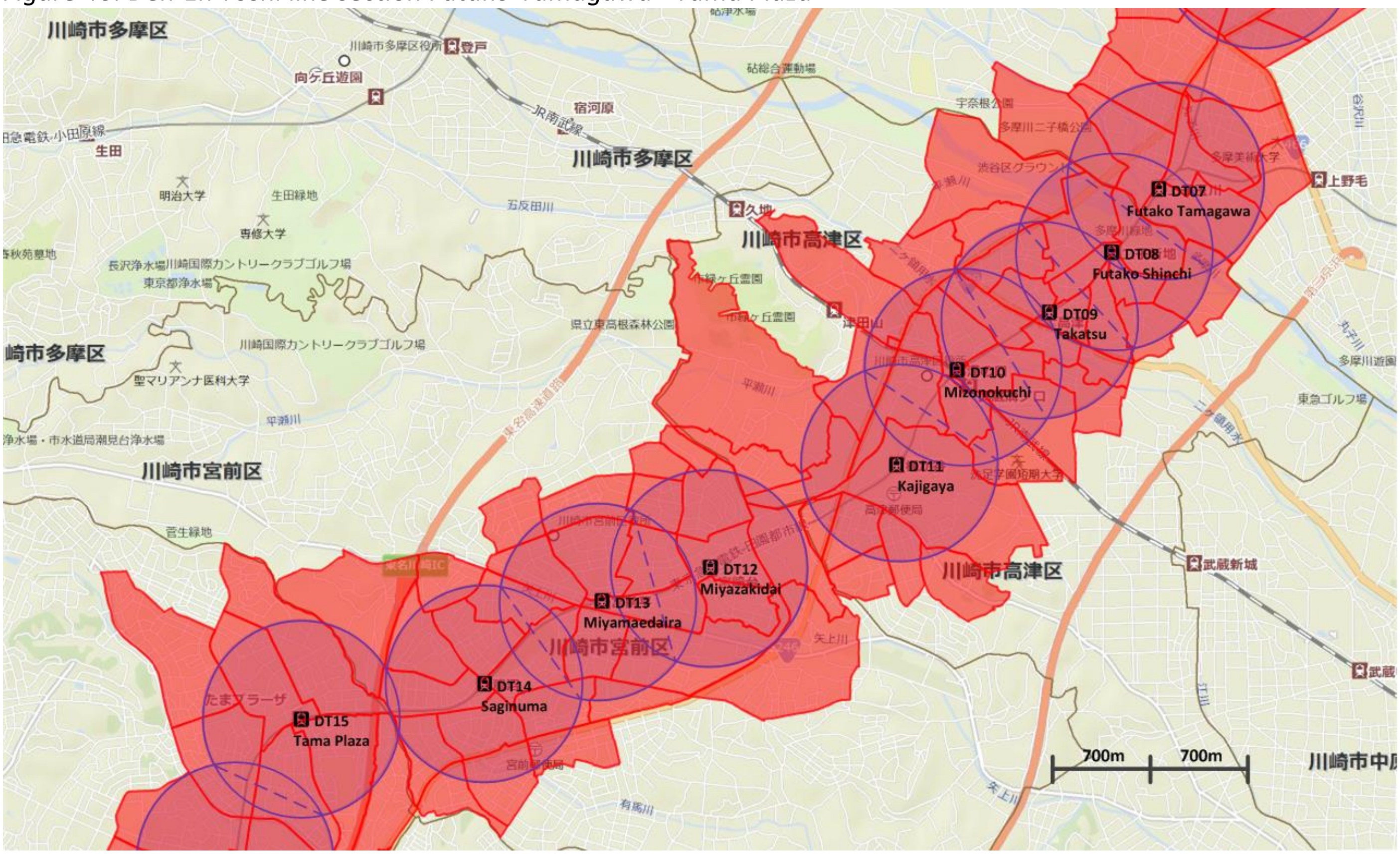


Figure 47: Den-En Toshi line section Futako Tama Plaza - Aobadai

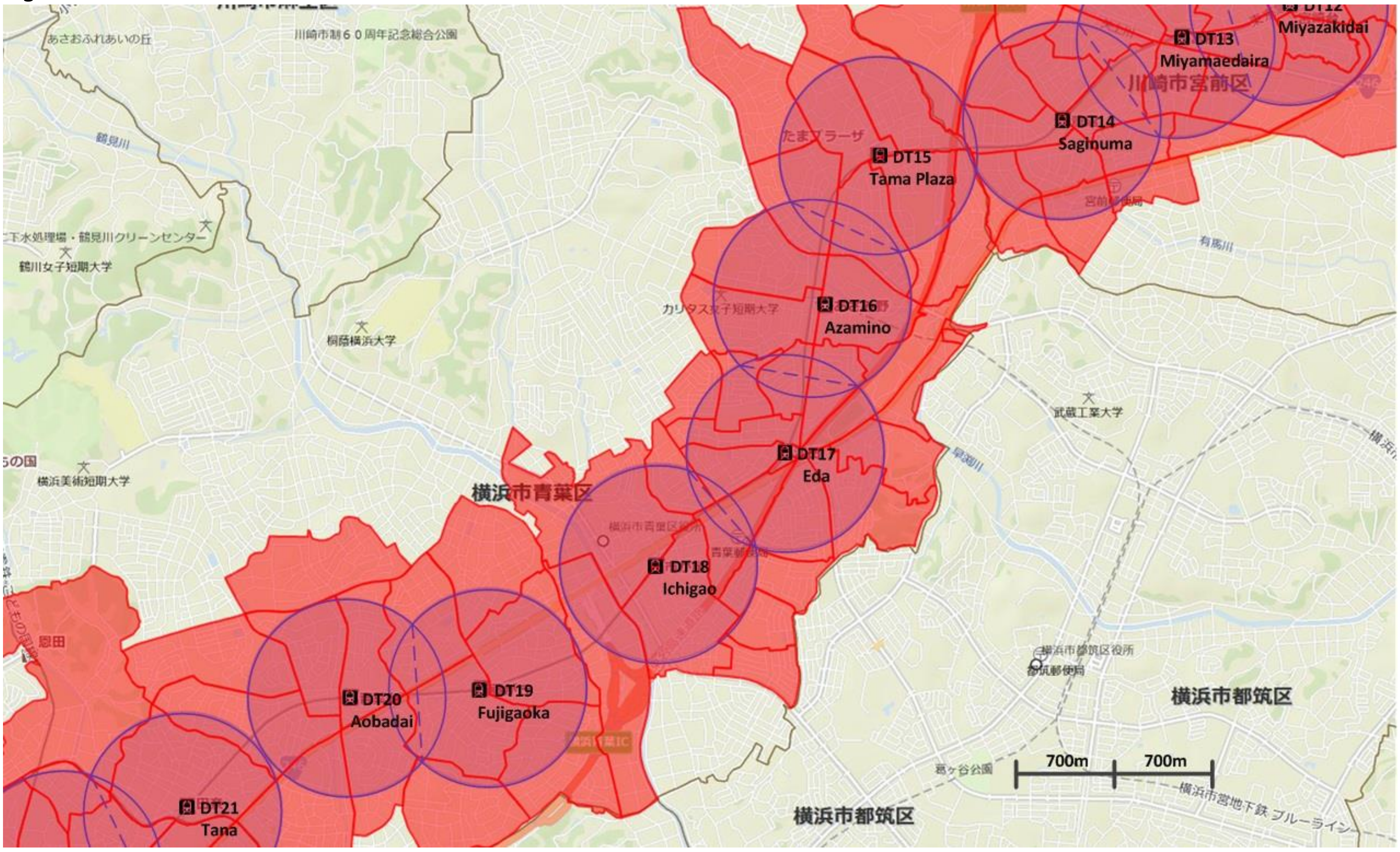
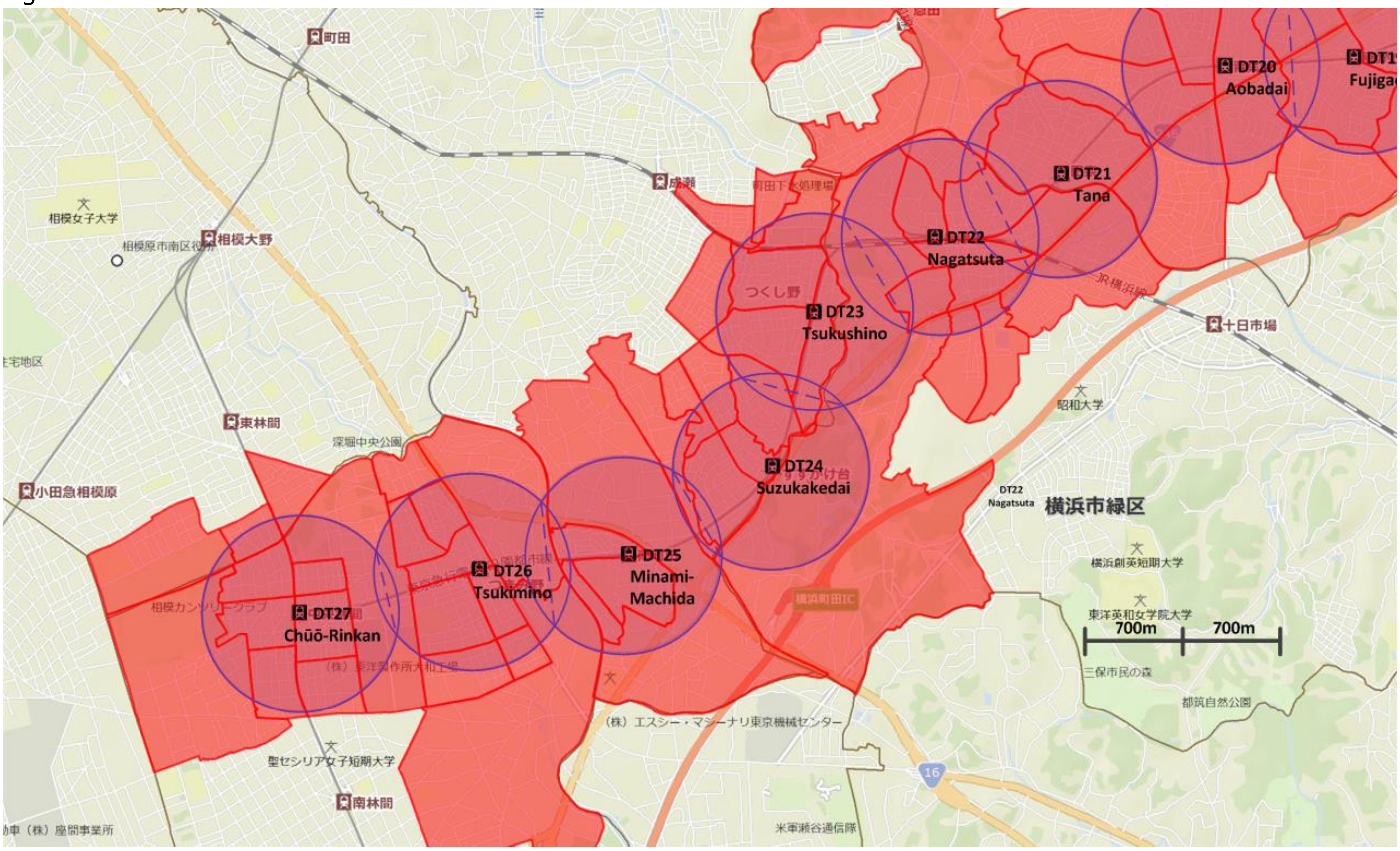


Figure 48: Den-En Toshi line section Futako Tana - Chūō-Rinkan



9.4 Workforce clustering

2000			2005			2010		
Cat.	***Content***	***Cluster***	***Cat.***	***Content***	***Cluster***	***Cat.***	***Content***	***Cluster***
A	Agriculture	3	A	Agriculture	3	A	Agriculture and forestry	3
B	Forestry	3	B	Forestry	3	B	Fishing	3
C	Fishing	3	C	Fishing	3	C	Mining and excavation	3
D	Mining	3	D	Mining	3	D	Construction industry	3
E	Construction industry	3	E	Construction industry	3	E	Manufacturing	3
F	Manufacturing	3	F	Manufacturing	3	F	Electricity, gas, heat and water supply	3
G	Electricity, gas, heat and water supply	3	G	Electricity, gas, heat and water supply	3	G	Information and communication industry	1
H	Transport and communications sector	1	H	Information and communication industry	1	H	Transportation and postal industry	1
I	Wholesale, retail and restaurant	2	I	Transport industry	1	I	Wholesale and retail	2
J	Finance and insurance	1	J	Wholesale and retail	2	J	Finance and insurance	1
K	Real estate	1	K	Finance and insurance	1	K	Real estate and goods leasing business	1
L	Service industry	1	L	Real estate	1	L	Academic research, expert and technical services	1
M	Public service (not elsewhere classified)	1	M	Restaurant and lodging	2	M	Accommodation, eating and drinking services	2
			N	Medical care and welfare	1	N	Living related, personal and amusement services	1
			O	Education and learning support	1	O	Education and learning support	1
			P	Compound services	1	P	Medical care and welfare	1
			Q	Services (not classified elsewhere)	1	Q	Compound services	1
			R	Public service (not elsewhere classified)	1	R	Services (not classified elsewhere)	1
						S	Public service (not elsewhere classified)	1

9.5 Multilevel modelling

When using panel data the assumption of independence is violated because the measurements of a subject measured over multiple moments in time will be correlated. When performing regression modelling on panel data techniques have to be utilised that can handle hierarchal structure of the data. This can be done with multi-level modelling.

At the bottom of the hierarchy, the level 1 variable, are the cases (or stations). The year in which a case is measured is a level up in the hierarchy, a level 2 variable. Hierarchal structures not only distinguish in between participant situations, but can also be nested within cases. The case variable becomes a higher level variable, and the level 1 variable becomes for example a repeated measures variable within the cases. But for this research only two levels can be identified.

There are several benefits of using multilevel linear models. The assumption of the homogeneity of regression slopes can be cast aside. That is the relationship between covariates and outcome does not need to be the same across different groups. Furthermore, the assumption of independence of observations can be violated, when a subject is measured more than once. And finally multilevel models can deal with missing data (Field, 2009).

In basic regression modelling effects are said to be **fixed**, meaning that an effect will not change over time or between subjects. The b-values in the regression equation are fixed; in subject A an increase in a predictor variable of one unit will result in the same outcome as when this increase takes place in subject B. But in multi-level modelling a distinction must be made between fixed coefficients and **random** coefficients.

When looking back to Equation 3 the Y, X and ε all vary as a function of *I*, representing a specific case or in this case a station. The equation itself is characterised by the intercept b_0 and the slope b_1 of the regression line. So when the basic regression model is revised this results in an equation where the intercept and the slope of the regression line can vary as a function of *j*, in this case time. The variability of the intercept can be described by u_{0j} and the variability of the slope by u_{1j} resulting in Equation 4. Note that the Y, X and ε now not only vary as a function of i, but also as a function of *j*.

Equation 4: Regression equation for multi-level regression modelling

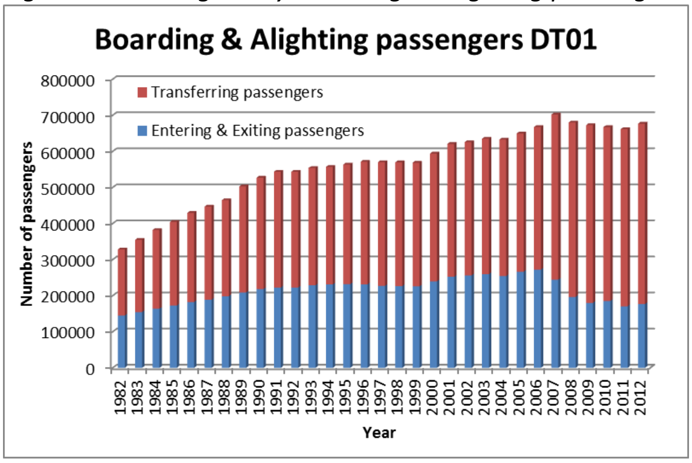
$$Y_{ij} = (b_0 + u_{0j}) + (b_1 + u_{1j})X_{ij} + \varepsilon_{ij}$$

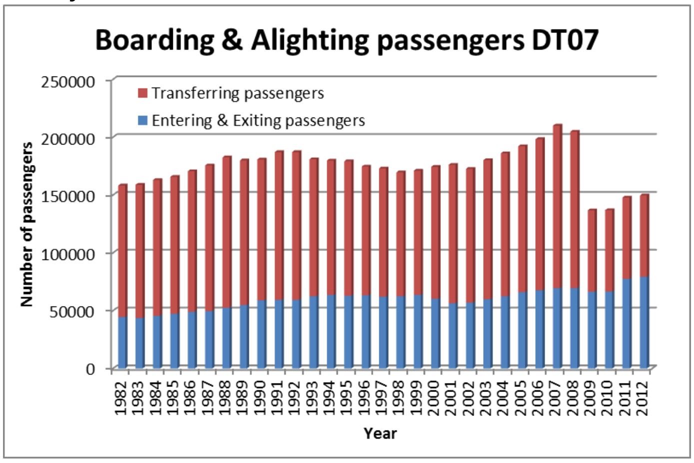
In multi-level modelling when all effects are assumed fixed, it is referred to as a **fixed effects** model. The same when all effects are assumed random, it is referred to as a **random effects** model. When both random and fixed effects are present, it is defined as a **mixed effects** model. When random effects are assumed, either just the intercept is varied (random intercept model), just the slope is varied (random slope model) or both intercept and slope are varied (random intercept and slope model) (Field, 2009).

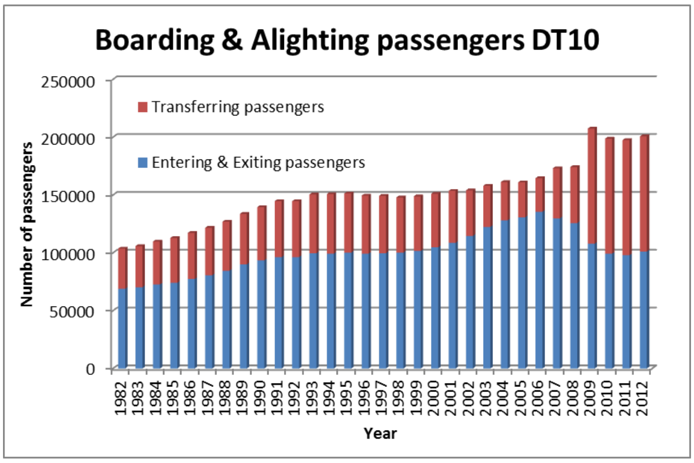
These are the basic principles of multi-level modelling. Though performing this modelling technique requires tackling some more practical issue, they won't be discussed here. Applying this modelling technique is recommended for further research.

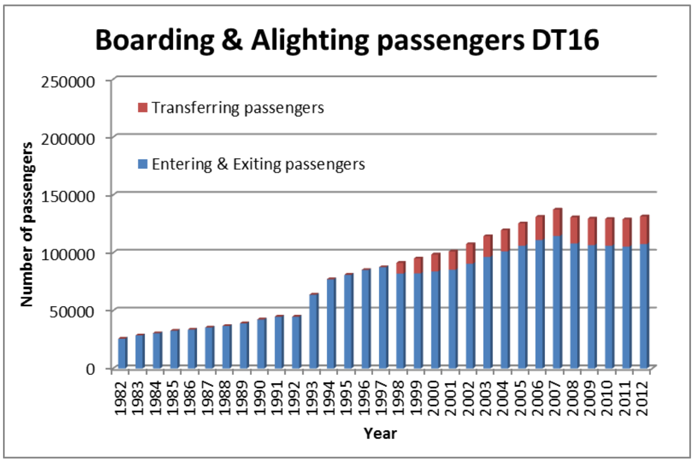
9.6 Passenger numbers

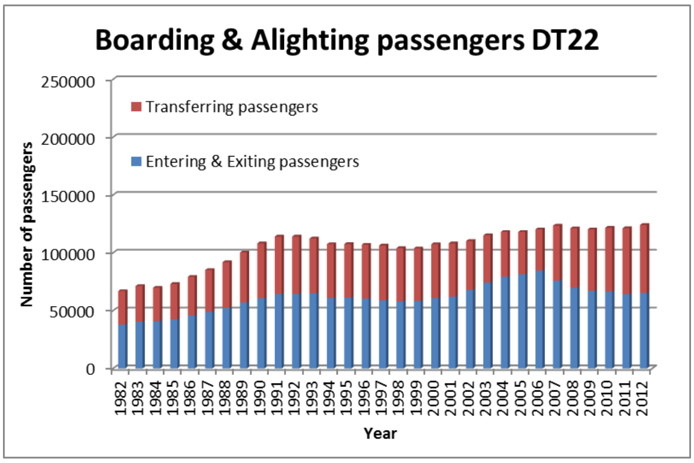
Figure 49: Average daily Boarding & Alighting passengers at transfer stations

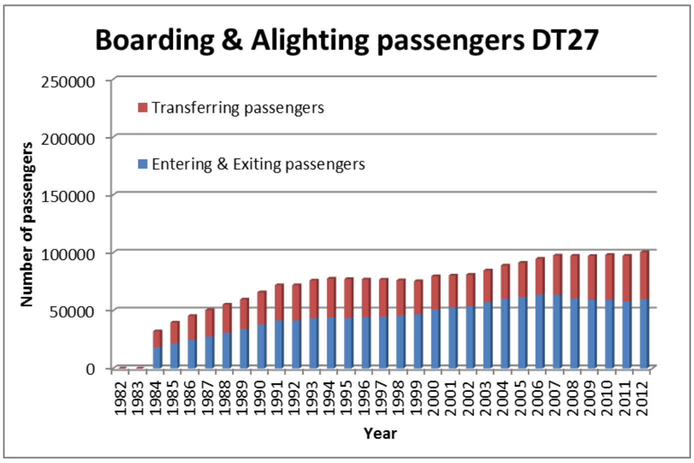












9.7 Between subject analysis

Table 16: Kendall's tau correlation table; Year 2000

		Population	Workforce-cluster 1	Workforce-cluster 2	Workforce-cluster 3	Multi-functionality	Station type	Number of directions	Frequency	Travel time to centre	Passengers
Population	**Corr.**	1,000	,932**	,889**	,758**	-,223	,072	-,112	,269	-,478**	,311*
	Sig.		,000	,000	,000	,112	,665	,488	,085	,001	,026
Workforce-cluster 1	**Corr.**	,932**	1,000	,932**	,727**	-,254	,072	-,112	,284	-,522**	,342*
	Sig.	,000		,000	,000	,070	,665	,488	,069	,000	,014
Workforce-cluster 2	**Corr.**	,889**	,932**	1,000	,721**	-,198	,072	-,093	,284	-,503**	,335*
	Sig.	,000	,000		,000	,158	,665	,567	,069	,000	,016
Workforce-cluster 3	**Corr.**	,758**	,727**	,721**	1,000	-,016	-,010	-,078	,159	-,297*	,203
	Sig.	,000	,000	,000		,912	,954	,629	,308	,034	,146
Multi-functionality	**Corr.**	-,223	-,254	-,198	-,016	1,000	-,175	,034	-,183	,392**	-,285*
	Sig.	,112	,070	,158	,912		,298	,833	,243	,005	,042
Station type	**Corr.**	,072	,072	,072	-,010	-,175	1,000	,504**	,787**	-,217	,572**
	Sig.	,665	,665	,665	,954	,298		,010	,000	,193	,001
Number of directions	**Corr.**	-,112	-,112	-,093	-,078	,034	,504**	1,000	,354	-,049	,444**
	Sig.	,488	,488	,567	,629	,833	,010		,051	,763	,006
Frequency	**Corr.**	,269	,284	,284	,159	-,183	,787**	,354	1,000	-,482**	,609**
	Sig.	,085	,069	,069	,308	,243	,000	,051		,002	,000
Travel time to centre	**Corr.**	-,478**	-,522**	-,503**	-,297*	,392**	-,217	-,049	-,482**	1,000	-,361**
	Sig.	,001	,000	,000	,034	,005	,193	,763	,002		,010
Passengers	**Corr.**	,311*	,342*	,335*	,203	-,285*	,572**	,444**	,609**	-,361**	1,000
	Sig.	,026	,014	,016	,146	,042	,001	,006	,000	,010	

***. Correlation is significant at the 0.01 level (2-tailed).*

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

Table 17: Kendall's tau correlation table; Year 2005

		Population	Workforce-cluster 1	Workforce-cluster 2	Workforce-cluster 3	Multi-functionality	Station type	Number of directions	Frequency	Travel time to centre	Passengers
Population	**Corr.**	1,000	,902**	,846**	,592**	-,482**	,013	-,073	,224	-,505**	,255
	Sig.		,000	,000	,000	,001	,936	,651	,146	,000	,067
Workforce-cluster 1	**Corr.**	,902**	1,000	,895**	,555**	-,532**	,040	-,063	,275	-,529**	,280*
	Sig.	,000		,000	,000	,000	,808	,695	,074	,000	,045
Workforce-cluster 2	**Corr.**	,846**	,895**	1,000	,622**	-,451**	,013	-,083	,209	-,461**	,212
	Sig.	,000	,000		,000	,001	,936	,608	,175	,001	,128
Workforce-cluster 3	**Corr.**	,592**	,555**	,622**	1,000	-,084	,027	-,098	,095	-,174	,117
	Sig.	,000	,000	,000		,551	,872	,546	,536	,217	,402
Multi-functionality	**Corr.**	-,482**	-,532**	-,451**	-,084	1,000	-,212	-,079	-,457**	,691**	-,389**
	Sig.	,001	,000	,001	,551		,205	,629	,003	,000	,005
Station type	**Corr.**	,013	,040	,013	,027	-,212	1,000	,726**	,678**	-,059	,668**
	Sig.	,936	,808	,936	,872	,205		,000	,000	,726	,000
Number of directions	**Corr.**	-,073	-,063	-,083	-,098	-,079	,726**	1,000	,448*	-,049	,542**
	Sig.	,651	,695	,608	,546	,629	,000		,012	,763	,001
Frequency	**Corr.**	,224	,275	,209	,095	-,457**	,678**	,448*	1,000	-,424**	,641**
	Sig.	,146	,074	,175	,536	,003	,000	,012		,006	,000
Travel time to centre	**Corr.**	-,505**	-,529**	-,461**	-,174	,691**	-,059	-,049	-,424**	1,000	-,300*
	Sig.	,000	,000	,001	,217	,000	,726	,763	,006		,032
Passengers	**Corr.**	,255	,280*	,212	,117	-,389**	,668**	,542**	,641**	-,300*	1,000
	Sig.	,067	,045	,128	,402	,005	,000	,001	,000	,032	

. Correlation is significant at the 0.01 level (2-tailed).

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

Table 18: Model parameters; Model 1

Year	Model	Parameters	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	Sig.	95,0% Confidence Interval for B Lower Bound	Upper Bound
2000	1a	(Constant)	-18785,629	12835,382		,156	-45276,556	7705,297
		Frequency	3813,067	700,548	,743	,000	2367,206	5258,928
	1b	(Constant)	-29415,233	13631,693		,042	-57614,538	-1215,928
		Frequency	3444,567	700,906	,671	,000	1994,633	4894,502
		Population	1,034	,576	,245	,086	-,157	2,225
	1c	(Constant)	-27033,607	13082,409		,050	-54096,632	29,417
		Frequency	3421,433	703,445	,667	,000	1966,247	4876,618
		WF cluster 1	3,340	1,843	,248	,083	-,473	7,152
	1d	(Constant)	-6785,826	21880,852		,759	-52049,818	38478,166
		Frequency	3479,566	861,176	,678	,001	1698,087	5261,045
		TT to centre	-225,542	331,068	-,114	,503	-910,407	459,324
2005	1a	(Constant)	-31369,202	13001,396		,024	-58202,765	-4535,640
		Frequency	4654,124	686,961	,810	,000	3236,307	6071,941
	1b	(Constant)	-41754,772	14732,899		,009	-72232,096	-11277,449
		Frequency	4424,734	692,923	,770	,000	2991,314	5858,155
		Population	,827	,588	,170	,173	-,390	2,044
	1c	(Constant)	-39425,759	14379,855		,012	-69172,755	-9678,763
		Frequency	4396,186	709,782	,765	,000	2927,891	5864,482
		WF cluster 1	2,624	2,101	,154	,224	-1,722	6,970
	1d	(Constant)	-25446,880	20076,764		,218	-66978,831	16085,071
		Frequency	4513,556	785,830	,786	,000	2887,943	6139,170
		TT to centre	-127,615	325,271	-,054	,698	-800,490	545,260
2010	1a	(Constant)	-20365,493	11390,990		,086	-43875,341	3144,355
		Frequency	3573,199	526,332	,811	,000	2486,902	4659,496
	1b	(Constant)	-25171,026	12450,287		,055	-50926,407	584,356
		Frequency	3271,104	613,292	,742	,000	2002,412	4539,796
		Population	,601	,624	,134	,345	-,689	1,891
	1c	(Constant)	-25270,231	12496,888		,055	-51122,014	581,552
		Frequency	3257,301	621,121	,739	,000	1972,415	4542,188
		WF cluster 1	2,499	2,599	,136	,346	-2,877	7,876
	1d	(Constant)	-32380,082	22299,775		,160	-78510,681	13750,516
		Frequency	3854,745	695,814	,875	,000	2415,344	5294,146
		TT to centre	217,666	345,731	,099	,535	-497,534	932,866

Figure 50: Scatterplot; Regression Standardised Residual VS Regression Standardised Predicted Value

2000 *2005* *2010*

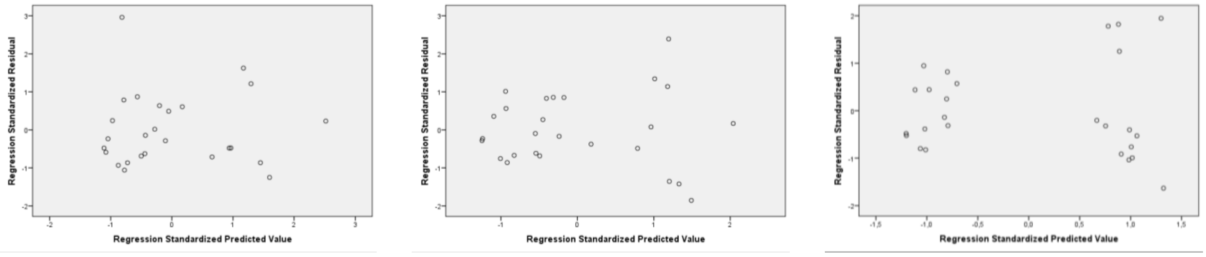
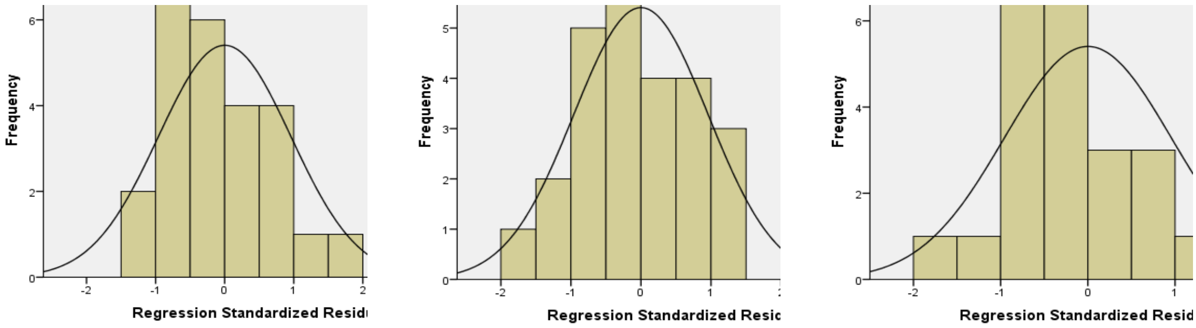


Figure 51: Histogram; Distribution Regression Standardised Residual, with normal curve

2000 *2005* *2010*



9.8 Trip distribution matrix

Table 19: Trip distribution matrix for 2009

2009	DT01	TRANS 01	DT02	DT03	DT04	DT05	DT06	DT07	TRANS07	DT08	DT09	DT10	TRANS10	DT11	DT12	DT13	DT14
DT01	0	0	5.632	11.930	6.462	5.575	3.917	4.897	2.593	1.382	1.907	6.110	1.471	2.157	2.426	2.358	2.978
TRANS 01	0	0	15.505	32.846	17.792	15.348	10.785	13.483	7.138	3.806	5.251	16.821	4.050	5.940	6.680	6.491	8.198
DT02	6.100	16.591	0	884	479	413	290	363	192	102	141	453	109	160	180	175	221
DT03	12.533	34.088	884	0	1.356	1.170	822	1.028	544	290	400	1.282	309	453	509	495	625
DT04	6.974	18.969	492	1.396	0	728	512	640	339	181	249	798	192	282	317	308	389
DT05	5.900	16.049	416	1.181	734	0	564	705	373	199	274	879	212	310	349	339	428
DT06	4.131	11.236	291	827	514	558	0	1.188	629	335	463	1.482	357	523	589	572	722
DT07	4.875	13.261	344	976	607	658	1.139	0	0	330	455	1.457	351	515	579	562	710
TRANS07	3.512	9.552	248	703	437	474	820	0	0	493	680	2.177	524	769	865	840	1.061
DT08	1.388	3.775	98	278	173	187	324	315	752	0	98	313	75	111	124	121	153
DT09	1.922	5.228	136	385	239	260	449	437	1.042	92	0	556	134	196	221	215	271
DT10	5.865	15.953	413	1.174	730	792	1.370	1.333	3.180	281	506	0	0	1.328	1.493	1.451	1.832
TRANS10	1.453	3.951	102	291	181	196	339	330	787	70	125	0	0	2.751	3.094	3.007	3.797
DT11	2.213	6.020	156	443	275	299	517	503	1.200	106	191	1.278	2.230	0	200	194	245
DT12	2.529	6.879	178	506	315	342	591	575	1.371	121	218	1.460	2.548	199	0	344	435
DT13	2.516	6.843	177	504	313	340	587	572	1.364	121	217	1.453	2.534	198	350	0	574
DT14	2.996	8.150	211	600	373	405	700	681	1.624	144	258	1.730	3.019	236	417	514	0
DT15	2.895	7.875	204	580	360	391	676	658	1.570	139	250	1.672	2.917	228	403	496	833
DT16	5.205	14.157	367	1.042	648	703	1.215	1.183	2.822	250	449	3.006	5.243	409	724	892	1.497
TRANS16	879	2.390	62	176	109	119	205	200	476	42	76	507	885	69	122	151	253
DT17	1.562	4.249	110	313	194	211	365	355	847	75	135	902	1.574	123	217	268	449
DT18	1.648	4.484	116	330	205	223	385	375	894	79	142	952	1.661	130	229	283	474
DT19	869	2.362	61	174	108	117	203	197	471	42	75	502	875	68	121	149	250
DT20	4.305	11.710	304	862	536	581	1.005	978	2.334	207	371	2.486	4.337	338	599	738	1.238
DT21	396	1.076	28	79	49	53	92	90	215	19	34	229	399	31	55	68	114
DT22	2.543	6.916	179	509	316	343	594	578	1.378	122	219	1.468	2.562	200	354	436	731
TRANS22	1.934	5.260	136	387	241	261	452	439	1.048	93	167	1.117	1.948	152	269	331	556
DT23	394	1.072	28	79	49	53	92	90	214	19	34	228	397	31	55	68	113
DT24	353	959	25	71	44	48	82	80	191	17	30	204	355	28	49	60	101
DT25	845	2.299	60	169	105	114	197	192	458	41	73	488	851	66	118	145	243
DT26	221	600	16	44	27	30	52	50	120	11	19	127	222	17	31	38	63
DT27	1.908	5.190	135	382	237	258	446	434	1.034	92	164	1.102	1.922	150	265	327	549
TRANS27	1.251	3.401	88	250	156	169	292	284	678	60	108	722	1.260	98	174	214	360
Colum total to Tokyo	92.116	250.546	6.064	14.707	8.274	8.184	13.189	10.928	26.071	2.241	3.859	21.632	37.740	2.770	4.551	5.176	7.826
Target to Tokyo	*92.014*	*250.269*	*6.058*	*14.698*	*8.271*	*8.183*	*13.189*	*10.933*	*26.084*	*2.242*	*3.862*	*21.658*	*37.785*	*2.774*	*4.558*	*5.185*	*7.841*
Column total from Tokyo	0	0	21.137	45.660	26.089	23.233	16.890	22.303	11.807	7.118	9.919	32.329	7.784	15.495	17.626	17.471	22.638
Target from Tokyo	*0*	*0*	*21.173*	*45.737*	*26.132*	*23.271*	*16.917*	*22.336*	*11.825*	*7.127*	*9.931*	*32.367*	*7.793*	*15.501*	*17.633*	*17.477*	*22.644*

2009	DT15	DT16	TRANS16	DT17	DT18	DT19	DT20	DT21	DT22	TRANS22	DT23	DT24	DT25	DT26	DT27	TRANS27	Row total to Tokyo	*Target to Tokyo*	Row total from Tokyo	*Target from Tokyo*
DT01	2.794	5.041	851	1.500	1.591	853	4.191	368	2.443	1.867	375	335	828	214	1.892	1.142	0	*0*	88.082	*88.082*
TRANS 01	7.692	13.878	2.344	4.130	4.379	2.349	11.539	1.013	6.726	5.139	1.032	922	2.279	589	5.210	3.145	0	*0*	242.502	*242.502*
DT02	207	374	63	111	118	63	311	27	181	138	28	25	61	16	140	85	22.691	*22.691*	6.111	*6.111*
DT03	586	1.058	179	315	334	179	879	77	513	392	79	70	174	45	397	240	47.504	*47.504*	14.796	*14.796*
DT04	365	658	111	196	208	111	547	48	319	244	49	44	108	28	247	149	27.831	*27.831*	8.367	*8.367*
DT05	402	725	123	216	229	123	603	53	352	269	54	48	119	31	272	164	24.280	*24.280*	8.416	*8.416*
DT06	678	1.223	206	364	386	207	1.017	89	593	453	91	81	201	52	459	277	17.557	*17.557*	13.234	*13.234*
DT07	666	1.202	203	358	379	204	1.000	88	583	445	89	80	197	51	451	272	21.859	*21.859*	11.228	*11.228*
TRANS07	996	1.796	303	535	567	304	1.493	131	871	665	134	119	295	76	674	407	15.746	*15.746*	16.774	*16.774*
DT08	143	258	44	77	82	44	215	19	125	96	19	17	42	11	97	59	7.290	*7.290*	2.342	*2.342*
DT09	254	459	78	137	145	78	382	34	222	170	34	30	75	19	172	104	10.189	*10.189*	3.987	*3.987*
DT10	1.719	3.102	524	923	979	525	2.579	226	1.503	1.149	231	206	509	132	1.164	703	31.597	*31.597*	22.278	*22.278*
TRANS10	3.563	6.428	1.086	1.913	2.028	1.088	5.345	469	3.115	2.380	478	427	1.056	273	2.413	1.457	7.825	*7.825*	46.168	*46.168*
DT11	230	415	70	124	131	70	345	30	201	154	31	28	68	18	156	94	15.431	*15.431*	2.804	*2.804*
DT12	408	736	124	219	232	125	612	54	357	273	55	49	121	31	276	167	17.832	*17.832*	4.620	*4.620*
DT13	538	971	164	289	306	164	808	71	471	360	72	65	160	41	365	220	18.087	*18.087*	5.639	*5.639*
DT14	817	1.473	249	439	465	249	1.225	108	714	546	110	98	242	62	553	334	22.057	*22.057*	7.683	*7.683*
DT15	0	2.666	450	793	841	451	2.217	195	1.292	987	198	177	438	113	1.001	604	22.146	*22.146*	12.424	*12.424*
DT16	2.672	0	0	932	988	530	2.603	229	1.518	1.159	233	208	514	133	1.175	710	42.482	*42.482*	10.932	*10.932*
TRANS16	451	0	0	367	389	209	1.025	90	598	457	92	82	203	52	463	279	7.171	*7.171*	4.305	*4.305*
DT17	802	928	368	0	366	196	965	85	562	430	86	77	191	49	436	263	14.047	*14.047*	3.706	*3.706*
DT18	846	979	388	357	0	393	1.930	170	1.125	860	173	154	381	98	872	526	15.179	*15.179*	6.682	*6.682*
DT19	446	516	205	188	383	0	1.433	126	835	638	128	114	283	73	647	391	8.381	*8.381*	4.668	*4.668*
DT20	2.210	2.558	1.014	933	1.898	1.409	0	467	3.097	2.366	475	424	1.049	271	2.399	1.448	42.951	*42.951*	11.996	*11.996*
DT21	203	235	93	86	174	130	475	0	303	232	47	42	103	27	235	142	4.423	*4.423*	1.129	*1.129*
DT22	1.305	1.511	599	551	1.121	832	3.052	279	0	0	392	350	865	223	1.977	1.193	28.697	*28.697*	4.999	*4.999*
TRANS22	993	1.149	455	419	853	633	2.321	212	0	0	373	333	824	213	1.884	1.137	21.827	*21.827*	4.764	*4.764*
DT23	202	234	93	85	174	129	473	43	387	375	0	79	196	51	448	271	5.212	*5.212*	1.045	*1.045*
DT24	181	209	83	76	155	115	423	39	346	336	78	0	221	57	506	305	4.740	*4.740*	1.090	*1.090*
DT25	434	502	199	183	373	277	1.014	93	830	804	188	215	0	273	2.416	1.459	11.576	*11.576*	4.148	*4.148*
DT26	113	131	52	48	97	72	265	24	217	210	49	56	260	0	1.058	639	3.283	*3.283*	1.697	*1.697*
DT27	979	1.134	449	413	841	624	2.290	209	1.873	1.816	424	486	2.252	1.018	0	0	29.404	*29.404*	0	*0*
TRANS27	642	743	294	271	551	409	1.501	137	1.227	1.190	278	318	1.476	667	0	0	19.270	*19.270*	0	*0*
Colum total to Tokyo	12.479	10.829	4.293	3.610	6.621	4.630	11.814	1.036	4.879	4.730	1.018	1.076	3.988	1.686	0	0				
Target to Tokyo	*12.506*	*10.860*	*4.305*	*3.621*	*6.643*	*4.646*	*11.863*	*1.040*	*4.907*	*4.757*	*1.024*	*1.082*	*4.012*	*1.696*	*0*	*0*				
Column total from Tokyo	22.060	42.464	7.171	13.937	15.142	8.517	43.264	4.266	28.619	21.866	5.157	4.684	11.804	3.321	30.457	18.387				
Target from Tokyo	*22.063*	*42.462*	*7.171*	*13.931*	*15.134*	*8.511*	*43.227*	*4.260*	*28.577*	*21.834*	*5.144*	*4.672*	*11.773*	*3.311*	*30.355*	*18.325*				

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