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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Public Transport Integration in Tabriz, Iran

Pouya Mohammadighazijahani

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Mobility Management

SUPERVISOR :
Prof. dr. An NEVEN

CO-SUPERVISOR :
Prof. dr. ir. Tom BELLEMANS

2019
2020

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Preface

I would like to express my appreciation to my supervisors Prof. dr. An Neven and Prof. dr. Tom Bellemans for their guidance during the preparation of this thesis. Their recommendations, feedbacks and comments helped me obtain a much better understanding of the topic and the process of carrying out research work in general and writing this thesis, in particular.

I would also like to express my gratitude to my mentor dr. Amirhassan Rezaei Farei, who helped me develop my topic and without his efforts despite all the obstacles, acquiring an important part of the research data was almost impossible.

Special thanks go to my friends in Iran who helped me acquiring vital data from different authorities which I was not able to contact.

This thesis is dedicated to my parent who without their love, prayers, support and motivations, I would not be who I am today.

Hasselt, 13.01.2020

Pouya Mohammadighazijahani

Summary

Integrating different public transport systems in large cities with several public transport option is attracting more and more attention among urban and transportation planners. To improve public transport service to a level that can compete with the door-to-door service of private cars, integrating different public transport in a city or a region into a seamless single service is of great importance. Many cities and regions have already implemented their plans for integration and many are planning for it.

However, Tabriz, a major city in Iran, does not yet have plans for integration of different public transport services. The city has recently opened a part of its first metro line and the research and construction work for the rest of the network is underway. A major station is about to be opened in the city centre where several urban bus terminal stations are located as well. Yet, the distance between the stations is an obstacle to fast and comfortable transfer. On the other hand, the fares of different public transport systems in Tabriz are not integrated which makes multi-leg public transport trips inconvenient and expensive.

This thesis aims at improving the level of service of public transport in Tabriz by introducing physical and operational integration measures. For this purpose, modelling the public transport system in Tabriz and designing different variants by making adjustments in the existing system, including the introduction of an intermodal transport station in the city centre and introduction of an integrated fare system, is carried out.

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Chapter 1: Introduction

1.1. Background

Transportation is often referred to as the “lifeblood of cities” because it provides the essential link among activities and, in the long run, to a large extent, it helps shape the city (V. Vuchic, 1999). An efficient public transport system is the backbone of a sustainable urban transport network. It provides a reliable, clean, fast, cheap and convenient travel option, as a strong rival for the private car.

However, public transport in many cities is unattractive. The quality and quantity of public transport services are not harmonized with population growth and social expectations (SUTP, 2018). The shortage of proper public transport results in a significant modal share of private vehicles on urban trips. This paves the road for a high modal share of private vehicles which causes problems such as traffic congestion, and air and noise pollution.

Thus, an effective solution for increasing public transport attractiveness is improving its level of service. The integration of different public transport systems may reduce travel time and cost (Auerbach et al., 2009) and enable the users to travel seamlessly using different modes of transport in a single trip. This may improve the service quality of public transport to the point where the service can be observed as an attractive alternative to private vehicles (SUTP, 2018).

As the largest city and the economic and industrial core of Northwest Iran, Tabriz is suffering from major traffic problems. In recent years, the city boundaries are expanded and the city has attracted a large number of people from all over the region who are seeking job opportunities or higher living standards in the city. As a result of this expansion, the growing number of population and private car ownership has caused traffic congestion and air pollution.

The city authorities have planned to take different countermeasures to cope with these consequences. These solutions include expanding the urban road network and introducing new public transport systems, namely the metro and the tram. However, A traffic prediction analysis report for Tabriz, which is done by (Pajoohesh, 2009), shows that taking into account the annual growth in urban journeys, despite the development of transport network –specifically assuming that two lines of the new metro mass transit network will be put to operation– the traffic congestion is predicted to increase and result in a more critical situation in 2021, especially in the central districts of the city.

The models predict that, despite the projected opening of two new metro lines in 2021, in case of taking no further actions to stimulate modal shift, the traffic congestion in Tabriz will become worse and traffic volume per capacity (v/c) ratio, which indicates the degree of saturation of roads, will considerably increase for most of the major roads. Figure 1 compares the v/c ratio in 2004 and 2021 in case of taking no actions (Pajoohesh, 2009).

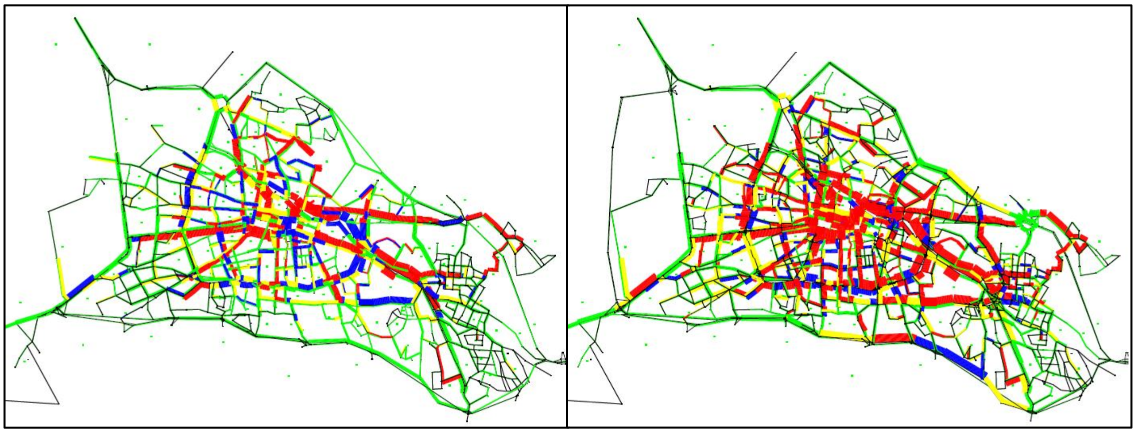


Figure 1: v/c ratio for major roads of Tabriz in 2004 (left) and 2021 (predicted) (right). Green: Free flow, Yellow: Convenient, Blue: Slow, Red: Critical (source: (Pajoohesh Consulting Engineers, 2009))

On the other hand, as a part of the approach to the traffic problems of Iranian major cities, the Iranian Ministry of Interior has set the goal to raise the mode share of public transport in metropolitans to 75% by 2021. However, this number includes the modal share of the shared taxi.

The latest statistics from (Naghsh-e-Moheet, 2013) shows that the modal share of the bus in Tabriz is 16.1%. Adding the share of the shared taxi, (Shared taxi cabs in Iran have a different function than conventional taxi cabs and are described as a semi-public mode of transport. It is explained in more details in chapter 3.) it can be stated that public transport takes a share of 36% of all urban trips in Tabriz; which is far behind the goal of 2021. This share is predicted to increase after completion of the construction of the metro lines. However, other factors can still change this trend.

The rapid growth of private car ownership in Iran in the last years can be effective in decreasing public transport ridership. According to the (Statistical Center of Iran, 2017), the private car ownership rate of the average Iranian households has increased from 35% in 2009 to 50.55% in 2017. Moreover, the emergence of Uber-like online taxi services which have become very popular in Iran due to their relatively lower cost and a better level of service compared to traditional shared taxi cabs is another new factor to be considered.

On the other hand, generally, the satisfaction level of public transport users was relatively low and among all transport systems, the bus has a lower level of satisfaction. A survey by (Pajoohesh, 2009) demonstrated that 31% of the respondents assess bus as a “bad” and “very bad”, and 33% see it as a “moderate” system and only 32% of respondents have seen the bus as a “good” or “excellent” transport system. The level of dissatisfaction for the bus is the highest among all transport systems. According to the survey, the majority of bus riders found the “long travel time” as the main reason for dissatisfaction (52%), followed by “low comfort”, “high travel costs” and “low safety”. Other problems such as poor coverage (Pajoohesh, 2009) contribute to this situation.

In this situation, the importance of the integration of different modes of transport to improve the level of service, and consequently the ridership of public transport can be highlighted. In general, integrated transport is highly neglected in Tabriz; On one hand in practice, other than a few minor measures such as introducing local smart cards that can be topped up for using both bus and metro, transport integration has not been paid enough attention. On the other hand, the topic has neither been investigated in previous studies. The research around public transport integration in Tabriz is so far limited to suggestions for adjustments in bus line routes and fleet after the introduction of the metro.

The current study is focusing on investigating feasible solutions for integrating different public transport systems. For the first time, two major integration fields: physical integration and operational integration, are applied to the modelled transport system of the city by means of developing different scenarios. These scenarios include introducing an intermodal bus and metro station, and the introduction of an integrated time-based fare system for all public transport systems in the city. The impact of applied changes on public transport level of service and ridership is thereafter studied through measuring the changes in total travel time, transfer time, transfer walking distance and number of assigned public transport trips.

In this thesis, after the introduction to the problem and the objectives of the research in chapter 1, the previous research works in the field are reviewed in chapter 2. Then, the study case is described in chapter 3. The methods that are employed to approach the research questions are defined and explained in chapter 4. The steps to develop the simulation model, including creating the model and developing different variants form chapter 5. The findings are explained and discussed in chapter 6 and finally, chapter 7 includes the conclusion and recommendations for future research.

1.2. Objective

As already mentioned, public transport integration has been highly neglected in Tabriz transport planning. This thesis attempts to find solutions to fill up this gap. This thesis, for the first time, aims at studying the predicted consequences of adjusting the public transport system of Tabriz to make different public transport systems more integrated.

After the introduction of the metro to Tabriz public transport system, the city now has two public transport systems: bus (including BRT) and metro. There is a network of shared taxis as well as unofficial ride-sharing by private cars that are quite wide-spread which are not taken into account and are not a part of the model since they don’t have either defined routes or scheduled departures.

This thesis mainly examines the effects of infrastructural as well as operational integration of these two systems on the level of service of public transport and its ridership. In other words, the main objective of this thesis is to study the effects of converting an interchange metro station (for lines 1 and 2) in the city centre to an intermodal bus/metro station, by combining 5 nearby urban bus stations, as well as introducing an integrated fare system on transfer time and distance, total travel time and ridership of public transport.

1.3. Research Question

The main research question is:

- What is the effect of the construction of an intermodal public transport station and/or fare integration on public transport level of service?

The level of service can be measured using different indicators such as travel time, transfer time, and walking distance. Thus, to answer the main research question, the following sub-questions should be answered:

- In what way does the construction of the intermodal public transport station and/or fare integration change the travel time?
- In what way does the construction of the intermodal public transport station and/or fare integration change the transfer time?
- In what way does the construction of the intermodal public transport station and/or fare integration change the walking distance?
- Does the physical and operational integration of different public transport systems cause a modal shift? In what way?

To approach these research questions, the following methodology is employed:

First, the existing literature is reviewed to gain a comprehensive understanding of the concept of public transport integration, the necessity for implementation, and fields of integration. Similar cases where public transport integration has been modelled or implemented are studied as well.

Afterwards, the necessary data for developing a simulation model is collected from different sources. Then, the transportation system of Tabriz, including private as well as public transport, is modelled using a traffic simulation software. After modelling the transport supply and Transport demand, the simulations model is adjusted in different ways to develop different variants of public transport integration. Different variants are then compared to each other, based on different indicators that are mentioned in the research sub-questions.

Chapter 2: Literature Review

2.1. The concept of public transport integration

Non-integrated public transport systems are subject to neglect the customer needs which leads to low ridership (SUTP, 2018). There are several obstacles to use non-integrated public transport systems, that can be summarized as follows: (Auerbach et al., 2009; SUTP, 2018)

- **Transfer time:** Long distances between transfer stops;
- **Travel time:** Unharmonized timetables and connections between operators;
- **Information:** Contradictory or insufficient information, or a non-transparent jungle of tariff systems;
- **Costs:** In some relations, parallel, competitive services exist;
- **Comfort:** More than one ticket is needed (or a surcharge exists) for a single-trip ride resulting in expensive fares, uncoordinated timetables, absence of connections at transfer stops;

Hence, striving for better integration of public transport means (in terms of physical infrastructure, fares and timetables) is the key move towards making public transport systems attractive.

On the other hand, (Prospects, 2003) lists the following as the benefits of the integrated transport systems:

- Reduction of travel times;
- Reduction of transportation costs;
- Reduction of traffic congestion and environmental pollution;

and states that transport integration solutions may also improve the accessibility and competitiveness, and assure a better utilization of different transportation modes and infrastructure.

2.1.1. Fields of integration

Different researchers have dealt with the concept of public transport integration. Even though the definitions for integration by different research works are varied, but all of them have pointed to a number of main fields and levels of integration. In this research, two journal papers: (Saliara, 2014) and (Solecka & Żak, 2014) and two transportation manuals: (Auerbach et al., 2009) and (SUTP, 2018) are discussed. Generally, the integration fields that they include are categorized as four main fields:

- Organizational integration
- Operational integration
- Physical integration

- Other fields of integration (including cooperation with other parties than public transport providers, external policy integration, etc.)

Table 1 lists the research works and the fields of public transport integration which they include. Out of four fields of integration which are classified in table 1, this research includes two fields: The operational integration and Physical integration. Operational integration in the case of the current research includes integrated fares and the physical integration is realized by an intermodal interchange station.

Table 1: Fields of public transport integration

Study	**Field of integration**			
	Organizational integration	**Operational integration**	**Physical integration**	**Other fields of integration**
(Auerbach et al., 2009)	- Integration of services between operators	- Integration of network and timetable: Using different transport modes according to their strength - Integrated fares and tariffs	–	- Cooperation with other parties: Third parties for advertisements, Other mobility service providers such as car and bike sharing, green energy and public health agencies and tourism industry
(Saliara, 2014)	- Arrangements between operators - Coordination of functions and cooperation of operators by an independent authority	- Network design - Schedules - Transfers - Information - Fares - Tickets	- Access to facilities - Location of facilities - Design of stations - Control of vehicle travels	–
(Solecka & Żak, 2014)	–	- Coordinated timetables and metropolitan tickets for different transportation modes - Economic integration: integrated tariffs - Informational integration: Passenger	- Spatial integration such as multimodal terminals and interchange platforms and shared lanes for means of public transportation - Infrastructural integration such as corridors connecting public	- Integration of transportation - a policy with other policies regarding spatial planning and urban management

		information systems such as web pages and electronic travel planners	transportation stops, overpasses, underpasses, shared stops for public transportation	
(SUTP, 2018)	- Transit Alliances	- Integrated fares and ticketing: Single ticket for covering the whole journey and reduced fares for monthly tickets, etc. - Integrated passenger information Coordinated timetables	- Transfer stations: a coordinated approach to planning transfer stations to support quick and comfortable interchanges	- Common marketing/corporate design

2.2. Transfers and its impact on travel time and mode choice

Travel time is an important factor in modal choice (Walle & Steenberghen, 2006). Public transport modes usually include longer walking distances (Brown et al., 2003) and higher travel times for public transport results in its lower share among transport options (De Vasconcellos, 2005). Generally, travellers are more sensitive to out-of-vehicle travel time than in-vehicle travel time (Bhat, 1998). By reviewing relevant papers, (De Witte et al., 2013) stated that the time spent in public transport is perceived worse than in a car.

(Zhang et al., 2013) highlighted that to relieve traffic congestion, enhancing the bus modal share is an important measure. By establishing MNL models based on both stated preference data, and combining stated preference and revealed preference data that they collected in Jinan, China, they analysed the effect of different influencing factors on the choice proportion of bus travel mode for the bus user groups and concluded that generally, bus modal share increases by improving the bus service level. They conducted a sensitivity analysis for both car and bus and for the bus, they chose bus travel time and the bus ticket. The results revealed that the bus user groups are more sensitive to the change of bus travel time than the change of bus ticket price.

The research work by (Parbo et al., 2014) dealt with minimizing the waiting time experienced by the passenger during the transfer from/to bus by means of optimization of the timetables. They applied a heuristic solution approach to the large-scale public transport network in Denmark. It is worth mentioning that (Parbo et al., 2014) also applied the approach to the transit network in the Greater Copenhagen area, where trains stations were regularly used as bus hubs as well. Several bus lines served as feeders and connecting modes for the trains. The timetable optimization approach resulted in a weighted waiting time equivalent to approximately 9 million USD.

(Krygsman et al., 2004) who analysed the interconnectivity ratio (the share of access and egress time in total trip times) in Amsterdam-Utrecht region, the Netherlands, highlights the access and egress as the weakest part of the public transport chain which determines the availability and convenience of public transport. The research shows that for all examined multimodal chains, i.e. bicycle-train-bicycle, walk-train-walk, walk-bus-walk and mixed (train combined with the bus, tram and metro) -train-mixed, the interconnectivity ratio is lower for longer travels. For bicycle-train-bicycle trips, the interconnectivity ratio starts to decrease after 60-70 min, where for walk-train-walk and mixed travels the decline in the ratio starts at 50-60 min. (Krygsman et al., 2004), studied the correlation between the interconnectivity ratio and the number of users of different transport chains as well. As illustrated in figure 2, only 10% of the bus, tram and metro (main mode) users have a ratio higher than 0.55, while no mixed train (multimodal) users have ratio of this size. Likewise, the cumulative distribution for train mixed users (i.e. in combination with bus, tram and metro) shows a much steeper slope.

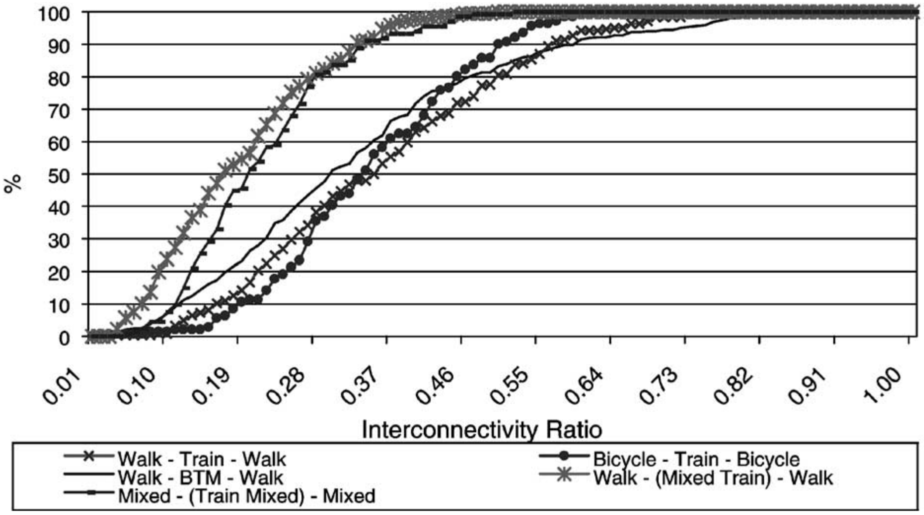


Figure 2: Cumulative percentage of different public transport chains user over increasing interconnectivity ratio. (source: (Krygsman et al., 2004))

On the other hand, the paper also mentions that transfers lead to shorter access times which may refer to the inverse relationship between access time and transfers. Thus, it can be concluded that by improving the transfers in terms of decreasing transfer times, the users with a lower access time threshold can be attracted to public transport.

Transfers are widespread in public transport systems, especially in large-scale multimodal networks (V. R. Vuchic, 2007). According to (Guo & Wilson, 2011), who assessed the "cost of transfer inconvenience in public transport systems" in London Underground (LUL), passengers in multimodal systems usually have to transfer between different modes and services to reach their destinations. Referring to the official figures from some of the major cities in the world, the paper mentions that a considerable share of public transport trips involves at least one transfer. For example, In London, about 70% of Underground trips and 30% of bus trips involve at least one transfer, while in New York City this figure reaches around 30% of subway and bus and 80% of commuter rail trips. In Munich, 70% and Paris 40% of all public transport trips include one or more transfers. Even with their popularity, transfers are often seen as a necessary evil in public transport. On the one hand, they support creating a hierarchical, multimodal network and extend the public transport service areas; on the other hand, they upset the travel experience and reduce the competitiveness of public transport with private cars that provide door-to-door service.

The transfer time (walking time) between vehicles in two lines at a transfer station is known. This value is the time that a passenger spends getting off a vehicle, walking to another vehicle and getting on it, provided that a vehicle is present when the passenger arrives at the stop. Thus, the waiting time that a passenger may experience is not a part of the transfer time definition.

2.2.1. Transfer components

As cited by (Guo & Wilson, 2011), Transfer experience can be divided into three components: transfer walking, waiting, and the transfer penalty, which is affected by the transfer environment. Transfer walking, which is mostly dealt with in this thesis, is defined by a network and station design.

- **Transfer walking time :** (Shafahi & Khani, 2010) defines transfer walking time as the time that a passenger spends to get off a vehicle, walk to another vehicle and get on it, on condition that a vehicle is present when the passenger arrives at the stop. Thus, transfer walking time is different than the transfer waiting time.
- **Transfer waiting time:** Transfer waiting time is the time that a passenger spends to wait for the vehicle to come to the stop/station, provided that the passenger is already present when the vehicle arrives. Transfer waiting time is determined by service operation and management Guo & Wilson, 2011).
- **Transfer penalty:** The transfer penalty is an extra psychological burden that public transport users face in the transfer phase. It does not directly contribute to the travel time, but perceived as comfort, security or other objective environments. It is also defined as the "traveller's perception of transfer time" (including transfer walking time and transfer waiting time) (Wang & Ke, 2017).

transfer penalty is determined by many different factors, including safety and security, ease of way-finding during transfers, availability of escalators, weather protection, seating availability, lighting, air conditioning and ventilation, and concessions on the platforms (Guo & Wilson, 2011).

2.2.3. The transport market

Based on the literature, a market can be identified for transport. This market functions independently of other markets. The important variables and functions in describing the functioning of the transport market can be listed as:

- Variables: the transport system, the activity system, the flow pattern, the level of service (travel times, fares, etc.), and the volume of the traffic flows
- Functions: supply function and demand function

A supply function in transport indicates the service that a certain transport system can offer at different traffic flow rates. That is why the supply function is also called a service function. A demand function defines the volume of the traffic flows as a function of the level of service in a certain activity system (Immers & Stada, 1998).

Thus, the transport model should consist of a supply model and a demand model. The road network and public transport services including fleet, lines, terminal stations, and stops form the supply side of a transport model. On the other hand, the origin-destination matrixes for private and public transport are the basic components of the demand side of the model.

Chapter 3: Study Case

3.1. Overview

Tabriz is the capital of East Azerbaijan province and is one of the biggest and most populated cities in Iran with an area of 190 km^2 and a population of over 1.7 million in its metropolitan area (Major Agglomerations of the World, 2019). Being the economic core of Northwest Iran, in recent years it has attracted a considerable number of people from the region which has resulted in a fast-growing population and horizontal expansion of the city boundaries. Figure 3 shows the situation of Tabriz in Iran and some views from Tabriz landmarks. According to (Naghsh-e-Moheet, 2013), in 2011, the total travel daily travel demand in Tabriz was 2,209,431; which based on the predictions, is foreseen to rise to around 3 million trips in 2021.

Figure 3: Left: Views from Tabriz (source). Right: Location of Tabriz on Iran map (source)

The study is focusing on two the metro station in the city centre of Tabriz; namely Shahid Mohaqqeqi (known as Mohaqqeqi) Metro Station and Meydan-e-Sa'at (known as Saat) Metro Station and 5 nearby urban bus terminal stations. Both metro stations are designed to be metro interchange stations. Figure 4 illustrated different metro and urban bus terminal stations in the city centre. Mohaqqeqi is an interchange station for lines 1 and 2, and Saat is an interchange station for lines 1 and 3. The stations are located in a densely populated area with many inhabitants and where many businesses are located as well. Except for Khaqai and East Mohaqqeqi terminal station, all other stations do not have a dedicated area, thus the buses park on the street which generates traffic problems. The city is split into 6 zones by Tabriz and Suburbs Bus Company: 4 zones of which have their dedicated terminal stations in the city centre, 1 zone covering east-west express lines and 1 zone for suburban buses

(*Tabriz and Suburbs Bus Company*, 2019a). The estimated walking distance between the stations varies between few meters or less than a minute (between Mohaqqeqi metro station and East Mohaqqeqi bus station) and 1,700 meters or 23 minutes (between Khaqani and Motahhari bus stations) (*Google Maps*, n.d.).

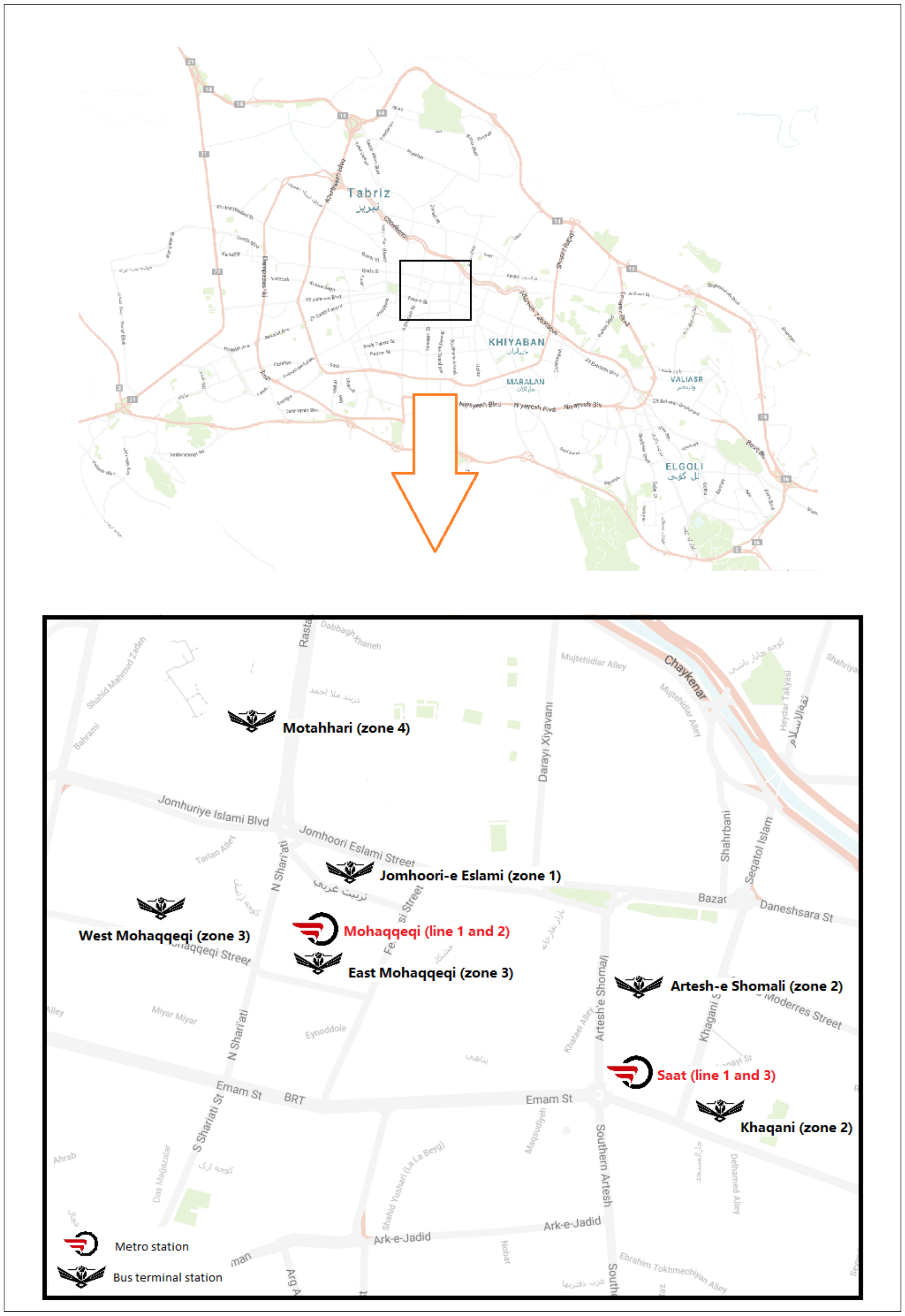


Figure 4: Tabriz map and the location of metro and bus stations in the study area in the city centre (source: EZ Map with additions by the author, August 2019)

3.2. Public Transport in Tabriz

As mentioned in chapter 1, public transport in Tabriz is mainly based on urban buses, shared taxi cabs and recently metro. However, nowadays online ride-sharing services have become popular. In this part, the overall situation of different modes of public transport in Tabriz is described.

3.2.1. Urban Bus and BRT

The Tabriz urban bus system of Tabriz is owned and managed by Tabriz and Suburbs Bus Company. The company was founded in 1952 and thereafter became a subdivision of the Municipality of Tabriz. (Tabriz and Suburbs Bus Company public relations, 2010)

According to (*Tabriz and Suburbs Bus Company*, 2019a), Tabriz has 75 urban bus lines. If the buses which either do not stop at all stops or have slightly different routes counted separately, 9 more lines can be added to the list as well. Geometry and the length of these lines are very different from each other. The figure shows an asymmetrical and central pattern. Almost all of these lines start and end in the Bazaar district (in the city centre).

The total length of bus lines is 1220 km and the average line length is 19.4 km. (Pajoohesh, 2009) The average speed for buses is 17 km/h. In total, the fleet consists of 800+ active buses of which 475 belong to the private sector and the rest to the public sector (Aslizadeh, 2018). According to the latest figures, 650,000 passengers are transported daily by urban buses (including BRT) in Tabriz (Mehr News Agency, 2018). In 2009, the average waiting time for passengers at urban bus stops was between 10 to 15 minutes (Naghsh-e-Moheet, 2013).

Figure 5 shows the East Mohaqqeqi bus terminal station before and after Mohaqqeqi metro station construction works. Some of the bus line stations are moved to West Mohaqqeqi street because of a lack of space after the construction started. After

Figure 5: East Mohaqqeqi bus terminal station before (left) and after (right) metro station construction works (source)

finishing the construction works, a wide area will be freed that potentially can be used as a main bus station terminal in the city centre.

Figure 6 shows all urban bus lines of Tabriz. The distance between the stations that are located in the city centre can obviously be seen on the map. As already mentioned, the stations are divided by zones, and bus lines of each zone usually depart from the specific station of the regarded zone.

Tabriz has 4 Bus Rapid Transit (BRT) lines of which 3 lines work on a single dedicated straight lane that connects the Railway Station at the Western corner of the city to the International Exhibition Centre at the East most point of the city. The fourth line works through a north-south corridor. BRT is the only mass transit option absence of the metro in Tabriz. The first phase of BRT was opened in 2008 and ever since 3 phases of it have been completed. BRT transports approximately 200,000 passengers daily in Tabriz (Tabriz and Suburbs Bus Company, n.d.). The average waiting time for passengers at BRT stops is 2 minutes (Hamshahri provinces service, 2016).

The payment method in BRT, as well as most of the regular bus lines, is by smart card only. However, it is still possible to pay by cash in some of the lines.

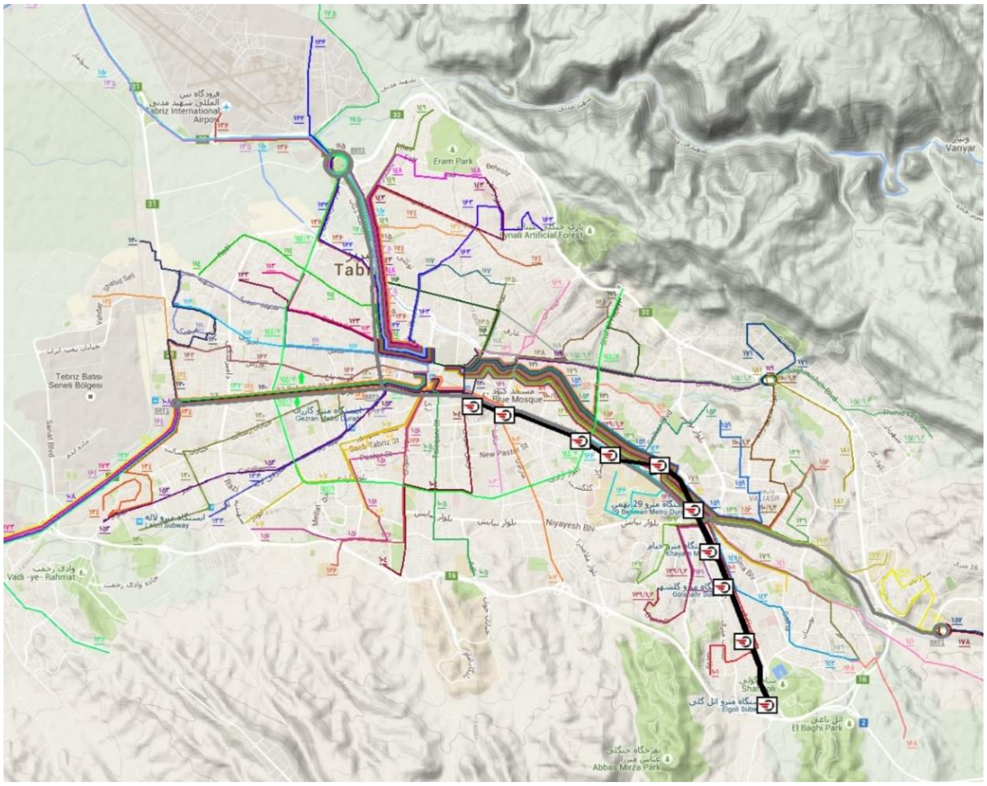


Figure 6: All active urban bus, BRT (grey line) and metro routes (thick black line) of Tabriz. The city centre (Bazaar), where is the start point for most of the lines, is visible in the centre of the map. The distance between different bus terminal stations is also visible. (Source:('Tabriz and Suburbs Bus Company', 2019c))

3.2.2. Taxi

Tabriz Taxi Organization which is also a subdivision of Tabriz Municipality is in charge of taxis in Tabriz. Taxis in Iran can be used either as a private mean of transport or also as a shared vehicle, hence it is defined as a "Semi-public" transport mode that has the capacity to transport one or a few (maximum 4) passengers. Taxi cabs usually are distinguishable by their special sign or colour and have permission for transporting individuals. Despite other countries, taxi is one of the main public transport systems in most of the Iranian cities (Naghsh-e-Moheet, 2013).

The shared taxis hold the predominance among all taxi services. The type of service they offer is similar to light minibuses. The taxi cab follows a determined unchangeable route and the passengers who have their destinations along the way can get in the taxi. As already mentioned, the trips are shared. Ordinary door-to-door taxi service is also possible through the same taxi cabs upon the request by the passenger; however, the cost would be much higher than a shared ride.

Compared to bus and minibus systems, the taxi has a larger fleet as well as higher flexibility regarding the route, nevertheless, it has less capacity. In addition to registered taxi cabs, a considerable number of private cars which are not registered as taxi cabs, transport passengers as well. (Pajoohesh, 2009)

The registered taxis operate either as line taxis or circulating taxis. The line taxis have defined routes while circulating taxis do not operate in defined routes and are free-floating. The line taxis are normally used by the citizens for their whole trips or in some cases for taking them to BRT or metro stations. Yet, there is not a clear figure showing the share of the trips that are done by taxi only or by a combination of taxi and other modes of transport.

Tabriz Taxi Organization has a total fleet of 5,300 vehicles where 4,950 vehicles are circulating taxi cabs and only 350 of them operate in lines. The number of unofficial taxis is estimated to be around 9, 000. Tabriz has 27 taxi lines. On average, a taxi cab operates 10 times a day. The total number of trips by circulating taxis is 155,400 per day (Pajoohesh, 2009). The method of payment in taxis is cash only. However, recently it has been possible in a limited number of taxis to pay by mobile app. Figure 7 shows taxi cabs waiting at the Abresan taxi terminal.

Figure 7: Taxi cabs waiting for passengers at Abresan taxi terminal (Source)

3.2.3. Metro

In 1990, the plan for Tabriz metro was passed by the Iranian parliament. However, it was only in 2001 that the preliminary studies regarding travel demand for the metro started. Finally, a metro network consisting of 5 lines (including 1 sub-urban line) with a total length of 100 km was proposed and the first part, which was the eastern section of line 1 with a length of 11km, was inaugurated in 2015. Four lines of Tabriz urban railway are designated to be served by urban underground train and line 4, which is planned to be a light rail line (tram) (Tabriz Urban Railways Organization, n.d.). Tabriz metro is predicted to transport 30,000 persons per hour using 30 trains (during peak hours) at the urban lines and 12,000 persons at the suburb line (Naghsh-e-Moheet, 2013). Figure 8 shows some parts of Tabriz metro line 1.

Currently, 11 stations out of a total of 18 are operated in line 1, connecting an important recreational centre in the south eastern corner of the city to a highly dense city centre. The construction work to continue the line towards the west is underway.

Figure 8: Left: Emam Reza (Golshahr) Station on metro line 1. Right: Metro line 1 moving towards 29 Bahman Station (source: TURO)

Lines 2 and 3 are also under construction (Tabriz Urban Railways Organization, n.d.). Figure 9 illustrates the 5 proposed lines and the operated part for Tabriz metro. In November 2019, the number of daily passengers of the operated part of Tabriz metro reached 15,000 (Bashirian Bonab, 2019).

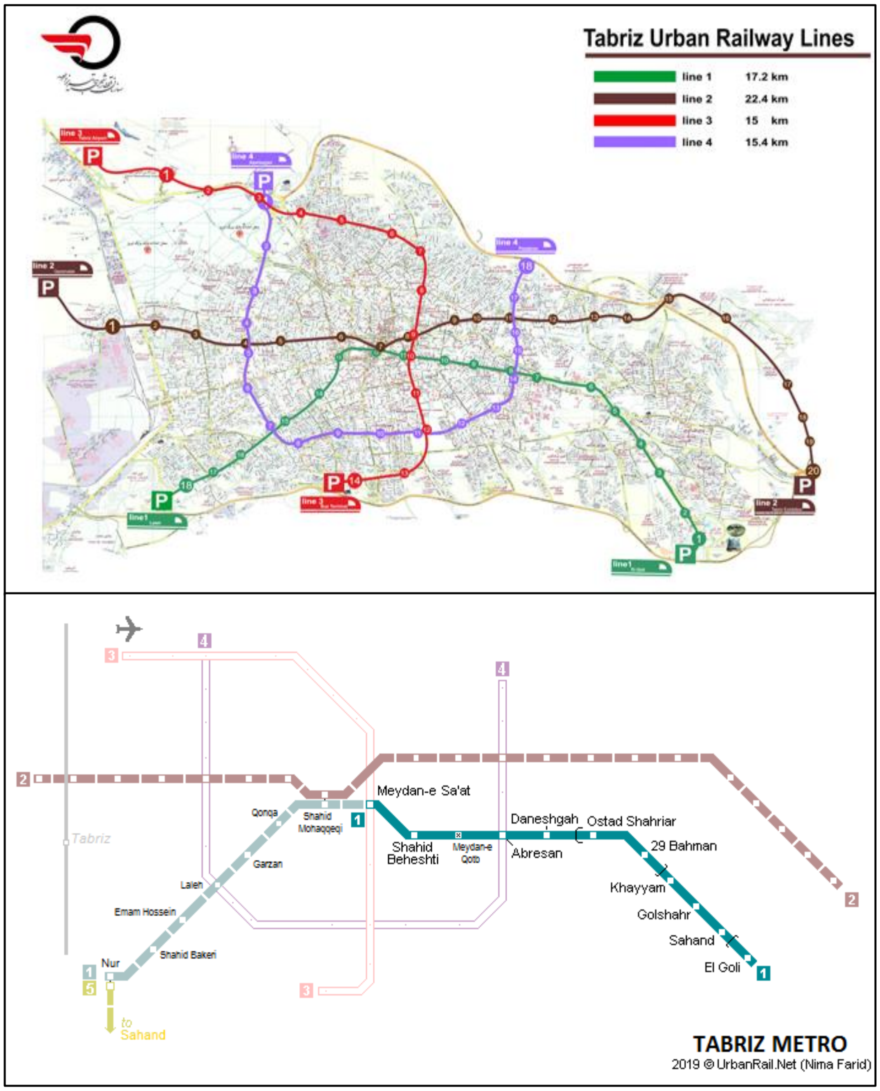


Figure 9: Up: Proposed Tabriz urban railway lines (source: UrbanRail). Down: Map of Tabriz Urban Railway lines and the operated part (highlighted). (source: TURO) The study area covers Mohaqqeqi and Saat station which are shown at the centre of the map (down)

(Pajoohesh, 2009) has modelled the metro lines 1 and 2 and after implementing the required adjustments in the transport network, assuming their full operation through the entire lines, predicted the daily travel demand to be 52,173 for line 1 and 41,521 for line 2.3.3. Trip purposes and modal split

The latest "Household Mobility Survey" is conducted by the "General Directorate of Roads and Urban Development in East Azerbaijan province" in 2011 and published by (Naghsh-e-Moheet, 2013). The survey has covered 1 out of every 30 households in Tabriz. The results reveal the trip purposes and modal split of urban trips of Tabriz inhabitants. The results are illustrated in figures 10 and 11.

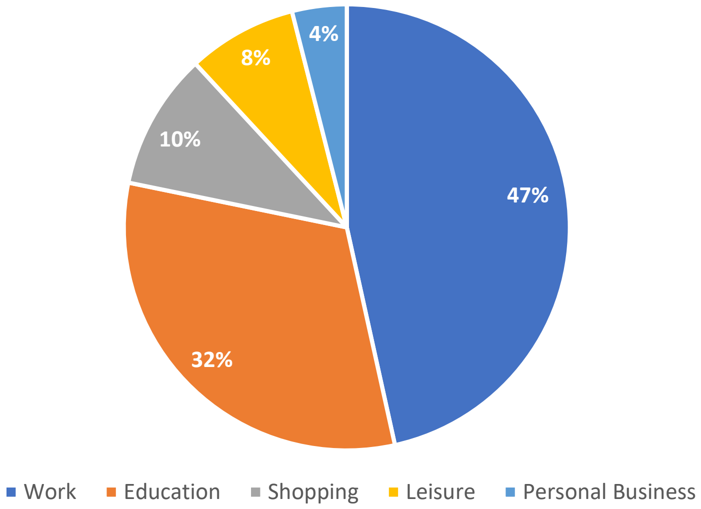


Figure 10: The relative shares of urban trip purposes in Tabriz (source: (Naghsh-e-Moheet, 2013))

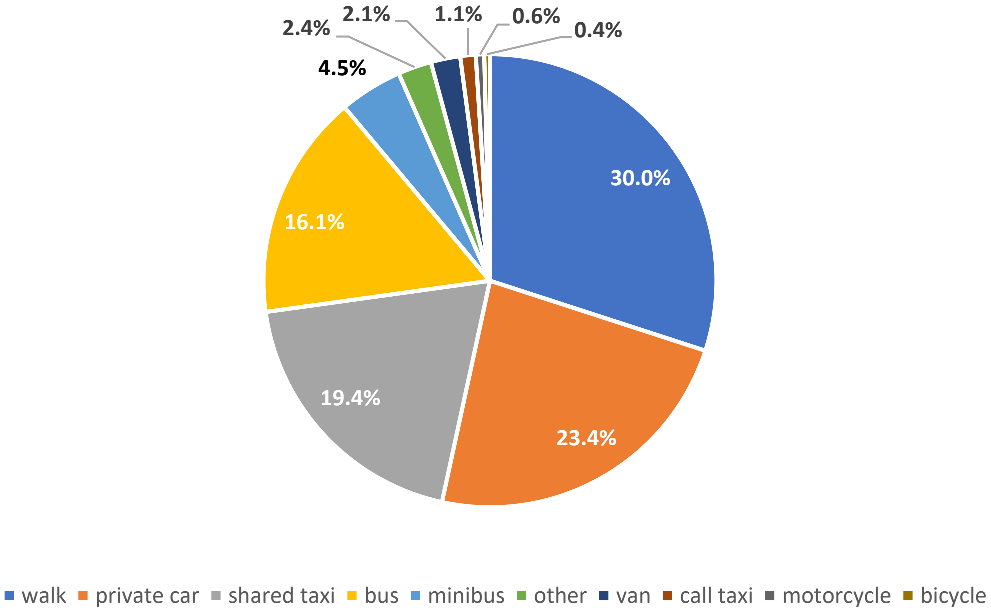


Figure 11: Modal split of urban trips in Tabriz (source: (Naghsh-e-Moheet, 2013))

As it is observable in figure 10, work and study are the dominant trip purpose among Tabriz inhabitants. Figure 11 reveals that a considerable share of all urban trips in Tabriz is done by walking, however, it needs to be noted that only the number of the trips, and not the distance, is measured in this survey. Another important result is the share of private and public transport. In case of considering bus as the only public transport system, the share of public transport is 16.1% and in case of including all shared taxi trips as public transport trips, the total share of public transport reaches 40%. Minibuses usually serve as a private system in Tabriz. They are normally used as school minibuses or as private shuttles for the companies.

Another survey by (Pajoohesh, 2009) investigated the modal split for different transport modes. The survey has categorised the modal split based on the purpose of trips. The results show that based on the purpose of the trip, public transport usage varies from 48% for shopping to 68% for studying purposes where the share of the bus remains more or less the half of the whole share of public transport. Figure 12 illustrates the modal split for different trip purposes in Tabriz in 2009.

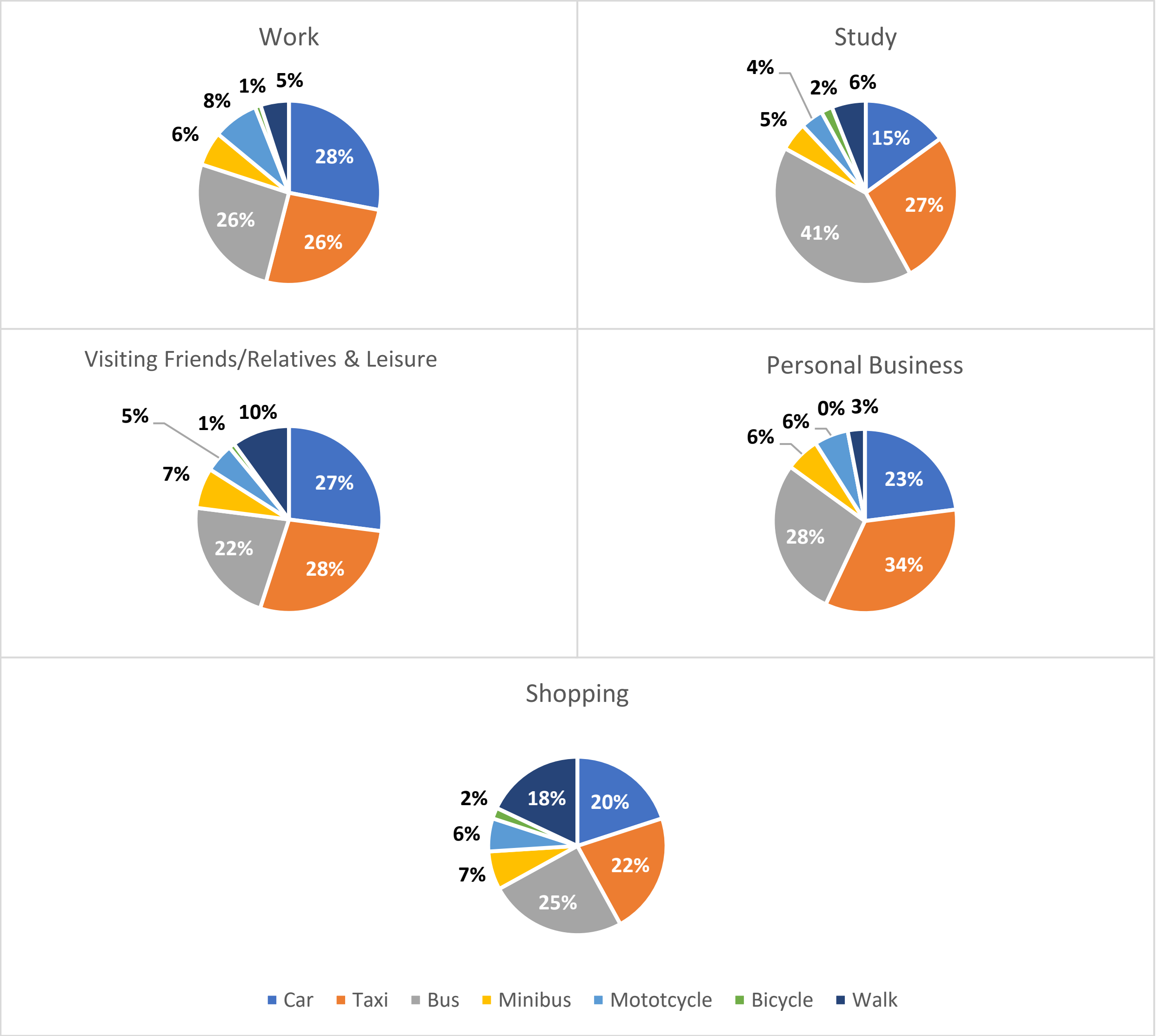


Figure 12: Modal split of urban trips in Tabriz based on trip purpose in 2009 (source:(Pajoohesh, 2009))

The obtained modal split by Naghsh-e-Moheet (figure 10), only classifies all trips with all purposes regardless of their trip purpose, while Pajoohesh (figure 11) has only classified the trips based on the trip purpose. Although the figures contain different types of classification, by an overall comparison between them, a considerable difference in modal split is noticeable. For instance, the share of walking in figure 10 is 30%, while in figure 11 it is considerably less in all categories. This difference might be attributable to the difference in conducting the surveys, such as number and combination of respondent, different execution dates and also different analysis methods.

In terms of the year of execution, Pajoohesh survey was conducted in 2008, while Naghsh-e-Moheet has conducted its survey in 2011. In terms of the number of populations, the respondents to the survey of Pajoohesh are 1943 people that are chosen randomly and proportionately to the population, while Naghsh-e-Moheet has conducted a household survey by choosing 1/30 of the household of Tabriz, which approximately equals 10,000 households. Thus, the results from (Naghsh-e-Moheet, 2013) are chosen as the source for the input data.

Chapter 4: Methodology

To carry out the current research, first, the required data is collected from concerned parties, sorted, and updated with the most recent figures. Then, the collected data are imported to the simulation software to create a simulation model. After developing the model, different variants are designed and their performance regarding different indicators of the level of service of the public transport system is compared.

The detailed description of the used methods in this thesis follows in this chapter.

4.1. Data collection

The first step to assess the effect of physical and/or operational integration on different indicators of public transport is to collect the required data. The required data include different types of information that require consulting different public and private parties.

The method for collecting the data is secondary data collection. The secondary data is collected from different authorities including different "Consulting Engineers" firms that collect and analyse data for the government and transportation organizations to support decision making for their future plans. There are several reasons to use secondary data; first, the scope of the required data does not fit the scope of a master thesis and is much bigger. Second, the required data was already acquired through different measures such as questionnaires, models, simulations, etc. Thus, the secondary data collection was preferred to the primary data collection.

Different data sources are used in this thesis. The main source of data is the "Transportation studies of Tabriz metro line 2 phase 1" which is carried out by Pajoohesh Consulting Engineers in 2009. A report of accomplished data collection and analysis activities is prepared and submitted to Tabriz Urban Rail Organization (TURO). Since the construction works were delayed and some adjustments in the line path were recognized, a revision of the report was inevitable. Thus, in 2015 the data (e.g. population, prospect year and public transport service providers properties) was inspected and updated by Imensazan Consultant Engineers.

(Pajoohesh, 2009) has summarized the former master plan as well as comprehensive urban and transport studies of Tabriz, carried out a survey regarding transportation travel behaviour of inhabitants of Tabriz and their attitude towards the metro, discussed different modes of private and public transport in the city and finally suggested the most appropriate locations for the stations of line 2. Additionally, the study has modelled the urban bus network of Tabriz and suggested some changes in its routes and fleet to operate more efficiently after the inauguration of the metro. It is worth mentioning that the adjustments for the bus network were only made to avoid the parallel activity of bus and metro in the same route and was not a part of the integration of two modes.

In addition, other data sources are used as well, to gather the required data. The data is acquired either without contacting the organizations (usually from their websites) or by contacting the concerned organizations by means of contacting in person, online communication (email) and phone calls to receive the data and ask for permission to use them as well. Table 2 lists the different types of data and the sources of acquiring them. In general, the types of required data can be categorized as follows:

- Demographic data
- Transport networks and systems data
- Geographic data

Table 2: Required data and their sources

Type of data		**Data source**
demographic	Population and area of Tabriz	Statistical centre of Iran website, other statistical websites
	Employment in different zones of Tabriz	Transportation studies of Tabriz metro line 2 phase 1 report
	Car ownership	Statistical centre of Iran website, news agencies websites
	Demographic maps	GIS maps provided by Tabriz detailed design plan and master plan
Transport network and modes	Travel demand for different transport modes	Transportation studies of Tabriz metro line 2 phase 1 report, Tabriz Urban Railway Organization website, Tabriz and Suburbs Bus Company website
	Modal split	Tabriz Development Master plan report
	Satisfaction level of different transport users	Survey results of Transportation studies of Tabriz metro line 2 phase 1 report
	Bus and metro network layout, schedules and fleet	Transportation studies of Tabriz metro line 2 phase 1 report, Tabriz Urban Railway Organization website, Tabriz and Suburbs Bus Company website, news agencies websites
	City traffic flow situation	Transportation studies of Tabriz metro line 2 phase 1 report
Geographic	Tabriz zones map	Tabriz Development Master plan report
	Different Land use maps of Tabriz and its zones	GIS maps provided by Tabriz detailed design plan and master plan
	Road networks	GIS maps provided by Tabriz detailed design plan and master plan

4.2. Model design and Simulation

The steps to carry out the model designing and simulation is explained in detail, as follows:

4.2.1. Reproducing the existing model

Model simulation for the public transportation network of Tabriz has been carried out by (Pajoohesh, 2009). It includes modelling the demand and supply for metro lines 1 and 2, the entire bus network and also private transport network of Tabriz. In 2015, Imensazan Consultant Engineers updated the report with new demographic and transportation figures, scrutinized the metro line 2 route and moreover, they adjusted the bus network to avoid parallel routes with metro. It included removing the lines which are parallel to the metro at most of their route and adding other lines that do not overlap with the metro but feed the previously uncovered areas. Yet, the report does not consider the integrated transport. Thus, in the model, each public transport mode is defined individually without any kind of relationship with each other.

In 2013, the third master plan for Tabriz (which was under preparation since 2011) was published. The master plan includes detailed land use and population distribution figures. The master plan determines the boundaries, land use and road networks of the city in the future decades. Hence, the input data of the previous model has to be updated with new figures.

4.2.2. Design, simulation, and evaluation of the integrated system

(Solecka & Żak, 2014) have conducted research on the integration of the urban public transportation system with the application of software simulation for the case of Krakow, Poland, using the Visum software package for the simulation. The research designs an integrated urban public transportation simulates it using Visum and compares it in a multidimensional – multiple parameter way with the existing solution.

Since (Solecka & Żak, 2014) are very similar to the current research in objective and used method, the steps for the simulation that are taken in that research can be followed in this thesis. Hence, the process of building and simulating the model can be done in three steps as follows: (Solecka & Żak, 2014)

- ***Heuristic design of concrete variants of integration:*** As far as it concerns this thesis, in this step integrating infrastructure such as multimodal terminals should be designed which includes moving the start points of the bus lines (terminal stations) to the vicinity or directly over the metro station. In other words, the variants include converting Mohaqqeqi and/or Saat metro station to intermodal metro/bus stations by means of relocating the six bus terminal stations to make the walking distance as short as possible. Different variants may include moving different bus stations to one or both of the metro station locations.

- ***Macrosimulation of the designed variants:*** The traffic simulation model expresses what travellers' need between origins and destinations and supports the execution of those needs using modelled road infrastructure and modes of transport. The traffic model that is generated in Visum is based on activity chains and origin-destination matrix. (Zak & Fierek, 2007) Hence, for carrying out the simulation of the designed variants of the integrated public transport system, a 4-stage model should be applied: Trip generation, trip distribution, modal split and traffic assignment. A part of this step is already taken since the model is built based on a previous simulation that was carried out by applying the 4-stage model. (Pajoohesh, 2009)
- ***Comparative analysis and evaluation of the variants:*** This step includes comparing different newly-designed variants to the existing transportation network variant (V0). The application of traffic macrosimulation can result in the computation of parameters such as "improvement of the overall travel time and transfer time" and "improvement of waiting time".

The output of the comparative analysis and the evaluation of the variants shows the best among all variants. Comparing the selected variant to the existing variant answers the research sub-questions of the research. As a result, the applied methodology for this research can lead to an answer to the main research question of this research.

A limitation for using this method is basing the whole study not on actual primary observations, but on software simulation which may cause a bias in results, e.g. in case of a new trend in modal share or mobility behaviour of the studied population.

Chapter 5: Simulation Model Development

A simulation model is required to evaluate the impact of a potential physical and/or operational intervention on public transport users in a certain area. To perform the simulation, first, the transportation network of the concerned area needs to be modelled (Immers & Stada, 1998). In the case of the current project, the urban private and public transport model of the city of Tabriz was required.

5.1. Software Package: PTV Visum

5.1.1. Overview

PTV Visum is a traffic analysis, forecasts, and GIS-based data management software. It is used to model road users and their interactions and to model transport networks and travel demand, to analyse expected traffic flows, to plan public transport services and to develop advanced transport strategies and solutions (*PTV Visum*, n.d.). For this case, modelling private and public transport supply and demand is taken place. Different scenarios are developed using Visum and it is made use of its network adjustment and fare system introduction facilities.

5.1.2. Software license

PTV offers different types of licenses for Visum, based on the type and volume of the project. A free student license is available for limited academic and educational purposes. Thus, it allows us to add a limited number of links (roads) and time profiles (for public transport) and therefore it does not meet the requirements of the current project. Hence, an expert thesis license was requested from PTV. Thesis license provides full access to the software and allows an unlimited network size as well.

The detailed procedure of developing the transport model of Tabriz follows.

5.2. Modelling the transport supply

As mention above, the transport supply is the service that the transport system offers. This service can be described as a combination of transport infrastructure and transport services offered by public transport providers. The infrastructure is a common supply for private and public transport, while public transport offers certain services as well.

5.2.1. Modelling the transport network

Visum uses OpenStreetMap API for providing satellite as well as street maps of different places. However, these maps only appear as a flat image and usable transport networks need to be inserted. This can be done in two general ways:

1. Importing the network from external sources (e.g. importing shapefiles created by GIS software or importing maps from OpenStreetMap online database and importing General Transit Feed Specification (GTFS) from different public transport providers around the world).
2. Creating the network using Visum network creation tools. Visum allows creating both private and public transport networks. Though, this method is suitable for small-scale network models, since adding all road details require a considerable amount of time.

Since the case of Tabriz is a transport network of a large city, to create an accurate and up-to-date private transport network, the most appropriate way was to import the map from an external database. The challenge at this step was that small and medium-sized maps such as the road network of a small town can be extracted directly from OpenStreetMap. However, the database doesn’t provide big road networks such as the current case of Tabriz directly. To import the road network of the entire city, an online download server provided by Geofabrik GmbH has been used. Geofabrik download server extracts data from the OpenStreetMap project which is normally updated every day (*Geofabrik*, 2019). The entire detailed road maps of a city or a country can be downloaded from Geofabrik and imported to Visum. Depending on the region, in some cases, the maps are available for cities as well as countries, while in some other cases, they only cover the road network of the whole country, without providing it in details. In the case of Tabriz, since the road network was only available for Iran as a country, the country road map was downloaded and during importing to Visum, by adjusting the geographic coordinates of the imported map, only the map that included the road network of Tabriz was imported. The imported road network of Tabriz is shown in figure 13.

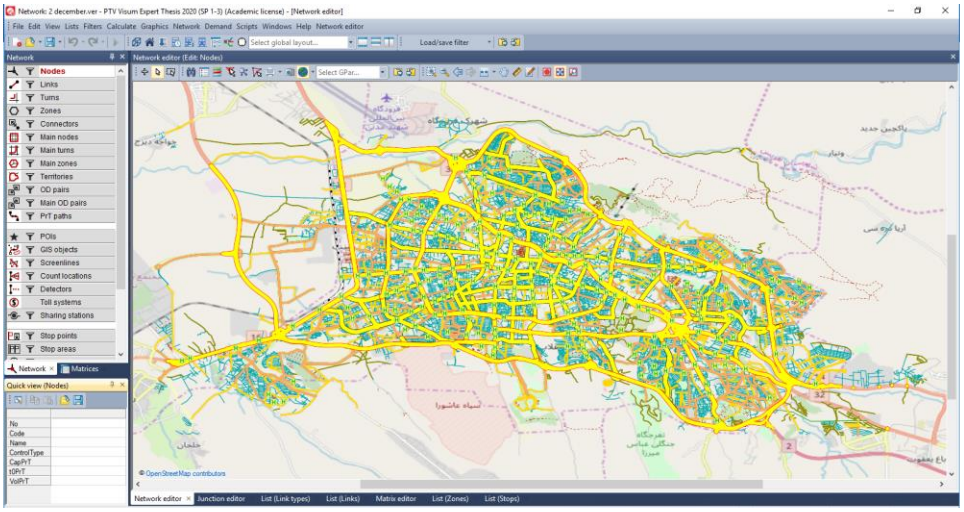


Figure 13: Road network of Tabriz imported to PTV Visum (Source: Created by the author in PTV Visum in September 2019)

5.2.2. Completing the public transport network

The imported network includes both private and public transport networks. The private transport network is fairly complete and includes all main roads and most of the local access roads. Furthermore, comparing the current network to 2021 projection by (Pajoohesh, 2009), it has been found out that no further major changes need to be made until the planning horizon.

As noted in previous chapters, the planned public transport network of Tabriz for 2021 consists of an urban bus as well as a metro network. Since the shared taxi is defined as a semi-public mode of transport (Naghsh-e-Moheet, 2013), and because of their unplanned and private-like nature, they are not considered as a public transport mode in this research.

The imported public transport network covers the operational part of the metro infrastructure and stops, while for the bus transport it includes only a small number of the stops. Moreover, public transport operators of Tabriz do not provide online GTFS. On the other hand, since the model is designed for the projection of 2021, the public transport network needed to be updated to match the projection. While the bus network did not need to be changed, parts of metro lines that currently are not under operation but predicted to be operational in the planning horizon were also missing in the imported map. Thus, the missing parts of the public transport network including a part of the infrastructure, all metro and bus lines and routes, missing stops, and frequency needed to be inserted into the network model.

5.2.2.1. Bus network

After requesting Tabriz & Suburbs Bus Company for the detailed route and stops map of urban bus lines, the recently-developed 'Geospatial Information System of Tabriz

Municipality' called 'SDI' (ICT Organization of Tabriz Municipality, 2019) was made accessible to the public on their website. The SDI database was used as a data source for the bus network. All active bus routes and stop points created in Visum using the SDI system. This way, 71 active bus lines, including 2 BRT lines are added and by adding missing bus stop points, the total number of bus stop points reached 933. Urban buses in Tabriz run on a headway basis. For urban lines, on average one bus departs every 10-15 minutes, while for suburban lines the frequency drops to one bus per 30-45 minutes. BRT lines have a headway of 3 minutes. The frequencies are imported from the report by (Pajoohesh, 2009) where they are listed for all existing lines. The average dwell time for all bus stops except the last stops of the lines assumed to be 30 seconds. The dwell time for the last stops assumed to be 7.5 minutes since it includes break time, turning, etc. (Pajoohesh, 2009). Figure 14 shows Tabriz bus networks defined on the map in Visum.

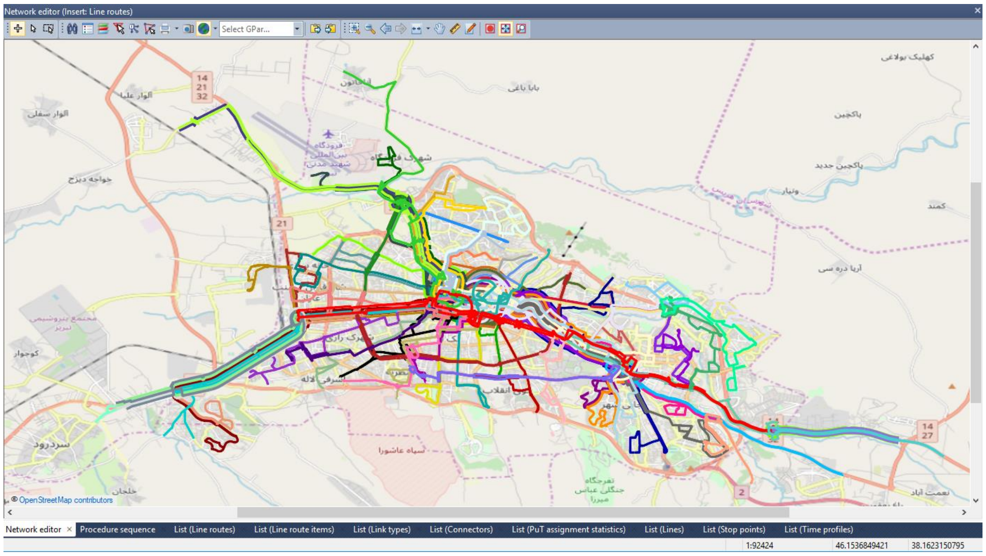


Figure 14: Bus network of Tabriz in PTV Visum (Source: Created by the author using Tabriz SDI system in PTV Visum in January 2020)

5.2.2.2. Metro network

For metro, first, by matching the routes with existing metro maps provided by (TURO, n.d.), the railroads were drawn and then the metro lines and stops were inserted. The metro headway for the operated part of line 1 is currently 15 minutes that after completion and inauguration of two lines, it will be 2 minutes for both lines. Average dwell time in metro stations is 30 seconds (Pajoohesh, 2009). Metro and bus operators defined in as well in Visum. Figure 15 shows Tabriz metro networks, including 2 metro lines, defined on the map in Visum.

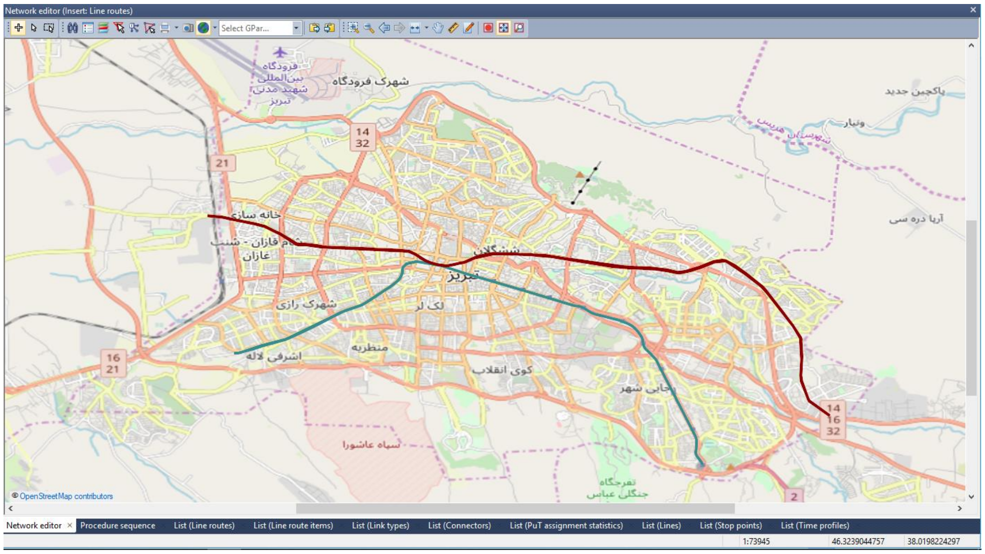


Figure 15: Metro network of Tabriz in PTV Visum (Source: Created by the author using TURO map in PTV Visum in January 2020)

5.2.3. Correcting road network specifications

The imported road network from the OpenStreetMap database through Geofabrik provides a quite detailed map of urban roads, nodes, turns, public transport stops, etc. However, the road and traffic specifications such as speed limits and road capacity are different than the ones suggested by the Tabriz Comprehensive Plan.

Road classifications

The first step in correcting the imported network is comparing the road classification systems used by OpenStreetMap to the one used by Tabriz Development Master plan Report.

Movement, accessibility and social factors are the main criteria of classification of the roads. There is no unique approach to the classification of the roads. Each project takes its own approach with regard to its viewpoint and goal. (Naghsh-e-Moheet, 2013)

OpenStreetMap: OpenStreetMap classifies the roads based on their degree of importance as follows: (*OpenStreetMap Wiki*, n.d.)

- **Motorway:** A restricted access major divided highway, normally with 2 or more running lanes plus emergency hard shoulder. Equivalent to the Freeway, Autobahn, etc.
- **Motorway Link:** The link roads (slip roads/ramps) leading to/from a motorway from/to a motorway or lower-class highway. Normally with the same motorway restrictions.

- **Trunk:** The most important roads in a country's system that aren't motorways.
- **Trunk Link:** The link roads (slip roads/ramps) leading to/from a trunk road from/to a trunk road or lower-class highway.
- **Primary:** The next most important roads in a country's system.
- Primary Link: The link roads (slip roads/ramps) leading to/from a primary road from/to a primary road or lower-class highway.
- **Secondary:** The next most important roads in a country's system.
- **Secondary Link:** The link roads (slip roads/ramps) leading to/from a secondary road from/to a secondary road or lower-class highway.
- **Tertiary:** The next most important roads in a country's system.
- **Tertiary Link:** The link roads (slip roads/ramps) leading to/from a tertiary road from/to a tertiary road or lower-class highway.
- **Residential:** Roads that serve as access to housing, without function of connecting settlements. Often lined with housing.

Tabriz Development Master Plan: In Iranian Urban Road Design Regulations (Regulations design and Preparation Organization, 1995), the roads have been classified as major arterial (freeway, highway, main passageway), arterial (primary and secondary) and local (primary and secondary). The consultancy agency has come across difficulties in using the abovementioned classification during various projects. The limited number of classes and the difficulty of putting a variety of different roads into these classes can be mentioned.

In the case of Tabriz, the classification which was used in the Tehran Development Master plan has been used as a basis. According to the description above, the functional classification used in the Tabriz Development Master plan are:

- **Freeway:** These roads provide regional and national fast connections between cities. The minimum number of lanes at each direction is 2. There is a median strip of a minimum of 3 meters wide. The speed limit is 120 km/h. The junctions are grade-separated and only greenery and facilities that are related to the network such as fuel stations are allowed to be built on the roadsides. It is not allowed to build bus stops or roadside parking.
- **Expressway:** Most of the features of the expressways are similar to the ones of the freeway, except that the expressways provide the fast connection between major areas of a city. The junctions are mostly grade-separated and it is allowed to build bus stops in a separated lane.
- **Major Arterial:** These roads provide the connection between the expressways and the collector-feeders or the connection between the main centres of the large neighbourhoods. The major arterials are divided by a median strip. The speed limit is 60 km/h and the accessibility to different urban land uses is possible through the collector lane. It is possible to build bus stops as well as roadside parking. The bicycles can use the collector lane.

- **Minor Arterial:** Most of the features of these roads are similar to the ones of the major arterials, except that minor arterial is shorter and direct access to urban land uses is possible. Mostly, minor arterials are not divided. It is possible to build bus stops and roadside parking, and bicycles can use these roads. The speed limit on these roads is 60 km/h.
- **Collector-Feeder:** Collector-Feeders connect the arterials to the local access roads or provide the connection between adjacent neighbourhoods. The speed limit is 50 km/h. Different land uses on a local scale can be located on the roadsides.
- **Local Access:** These roads provide direct access to residential land uses and related service units (kindergarten, primary school, bakery, local grocery store, etc.) around them. The speed limit is 30 km/h and different residential land uses and related service units can be located on the roadsides.

Matching the road classification systems

Based on the definitions of different road classes presented by OpenStreetMap and Tabriz Development Master plan, the road classes which are defined by the master plan can be easily interpreted to the road classes which are defined by OpenStreetMap. The road classes and their equivalency are listed in table 3.

Table 3: Road classification systems in Tabriz Development Master plan and OpenStreetMap

Road classes defined in Tabriz Development Master plan	**Equivalent in OpenStreetMap (used for the simulation)**
Freeway	Motorway
Expressway	Trunk
Major Arterial	Primary
Minor Arterial	Secondary
Collector-Feeder	Tertiary
Local Access	Residential

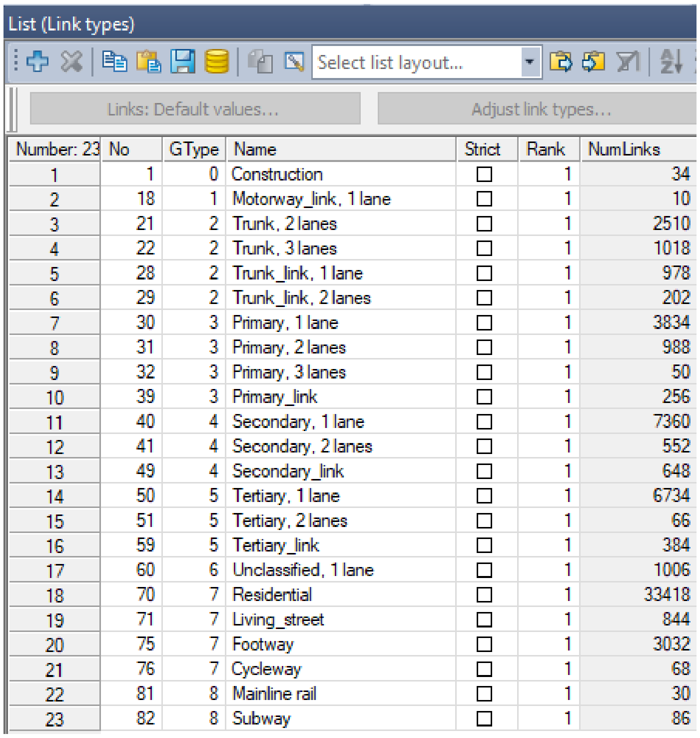
Other than 6 abovementioned road classes, there are other road classes that appear in Tabriz roads map feed imported to Visum. These road classes are: (*OpenStreetMap Wiki*, n.d.)

- **Unclassified roads:** OpenStreetMap defines unclassified roads as "The least important through roads in a country's system – i.e. minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties". However, in Tabriz map, the exclusive roads such as the paths inside a university campus are defined as unclassified. Based on the field observations in Tabriz, the maximum and free-flow speeds for these roads are set equal to tertiary roads.

- **Construction:** The construction roads are the roads that are not yet completely constructed and thus are not open to traffic.
- **Living streets:** These are defined as roads with very low speed limits and other pedestrian-friendly traffic rules. However, since Tabriz has not classified living streets as a separate class, these roads are assumed to have the same characteristics as residential roads.
- **Other types of roads:** Include footway, cycleway, mainland rail, and metro. For the footways and cycleways, the settings of OpenStreetMap are kept. The adjustments for the rail transport network will be discussed in another chapter.

Since in the current simulation model the OpenStreetMap classification is used, the aforesaid system is replaced with the classification of Tabriz Development Master plan. The list of all road link types (road classes) is shown in table 4. Residential roads shape the largest number of the existing roads in Tabriz network among all road classes; followed by secondary and tertiary roads.

Table 4: Link Type list in PTV Visum



Number: 23	No	GType	Name	Strict	Rank	NumLinks
1	1	0	Construction	☐	1	34
2	18	1	Motorway_link, 1 lane	☐	1	10
3	21	2	Trunk, 2 lanes	☐	1	2510
4	22	2	Trunk, 3 lanes	☐	1	1018
5	28	2	Trunk_link, 1 lane	☐	1	978
6	29	2	Trunk_link, 2 lanes	☐	1	202
7	30	3	Primary, 1 lane	☐	1	3834
8	31	3	Primary, 2 lanes	☐	1	988
9	32	3	Primary, 3 lanes	☐	1	50
10	39	3	Primary_link	☐	1	256
11	40	4	Secondary, 1 lane	☐	1	7360
12	41	4	Secondary, 2 lanes	☐	1	552
13	49	4	Secondary_link	☐	1	648
14	50	5	Tertiary, 1 lane	☐	1	6734
15	51	5	Tertiary, 2 lanes	☐	1	66
16	59	5	Tertiary_link	☐	1	384
17	60	6	Unclassified, 1 lane	☐	1	1006
18	70	7	Residential	☐	1	33418
19	71	7	Living_street	☐	1	844
20	75	7	Footway	☐	1	3032
21	76	7	Cycleway	☐	1	68
22	81	8	Mainline rail	☐	1	30
23	82	8	Subway	☐	1	86

5.2.4. Correcting road and traffic characteristics

5.2.4.1. Maximum Speed

The speed limits for different classes of roads in the imported road network are defined in a different way than actual speed limits set for the roads in Tabriz. Therefore, they should be adjusted to match the real situation. According to (Naghsh-e-Moheet, 2013), the speed limits for road classes are as follows in table 5. (The maximum speed, as well as free-flow speed for the cycleway, is equivalent to 20 km/h (Iranian National Standardization Organization, 2016)):

Table 5: Maximum speed limit for roads in Tabriz

Road class	**Maximum speed (km/h)**
Motorway	120
Trunk	100
Primary	60
Secondary	60
Tertiary	50
Residential	30
Cycleway	20

For the link roads, neither (Regulations design and Preparation Organization, 1995) nor (Naghsh-e-Moheet, 2013) regulations for the maximum speed. Thus, the maximum speed limits set by OpenStreetMap is used.

5.2.4.2. Free-Flow Speed

Another determining factor in road network simulation in Visum is the free-flow speed of the vehicles. Highway Capacity Manual by (National Research Council (U.S.), 2000) defines the free-flow speed for an urban road as the speed that a vehicle travels under low-volume conditions when all the signals on the urban road are green for the entire trip. Thus, all delay at signalized intersections, even under low flow conditions, is excluded from the computation of urban road free-flow speed. A driver can seldom travel at the free-flow speed. happens to vehicles to travel at free-flow speed and the actual average speed is often lower than free-flow speed, depending on the level of service of the road (National Research Council (U.S.), 2000).

The average speeds for different classes of roads in Tabriz under different levels of service are calculated based on field observation by (Naghsh-e-Moheet, 2013) and illustrated in table 6.

Table 6: Average speed for different road classes in Tabriz

Level of Service	**Average speed (km/h)**				**Quality description**
	Motorway	**Trunk**	**Primary**	**Secondary**	
A	105	77	57	48	Excellent
B	100	72	54	45	Very good
C	90	66	50	41	Good
D	77	56	42	35	Minimum acceptable
E	55	40	30	25	Near capacity utilization (unstable)
F	<45	<30	<24	<20	Very bad (unstable and traffic jams)

The average speed at the level of service A is assumed to be equal to 90% of the free-flow speed (National Research Council (U.S.), 2000). Thus, the free-flow speed is equal to 111% of average speed at Level of Service A. For tertiary and residential roads, the levels of service are not determined. Given that for the secondary roads, the speed at the level of service A is 80% of the maximum speed, the same ratio assumed for tertiary and residential roads. Thus, the speed at the level of service A for tertiary and residential roads assumed to be equal to 40 km/h and 24 km/h, respectively. For the link roads, the free-flow speed is estimated based on the respective road (e.g. the free-flow speed on trunk link roads is estimated based on the free-flow speed on trunk roads). Table 7 shows the free-flow speed of different classes of roads.

Table 7: Free-flow speed of different road classes

Road class	**Free-flow speed (km/h)**
Motorway link	80
Trunk	86
Trunk link	60
Primary	63*
Primary link	40
Secondary	53
Secondary link	30
Tertiary	44
Tertiary link	25
Residential	27
Cycleway	20

*The primary roads in Tabriz usually have 2 or 3 lanes per direction with fewer intersections and traffic lights. Thus, even though the maximum speed limit is set to 60 km/h, the actual free-flow speed is expected to exceed the maximum speed limit.

5.2.4.4. Road Capacity

The capacity of a road class at a specific level of service is a function of the free-flow speed of vehicles on that road. Since the flow rate reaches or approaches the capacity of the road at level of service E (National Research Council (U.S.), 2000), by using the graph suggested by Highway Capacity Manual, the capacity of different road types can be obtained. Figure 16 shows the relation between flow rate, free-flow speed and level of service.

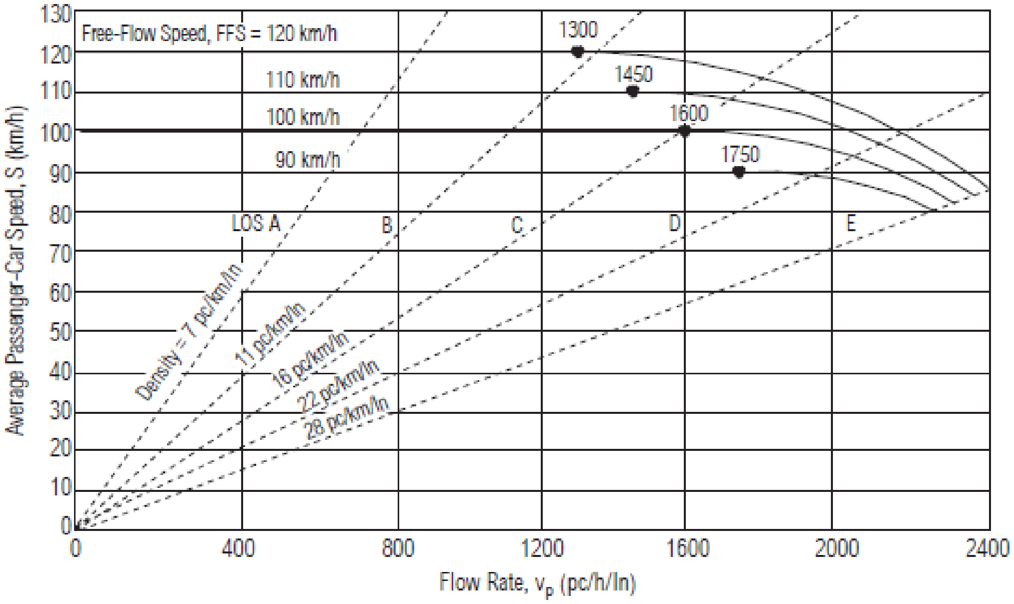


Figure 16: Relation between flow rate, free-flow speed and level of service (Source: HCM)

The intersection point between the lower threshold of the level of service E and the free-flow speed curves show the capacity of the respective roads. Since the capacity in this figure is defined as passenger car per hour per lane, the capacity for multilane roads is multiplied by the number of lanes. Based on the information from table 7 and figure 16, the estimated capacity for different road classes in Tabriz is illustrated in table 8. The capacity of the cycleway is assumed to be 850 bicycles/hour for two-way cycleways (Iranian National Standardization Organization, 2016). Given the passenger car equivalence coefficient of 0.3 for bicycle (Naghsh-e-Moheet, 2013), the capacity of cycle lanes (pc/h) is equal to 283.

Table 8: Road capacity for different road classes in Tabriz

Road class	**Capacity per lane (pc/h/ln)**	**Total capacity (pc/h)**
Motorway link 1 lane	1750	1750
Trunk 2 lanes	1900	3800
Trunk 3 lanes	1900	5700
Trunk link 1 lane	1300	1300
Trunk link 2 lanes	1300	2600
Primary 1 lane	1350	1350
Primary 2 lanes	1350	2700
Primary 3 lanes	1350	4050

Primary link	800	800
Secondary 1 lane	1100	1100
Secondary 2 lanes	1100	2200
Secondary link	600	600
Tertiary 1 lane	900	900
Tertiary 2 lanes	900	1800
Tertiary link	500	500
Residential	550	550
Cycleway	283	283

5.2.5. Modelling fares

Public transport systems in Tabriz use a traditional ticketing system which allows the user to have a single trip. Bus and metro fare systems are not integrated; Using a single credit ticket card is possible for both systems, however, each trip leg using any transport system is charged separately. There are no time-based, distance-based or zone-based tickets. The most recent bus (Tabriz and Suburbs Bus Company, 2019b) and metro (Fars News Agency, 2019) fares are listed in table 9. All fares are in Iranian rials (IRR). At the time of writing this report in (January 2020), 10,000 IRR equals 0.75 USD.

Table 9: Public transport fares in Tabriz

Line	Single Ride Fare (IRR)
Metro	7,000
Regular urban bus lines	6,000
BRT line (Rah Ahan - Basij)	7,500
BRT line (Abresan - Shariati)	4,500
Express bus lines	9,000
Suburban bus lines	10,000
Azad Eslami University	10,000
Sahand city	12,000
Sardroud city	9,000

5.3. Modelling the transport demand

The current simulation aims to predict the consequences of an intervention in the transport system. It is vital to optimally estimate or calculate the implications to assure the maximum possible certainly in the solution that is offered to the identified problem. To calculate the impact of the intervention on the transport system, the flow pattern needs to be predicted for the given transport system and the given activity system (Immers & Stada, 1998).

There are several transport demand structures that can be used as a basis for the demand modelling of the current case. The model can be built in Visum using the standard 4-step model (traditional traffic model) and tour-based model. Since the model which was developed by (Pajoohesh, 2009) for Tabriz was based on the 4-step model structure, the current research likewise is based on this model. This model is a result of years of research and application which has led to a commonly accepted model structure (Immers & Stada, 1998). Following is a description of the application of the 4-step model to the Tabriz transport system.

5.3.1. 4-step demand model

The 4-step model is a universal framework for the determination and prediction of transportation forecast. The model dates back to the 1950s and was one of the first transport demand models that desired to connect land use and travel behaviour (McNally, 2000).

The 4 steps are described as follows: (McNally, 2000), (*Four-step travel model—TransitWiki*, n.d.)

- **Trip Generation:** Determines the frequency of origins or destination of trips in each zone. Trips are characterized as the trip ends, generations and attractions. The trip purpose is a function of land use, household demographics, and other socioeconomic determinants.
- **Trip Distribution:** This step distributes the generated trips to match the attraction destination and to reproduce fundamental travel impedances. (e.g. travel time and travel cost), generating tables of person-trip demands.
- **Mode Choice:** Factors trip tables to calculate the proportion of trips by each alternative mode of transport.
- **Route Assignment:** In this step, the trips that are allocated between an origin and a destination by a particular mode of transport, are assigned to the routes.

5.3.2. Applying the 4-step demand model to Tabriz transport system

In the case of Tabriz, a household mobility survey which was conducted in 2011 and published in by (Naghsh-e-Moheet, 2013) has asked the participants their travel patterns (origins and destinations, trip purpose, modes of transport, etc.). By means of analysing the survey results, the report has created a standard origin-destination matrix for the trips between defined zones.

5.3.2.1. Defining zones

Urban built-up areas consist of different smaller parts, namely: Building units, block, district, area, zone, and city. Transport studies can ideally be done in such a way that provides travel information between blocks; however, since it may lead to a large number of zones, considering the size of the city, it would require numerous input data. Thus, normally by aggregating blocks, larger boundaries called traffic areas are formed and data is collected in these areas. According to this, the Tabriz urban area has been divided into 166 traffic areas and the household survey has been distributed in these areas. Afterwards, in order to ease the comparison and analysis of data, a set of areas are aggregated together to form a district, and an aggregation of a set of districts has formed a traffic zone. Data analysis has been done in these zones. Defined zones comply with the municipal zones of Tabriz (Naghsh-e-Moheet, 2013). Figure 17 demonstrates traffic areas, districts, and zones.

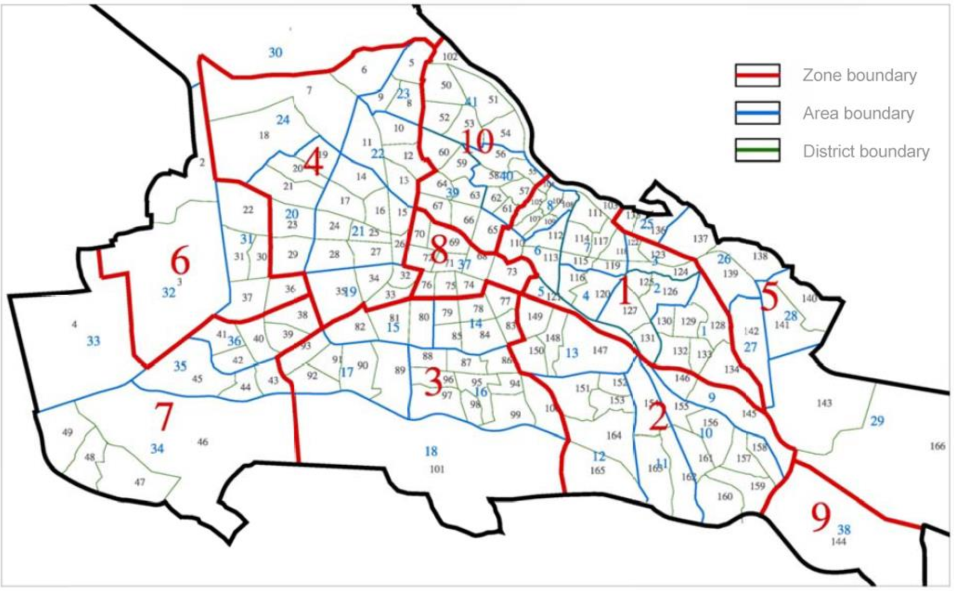


Figure 17: Traffic areas, districts, and zones in Tabriz (Source: (Naghsh-e-Moheet, 2013))

The zones are imported to Visum as a shapefile from the Tabriz master plan.

5.3.2.2. Defining connectors

In PTV Visum, connectors connect the zones to the link (road) network. Each zone needs to be connected to at least one origin, and one destination connector to the network for the assignment. Connectors resemble the enter and exit routes from/to zones for the road users. A connector corresponds to an access, as well as an egress route between the zone centroid and the connector node. Therefore, a connector has two directions (*PTV Visum Help—Connectors*, n.d.). For public transport, a connector is defined for PUTW (Public transport walk) and allows the users to go from the zone centroid to a public transport stop.

5.3.2.3. Defining the origin-destination matrix

The origin-destination matrix is suggested for 2011, while the model for the current research is designed for 2021; hence the population growth and consequently the growth in the number of trips has to be calculated. Since the survey of 2011 is the latest of its kind and there are no other figures available, a growth rate should be applied to the existing numbers.

Assuming a linear growth rate for the trips for all zones and all modes of transport might not provide an ideally accurate input; however, using a cautious estimation can provide a highly reliable result. Thus, a uniform growth factor has to be applied the existing origin-destination matrix.

The report of (Pajoohesh, 2009) has predicted the travel demand in Tabriz without any infrastructural integration. It has calculated an average growth rate of 2.8% for the total urban trips in Tabriz between 2004 and 2021 and suggested the following equation for calculating the travel demand at each year:

$$D_T = D_B(1+r)^{T-B}$$

Where; D_T is total travel demand at target year,

D_B is total travel demand at the base year,

r is the growth rate which in this case equals to 0.028,

T is the target year.,

and B is the base year.

Assuming T=2021, B=2011, and r=0.028, it can be concluded that travel demand in 2021 will grow by approximately 32% compared to 2011.

The corrected origin-destination matrix (person-trips per day) for 2021 is shown in table 10. The 'gate' zone represents the destination of all trips that are originated in one of the zones in the city and destinated outside the city. Since the survey was conducted in the city, there is no information on the trips that are originated outside the city and destinated in the city.

Table 10: Origin-destination matrix for all trips in Tabriz in 2021

Gen. **Attr.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Gate**	**Total Generated**
1	125091	36440	20396	24747	26921	6527	7071	35353	2176	20668	8701	**314091**
2	30097	136740	60628	6543	22681	9596	3925	42309	0	873	26606	**339998**
3	33786	38611	214133	72396	20592	19949	8365	47942	322	3539	7079	**466714**
4	25648	37048	58136	263749	21943	22228	3134	36763	2280	27073	4845	**502847**
5	15898	29265	6503	8671	91047	1083	3252	29265	1083	3252	10478	**199797**
6	15595	22741	14295	17544	5848	51331	9097	16244	0	0	16244	**168939**
7	13855	75726	22455	26277	33683	24366	40132	231715	23172	23410	956	**515745**
8	8145	15005	1930	7289	10933	215	0	22186	428	1715	3859	**71704**
9	0	112	0	224	0	0	0	112	1290	224	0	**1963**
10	13711	17591	16557	40357	17075	11382	4140	47343	1811	155608	4656	**330231**
Total Attracted	**281825**	**409279**	**415032**	**467796**	**250724**	**146678**	**79116**	**509232**	**32563**	**236361**	**83425**	**2912030**

5.3.2.4. Defining modal split

The origin-destination matrix provides information about all person-trips which are made on a daily basis; though, it does not include any information about the modes of transport that the individuals use to go from one zone to another. The latest modal split of different modes of transport in the city (Naghsh-e-Moheet, 2013) was mentioned in chapter 3.

In order to define the modal split for each origin-destination pair, first, the modal split for the project horizon has to be determined. There are two challenges in predicting modal split: Different classification systems for transport systems and unclear trends of change in the modal split. These challenges are discussed below.

Different transport mode classification systems

Visum differentiates between definitions of ‘transport system’ and ‘transport mode’; where public transport mode contains all vehicles that are served as public transport e.g. train, metro, bus, etc.

In the Visum model, the transport systems which are defined by default are different than of the Tabriz master plan and include car, pedestrian, bike, HGV (heavy good vehicles), and public transport (bus and metro). As the first step for defining modal split in the Visum model, the transport modes which are defined in the Tabriz master plan should be equivalated to the defined transport modes in the Visum model. Transport modes: walk, private car, bus and bicycle have their equivalent in the Visum model. Though, there are 6 other modes that have no equivalent in Visum. 3 new modes are defined: shared taxi, van, and motorcycle. Shared taxi is assumed to have the same properties of car except that its PCU is assumed to be 1.4. The remaining 3 modes ad to be classified in such a way to drop in one of the categories in the Visum model. These modes were: shared taxi, minibus, call taxi, and other. On the other hand, the transport mode HGV in Visum has no equivalent in Tabriz master plan, since the model contains only an urban area. Table 11 summarizes this equivalency.

Table 11: Equivalency of Transport Modes in Tabriz master plan and Visum model

Transport mode (Tabriz master plan)	Equivalent Transport mode (Visum model)	Description
Minibus	Van	The minibus has the same PCU coefficient as van and mostly serve a private mode of transport. (e.g. as private shuttles for schools or company employees).
Call taxi	Taxi	Since in the current model, the shared taxi is assumed as a private mode of transport, call taxi falls in the same category as the shared taxi.
Other	Pick-up truck	The 'Other' category contains vehicle types that are missing in the list of the master plan; hence, it is relatable to pick-up trucks and HGVs. Since pick-up trucks are prevalent in urban goods and materials transport in Tabriz, this category is assumed pick-up truck with PCU=1.3.

Unknown modal shift trend

The most recent modal split study in Tabriz has been done in 2011 by (Naghsh-e-Moheet, 2013), while the first part of the metro was opened later in 2015. Hence, there is no information about the current modal share of the metro. In the absence of actual figures regarding the trends in mode shift, a logical assumption should be made to figure out the predicted share of different modes of transport after the introduction of the metro.

(Pajoohesh, 2009), has assumed a modal share of 75% for public transport in their transport prediction model for 2021 and has determined that 51.3% of all public transport trips will be done by the metro and 48.7% will be done by bus and shared taxis. This assumption does not seem to be realistic because:

- Results from similar cases in Iran (e.g. Tehran) and around the world (which are explained below) do not comply with the stated modal shift.
- As an initial general assumption, after opening 2 metro lines, besides the trips that shift from private modes to metro, a great portion of the passengers of

parallel bus lines and shared taxis will shift their trips to metro; especially after removing and adjusting some of the bus lines.

In order to have an accurate logical assumption, related studies in the field are reviewed. A good example of illustrating the modal share in Tabriz after the opening of the metro can be the capital, Tehran. Tehran has a quite complex metro system which started operating in 1998. Currently, it has 7 active lines and 125 active stations (*Tehran metro history*, n.d.) and 234km active operational network and 2.5 million person-trips are done using this system on a daily basis. Currently, the modal share of the metro in Tehran is approximately 15%. Though, the city is still halfway to reaching its long-term goal of reaching a 30% mode share of the metro by 2041 (Emam, 2019). In the case of Tabriz, 2 out of 5 (4; considering only urban lines) planned metro lines are supposed to be opened by the target year. Taking into account similar demographic characteristics and similar modal split between two cities, a 15% share can be safely assumed for the metro.

The next step is determining the patterns of modal shift to the new mode (metro) from other modes of transport. Reviewing revealed preference studies from different cities shows that (Vuk, 2005) has studied transport impacts of the Copenhagen metro and has found that 70-72% of metro passengers have shifted from the bus, while 8-14% of passengers have shifted from the private car. The figures are rather similar in other study cases. In the Madrid subway project, a modal shift of 50% from the bus and 26% from private cars was observed (Vuk, 2005). These numbers reach 56% of public transport (53% from bus passengers and 3% from train passengers) and 16% of car users (Golias, 2002). In the UK, the Croydon Tramlink has attracted 69% of its passengers from former bus users and 19% from car users (Copley et al., 2002) and in Manchester, 50% of the Metrolink passengers were formerly bus and train users, while 27% used to be car users (Knowles, 1996).

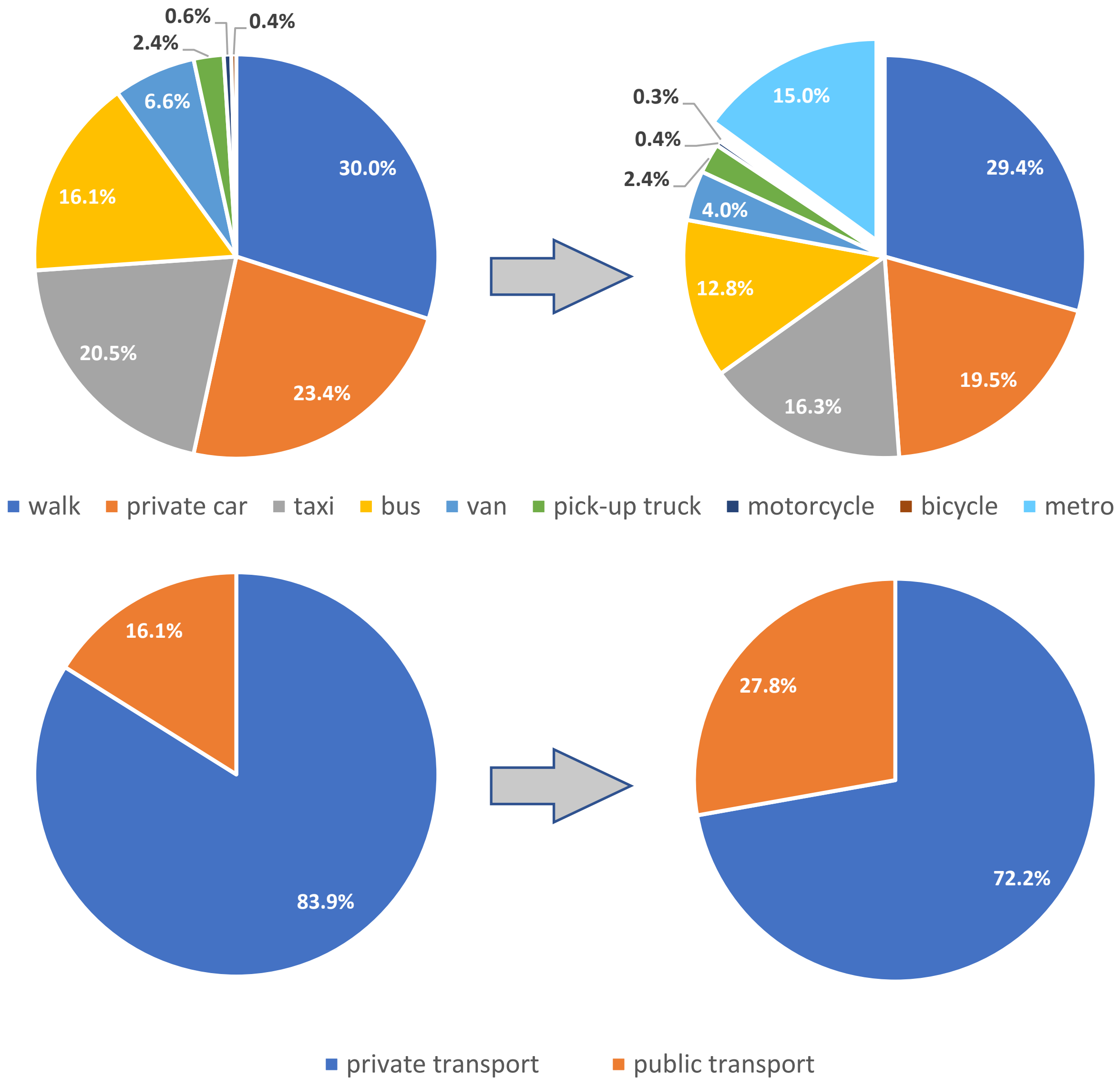
According to the findings from former studies, it can be foreseen that the bigger portion of the modal shift to the new metro system will be from former public transport users. Even though in the developed model, shared taxi is assumed a private mode of transport, in modal shift it can be assumed that it will follow the modal shift trend of public transport; since according to (Pajoohesh, 2009) survey, 68% of shared taxi users use it because they do not have any other options. Thus, it can be inferred that after the opening of the metro, a considerable portion of shared taxi users in the areas where the metro will be operating, will shift to the metro because of its shorter travel time, cheaper price and more reliability.

As a conclusion, the following modal shift is predicted:

- 50% from bus and taxi
- 26% from car
- 20% from motor, van, and bike

- 4% from walking

The modal split for transport systems as well as transport modes before and after the introduction of 2 metro lines are demonstrated in figure 18.



The only transport mode which will not be (or will be negligibly) affected is the pick-up truck, as it is mostly used for transport of goods.

Figure 18: Predicted modal shift in Tabriz after introduction of two metro lines in 2021.

Since an origin-destination matrix has already been created for all trips, one way of entering the modal split to Visum is to define separate origin-destination matrixes for each mode of transport. Since in the current research the goal is to study only public transport, two matrixes have been created: one for private transport and another one for public transport. According to figure 18, the share of public transport (bus and metro) is 27.8% and the share of private transport is 72.2%. The two matrixes are created as shares of the total origin-destination matrix. For two zones, namely zone 9 and zone 11, there is no metro connection. Thus, for these two zones, the mode share is assumed to be unchanged and the modal split of (Naghsh-e-Moheet, 2013) (figure 12) has been used.

5.4. Traffic assignment

After defining the modal split, the last step of applying the 4-step model is to assign the trips to the existing network. The traffic assignment needs to be run by means of computer software. In this case, PTV Visum is used to assign traffic on the road network of Tabriz.

Traffic assignment in Visum is done separately for private transport and public transport. To simulate a transport system which includes both private and public transport, traffic assignment for private and public transport should be put separately in the 'procedure sequence' in the software. It should be noted that since this thesis is focusing only on public transport and integrating different public transport systems, running traffic assignment for public transport suffices. After assigning private transport along with public transport, no difference is recorded. Thus, the simulation continued only with the public transport assignment.

Before assigning the traffic, in order to apply default dwell times that were defined for each stop point, 'set run and dwell time' procedure is run. The public transport assignment procedure needs to run after setting the dwell time.

5.4.1. The public transport assignment procedure

The assignment type 'headway-based' is chosen for the procedure. The assignment is done for a day (24 hours). Hence, the assignment time period is set to one day from 00:00 to (24:00). The next step is to define different components of transit impedance. The impedance describes the level of difficulty when going from point A to point B. It is usually considered as travel time, travel costs, or a combination of both, called generalized costs (*Impedance—Travel Forecasting Resource*, 2017). In the Visum transport assignment procedure, impedance equals the sum of PJT (Perceived Journey Time) and fare. PJT, consequently, has different components: in-vehicle time, access time, egress time, walk time, origin wait time, transfer wait time, the number of transfers, boarding penalty and mean delay (*PTV Visum Help—Perceived journey time*, n.d.).

Depending on the sensitivity level of each of the abovementioned variables in a specific case, they can be given different weights. Since limited research has been carried out around transit impedance and its factors in Tabriz, an assumption had to be made. Thus, it was assumed that all PJT components have equal weight. To have a logical assumption about the coefficient of fare, by the trial-and-error method, it was revealed that a 0 coefficient will result in no fare impedance; meaning that any ticket price would not affect public transport ridership. On the other hand, according to survey results of (Pajoohesh, 2009), (which has found that 52% of bus users state long travel time as their biggest reason of dissatisfaction with bus, while only 11% state high travel costs as their main reason for dissatisfaction) it can be assumed that the impedance is less sensitive to the fares than to the travel time; hence the coefficient of fate should be less than 1. Thus, after a number of trials within this range, 0.4 was chosen to be the coefficient of fare.

Therefore, the equation of impedance for public transport assignment would look like the following:

$$Impedance = 1\,PJT + 0.4fare$$

5.4.2. Assignment results

After running the assignment, Visum displays the results both on the map and in tables. Figure 19 shows the public transport assignment results on the Tabriz map.

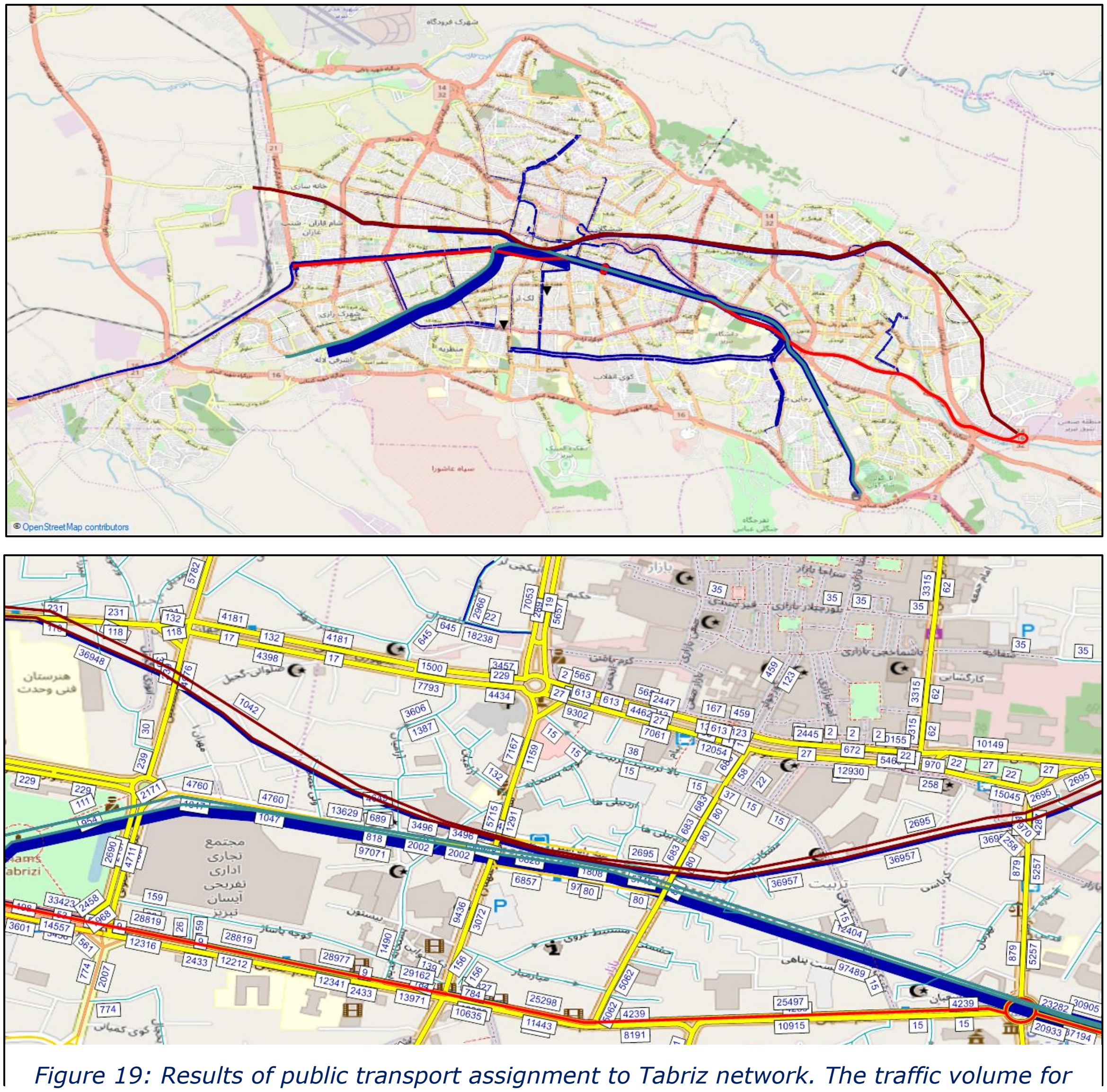


Figure 19: Results of public transport assignment to Tabriz network. The traffic volume for each road is written beside it. (Blue line: The number of passengers using a certain link. The thicknes of the line is a function of the number of passengers. Turquoise line: Metro line 1. Dark red line: Metro line 2. Light red line: BRT.) (Source: Created by the author in PTV Visum in January 2020)

The results show that two metro lines (M1 & M2) would play the biggest role in the public transport system of Tabriz. They are followed by the BRT line (177) and the Middle Ring line (182). A summary of the important results of the public transport assignment follows.

- 3,319,119 passenger-kilometres are done by public transport on a daily basis.
- Mean journey time is 55min 50s, while mean perceived journey time is 58min 27s.
- Mean ride time (including total in-vehicle time + transfer walk and wait times) is 18min 42s, while mean in-vehicle time is 12min 28s.
- Mean number of transfers is 0.3 transfer per trip.
- Mean transfer wait time for public transport trips with at least one transfer is 4m 13s.
- Mean transfer walk time for all public transport trips (including trips with zero transfer) is 5min 26s.
- Out of a total of 46,751 passengers who transfer between public transport stops, 26,866 passengers (57%) change between two metro lines in Mohaqqeqi station.

In the next chapter, where different variants are developed and discussed, the results are further discussed.

5.5. Developing integration scenarios

This thesis studies the effects of integrating different public transport systems. This includes physical and operational integration. With the intention of measuring the effects of each field of integration, different modifications are made in the model and as a result, four variants are developed.

5.5.1. Base situation

The base situation is defined as the transport network designed for 2021 without any proposed physical or operational changes. This situation of which the assignment results are briefly described in the previous chapter is defined as the base variant. Figure 20shows all stations and lines in the city centre before the adjustments. The fares are assumed to remain the same as defined before. In the base situation, there are 6 separate bus stations in the city centre of Tabriz (Bazaar). Either of these stations serves one of the zones defined by Tabriz & Suburbs Bus Company. 46 lines out of 67 bus lines in Tabriz depart from the mentioned stations. These stations are distant from each other, varying from 310m walking distance (between East and West Mohaqqeqi stations) to 1630m walking distance (between Saat and Motahhari stations). Also, it is planned to open an interchange metro station by the target year in this area (Mohaqqeqi street).

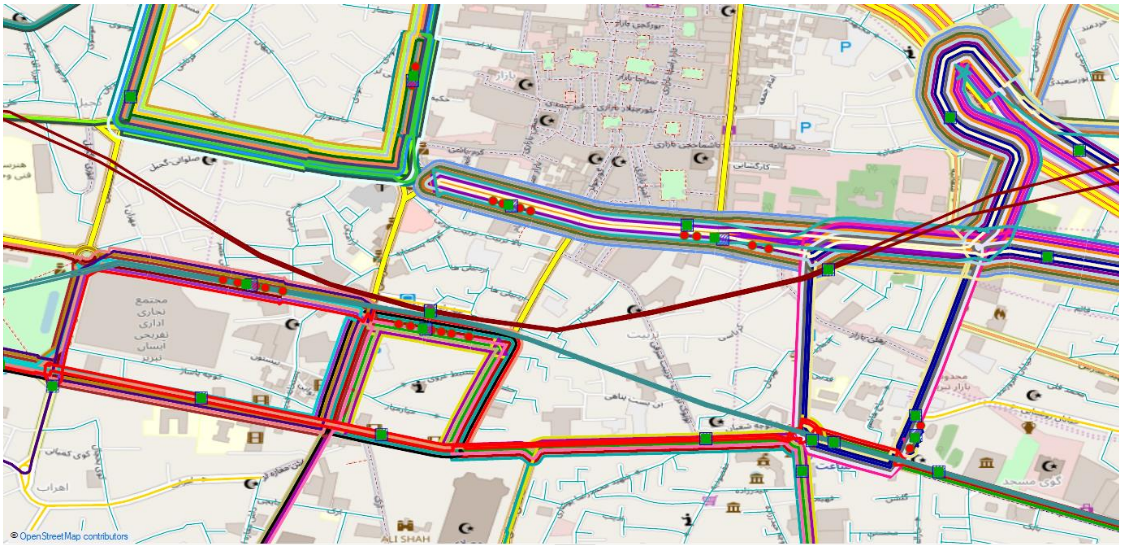


Figure 20: All bus and metro stations and lines in the city centre of Tabriz in the base situation. (Red dots: Stop point. Green dots: Stop. Turquoise line: metro line 1. Dark red line: Metro line2. Coloured lines: bus lines.) (Source: Created by the author in PTV Visum in January 2020)

5.5.2. Adjustments

Two adjustments are made in the model, in order to develop the variants and measure the effects of the adjustments. These adjustments are discussed in this chapter.

5.5.2.1. Physical Integration: combining bus and metro stations

As an infrastructural intervention, this adjustment includes combining 5 out of 6 bus stations in the city centre with the metro interchange station. This required moving all stop points of these stations to Mohaqqeqi street. To give a clearer image of this adjustment, the stop hierarchy in Visum has to be defined.

Visum stop hierarchy: In the public transport sector, there are a variety of stops, which can enormously differ in structure and size. This variety can range from simple road-side stops which simply consist of a stop sign to large multi-story (and/or multimodal) terminals and stations. Linked to this, Visum has a concept, which allows illustration of large stations in detail, as well as including simpler situations. This concept is shown in Visum by so-called stop area hierarchy, which is composed of: stop, stop area and stop point. Each of these levels realizes certain tasks within the transport network. The following paragraphs and Figure 21 illustrate the levels of stop hierarchy (PTV Visum Help—Stop hierarchy: Stops, stop areas, stop points, n.d.).

Stop point: Specified arrival and departure point for one or more lines. Public transport lines stop here for passenger boarding and alighting. In the most detailed model, the stop point corresponds to a stop sign for bus services or the edge of a platform for rail services.

Stop area: Combines several stop points in close proximity.

Stop: Stop comprises the entire complex of stop points and stop areas. It is the highest object in the stop hierarchy and carries the stop name. In the real network, it is consequently of more organizational nature.

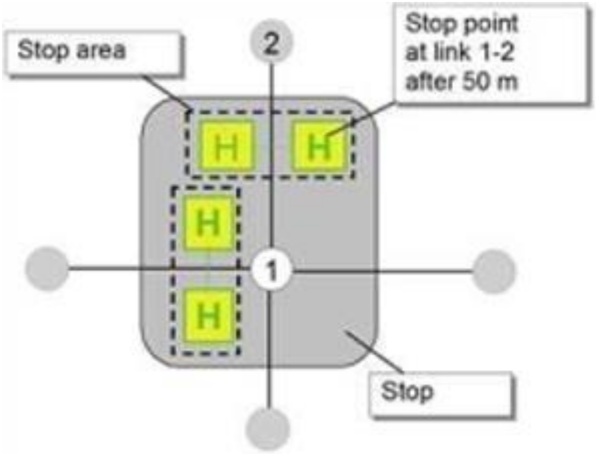


Figure 21: Levels of stop hierarchy in PTV Visum (Source)

To realize the adjustment, all stop points of the previous 5 bus terminal stations have to move to Mohaqqeqi street. Mohaqqeqi is a short street (250m long), but broad (60m) wide. Thus, in case of being used as a bus-only street, it can easily accommodate all bus stop points and function as a large urban bus terminal station.

Hence, four 2-lane one-way East-West bus paths in addition to a 2-lane 2-way West-East bus path (for return to stops) are defined, where every single path is assumed to be a stop area, containing 4 or 5 stop points. All stop areas together with two metro stop areas form a stop in Visum, called 'Mohaqqeqi Interchange Station'. The adjusted area is shown in figure 22.

Figure 22: Simulation of Mohaqqeqi Interchange Station (Red dots: stop pint. Blue squares: Stop area. Green dot: stop.) (source: Created by the author in PTV Visum in January 2020)

The only bus terminal station in the city centre which is not relocated is the Khaqani bus terminal station. That station, despite others, doesn't consist of road-side stop points but has been recently allocated an exclusive space. Moreover, being in the proximity of Saat metro station, it is assumed that it can provide feasibility to transfer. To validate the assumption, moving Khaqani station to Mohaqqeqi is also modelled and the results showed negligible difference with the proposed adjustment; hence, the station was modelled to stay in its current situation. Figure 23 shows the Khaqani bus station and Saat metro station.

Figure 23: View of Khaqani bus terminal station (left) and the entrance of Saat metro station (right). (source: Taken by the author in July 2019)

5.5.2.2. Operational Integration: fare integration

A prevalent level of integration is operational integration and one of the most effective ways of operational integration is the instruction of integrated public transport fares. As already described in the previous chapters, public transport fares in Tabriz follow a traditional single-ride ticket system with no incentive for transfers or short distances.

A time-based ticket is proposed to be introduced to the system. To define the original and transfer fares as well as the time limit, the trial and error method has been used to find the numbers which lead to more ridership as well as more trips with transfers. Finally, a 1-hour fare defined. It originally costs 6,500 IRR and every transfer within this period is free of charge. Another type of ticket which covers more than 3 hours is the day ticket which costs 20,000 IRR. All other ticket types are be removed.

5.5.3. Designing Variants

By adjusting the transport system in the aforementioned ways, four variants can be designed:

1. **No Action (V0):** This variant is the base situation after opening 2 metro lines and the adjustments that are suggested by (Pajoohesh, 2009). No further adjustments are made.
2. **Physical Integration (V1):** This variant includes a combination of bus terminal stations with Mohaqqeqi metro station and constructing a bus and metro interchange station. No changes are made to the fares in this variant.

3. **Operational Integration (V2):** This variant is designed by replacing the existing fare system with a time-based fare system that offers incentives for trips including transfers. In this variant, no physical interventions are made in the network; meaning that bus terminal stations are not relocated.
4. **Physical & Operational Integration (V3):** This variant includes both physical and operational integration. The bus/metro interchange station is designed and the single-ride fare system is replaced with a time-based system.

All of these four variants are designed separately in Visum. All other variants including network specifications, impedance, etc. remain the same for all variants. After designing the variants, a traffic assignment procedure is run separately for each of them. The results are discussed and compared in the following chapter.

Chapter 6: Findings, discussion and recommendations

6.1. Findings

After running a traffic assignment as the last step of the 4-step model for the variants, noteworthy results were obtained. The most determining indicators are summarized and compared for different variants in table 12.

Table 12: Comparing the results of traffic assignment between different variants. The numbers in bold show the smallest/largest among all variants, depending on the indicator)

Indicator	**Variant**			
	V0	**V1**	**V2**	**V3**
Mean Journey Time	55min 50s	54min 59s	55min 42s	**54min 14s**
Mean Perceived Journey Time	58min 27s	58min 29s	**58min 21s**	58min 46s
Mean Ride Time *(in-vehicle time + transfer walk time)*	18min 42s	18min 58s	**18min 33s**	18min 58s
Mean Transfer Wait Time	48s	1min 5s	**46s**	1min 20s
Mean Transfer Walk Time	5min 25s	4min 40s	5min 26s	**4min 3s**
Mean Number of Transfers	0.26	0.35	0.27	**0.45**
Mean Transfer Walk Distance	450m	350m	450m	**300m**
Total Number of Transfers	129,334	173,337	131,175	**224,661**
Total Number of Unlinked* Trips	604,339	651,586	605,922	**709,585**
Total Number of Linked** Passenger Trips	494,690	494,690	494,690	494,690
Number of Linked Passenger Trips with no Transfer	**356,965**	318,039	355,526	281,853
Number of Linked Passenger Trips with 1 Transfer	106,826	147,084	107,301	**181,688**
Number of Linked Passenger Trips with 2 Transfers	11,134	13,126	11,887	**21,175**
Number of Linked Passenger Trips with >2 Transfers	80	0	33	**208**
Number of Passengers who have been Assigned a Trip	475,005	478,250	474,747	**484,924**
Number of Passengers who haven't been Assigned a Trip	19,685	16,440	19,943	**9,766**

*Unlinked=Each person can count more than once.
**Linked=Each person only counts once.

The findings can be explained in three categories:

6.1.1 Total Travel Time

The results show that total journey time, as well as perceived journey time, are not significantly affected by any of the adjustments. This can be attributable to the inaccessibility of public transport as well as slow vehicles. Hence, even though a shorter transfer walk and transfer wait times are provided and as a result, a new public transport path is created, it would require longer walk time during access and/or egress, or longer waiting at the origin or longer in-vehicle time, which leads to a quite unchanged total travel time.

6.1.2. Transfers

This category has been affected more than others by the adjustments. Both adjustments have had a positive effect on the number of transfers. While V2 does not show a significant increase in the number of transfers, V1 and V3 have a higher ratio which can be attributed to the infrastructural integration. V3 has a considerably higher mean number of transfers. This can be interpreted as the positive impact of both physical and operational integration on the number of transfers.

The mean and total transfer walk time follows the same pattern. This can be noted that mean numbers include the trips with zero transfers. Hence, short transfer times can be attributed to that fact. The mean transfer wait time follows a reverse pattern which is attributable to the fact that these figures include all trips.

6.1.3. Number of Public Transport Passengers

The present simulation model has assigned traffic only to public transport systems. Thus, some passengers are not assigned any trips, because of a lack of connectivity. It can be inferred from the results that integration can provide public transport connections for more people.

6.2. Critical discussion of the findings

All of the indicators except the number of assigned/not assigned trips are indicators of public transport level of service. In the current traffic assignment procedure for the base variant (V0), there are a number of passengers (3% of all), that could not be assigned any trips. In the real world, these trips passengers to be transported by other modes, e.g. private cars. This indicator can indicate the public transport ridership; meaning that if any of the variants can decrease the number of passengers who aren’t assigned a public transport trip, it has increased the public transport ridership.

In general, all adjustments show, more or less, a positive impact on the level of service and ridership of public transport. In other words, except for few indicators that are explained above, all other indicators show a positive response to the adjustments.

V1 shows a good performance, especially by increasing the number of transfers by 34%, cutting the mean transfer walking distance by 22% and decreasing the transfer walk time by 14%. It should also be mentioned that despite the number of trips with 1 and 2 transfers, the number of trips with more than 2 transfers are decreased and reached 0 in this variant. However, taking into account the total number of assigned public transport trips which is only increased by 0.6%, it can be stated that in this case, the increased number of transfer trips means that the direct trips are shifted to transfer trips, rather than providing a new connection. Thus, even though the quality and consequently, the attractiveness of transfer trips are increased in this case, it does not attract many new passengers.

V2 In all indicators shows very close results to the one of V0. This means that the introduced time-based integrated ticket system alone does not change the trends in public transport significantly. This result becomes important especially after comparing it to the results that are obtained from V3.

V3, increases the number of transfers by 73%, and also decreases the transfer walk time by 73%. This variant decreases the transfer walk distance by 33% as well. Even though the total travel time is not affected as significant as transfer components, though it also decreases by around 3%. V3 increases number of all transfer trips, including trips with 1, 2 and more transfers. While improving the quality of transfer, this variant increases the passengers who use public transport by 2%, decreasing the number of passengers without a connection to half. Hence, V3, which includes physical as well as operational integration, showed the best performance among all variants.

The obtained results prove the effectiveness of public transport integration on the number of transfers, transfer walk time, transfer walk distance, and in general, on the level of service of public transport, as well as on public transport ridership. This way, the presuppositions of this research are mostly correct. The only assumption that revealed that is not valid in this study is the effect of integration on total travel times, where it was assumed that a shorter transfer time in addition to providing more connections, will lead to a shorter total travel time. In this case, providing better integration of different public transport systems did not lead to a shorter total travel time. As already mentioned earlier in this chapter, it might be attributable to the poor public transport coverage in Tabriz, where providing a shorter transfer time might cut the total travel time; however, on the other hand, since access and egress times remain high (around 15minutes and 17 minutes on average) this change is negligible.

Another important result is the share of intermodal transfers. While in V0, 57% of all transfers are metro to metro transfers taking place between metro station platforms in Mohaqqeqi metro interchange station, the intermodal transfers are negligibly low. While in V3, the share of all transfers in Mohaqqeqi intermodal station reaches 78% of which, 21% are metro to metro, 28% are bus to bus transfers, and 51% are intermodal transfers between metro and bus. This means that nearly 40% of all transfers in the studied area transfers between bus and metro in Mohaqqeqi intermodal station, which can be considered as a considerable change in the number of transfer trips.

The results of similar studies around the topic show similarities in the results. A similar simulation study by (Solecka & Żak, 2014), where they developed a new variant for the city of Krakow in Poland, shows more or less similar results. The developed variant included two new lines of light express city train. After modelling the system and developing the scenarios, they concluded that the number of trips with transfer increases by 51% in the integrated system. The decrease in total travel time is reported to be 7% and the average waiting time is decreased by 18%. However, in the case of Krakow, the results show a 7% increase in the average transfer time. The authors attribute it to the weakness of transfers in infrastructure, which is not efficiently providing easy transfers. In terms of ridership, the users of a certain public transport system in the integrated system in Krakow is supposed to increase by 3%. As it is observable, the results of that study are mostly similar to the ones of the case of Tabriz.

6.3. Practical implications

The results of this study show that an infrastructural integration alone, can improve the transfers by cutting transfer distance and transfer walking time. However, it doesn’t result in a huge difference in the number of riders of the public transport. On the other hand, introducing an integrated fare system alone doesn’t make a significant change in the whole transport system. This means that without having good physical connections, integrated fares may not lead to a higher level of service of public transport. Thus, to have an efficient integrated system, both measures should be taken at the same time. For the city authorities, avoiding any infrastructural changes and only integrating the fares would have less cost. However, since the suggested are for the intermodal transport station in Mohaqqeqi street is already under construction and closed to traffic, changing the street into a large bus station area and providing good connections between the platforms of bus station, as well as easy access to the metro station that is going to be inaugurated in the near future, might not have very high costs. The author believes that by making physical adjustments to the system, as well as providing an integrated and cheap fare system, the public transport in Tabriz may see a huge improvement.

In terms of transferability of the results of this thesis, since neither of Iranian major cities which have a bus as well as a metro system has implemented an integration plan, the results of this study may be beneficial for them. Especially in major cities other than Tehran, namely Mashhad, Isfahan, Shiraz and Karaj, that have a similar population and other demographic characteristics to Tabriz, these results can be transferable.

6.4. Research limitations and recommendations for future research

This research is carried out by means of collecting secondary data from different authorities and conducting a model simulation study. The major shortcoming in this research is the reliability and accuracy of data. Some of them are not updated for a quite long time, while others do not seem to be sufficiently accurate. For example, the survey by Pajoohesh is conducted in 2008 and the study by Naghsh-e-Moheet for updating the master plan of Tabriz is done in 2013 and since then, no further researches are done. In terms of accuracy, the origin-destination zones of Tabriz comply with the municipal zones, which are too large for the traffic generation and attraction studies.

Another problem is the shortage of data, which made the author take several assumptions. The share of metro in the transport system and the sensitivity of the impedance to different factors are among these assumptions.

Thus, it would be recommended that different studies in the following fields can be carried out to update the results and make it even more accurate.

- Conducting travel surveys by dividing the city to smaller regions, and scheming the modal split in more details (containing trip purpose) to make the results more reliable.
- Different sensitivity analysis around the impedance and its sensitivity to different components of travel time as well as travel costs.

In addition, since this research is first of its kind in the region, it opens many research occasions. Some of these occasions are listed below.

- Microsimulation of the proposed area for the intermodal station and assessing its technical feasibility.
- Optimization study to find the optimal ticket type and ticket price.
- Cost-benefit analysis for construction of the intermodal station as well as introduction of the new fare system.
- Developing more integration scenarios including other integration fields, such as organizational integration, as well as more operational integration scenarios such as timetable integration, etc.

Chapter 7: Conclusion

Creating an effective public transport system in large and populated cities is not feasible without effective integration and continuous coordination between different public transport modes and service providers, which can significantly improve the level of service of public transportation.

Some cities, especially in developed countries, have already established a fully integrated public transport system and some other cities have developed a partially integrated system and are planning to move towards full integration. Nevertheless, the implementation of public transport integration is not always considered a priority. In some other cities, usually in developing countries, even though there might be high investments for running new modes of public transport such as metro or tram, but the mobility planning authorities still neglect a comprehensive plan for public transport integration.

Tabriz is one of those cities in which existing mobility plans highly neglect public transport integration. On the one hand, transport integration in Tabriz is so far only limited to defining a single type of smart card for payments of the metro, BRT and bus. On the other hand, Tabriz metro is a new system that only one of its lines has been recently partially opened and the rest of the line, as well as other lines, are either under construction or still being studied.

In this situation, implementing infrastructural as well as operational integration of metro with other modes of transport (particularly with the urban bus) can cut the transfer walking time and distance, and consequently increase the number of passengers for both metro and bus. Building intermodal public transport stations in the city centre and introducing an integrated fare system are the main tools to achieve this goal.

In this thesis, different variants of integrated public transport, including physical and operational integration are designed and their performance in terms of total travel time, transfer time and distance, and the number of public transport passengers are compared. As a result of the simulation, according to performance of variants in the case of Tabriz, physical integration of public transport stations can considerably affect the public transport level of service in a positive way by providing shorter transfer time and transfer distance and creating new connections in the network; while fare integration alone does not have a significant effect. However, when operational integration is accompanied by physical integration, it becomes much more effective.

Building an intermodal station with at least two metro lines and many bus lines at a single location in the highly-populated city centre of Tabriz can be the basis and a turning point for the concerned authorities in re-designing the public transport network of Tabriz with focusing on integrated transport to increase the public transport level of service as much as possible.

These steps for infrastructural integration (intermodal station) and operational integration (integrated fare system), if implemented, will pave the road to other fields of transport, such as passenger information, integrated timetable plans and finally, organizational integration.

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