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MASTER'S THESIS

Impact of Weather on Public Transport Users' Satisfaction

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Abstract

A satisfaction survey for bus and U-Bahn in Munich with 191 interviewees has been conducted to investigate the most influential specific satisfactions on the overall satisfaction for bus and U-Bahn in Munich respectively. The questionnaire consists of three parts, personal information, judgment of the importance and satisfaction for several aspects in bus and U-Bahn service, and the influence of weather on bus and U-Bahn ridership. Two statistical methods (factor analysis and ordered logit modeling) have been applied. In the satisfaction model for U-Bahn, the most influential specific satisfaction is waiting time at stations during peak hours, followed by travel speed, temperature at stations in summer times and vehicles' modernity. In the satisfaction model for bus, the most influential specific satisfaction is network coverage of bus line, followed by walk distance to next line when transfer, travel speed, clear timetable information at stops and driving style. In addition, the impact of adverse weather on the ridership of bus and U-Bahn has also been estimated through the statistical test.

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1 Introduction

With the development of the economy and in the process of urbanization, demand for mobility in urban areas is fast growing and becomes a challenge for urban planners from all over the world.

According to The German Mobility Panel (Deutsches Mobilitätspanel), which is a longitudinal survey that collects travel data in Germany since 1994, we could find in Fig. 1.1 and Fig. 1.2 that everyday travel distance and travel time has increased in Germany in recent 15 years. Increasing travel distance and travel time mean long distance traffic mode like individual cars or public transport might play more and more important roles than short distance traffic mode like cycling or walking. We could find in Fig. 1.3 that in 2012-2015 more than 50% of traffic demand depended on individual car and public transport still played a less important role compared to private cars and walking.

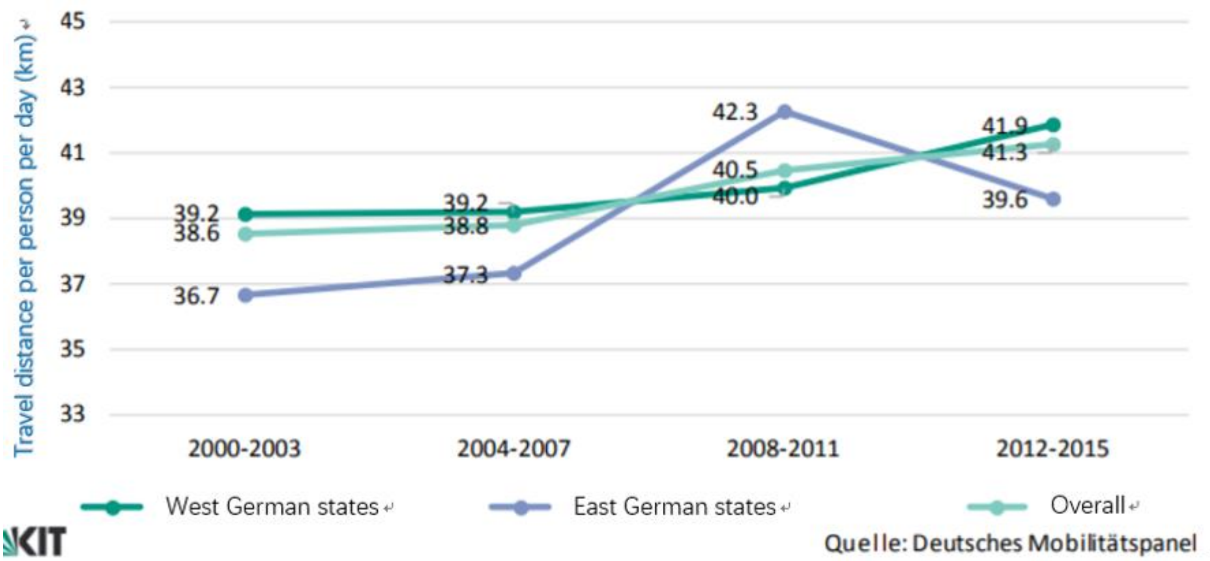

Fig 1.1 Development of the Travel Distance per Person per Day (km) in Germany [MOP REPORT 2015/2016]

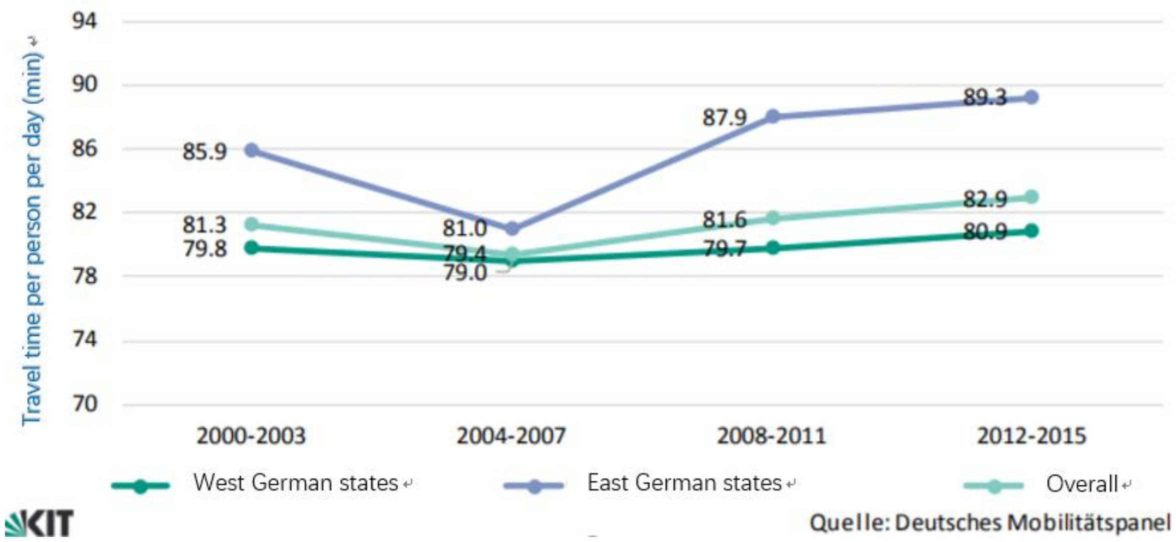

Fig 1.2 Development of the Travel Time per Person per Day (min) in Germany [MOP REPORT 2015/2016]

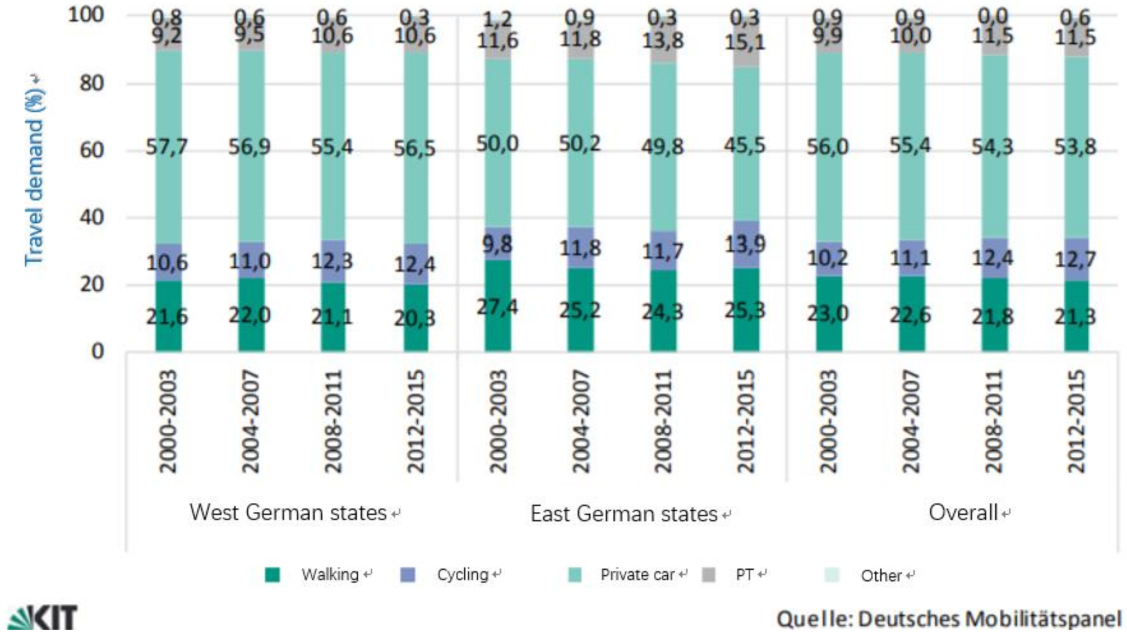

Fig 1.3 Development of the Model Split in Germany [MOP REPORT 2015/2016]

Since private vehicles have been proved as an inefficient mode of transport in respect of environmental protection and congestion during peak hour, how to organize public transport service well and how to increase the ridership of public transport have been important topics and concerned by experts in traffic engineering. One of the methods to increase the ridership of public transport is to identify users' demand and increase users' satisfaction.

Several surveys have been conducted all over the world to investigate the most important factors that influence public transport users' satisfaction [DEL CASTILLO and BENITEZ, 2012] [D'OVIDIO et al., 2014]. In this thesis, the author conducted a public transport users' satisfaction survey in Munich, which includes bus and U-Bahn service, and tried to figure out the most influential factors in case of Munich.

Weather and transport have been proved linked closely to each other [STERN and ZEHAVI, 1990] [KYTE et al., 2001]. However, most researchers focused on the influence of weather on road traffic [TSAPAKIS et al., 2013], pedestrians [AULTMAN-HALL et al, 2009] and cyclists [HELBICH et al., 2014], few previous researches talked about the influence of weather on public transport, especially on users' satisfaction. In this thesis, the author tries to fill this gap and through a questionnaire survey to find the relationship between weather and public transport users' behavior.

2 Literature review

2.1 Public transport users' satisfaction

2.1.1 Definition

Public transport providers are always dedicating to improving ridership of their service. Understanding customers' needs and knowledge about how customers make decisions are important. PERK et al. [2008] investigated the characteristics of people who used to use public transport, who keeped using public transport, who began a new customer of public transport and the reason why people changed traffic mode. According to the data from household travel surveys in Washington, D.C. and Pinellas County, Florida, the main reason people give up public transport was gaining access to a car. The second most important reason was the change of job location or residential location. Data from the Puget Sound Transportation Panel (PSTP) indicated that those focused more on punctuality of service tended to switch to driving an individual car. Researchers also pointed out that it was easier to encourage infrequent riders to use public transport more than to attract new riders. Infrequent riders meaned the huge potential market for public transport.

In the late of 1970s customer satisfaction/ dissatisfaction (CS/D) research began to solve the problems connected to customers. From 1975 to 1985 most studies served in product and goods industries, after 1980 CS/D studies were involved in service industries [Transportation Research Board,1991]. Since the 1990s, the American Customer Satisfaction Index, a market-based performance measure has been applied in transportation industry [FORNELL et al.,1996].

TYRINOPOULOS and ANTONIOU [2008] gave a definition of the customer satisfaction with respect to public transport, customer satisfaction in public transit is associated with how much percentage of customers' expectations has been fulfilled by public transport service. And overall satisfaction could be measured with specific satisfactions in several aspects of service [DEL CASTILLO and BENITEZ, 2012].

2.1.2 Methodology

Satisfaction analysis is based on data, which are directly collected from public transport users. These data could be collected through in-person on-board/ off-board or online questionnaire surveys, or telephone interviews. Sample sizes could have huge differences, which are usually decided by researchers according to examined transit systems, focus groups and research scopes. Sample sizes could range from qualitative research of focus groups with 88 respondents, to nation-wide study with 180,000 participants [VAN LIEROP et al., 2017].

One survey conducted in the Spanish city of Bilbao in 2010 had 1508 respondents. It covered most of the bus network in that city and all respondents were randomly chosen. Respondents had to evaluate different aspects of bus service in Bilbao in 8 categories and their global satisfaction with the service in a 10-levels Likert Scale [DEL CASTILLO and BENITEZ, 2012]. In another survey focused on bus service conducted in Bari, a city in Italy, researchers gave more information about the questionnaire. The questionnaire was divided into 3 sections. Section A gave the general information of the respondents and their characteristics of the bus use. General information included age, educational qualifications and working / non-working conditions. Characteristics of the service's use were divided by the frequency of use buses in the last year, the main reason to use the bus service, usual ticket and dynamics of bus service like improved, unchanged or worse in the last year. Section B concerned specific satisfactions in several aspects of the bus service and Section C contained a few questions about general satisfaction for the whole bus service [D'OVIDIO et al., 2014]. MOUWEN [2015] used data including 90000 answers collected in Netherlands from 2010 to 2011. This nationwide sample contained satisfaction scores for urban and regional public transport service including bus, tram, metro and regional train. This researcher added a location tag to these data to record where respondents were questioned. YE and TITHERIDGE [2017] investigated commute satisfaction in Xi'an. Employers were sampled by industry type. To represent each industry type in the survey researchers used a quota-based approach. They collected finally 794 web-based surveys and 570 paper-based surveys. STUART et al. [2000] compiled data from the Transportation Panel of the Metropolitan Transit Authority's (MTA's) New York City Transit. Authors described that interviewees were asked via telephone quarterly about their general and detailed travel behavior for the most recent 2 days, and the attitudes toward subway, bus, taxi, and automobile.

VAN LIEROP et al. [2017] found there are 7 overarching categories in users' satisfaction survey after reviewing 13 articles. They were onboard experience, customer service, service delivery, waiting conditions, costs, quality of transfers and image. Each category had different service factors. Cleanliness, comfort, seating capacity, onboard information, crowding, quality of vehicles, safety, temperature and accessibility (physical) belonged to onboard experience category. Driver and personnel's attitudes, personnel skills and complaint dealing were involved in customer service. Reliability, on-time performance/ punctuality, frequency, travel time, access time, network coverage, number of transfers, service provision hours, convenience, stop location, station parking and waiting time were most common factors in service delivery category. Waiting conditions, information at stops and safety at stops belonged to waiting conditions. Value, types of tickets and passes and ticket selling network were considered in costs category. Quality of transfers category contained transfer time and ease of transfer. Image category contained image and environmentally friendly. These categories and service factors were investigated by researchers in these 13 reviewed articles, but none of them was involved in all these surveys at the same time.

The most used approaches to data analysis for customer satisfaction are regression analysis, Principal Component Analysis (PCA) and Structural Equation Models (SEM) [DE OÑA et al., 2013].

In transport satisfaction surveys, respondents are usually used how satisfied are they, it means they must answer in surveys very satisfied, somewhat satisfied, neutral, somewhat dissatisfied and very dissatisfied, or in Likert- Scale, which are called ordinal data. If we want to predict the overall satisfaction with specific satisfactions for each service aspects, ordinal regressions [MCCULLAGH, 1980], such as ordered logit or ordered probit, are commonly used.

TYRINOPOULOS and ANTONIOU [2008] investigated most important satisfaction attributes for different operators in Athens and Thessaloniki, Greece, using ordered logit model.

Researchers usually apply principal components analysis to reduce a relatively large multivariate data set into a smaller dataset and to interpret data [JOHNSON and WICHERN,1992].

First, we obtain $n \times P$ matrix X with n observations, each with P variables:

$$X_{n\times p} = \begin{bmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{bmatrix} \qquad (2.1)$$

Then principal components analysis is done with following steps: standardizing all variables in the n × P matrix X, then calculating the variance-covariance matrix, deciding the eigenvalues and corresponding eigenvectors of the correlation matrix and deleting components with a small proportion of the variation [WASHINGTON et al., 2003].

NWACHUKWU applied principal components analysis and found four most influential factors for the satisfaction of bus service in in Abuja, Nigeria. They were comfort on board, accessibility to bus services, stop facilities and bus capacity [NWACHUKWU, 2014].

Unlike principal components analysis, factor analysis is a statistical method for identifying the underlying structure in the multivariate dataset [WASHINGTON et al., 2003].

Structural Equation Models is developed to deal with a model with unobservable or latent variables, which are measured using one or more exogenous variables, and there is endogeneity among variables. For example, in transport survey researchers want to measure the respondents' attitude towards public transport, but the attitude is hard to be measured directly and survey designers tend to measure this unobservable variable with some observable variables [WASHINGTON et al., 2003].

We could develop an equation for the latent variable model with:

$$\eta = \beta\eta + \Gamma\xi + \zeta \qquad (2.2)$$

Where β and Γ are structural coefficients, η is $M \times 1$ vector of the endogenous variables, ξ is $N \times 1$ vector of the exogenous variables and ζ is $M \times 1$ vector of the random variables.

And the equation for the measurement model consists of,

exogenous variables:

$$\chi = \Lambda_X \xi + \delta \qquad (2.3)$$

and endogenous variables:

$$\gamma = \Lambda_Y \eta + \varepsilon \qquad (2.4)$$

Where χ and δ are column q- vectors related to the observed exogenous variables and errors, γ and ε are column p- vectors related to the observed endogenous variables and errors. Λ_X and Λ_Y are structural coefficient matrixes [BOLLEN, 1989].

STUART et al. [2000] and GITHUI et al. [2010] have applied SEM to investigate public transport users' satisfaction.

VAN LIEROP et al. [2017] found through literature review the most influential service attributes were: onboard cleanliness, comfort and the behavior and attitudes of the personnel, these three attributes were mentioned in 10 out of 13 papers, safety, which was mentioned in 9 out of 13 papers, and the punctuality and frequency of the service, which were mentioned in 8 out of 13 papers.

2.2 Impact of weather on individual travel behavior and transport

2.2.1 Impact of weather on individual travel behavior

Transportation is a process to bring people between two activities. Most transportations are exposed outdoors and influenced by weather, especially adverse weather. Adverse weather conditions has been proved to influence safety and performance of transportation service. STERN and ZEHAVI [1990] found that probability of road accidents increased with hotness. KOETSE and RIETVLD [2009] thought the most influential variable was precipitation. There were a lot of empirical evidence on the influence of rain and snow on the severity and frequency of road accidents. CALIENDO et al. [2007] developed a crash-prediction model for multilane roads and found wet pavements remarkably increased the number of crashes. Some other studies showed that travel speed would be reduced due to adverse weather. KYTE et al. [2001] identified that wind speed and visibility were factors affecting free-flow speed, and drivers would reduce their speeds on wet and snow-covered pavements. SMITH et al. [2004] found the capacity of the highway was significantly reduced at each rainfall intensity level. Adverse weather has influence also on travel time. In the Greater London area (UK) during the period 1 October-10 December 2009 travel time was observed increasing 0.1-2.1%, 1.5-3.8% and 4.0.6.0% due to light, moderate and heavy rain. In light and heavy snowy days, delay was 5.5-7.6% and 7.4-11.4% [TSAPAKIS et al., 2013].

Adverse weather has also influence on travelers' decision and behavior. SPINNEY and MILLWARD [2011] investigated the relationship between weather conditions and daily leisure activity engagement and found uncomfortable weather conditions promoted home-based leisure activities. COOLS et al. [2010] conducted an online and traditional paper-and-pencil survey, collecting 586 respondents. They identified that travel demand changed with weather conditions, and travel purpose also mattered. Departure times would be changed according to weather conditions. Leisure trips and shopping trips were more dependent on weather than commuting trips. MAZE et al. [2006] concluded that roadway traffic volumes would be reduced to less than 5% in rainstorms and from 7% to 80% in snowstorms, and the exact number depended on precipitation severity and purpose of travel, such as commuter, commercial, long-distance travel. HOFMANN and O'MAHONY [2005] investigated the impact of adverse weather on bus service. They found people tried to use alternative modes of transport when it rained.

Most related studies focus on the impact of weather on walkers and cyclists. AULTMAN-HALL et al. [2009] collected hourly pedestrian volume during 12 months in downtown Montpelier, Vermont. These data were analyzed with weather data like temperature, relative humidity, precipitation and wind to investigate the impact of weather and season on pedestrian traffic volumes. They found average hourly volume level was reduced by nearly 13% by precipitation and in winter times pedestrian volume was less by 16%. SHAABAN and MULEY [2016] collected pedestrian volume data with video in a major neighborhood located in Doha, Qatar, where the average daily temperature in summer times was above 50 °C. They used multiple linear regression to investigate the relationship between pedestrian volume and weather characteristics, they found the temperature was the only significant parameter which influenced pedestrian volume. HELBICH et al. [2014] collected cyclist data in the Greater Rotterdam area, they found leisure trips seemed to be more sensitive to weather and had more significant spatial patterns than commute trips.

2.2.2 Impact of weather on public transport

Scientists study the relationship between adverse weather and public transport ridership to know more details about how weather influence travelers' mode choice. KASHFI et al. [2013] focused on the impact of rain on bus ridership in Brisbane. They found in general rainfall had a negative influence on the daily bus ridership. During morning rush-hours and weekends, it was found that ridership was more sensitive to rain than other periods of time. Their study also found that the ridership of the whole day would be significantly reduced by a small amount of morning-peak-hour rain and summer rain was most influential on ridership than the other three seasons. TAO et al. [2016] used smart card data to investigate weather's impact on bus ridership in Brisbane, they concluded that heavier rain seemed to markedly increase bus ridership compared with light rain, it meant there should be a threshold of rainfall that might trigger increase of bus demand from some transport modes, such as car users, cyclists and pedestrians. Smart card data were also used to investigate intra-day variations in weather as well as public transport ridership in Shenzhen, China. Ridership data for each metro station was collected on not only daily, but also the hourly basis, and research result confirmed hypotheses that some weather elements were more influential than others on public transportation [ZHOU et al., 2017].

3 Methodology

3.1 Questionnaire design

The questionnaire designed for this survey consists of four parts. The first part includes general information of respondents and their characteristics of public transportation use. In second part interviewees are asked about the importance of several aspects of bus and U-Bahn service. They need to qualitative service aspects on a scale of 1 to 5 (1 = totally not important, 3 = neutral, 5 = totally important). In third part satisfaction for these aspects mentioned above in bus and U -Bahn service is asked to be valued on a scale of 1 to 5 (1 = totally not satisfied, 3 = neutral, 5 = totally satisfied). The fourth part consists of general satisfaction of overall public transport service and some specific questions about the impact of adverse weather on mode choice.

In first part general information includes gender, age, occupation, ownership of car driving license, car ownership details. Characteristics of public transportation use include frequency of bus/ U-Bahn use, usual ticket type, main purpose to use public transport service (multiple choice when necessary), usual time slots to use public transport service (multiple choice when necessary), main reason to use public transport service. The main purpose and usual time slots are multiple choice questions, which use square option boxes to differ from single choice questions using circle option boxes.

Gender, age and occupation are most common questions appearing in questionnaires. Public transport is in competition with personal mobilities, and public transport operators always contribute to increasing ridership, so the information about car and driving license ownership is important. In car ownership question interviewees must decide between four answers, they are I own a car, my family owns a car that I can use, I use a company’s car, I don’t have/use a car. We need details about the accessibility of different type of car because family’s car and company’s car are not available every moment and might influence mode choice.

D’OVIDIO et al. [2014] conducted a public transport satisfaction survey in Bari, Italy, and in the first part of their questionnaire, there were some questions about frequency of bus use, usual ticket, and the main reason to use bus service. We use the same questions in our questionnaire to investigate the influence of different frequencies of public transport use, different ticket types and different main reasons to use public transport on satisfaction. We ask interviewees about use frequency for bus and U-Bahn separately because we want to investigate the impact of weather on the satisfaction of both bus and U-Bahn service in this research. According to other research results [COOLS et al., 2010], travel purpose might influence people's travel decision and behavior. Therefore we add main purpose question in the first part and use usual time slots question to differ travels during peak and off-peak hours.

To develop satisfaction model, we need interviewees' opinions for importance and satisfaction of each aspect for bus and U-Bahn service. In part two and part three we use the same table to display several service aspects and respondents must qualitative them on a scale of 1 to 5 for bus and U-Bahn service separately. Part two focuses on the importance and part three is about satisfaction.

In our questionnaire public transport service is divided into seven categories, they are comfort on board, comfort at stops, service's organization, information's availability, service's accessibility, cost and staff's behavior. These seven categories are borrowed from a survey in Bari, Italy [D'OVIDIO et al., 2014] except the last category behavior of inspectors. Because there are no fixed inspectors working in public transport in Munich, the category behavior of inspectors has been removed from our questionnaire. Normally comfort on board and comfort at stops are considered together and belong to one category, but purpose of this research is to study the impact of weather, therefore we need more details about comfort than usual and impact of weather is different between stops and vehicles, so we decide comfort on board and comfort at stops as first two categories.

There are nine aspects belonging to comfort on board: cleanliness and hygiene on board, vehicles' crowding, vehicles' modernity, safety for passengers against theft on board, number of seats, temperature on board in summer times, temperature on board in winter times, temperature on board in spring/autumn times, illumination in vehicles. Hygiene, crowding, modernity and safety are borrowed from Bali's survey [D'OVIDIO et al., 2014], and illumination is from Bilbao's survey [DEL CASTILLO and BENITEZ, 2012]. The author adds number of seats and temperature aspects to the first category. Since temperature is different in different seasons and public transport in Munich does not supply air conditioner in summer times, temperature is separately asked for summer, winter and spring/ autumn times.

There are eight aspects in category comfort at stops: cleanliness and hygiene at stops, safety for passengers against theft at stops, stops illumination, percentage of stops with shelter, protection of shelter from rain/snow/sunlight, temperature at stops in summer times, temperature at stops in winter times and temperature at stops in spring/autumn times. Hygiene, safety, illumination and temperature are similar to the aspects above, author writes percentage of stops with shelter and protection of shelter from rain/snow/sunlight into this category, because we want to focus on impact of weather and know how important in respondents' opinion are these shelters and are respondents satisfied with current shelter facilities.

Waiting time at stops during off-peak hours, waiting time at stops during peak hours, service punctuality, service frequency during off-peak hours, service frequency during peak hours, travel speed, walk distance to next line when transfer and waiting time at stops when transfer belong to third category service's organization. Waiting time and punctuality are learned from D'OVIDIO et al.'s [2014] questionnaire, and service frequency also appeared in DEL CASTILLO and BENITEZ's [2012] survey. Travel speed is travel distance divided by travel time, and it might represent one part of the overall character of public transport service. Public transport in Munich have complicated transfer systems, so how do transfer systems work is also what we are interested. Waiting time and walk distance might be the most common problems customers will complain about.

Information's availability category consists of clear timetable information at stops, timetable information on Apps or website and informative screens in vehicles. These three aspects are direct from D'OVIDIO et al.'s [2014] questionnaire.

Service's accessibility category consists of network coverage of transport line and distance between stops and destination/ home. DEL CASTILLO and BENITEZ [2012] divided accessibility category into accessibility of the bus network (number of bus stops), reduced mobility users' accessibility and adequacy of the most used bus stop location. The author uses these questions for reference.

Cost category is divided into current ticket price and variability of ticket type. We want to investigate if cost and ticket variability influence users' satisfaction.

Driver kindness and driving style belong to staff's behavior category. They appeared also in D'OVIDIO et al.'s [2014] questionnaire.

Category	Aspect
Comfort on board	Cleanliness and hygiene on board
	Vehicles' crowding
	Vehicles' modernity
	Safety for passengers against theft on board
	Number of seats
	Temperature on board in summer times
	Temperature on board in winter times
	Temperature on board in spring/autumn times
	Illumination in vehicles
Comfort at stops	Cleanliness and hygiene at stops
	Safety for passengers against theft at stops
	Stops illumination
	Percentage of stops with shelter (bus only)
	Protection of shelter from rain/snow/sunlight (bus only)
	Temperature at stops in summer times
	Temperature at stops in winter times
	Temperature at stops in spring/autumn times
Service's organization	Waiting time at stops during off-peak hours
	Waiting time at stops during peak hours
	Service punctuality
	Service frequency during off-peak hours
	Service frequency during peak hours
	Travel speed
	Walk distance to next line when transfer
	Waiting time at stops when transfer
Information's availability	Clear timetable information at stops
	Timetable information on Apps or website
	Informative screens in vehicles
Service's accessibility	Network coverage of transport line
	Distance between stops and destination/home
Cost	Current ticket price
	Variability of ticket type
Staff's behavior	Driver kindness
	Driving style (bus only)

Tab 3.1 List of Service Aspects

In fourth part, interviewees are asked about general satisfaction for whole bus, U-Bahn and overall public transport in Munich. In satisfaction survey both specific and general satisfaction will be recorded to do the factorial analysis.

EFTHYMIOU and ANTONIOU [2017] investigated impacts of economic crisis on public transport users' satisfaction in Greece. They asked interviewees how much more -or less- they used public transport now compared to five years ago and the reason why do they used more or less public transport to find the relationship between economic crisis and public transport ridership. Using their experience for reference, in this survey respondents are asked "You will use more or less Bus and U-Bahn service in following weather conditions? Please qualitative them on a scale of 1 to 5. (1 = much less, 3 = same, 5 = much more)" to focus on the effects of adverse weather. Respondents have to select the change of frequency separately for bus and U-Bahn because the impact of weather on these two traffic modes in our opinion is different, for example, most U-Bahn stations are operated indoors, and people do not need to worry about rain and getting wet when they wait for U-Bahn. Through this question, we can find if people will switch between these two modes in adverse weather besides converting from individual cars or bicycle. Adverse weather conditions are rain, snow, wind, >30°C and <0°C, because we do not want to focus on extreme weather conditions, in which people cannot go to work or go to school, extreme weathers are rare, and for us it is more important to know how people feel in normal adverse weather and how they change their behavior. According to local temperature in winter and summer, we use 30°C and 0°C to represent hotness and coldness.

Then there are questions about the reason why people use more or less bus or U-Bahn in adverse weather. The options of reason why people use more bus and U-Bahn are the same, because they have similar advantages in competition with each other, they are public transport is safer in adverse weather and public transport is more comfortable, besides these two options interviewees could fill the blank named "other" to give their own reasons, since these two given answers are obviously limited. As we mentioned above, the effect of weather on bus and U-Bahn might be different, therefore the options of the reason for less bus or U-Bahn use are slightly different. On the bus's side, these reasons are too hot/cold at stops and in vehicles, poor protection of shelter from rain/snow, adverse weather influences travel speed, prefer to stay at home in adverse weather, delay in adverse weather and blank named "other". On U-Bahn's side, these reasons are too hot/cold at stations and in vehicles, rain/snow on the way to stations, adverse weather influences travel speed, prefer to stay at home in adverse weather, delay in adverse weather and blank named “other”. The second option for bus focuses on the protection of shelter from adverse weather and the second option for U-Bahn focuses on the impact of weather on the way to stations, since there are no such protection problems when people have arrived stations.

3.2 Data collection

Munich Transport Corporation (MVG) is Germany’s biggest exclusively municipal transportation company. MVG enjoys a close partnership with the Munich Transport and Tariff Association (MVV). MVG also cooperates with private partners, S-Bahn München (suburban rail) and other regional rail companies. A 2013 mobility survey showed that 96 percent of Munich’s residents use buses, trams and U-Bahn [Münchner Verkehrsgesellschaft mbH (MVG), 2015]. Followings are some facts about MVG’s network and service [Münchner Verkehrsgesellschaft mbH (MVG), 2016].

Aspects	U-Bahn	Bus
Service routes in km	95	495
Lines	8	73
Stops	100	987
Average distance between stops in m	948	501
No. of passengers conveyed in millions in 2016	408	200

Tab 3.2 Network and Service of MVG

Followings are bus and U-Bahn network maps.

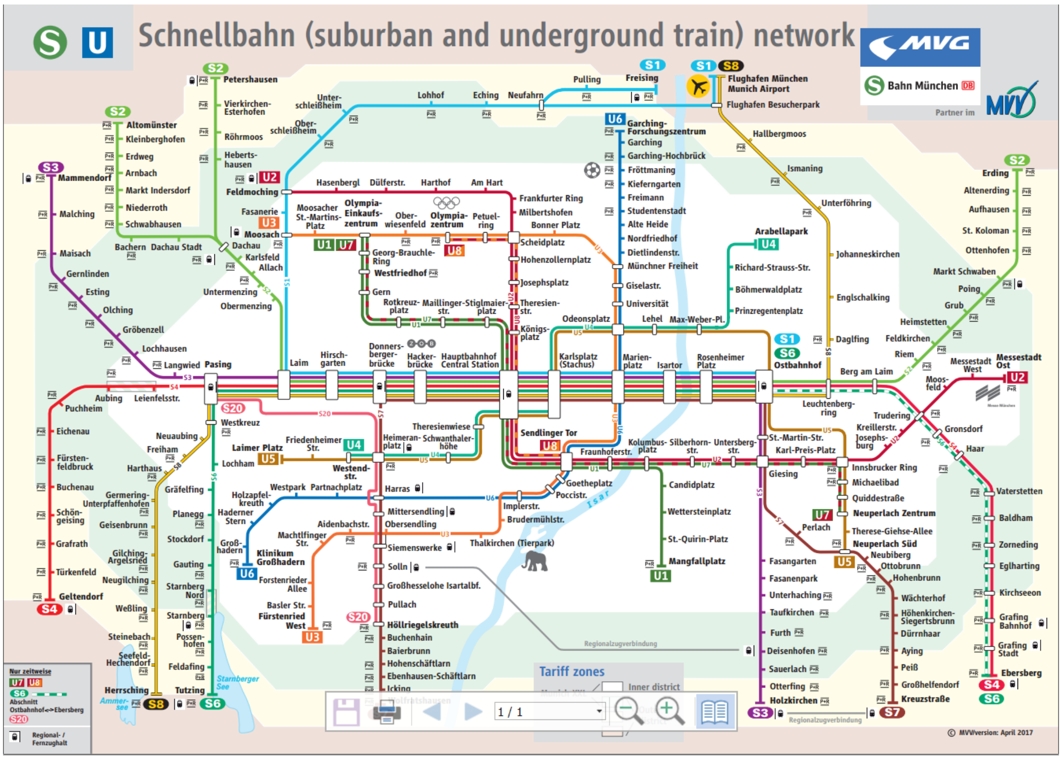

Fig 3.1 All S- and U-Bahn Lines of the Entire MVV Network[1]

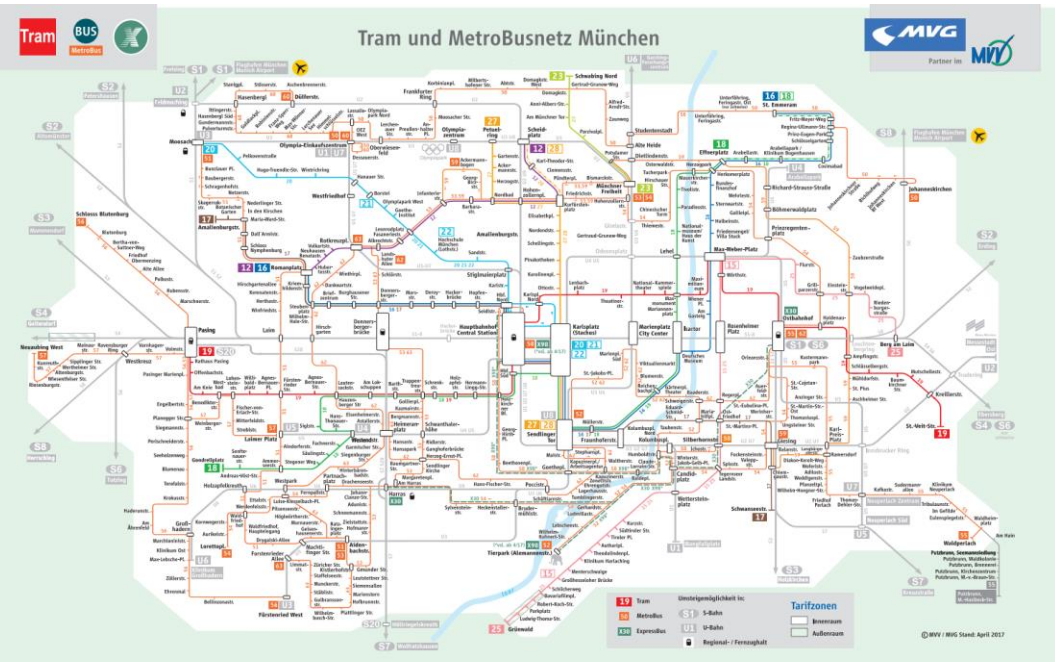

Fig 3.2 All Tram and Metrobus Lines in Munich[1]

[1] Available at http://www.mvv-muenchen.de/en/network-stations/network-maps/index.html.

Now we talk about how author conducted the survey and collected data.

After designing the questionnaire, author translated it from original English version into a German version, since this survey would be conducted in Munich, Germany and a lot of interviewees would prefer German version than the English version. Interviewees could choose the English version or German version by themselves.

There was a pilot survey conducted in July and its aim was to check the feasibility of the questionnaire. There were some problems found after pilot survey. First, the assumed survey time was not practical. In first version, author assumed total time this survey would take was eight to ten minutes. The author asked two students to do this survey and used their time as a reference. But during pilot survey, it was found that people averagely needed more time than assumed ten minutes. After observing the average time people needed, the author changed the assumed total time into ten to thirteen minutes. The possible reason of the difference between used time is that students might be more familiar with filling the questionnaire and valuing aspects, and sometimes more get used to specific professional words, for example in survey author had to sometimes explain the meaning of word “ÖPNV” in the German version. In the second version of the questionnaire, the meaning of “ÖPNV” has been explained.

Secondly, the question main reason to use public transport service in first part of survey is a single choice question, but it stands after two multiple-choice questions, and it is found that some people would treat it as multiple-choice question and selected more than one reason for using public transport, although this question has circle option boxes to differ from multiple-choice questions’ square option boxes. In the second version of the questionnaire, we emphasize that this is a single choice question and please choose only one option, but unfortunately, there were still some people ignoring this remind. The possible reasons might be that people insisted there were more than one reasons to use public transport and they could not tell which was the main reason. The second reason might be the position of this question. Standing after two multiple-choice questions might has confused interviewees.

Thirdly, author extended options for questions about the reason to use more or less public transport. In first version, there were few options for advantage and disadvantage, but the author used some answers appeared in the pilot survey for reference and extended the options.

During pilot survey author tried to collect data along U-Bahn and S-Bahn line because U-Bahn and S-Bahn service concentrate more passengers and provide better waiting environment in stations than bus, which will contribute to finding more people who would like to take part in the survey. Usually the author asked passengers who were waiting on the platform for the next train to join in the survey, because this period of waiting time was usually a little bit boring, and passengers would be less likely to refuse survey during this time. Author found it was better and easier to conduct survey along S-Bahn stations than U-Bahn stations, since the service frequency of S-Bahn is twenty minutes and service frequency of U-Bahn is ten minutes, and the real average time survey will take is thirteen minutes, which means survey conducted along S-Bahn service could help interviewees to avoid interruption of next train. In those surveys happened along U-Bahn stations people usually could not finish the survey and author had to travel with them until the questionnaire was filled completely. Therefore, most surveys were conducted along S-Bahn line after pilot survey. Although our survey focuses on bus and U-Bahn service in Munich, this method also worked, since Munich has a complicated transfer system and there are few people take only S-Bahn and take no Bus and U-Bahn.

The survey started from July 2017, and it lasted two months. Author waited along S-Bahn stations and invited passengers randomly to take part in the survey. The survey has taken place on weekdays and weekends, during peak hours and off-peak hours to cover every possible purpose of travel. Finally, we collected 191 questionnaires and 177 of them were valid.

There were some typical kinds of invalid questionnaires. The most common reason was having no enough time. Some people took much longer time than average to fill this questionnaire because neither German nor English were their mother language. Some people quitted when next train coming. The second most common reason was that some people claimed the importance and satisfaction for those aspects were the same or they chose same options for all these aspects, for example, they chose neutral for all service aspects. These answers were obviously not serious and could not be used in data analysis and model development.

There were some questionnaires not so ideal but still useable. Some people claimed that they use only bus or U-Bahn service so were not able to fill the questionnaire for both service. Some people chose the same options for Bus and U-Bahn and there were no obvious differences between these too traffic modes in their eyes. These two kinds of answers will be used for further research.

4 Data analysis

4.1 Visualization

Because of limited time and limited manpower, the distribution of the sample in this survey is asymmetrical, 58.8% of respondents are male, and 41.2% of respondents are female. 41.8% of the respondents are people by age 20-29 because author started to find respondents with similar age at the very beginning.

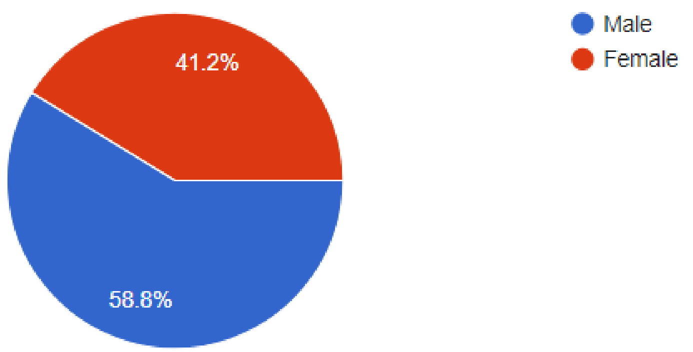

Fig 4.1 Percentage of Respondents by Gender

Age	Male	Female	Total	TotalNr
<20	4.8	11.0	7.3	13
20-29	47.1	34.2	41.8	74
30-39	22.1	17.8	20.3	36
40-49	11.5	13.7	12.4	22
50-59	7.7	15.1	10.7	19
60-69	3.8	5.5	4.5	8
>69	2.9	2.7	2.8	5

Tab 4.1 Percent Distribution of the Interviewees According to Age by Gender

Almost half of respondents (47.2%) have a full-time job. Because of the same reason mentioned above, we have 33% students in our sample.

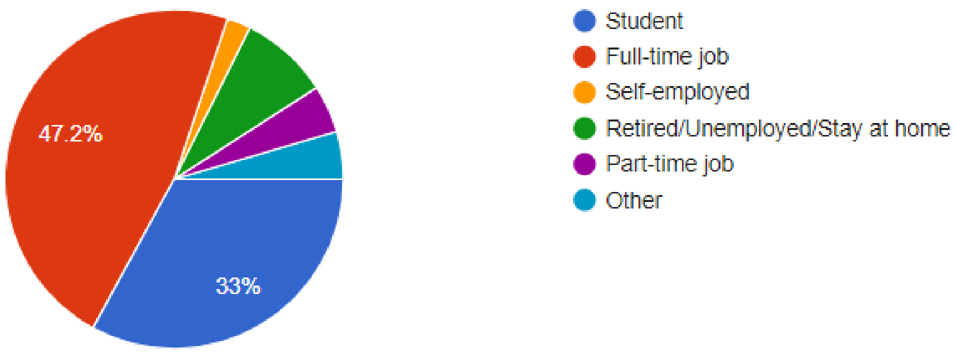

Fig 4.2 Percentage of Respondents by Occupation

Occupation	Male	Female	Total	TotalNr
Student	30.8	35.6	33	58
Full-time job	53.8	37.0	47.2	83
Self-employed	1.9	2.7	2.3	4
Retired/ Unemployed/ Stay at home	5.8	12.3	8.5	15
Part-time job	2.9	6.8	4.5	8
Other	4.8	4.1	4.5	8

Tab 4.2 Percent Distribution of the Interviewees According to Occupation by Gender

59.9% of respondents have driving license and percentage of male who have driving car license is a little bit higher than female.

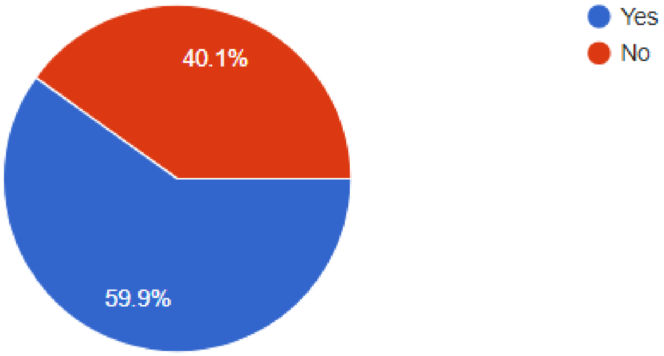

Fig 4.3 Percentage of Respondents by Driving Licence

Ownership of Car Driving Licence	Male	Female	Total	TotalNr
Yes	61.5	57.5	59.9	106
No	38.5	42.5	40.1	71

Tab 4.3 Percent Distribution of the Interviewees According to Ownership of Car Driving Licence by Gender

It is noticeable that 59.9% of respondents don’t have a car. It means they have no choice by long-distance travel. It is a common motivation to use public transport. VAN LIEROP and El-GENEIDY [2016] mentioned that there were two types of public transport users in previous studies, they were users who were dependent on transit called captive riders and car owners who chose to take transit called choice riders. It means 59.9% of respondents are captive riders in our survey.

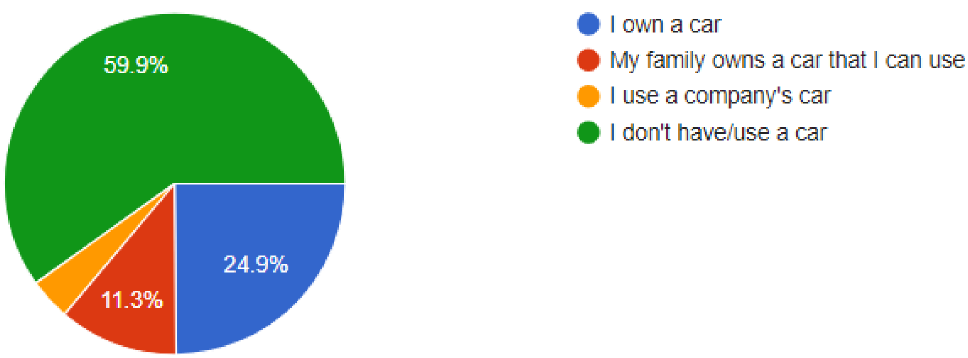

Fig 4.4 Percentage of Respondents by Access to Car

Car Ownership Details	Male	Female	Total	TotalNr
I own a car.	22.1	28.8	24.9	44
My family owns a car that I can use.	11.5	11.0	11.3	20
I use a company car.	3.8	4.1	4.0	7
I don't have/use a car.	62.5	56.2	59.9	106

Tab 4.4 Percent Distribution of the Interviewees According to Car Ownership by Gender

Almost one-third of the sample (32.7%) take bus every day and this number increases to more than half (54.0%) when it comes to U-Bahn.

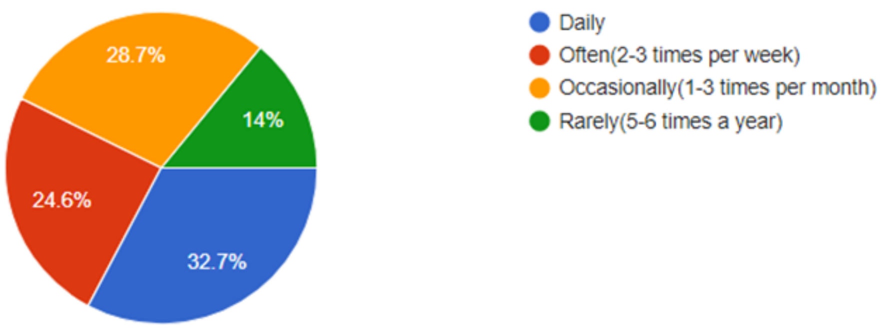

Fig 4.5 Percentage of Respondents by Bus Use Frequency

Frequency of Bus Use	Male	Female	Total	TotalNr
Daily	32.7	30.1	32.7	56
Often (2-3 times per week)	23.1	24.7	24.6	42
Occasionally (1-3 times per month)	27.9	27.4	28.7	49
Rarely (5-6 times a year)	13.5	13.7	14.0	24

Tab 4.5 Percent Distribution of the Interviewees According to Frequency of Bus Use by Gender

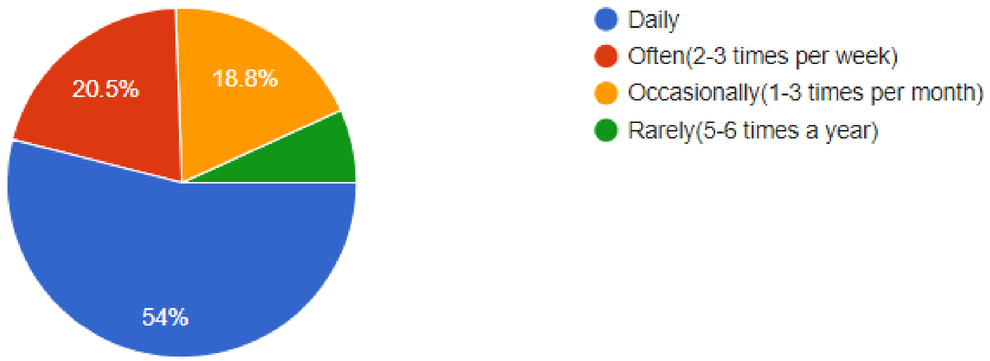

Fig 4.6 Percentage of Respondents by U-Bahn Use Frequency

Frequency of U-Bahn Use	Male	Female	Total	TotalNr
Daily	58.7	46.6	54.0	95
Often (2-3 times per week)	18.3	23.3	20.5	36
Occasionally (1-3 times per month)	14.4	24.7	18.8	33
Rarely (5-6 times a year)	8.7	4.1	6.8	12

Tab 4.6 Percent Distribution of the Interviewees According to Frequency of U-Bahn Use by Gender

44.9% of respondents are using the annual ticket, but we must take the large percentage of students into account. Another important component of respondents are people who use the monthly ticket.

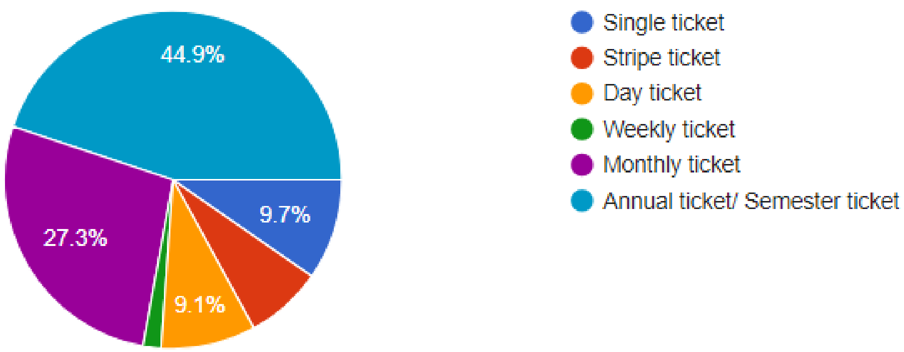

Fig 4.7 Percentage of Respondents by Ticket Type

Usual Ticket Type	Male	Female	Total	TotalNr
Single ticket	9.6	9.6	9.7	17
Stripe ticket	6.7	8.2	7.4	13
Day ticket	7.7	11.0	9.1	16
Weekly ticket	1.0	2.7	1.7	3
Monthly ticket	25.0	30.1	27.3	48
Annual ticket/ Semester ticket	50.0	37.0	44.9	79

Tab 4.7 Percent Distribution of the Interviewees According to Usual Ticket Type by Gender

Since almost half of respondents have a full-time job, the most common purposes to use public transport are work and leisure.

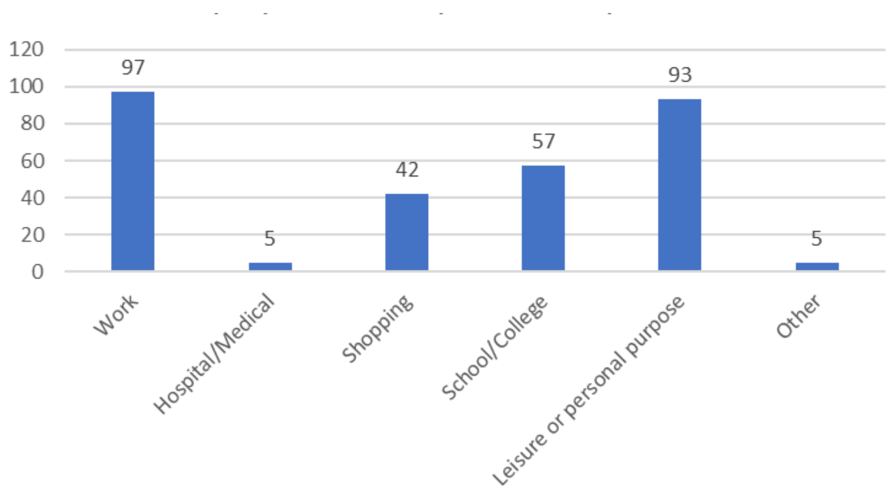

Fig 4.8 Main Purpose to Use Public Transport Service

Most usual time slots to use public transport are 07:00 to 09:59 and 16:00 to 18:59 since these time slots are rush hour.

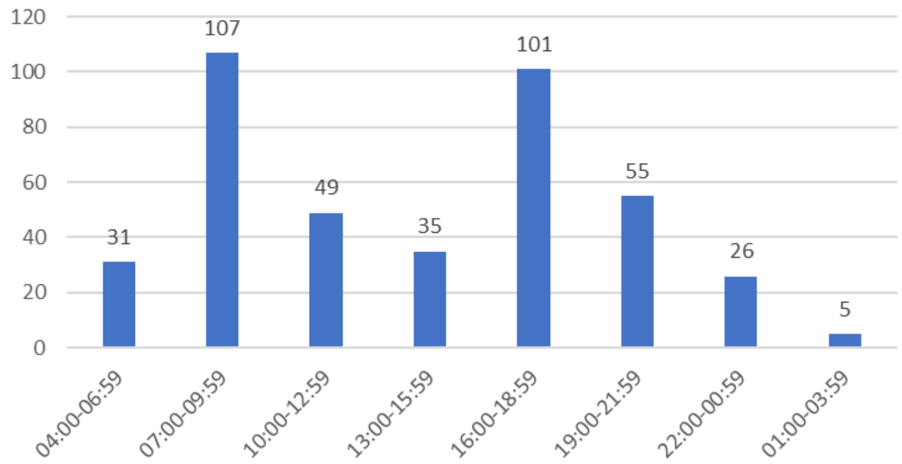

Fig 4.9 Usual Time Slots to Use Public Transport Service

The question of the main reason to use public transport is designed as a single-choice question but we found respondents tended to treat it as a multiple-choice question. The most common reason is lack of own transport (no license/ no car/ car is occupied by others).

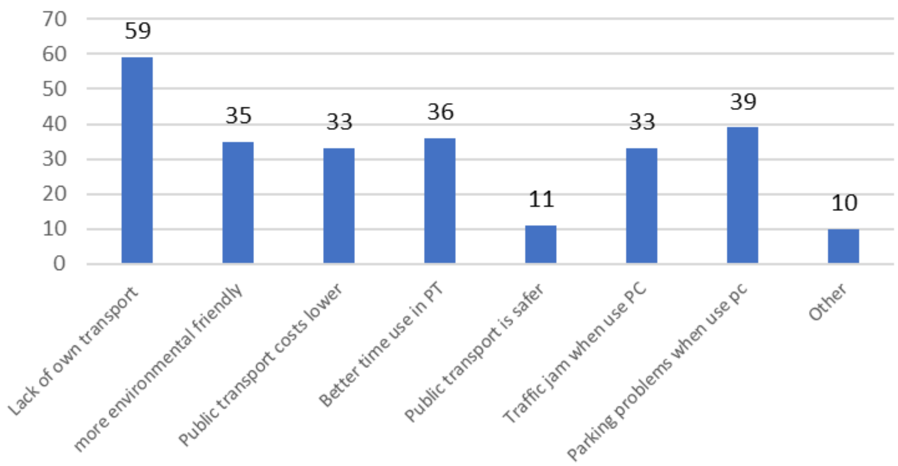

Fig 4.10 Main Reason to Use Public Transport Service

Now we use R-studio to calculate the mean value, standard deviation, skewness and kurtosis of importance and satisfaction on different service aspects of bus and U-Bahn. Code is as following.

```
>library(gdata)
>mydata <- read.xls("ts4.xls", header=TRUE, perl="C:\\Strawberry\\perl\\bin\\perl.exe")
> names(mydata)
> vars <- c( "IBCleanHygieBoard" , "IBVehiclCrowd" , "IBVehiclModern",
"IBSafeForPassengBoard", "IBNumbOfSeat", "IBTemperBoardSummer",
"IBTemperBoardWinter", "IBTemperBoardSpring", "IBIlluminaInVehicl", "IBCleanHygieStop",
"IBSafeForPassengStop", "IBStopIllumina", "IBPercentaStopWiShelter",
"IBProtectShelterFrRain", "IBTemperStopSummer", "IBTemperStopWinter",
"IBTemperStopSpring", "IBWaitTimeStopOffPeak", "IBWaitTimeStopPeak", "IBServPunctu",
"IBServFrequenOffPeak" , "IBServFrequenPeak", "IBTravSpeed", "IBWalkDistanTransfer",
"IBWaitTimeStopTransfer", "IBClearTimeTableStop", "IBTimeTableAPP",
"IBInfoScreenVehicl", "IBNetworkCoverage", "IBDistanStopHome", "IBCurrenTicketPrice",
"IBVariabiliTicketTyp", "IBDriverKind", "IBDrivStyle")
> install.packages("psych")
> library(psych)
> describe(mydata[vars])
```

Function “describe” are defined in package “psych”, researchers must install the package “psych” to call “describe” function. Codes above are applied to calculate basic descriptive statistics on the importance of bus service and following codes are applied to calculate basic descriptive statistics on the importance of U-Bahn service, the satisfaction of bus service and satisfaction of U-Bahn service.

```
> describe(mydata[48:81])
> describe(mydata[78:111])
> describe(mydata[112:142])
```

To make variables easier to deal with, author gave these variables shorter names in XLS file. Followed are a checklist of variables with original and shorter names and the results of calling “describe” function.

After comparing Tab. 4.9 and Tab. 4.10 we could have some conclusions: Respondents think cleanliness and hygiene on board (4.04, 4.05)[2], temperature on board in summer times (4.15,4.11), protection of shelter from rain/snow/sunlight (4.24), waiting time at stops during peak hours (4.13, 4.11), service punctuality (4.43, 4.39), service frequency during peak hours

[2] First number represents mean value of importance in bus service, and second number represents mean value of importance in U-Bahn service.

(4.17, 4.10), clear timetable information at stops (4.34, 4.41), timetable information on Apps or website (4.08, 4.06) and current ticket price (4.04, 4.02) are more important than other variables, service punctuality and clear timetable information at stops are most important ones. Vehicles' modernity (3.16, 3.11), temperature on board in spring/autumn times (3.23, 3.28), illumination in vehicles (3.27, 3.42), temperature at stops in summer times (3.40, 3.42), temperature at stops in winter times (3.49, 3.50) and temperature at stops in spring/autumn time (2.93, 3.11) are least important variables. In addition, temperature on board in summer times (4.15, 4.11) and temperature on board in winter times (3.92, 3.89) are more important than temperature at stops in summer times (3.40, 3.42) and temperature at stops in winter times (3.49, 3.50) according to respondents' opinion. Stops illumination (3.86, 3.88) is more important than illumination in vehicles (3.27, 3.42). Service frequency during peak hours (4.17, 4.10) and waiting time at stops during peak hours (4.13, 4.11) are a little bit more important than service frequency during off-peak hours (3.92, 3.88) and waiting time at stops during off-peak hours (3.94, 3.94). Illumination in vehicle of bus service (3.27) is less important than illumination in vehicle of U-Bahn service (3.42). Driver kindness of bus service (3.76) is more important than driver kindness of U-Bahn service (3.56).

After comparing Tab. 4. 11 and Tab. 4.12 we could have some conclusions: Respondents are more satisfied with safety for passengers against theft on board (3.75, 3.71), temperature on board in spring/autumn times (3.78, 3.79), illumination in vehicles (3.92, 3.95), timetable information on Apps or website (3.83, 3.88) and informative screens in vehicles (3.78, 3.70) than other variables. The performance in aspects vehicles' crowding (3.25, 3.10), temperature on board in summer times (3.23, 3.26), service frequency during off-peak hours (3.10, 3.23), current ticket price (2.85, 2.84) and variability of ticket type (3.21, 3.23) perform not as well as other aspects. In addition, respondents are more satisfied with cleanliness and hygiene on board in bus service (3.67) than cleanliness and hygiene at stops in bus service (3.37). This aspect has no such big difference in U-Bahn service. Temperature on board in summer times (3.23, 3.26) earns less satisfaction than temperature on board in winter times (3.67, 3.70) and temperature on board in spring/autumn times (3.78, 3.79). Respondents are less satisfied with waiting time at stops during off-peak hours (3.15, 3.31) and service frequency during off-peak hours (3.10, 3.23) than waiting time at stops during peak hours (3.24, 3.36) and service frequency during peak hours (3.32, 3.43). People are more satisfied with stops illumination in U-Bahn service (3.88) than in bus service (3.61). Temperature at stops in summer times and temperature at stops in winter times earn more satisfaction in U-Bahn service (3.49)[3] than bus service (3.14)[3]. U-Bahn has better performance in aspect clear timetable information at stops (3.75) than bus (3.56). Network coverage of transport line in bus service (3.57) is better than U-Bahn service (3.35).

[3] Mean value for winter and summer times are the same.

Shortened Form	Original Form
CleanHygieBoard	Cleanliness and hygiene on board
VehiclCrowd	Vehicles' crowding
VehiclModern	Vehicles' modernity
SafeForPassengBoard	Safety for passengers against theft on board
NumbOfSeat	Number of seats
TemperBoardSummer	Temperature on board in summer times
TemperBoardWinter	Temperature on board in winter times
TemperBoardSpring	Temperature on board in spring/autumn times
IlluminaInVehicl	Illumination in vehicles
CleanHygieStop	Cleanliness and hygiene at stops
SafeForPassengStop	Safety for passengers against theft at stops
StopIllumina	Stops illumination
PercentaStopWiShelter	Percentage of stops with shelter
ProtectShelterFrRain	Protection of shelter from rain/snow/sunlight
TemperStopSummer	Temperature at stops in summer times
TemperStopWinter	Temperature at stops in winter times
TemperStopSpring	Temperature at stops in spring/autumn times
WaitTimeStopOffPeak	Waiting time at stops during off-peak hours
WaitTimeStopPeak	Waiting time at stops during peak hours
ServPunctu	Service punctuality
ServFrequenOffPeak	Service frequency during off-peak hours
ServFrequenPeak	Service frequency during peak hours
TravSpeed	Travel speed
WalkDistanTransfer	Walk distance to next line when transfer
WaitTimeStopTransfer	Waiting time at stops when transfer
ClearTimeTableStop	Clear timetable information at stops
TimeTableAPP	Timetable information on Apps or website
InfoScreenVehicl	Informative screens in vehicles
NetworkCoverage	Network coverage of transport line
DistanStopHome	Distance between stops and destination/home
CurrenTicketPrice	Current ticket price
VariabiliTicketTyp	Variability of ticket type
DriverKind	Driver kindness
DrivStyle	Driving style

Tab 4.8 Variables in Shortened and Original Form

Aspect	n	mean	sd	skew	kurtosis
IBCleanHygieBoard	169	4.04	1.03	-1.06	0.74
IBVehiclCrowd	169	3.60	1.06	-0.43	-0.20
IBVehiclModern	169	3.16	1.15	-0.15	-0.53
IBSafeForPassengBoard	169	3.96	1.16	-0.85	-0.25
IBNumbOfSeat	169	3.65	1.16	-0.52	-0.56
IBTemperBoardSummer	169	4.15	1.11	-1.26	0.73
IBTemperBoardWinter	169	3.92	1.12	-0.72	-0.42
IBTemperBoardSpring	169	3.23	1.21	-0.20	-0.67
IBIlluminaInVehicl	169	3.27	1.14	-0.17	-0.73
IBCleanHygieStop	169	3.82	1.04	-0.63	-0.26
IBSafeForPassengStop	169	3.93	1.18	-0.78	-0.43
IBStopIllumina	169	3.86	1.07	-0.82	0.15
IBPercentaStopWiShelter	169	3.95	1.03	-0.65	-0.34
IBProtectShelterFrRain	169	4.24	0.95	-1.26	1.20
IBTemperStopSummer	169	3.40	1.29	-0.34	-0.85
IBTemperStopWinter	168	3.49	1.30	-0.41	-0.88
IBTemperStopSpring	169	2.93	1.20	-0.04	-0.59
IBWaitTimeStopOffPeak	169	3.94	1.06	-0.70	-0.28
IBWaitTimeStopPeak	169	4.13	1.07	-0.99	0.09
IBServPunctu	169	4.43	0.92	-1.79	2.84
IBServFrequenOffPeak	169	3.92	0.98	-0.43	-0.64
IBServFrequenPeak	169	4.17	0.99	-0.81	-0.49
IBTravSpeed	169	3.84	0.95	-0.38	-0.66
IBWalkDistanTransfer	169	3.92	0.97	-0.57	-0.35
IBWaitTimeStopTransfer	169	4.01	0.96	-0.62	-0.50
IBClearTimeTableStop	169	4.34	1.09	-1.69	1.94
IBTimeTableAPP	169	4.08	1.19	-1.09	0.13
IBInfoScreenVehicl	169	3.88	1.23	-0.82	-0.30
IBNetworkCoverage	169	3.94	1.09	-0.88	0.14
IBDistanStopHome	169	3.90	1.04	-0.69	-0.08
IBCurrenTicketPrice	169	4.04	1.14	-0.92	-0.14
IBVariabiliTicketTyp	169	3.91	1.19	-0.78	-0.40
IBDriverKind	169	3.76	1.15	-0.63	-0.43
IBDrivStyle	169	3.89	1.16	-0.79	-0.16

Tab 4.9 Basic Descriptive Statistics on Importance of Bus Service

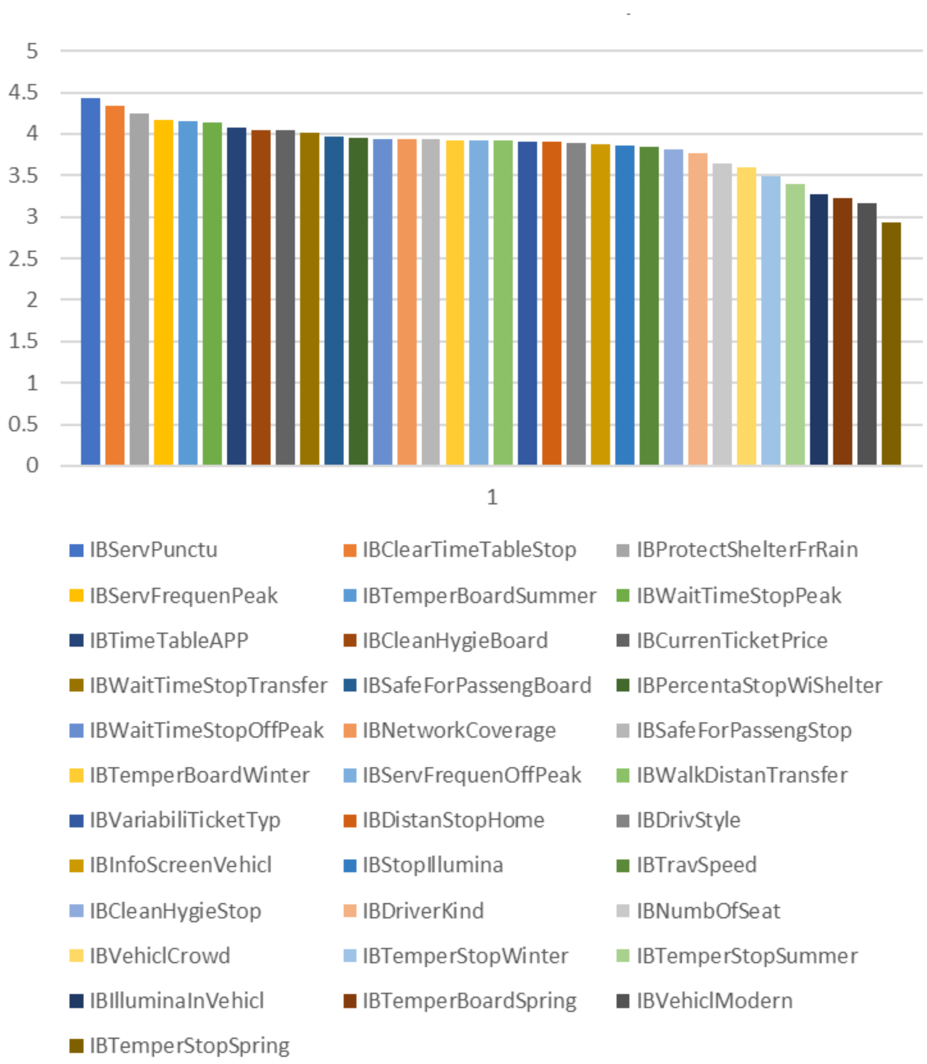

Fig 4.11 Mean Value of Bus Service Importance

Aspect	n	mean	sd	skew	kurtosis
IUCleanHygieBoard	176	4.05	1.02	-0.93	0.27
IUVehiclCrowd	176	3.57	1.10	-0.43	-0.39
IUVehiclModern	176	3.11	1.16	-0.09	-0.62
IUSafeForPassengBoard	176	3.98	1.18	-0.90	-0.18
IUNumbOfSeat	176	3.60	1.19	-0.49	-0.64
IUTemperBoardSummer	176	4.11	1.12	-1.20	0.55
IUTemperBoardWinter	176	3.89	1.16	-0.71	-0.53
IUTemperBoardSpring	176	3.28	1.23	-0.17	-0.80
IUIlluminaInVehicl	176	3.42	1.12	-0.25	-0.70
IUCleanHygieStop	176	3.89	1.00	-0.76	0.22
IUSafeForPassengStop	176	3.89	1.17	-0.72	-0.49
IUStopIllumina	176	3.88	1.06	-0.73	-0.01
IUTemperStopSummer	176	3.42	1.19	-0.28	-0.61
IUTemperStopWinter	175	3.50	1.19	-0.34	-0.62
IUTemperStopSpring	176	3.11	1.16	-0.01	-0.45
IUWaitTimeStopOffPeak	176	3.94	1.04	-0.58	-0.53
IUWaitTimeStopPeak	176	4.11	1.06	-0.94	0.04
IUServPunctu	176	4.39	1.03	-1.81	2.62
IUServFrequenOffPeak	176	3.88	1.05	-0.53	-0.47
IUServFrequenPeak	176	4.10	1.07	-0.80	-0.55
IUTravSpeed	176	3.86	1.00	-0.60	-0.16
IUWalkDistanTransfer	176	3.92	0.98	-0.54	-0.59
IUWaitTimeStopTransfer	176	3.98	1.00	-0.78	0.14
IUClearTimeTableStop	175	4.41	1.03	-1.87	2.78
IUTimeTableAPP	176	4.06	1.19	-1.09	0.15
IUInfoScreenVehicl	176	3.86	1.23	-0.80	-0.31
IUNetworkCoverage	176	3.99	1.14	-1.02	0.30
IUDistanStopHome	176	3.84	1.10	-0.69	-0.21
IUCurrenTicketPrice	175	4.02	1.14	-0.91	-0.17
IUVariabiliTicketTyp	175	3.87	1.23	-0.79	-0.43
IUDriverKind	176	3.56	1.25	-0.47	-0.75

Tab 4.10 Basic Descriptive Statistics on Importance of U-Bahn Service

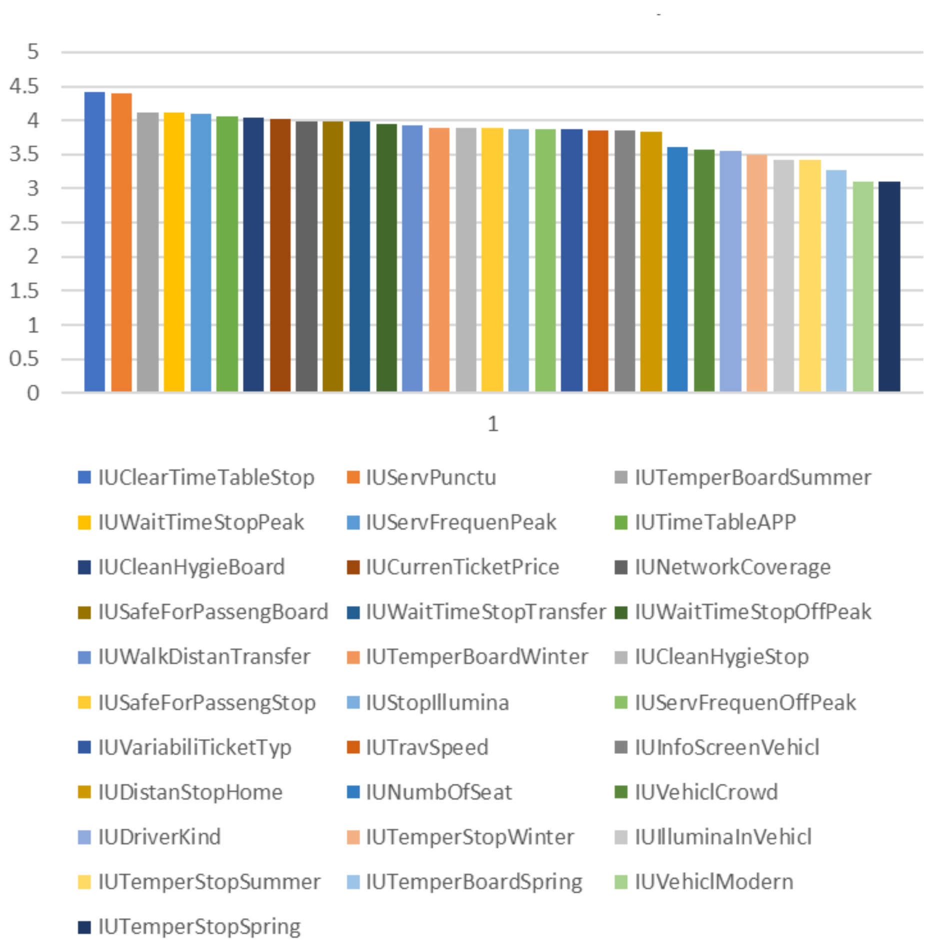

Fig 4.12 Mean Value of U-Bahn Service Importance

Aspect	n	mean	sd	skew	kurtosis
SBCleanHygieBoard	169	3.67	1.08	-0.38	-0.74
SBVehiclCrowd	169	3.25	0.97	-0.16	-0.14
SBVehiclModern	169	3.60	0.99	-0.34	-0.21
SBSafeForPassengBoard	169	3.75	1.08	-0.44	-0.45
SBNumbOfSeat	169	3.67	1.00	-0.34	-0.39
SBTemperBoardSummer	169	3.23	1.24	-0.22	-0.93
SBTemperBoardWinter	169	3.67	1.04	-0.40	-0.32
SBTemperBoardSpring	169	3.78	1.05	-0.49	-0.25
SBIlluminaInVehicl	169	3.92	0.94	-0.61	0.02
SBCleanHygieStop	169	3.37	1.03	-0.16	-0.53
SBSafeForPassengStop	169	3.63	1.02	-0.24	-0.52
SBStopIllumina	169	3.61	1.09	-0.43	-0.55
SBPercentaStopWiShelter	169	3.42	1.00	0.02	-0.66
SBProtectShelterFrRain	169	3.38	1.01	-0.05	-0.61
SBTemperStopSummer	169	3.14	1.12	-0.08	-0.44
SBTemperStopWinter	169	3.14	1.14	-0.03	-0.61
SBTemperStopSpring	169	3.56	0.96	0.12	-0.52
SBWaitTimeStopOffPeak	169	3.15	1.12	-0.16	-0.64
SBWaitTimeStopPeak	169	3.24	1.17	-0.15	-0.78
SBServPunctu	169	3.22	1.14	-0.04	-0.87
SBServFrequenOffPeak	169	3.10	1.08	-0.14	-0.50
SBServFrequenPeak	168	3.32	1.11	-0.32	-0.45
SBTravSpeed	168	3.51	0.98	-0.32	-0.38
SBWalkDistanTransfer	169	3.57	0.92	-0.33	-0.19
SBWaitTimeStopTransfer	169	3.30	1.06	-0.17	-0.57
SBClearTimeTableStop	169	3.56	1.25	-0.37	-1.01
SBTimeTableAPP	169	3.83	1.08	-0.62	-0.29
SBInfoScreenVehicl	169	3.78	1.13	-0.65	-0.32
SBNetworkCoverage	169	3.57	1.00	-0.53	0.20
SBDistanStopHome	169	3.69	0.97	-0.37	-0.19
SBCurrenTicketPrice	169	2.85	1.28	0.11	-1.01
SBVariabiliTicketTyp	169	3.21	1.16	-0.14	-0.66
SBDriverKind	168	3.66	1.00	-0.39	-0.36
SBDrivStyle	168	3.65	1.03	-0.38	-0.23

Tab 4.11 Basic Descriptive Statistics on Satisfaction of Bus Service

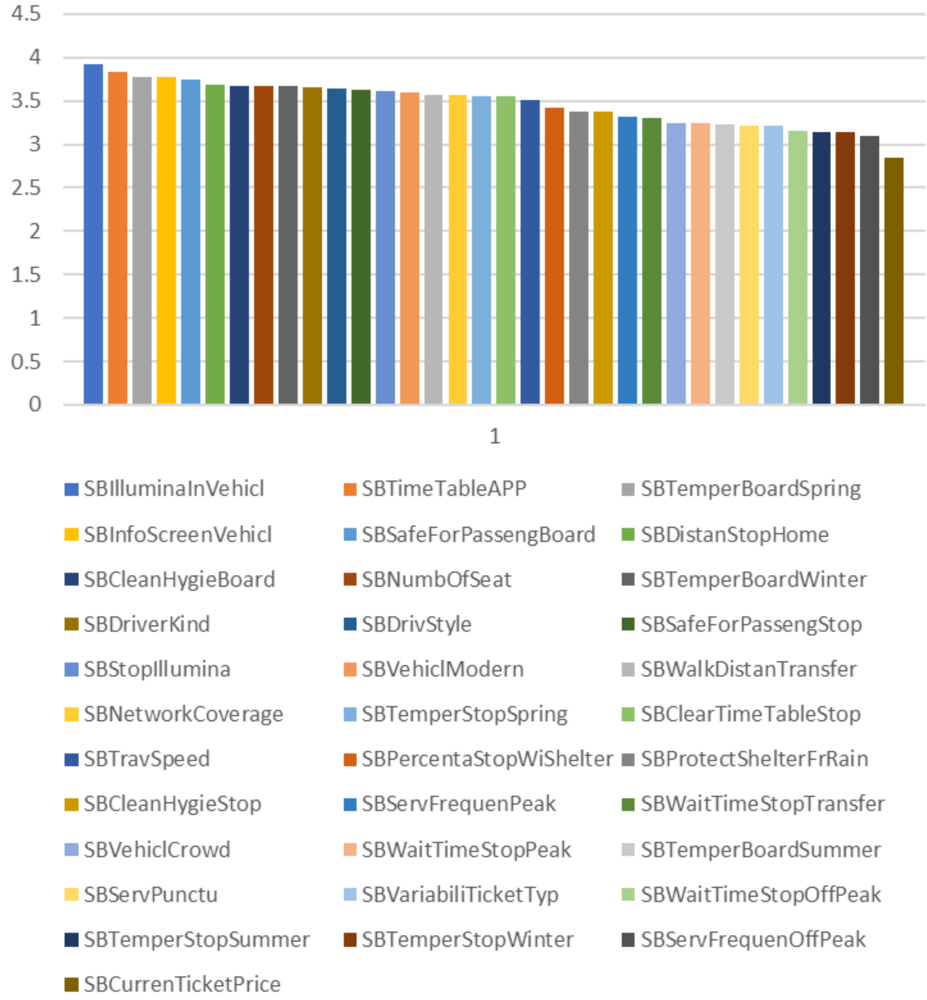

Fig 4.13 Mean Value of Bus Service Satisfaction

Aspect	n	mean	sd	skew	kurtosis
SUCleanHygieBoard	176	3.55	1.09	-0.30	-0.70
SUVehiclCrowd	176	3.10	0.98	-0.12	-0.23
SUVehiclModern	176	3.42	0.98	-0.22	-0.21
SUSafeForPassengBoard	176	3.71	1.10	-0.42	-0.48
SUNumbOfSeat	176	3.66	1.03	-0.38	-0.42
SUTemperBoardSummer	176	3.26	1.25	-0.14	-1.00
SUTemperBoardWinter	176	3.70	1.10	-0.50	-0.46
SUTemperBoardSpring	176	3.79	1.04	-0.52	-0.20
SUIlluminaInVehicl	176	3.95	1.05	-0.74	-0.18
SUCleanHygieStop	176	3.49	1.03	-0.29	-0.42
SUSafeForPassengStop	176	3.66	0.99	-0.20	-0.61
SUStopIllumina	176	3.88	1.01	-0.67	0.03
SUTemperStopSummer	176	3.49	1.12	-0.19	-0.67
SUTemperStopWinter	176	3.49	1.07	-0.12	-0.56
SUTemperStopSpring	176	3.65	0.98	0.06	-0.84
SUWaitTimeStopOffPeak	176	3.31	1.11	-0.07	-0.71
SUWaitTimeStopPeak	176	3.36	1.20	-0.23	-0.90
SUServPunctu	176	3.33	1.16	-0.26	-0.80
SUServFrequenOffPeak	176	3.23	1.09	-0.09	-0.69
SUServFrequenPeak	176	3.43	1.12	-0.35	-0.55
SUTravSpeed	176	3.69	1.06	-0.68	-0.01
SUWalkDistanTransfer	176	3.59	1.01	-0.33	-0.50
SUWaitTimeStopTransfer	176	3.41	1.09	-0.37	-0.49
SUClearTimeTableStop	176	3.75	1.27	-0.73	-0.58
SUTimeTableAPP	176	3.88	1.11	-0.76	-0.17
SUInfoScreenVehicl	176	3.70	1.17	-0.56	-0.57
SUNetworkCoverage	176	3.35	1.07	-0.35	-0.28
SUDistanStopHome	176	3.59	1.08	-0.37	-0.50
SUCurrenTicketPrice	176	2.84	1.24	0.19	-0.87
SUVariabiliTicketTyp	175	3.23	1.19	-0.18	-0.73
SUDriverKind	176	3.60	1.07	-0.49	-0.18

Tab 4.12 Basic Descriptive Statistics on Satisfaction of U-Bahn Service

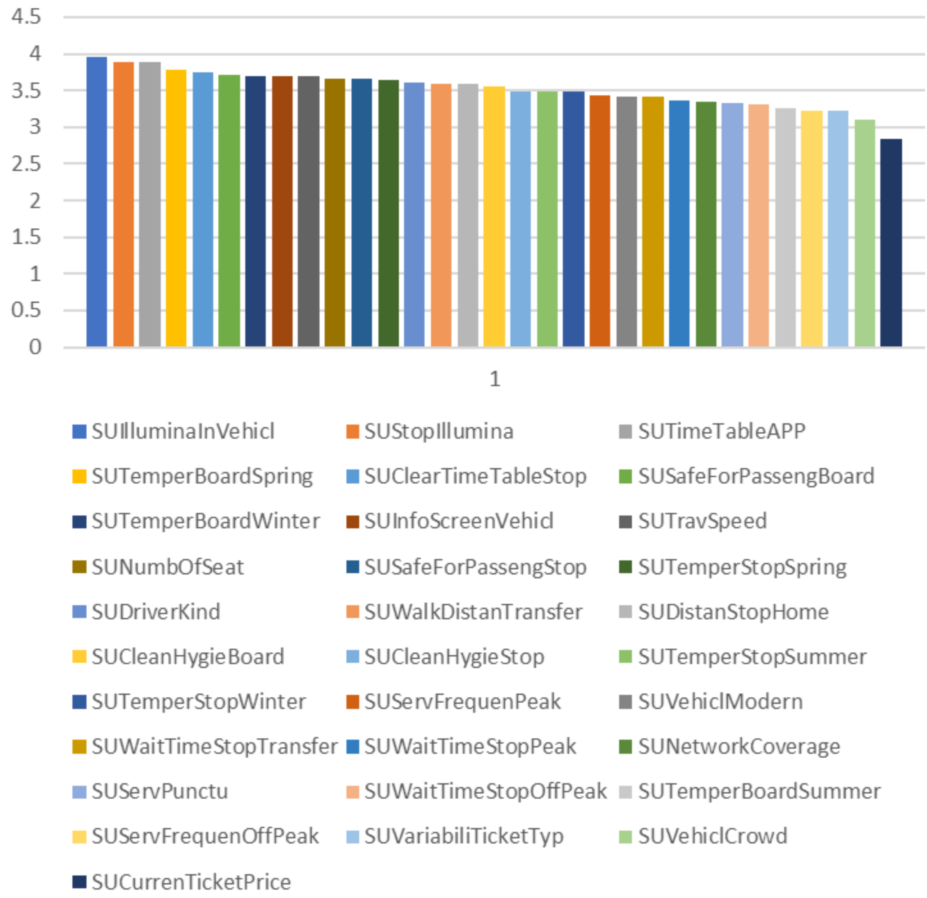

Fig 4.14 Mean Value of U-Bahn Service Satisfaction

We could find in Fig. 4.15 that most respondents are satisfied with bus (42.2%), U-Bahn (43.2%) and overall public transport (52.5%) in Munich. We should notice that overall public transport in Munich includes Tram, S-Bahn, bus, and U-Bahn. It is also noticeable that more people choose neutral or not satisfied for bus than U-Bahn, more people are satisfied or totally satisfied with U-Bahn than bus. The difference is obvious in options not satisfied and totally satisfied. 13.9% of respondent are not satisfied with bus and 9.1% with U-Bahn, and 13.9% of respondents are totally satisfied with bus and 21% with U-Bahn.

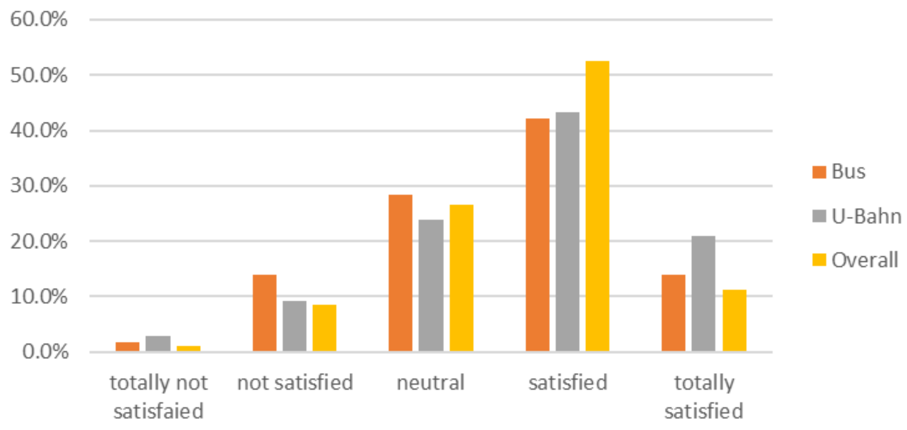

Fig 4.15 How Satisfied are you with Public Transport in Munich

If we compare Fig. 4.16 and Fig. 4.17, we could find that most people use the same traffic mode in adverse weather conditions. Wind has the least influence on mode choice, 64.7% of respondents will use bus as usual and 64.4% use U-Bahn as usual on windy days. It is obvious that more people tend to choose more U-Bahn than bus in adverse weather conditions. In addition, people will use much more bus and U-Bahn in rainy and snowy days than other weather conditions.

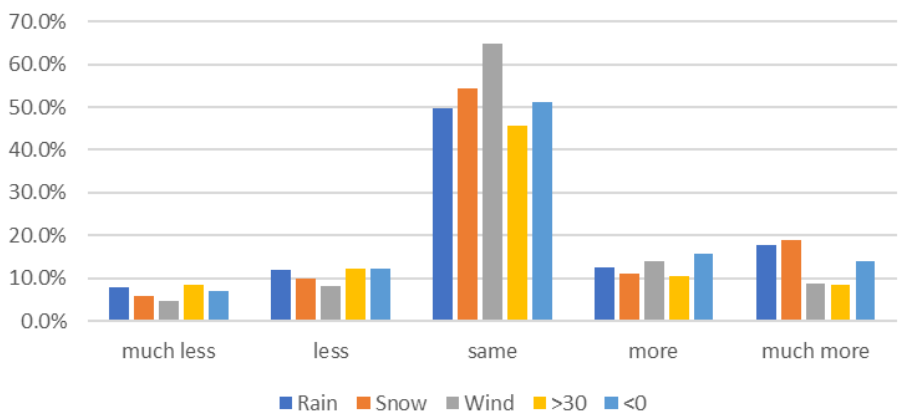

Fig 4.16 You will Use More or Less Bus Service in Following Weather Conditions

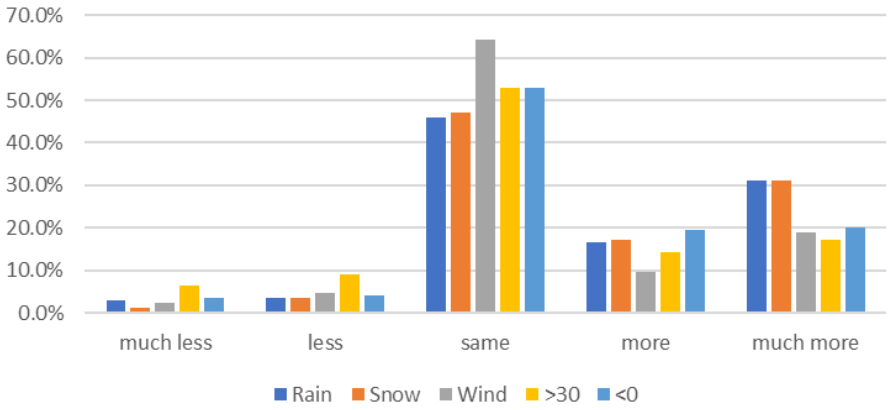

Fig 4.17 You will Use More or Less U-Bahn Service in Following Weather Conditions

In Fig. 4.18 and Fig. 4.19 we could find more people give the reason for less use of bus service in adverse weather conditions. Too hot/cold at stops and in vehicles, poor protection of shelter from rain/snow and delay in adverse weather are main reasons to use less bus. More people give a reason for more use of U-Bahn service. Main reasons are public transport is safer in adverse weather and public transport is more comfortable.

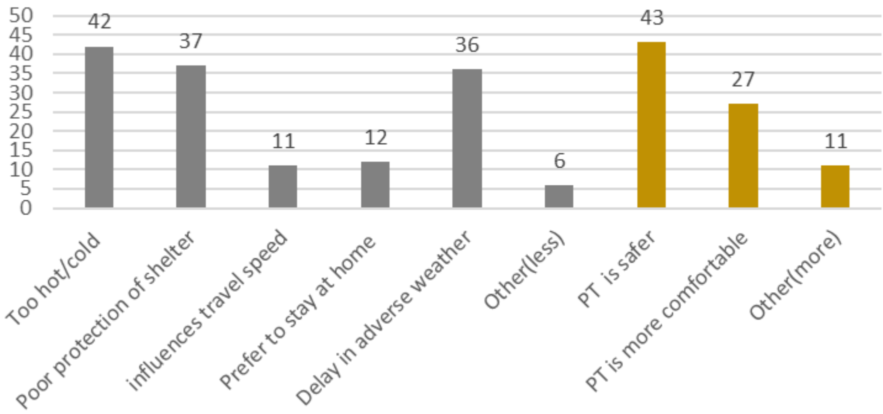

Fig 4.18 Why do You Use More/ Less Bus Service in Adverse Weather

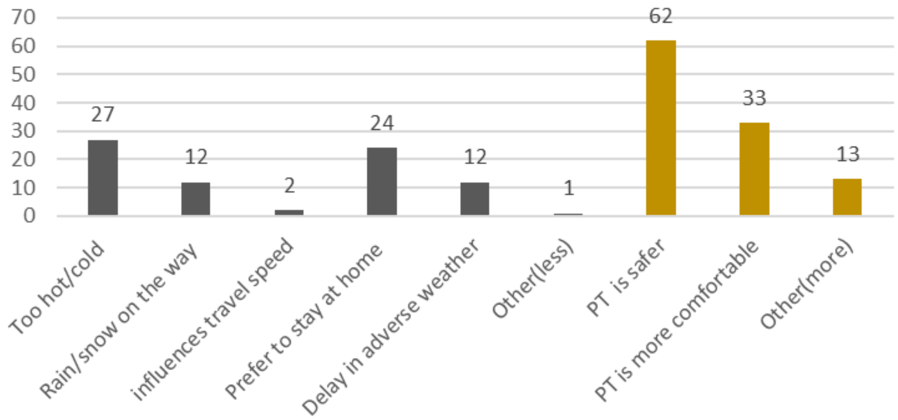

Fig 4.19 Why do You Use More/ Less U-Bahn Service in Adverse Weather

4.2 Statistical test

T-test could be applied to identify whether two sets of data are significantly different from each other and the test statistic would follow a normal distribution [STUDENT, 1908]. The null hypothesis is that the means of two populations are equal. If the variances of the two populations are assumed to be equal, Student's t-tests could be applied.

Welch's t-test, is applied only when the two population variances are assumed to be unequal (the two sample sizes could be different) and hence must be calculated separately [WELCH, 1938].

The author used a t-test to compare satisfaction for bus, U-Bahn and overall service and the use frequency of bus and U-Bahn in adverse weather between different groups, divided by different characteristics, such as gender, age, ownership of the driving license, ownership of car, and use frequency of bus and U-Bahn. The null hypothesis is that difference in means is equal to 0, and statistical significance of the teat is 5%. Followings are groups whose p-value <0.05, it means null hypothesis might be rejected, the satisfaction or use frequency might be different.

We could do Welch two-sample t-test in RStudio using

```
>t.test (y~x, data)
```

where data is the name of dataset we used, y is numerical variable and x is dichotomous variable.

First, female and male might behave differently on windy days. Female tend to use more U-Bahn on windy days and wind seems to make no influence on the male respondents.

Aspect	Group1	Group2	p-value
MoreLessUbahnWind	Female	Male	0.04367
	3.556	3.265	

Tab 4.13 Means of Use Frequency of U-Bahn in Windy Days between Different Gender Group

To have a clearer view of the difference between groups, we use dotchart in R Studio. Different colors represent different groups, and each point represents the answer of respondents. The command statement in R Studio for the Fig. 4.20 is shown as an example. We could find in Fig. 4.20 that there are more females choose to use much more U-Bahn on windy days.

```
> x <- mydata[order(mydata$MoreLessUbahnWind),]
> x$Gender <- factor(x$Gender)
> x$color[x$Gender== "Male"] <- "darkgreen"
> x$color[x$Gender== "Female"] <- "red"
> dotchart(x$MoreLessUbahnWind, groups=x$Gender,color=x$color,pch=19)
```

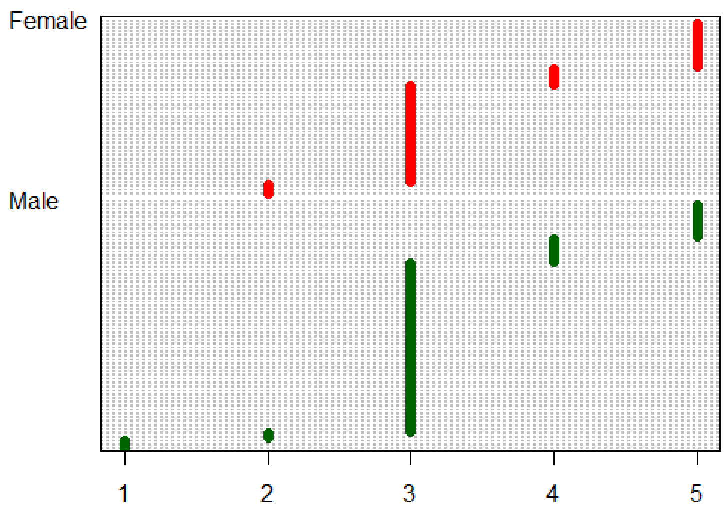

Fig 4.20 Use More or Less U-Bahn in Windy Days by Gender

For people who have no driving license, high temperature will make them use more bus and U-Bahn, on rainy days they will use more U-Bahn than before. But for people who have a driving license, they use less bus in hot weather and use more U-Bahn on rainy days.

Aspect	Group1	Group2	p-value
MoreLessBus30	No	Yes	0.001823
	3.286	2.765	
MoreLessUBahnRain	No	Yes	0.003892
	3.971	3.510	
MoreLessUBahn30	No	Yes	0.001848
	3.571	3.067	

Tab 4.14 Means of Use Frequency of U-Bahn and Bus between Respondents Owning or not Owning Driving Licence

It is obvious in Fig. 4.21 that respondents without driving license tend to use more bus and respondents with driving license tend to use less bus because of hotness. In Fig. 4.23 we find hotness does not influence the U-Bahn ridership in the group of people with a driving license. And rain has a similar effect on both groups.

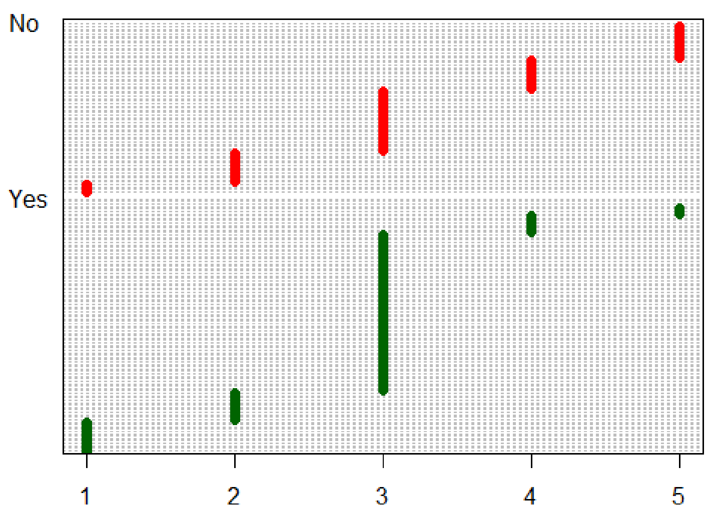

Fig 4.21 Use More or Less Bus in Hot Days by Driving Licence

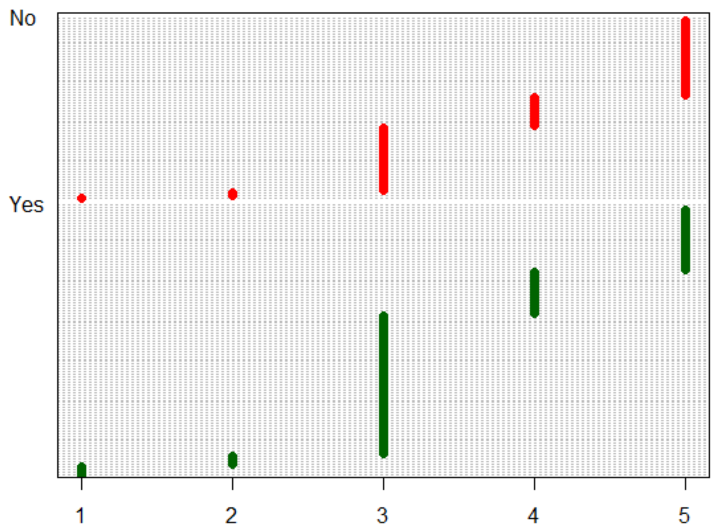

Fig 4.22 Use More or Less U-Bahn in Rainy Days by Driving Licence

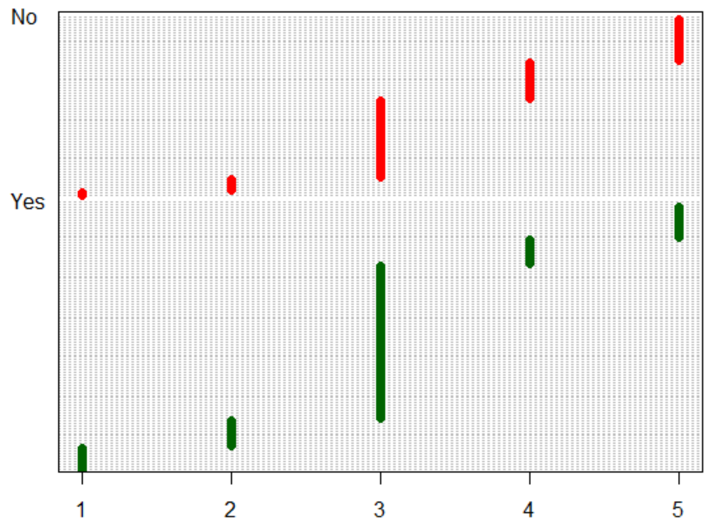

Fig 4.23 Use More or Less U-Bahn in Hot Days by Driving Licence

We divided respondents who have access to cars (individual cars, family's cars, and company's cars) into group 2, and respondents who have no access to cars into group 1. We could find people in group 2 will use less bus in hot days.

Aspect	Group1	Group2	p-value
MoreLessBus30	1	2	0.02251
	3.114	2.761	

Tab 4.15 Means of Use Frequency of Bus between Respondents Owning or not Owning Cars

In Fig. 4.24 we could find that high temperature has almost no obvious influence on bus ridership in the no access to car group, and people who have access to a car (including family car and company car) will tend to use less bus because of hotness.

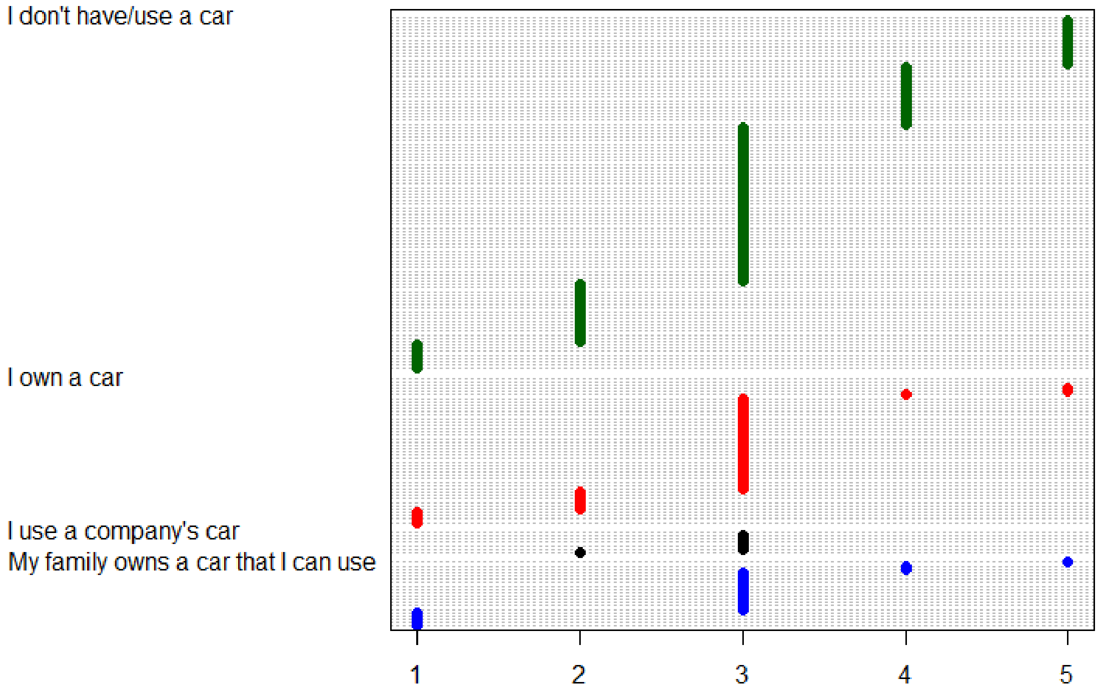

Fig 4.24 Use More or Less Bus in Hot Days by Car Ownership

When it comes to overall satisfaction, teenagers tend to be neutral and less satisfied than people in their 20s or 40s. And people in their 20s will use more U-Bahn on rainy days than people in their 50s, 60s, and 70s. In windy days people in their 20s and 50s will use more U-

Bahn than people in 60s and 70s. In hot weather, people in their 60s and 70s will use less U-Bahn and people in their 10s and 50s will use more U-Bahn.

Aspect	Group1	Group2	p-value
SALL	11-19	20-29	0.04019
	3.154	3.743	
SALL	11-19	40-49	0.02402
	3.154	3.864	
MoreLessUBahnRain	20-29	50-59	0.03277
	3.919	3.316	
MoreLessUBahnRain	20-29	60-74	0.03263
	3.919	3.167	
MoreLessUbahnWind	20-29	60-74	0.01994
	3.405	3.083	
MoreLessUbahnWind	40-49	60-74	0.02946
	3.591	3.083	
MoreLessUbahnWind	50-59	60-74	0.03622
	3.579	3.083	
MoreLessUBahn30	11-19	60-74	0.04936
	3.538	2.833	
MoreLessUBahn30	50-59	60-74	0.03777
	3.474	2.833	

Tab 4.16 T-Test between Age Group

To have more details about the difference among different age groups, we use spinogram in R Studio, in which we could know the percentage distribution of choices between different age groups. The y-axis on the left side in the diagram is the options provided in the questionnaire, and the y-axis on the right side is the percentage number. The width of each group represents the number of interviewees. Command statements for Fig. 4.25 is shown as an example.

```
> library(vcd)
>counts <- table(mydata11$age1020,mydata11$SALL1060)
>spine(counts)
```

We could find in Fig. 4.25 and Fig. 4.26 more than 60% of teenaged people are not satisfied or neutral in overall satisfaction. In Fig. 4.27 and Fig. 4.28 more than 60% interviewees in their 20-29 chose more or much more U-Bahn on rainy days. After comparing Fig 4.29, Fig. 4.30 and Fig. 4.31 we find around 30% to 40% interviewees in their 20s, 40s, and 50s chose more or much more U-Bahn on windy days. In their 10s and 5s, interviewees seem to prefer more or much more U-Bahn in summer times.

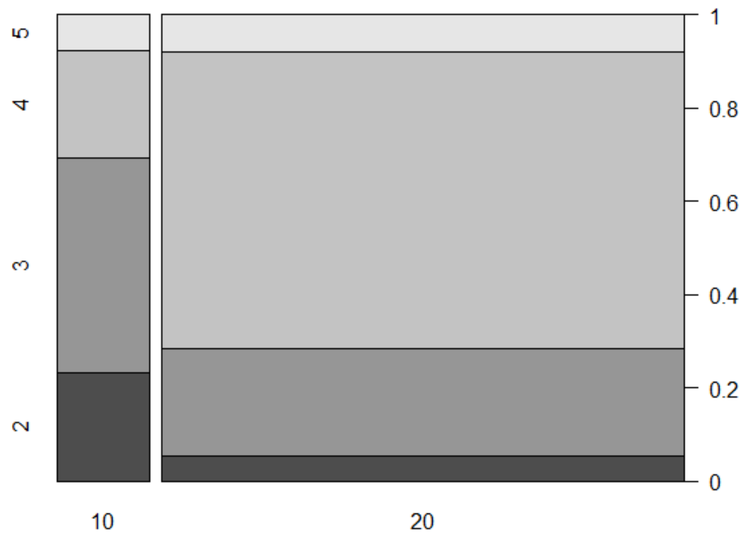

Fig 4.25 Frequency Distribution of Overall Satisfaction between Age group 10-19 and 20-29

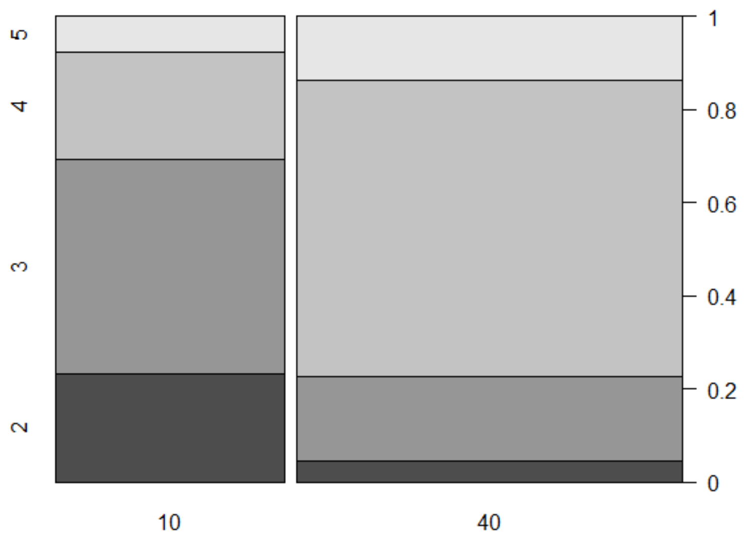

Fig 4.26 Frequency Distribution of Overall Satisfaction between Age group 10-19 and 40-49

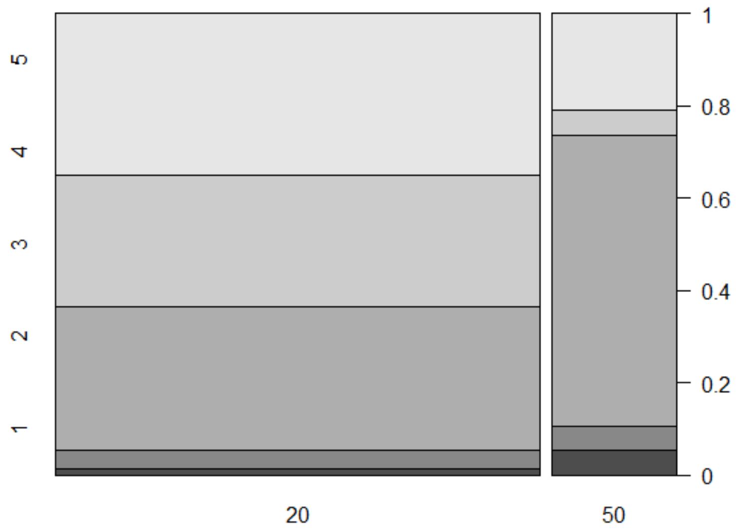

Fig 4.27 Frequency Distribution of Use More or Less U-Bahn in Rainy Days between Age group 20-29 and 50-59

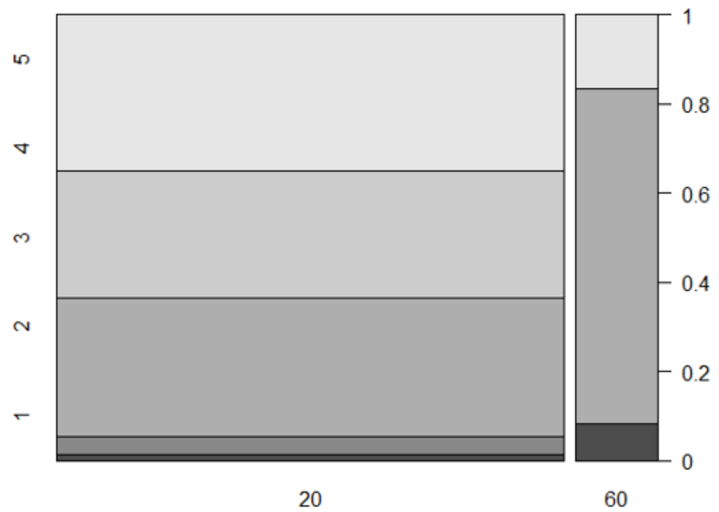

Fig 4.28 Frequency Distribution of Use More or Less U-Bahn in Rainy Days between Age group 20-29 and 60-74

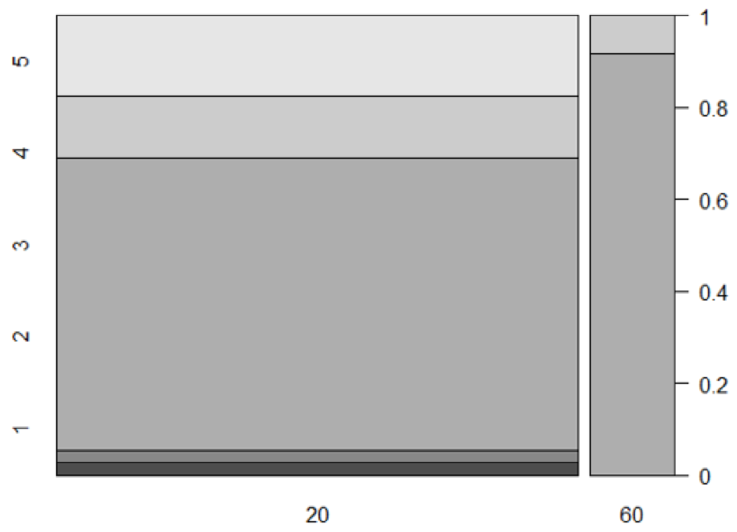

Fig 4.29 Frequency Distribution of Use More or Less U-Bahn in Windy Days between Age group 20-29 and 60-74

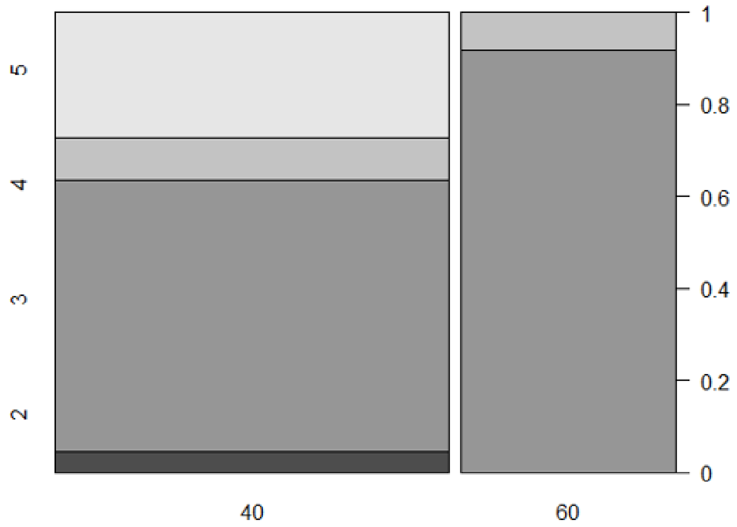

Fig 4.30 Frequency Distribution of Use More or Less U-Bahn in Windy Days between Age group 40-49 and 60-74

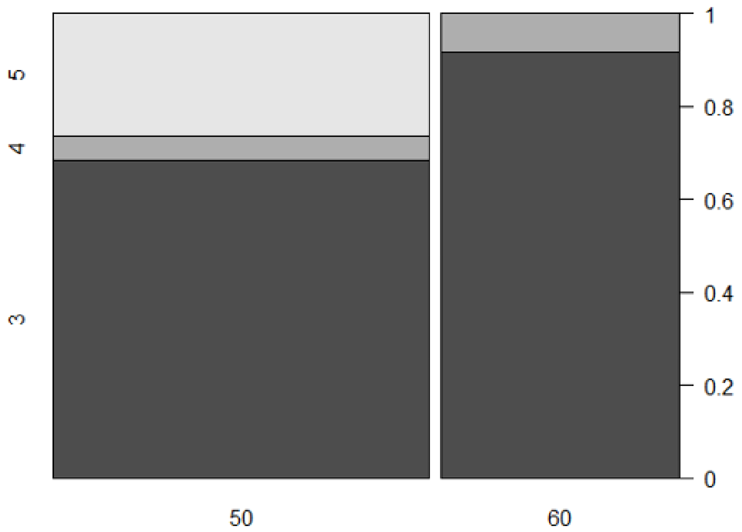

Fig 4.31 Frequency Distribution of Use More or Less U-Bahn in Windy Days between Age group 50-59 and 60-74

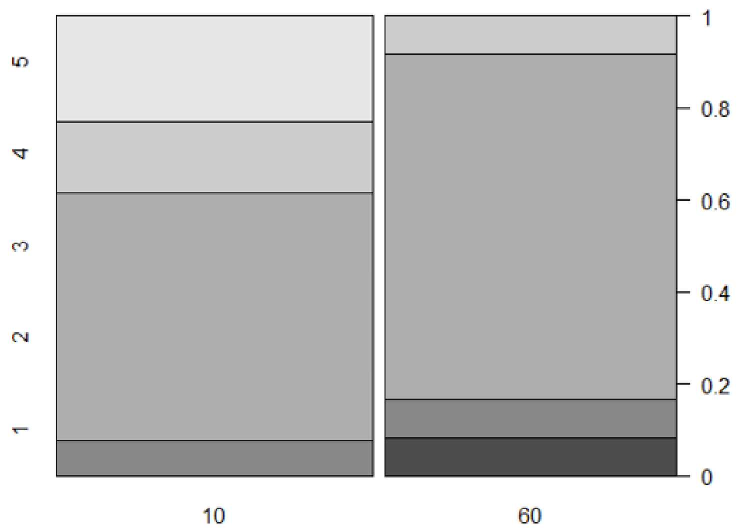

Fig 4.32 Frequency Distribution of Use More or Less U-Bahn in Hot Days between Age group 10-19 and 60-74

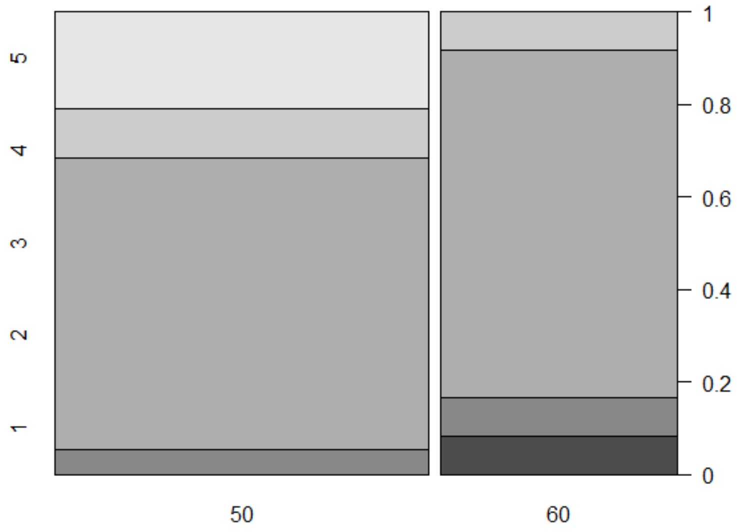

Fig 4.33 Frequency Distribution of Use More or Less U-Bahn in Hot Days between Age group 50-59 and 60-74

From the Tab. 4.17, we could conclude that adverse weather has more influence on people who use occasionally or rarely bus. In rainy, windy, snowy and hot days, people who use 1-3 times per month (occasionally) and 5-6 times a year (rarely) bus service will use less bus than people who use bus service daily or 2-3 times per week (often).

A similar conclusion could be made from Tab. 4.18, on rainy, windy, hot and cold days, people who use rarely or occasionally U-Bahn will use less U-Bahn than people take U-Bahn daily or often.

More details are shown in Fig 4. 34 to Fig. 4. 41.

Aspect	Group1	Group2	p-value
MoreLessBusRain	Daily	Rarely	0.0054
	3.393	2.708	
MoreLessBusRain	Often	Occasionally	0.03607
	3.524	3.020	
MoreLessBusRain	Often	Rarely	0.00241
	3.524	2.708	
MoreLessBusSnow	Daily	Rarely	0.04533
	3.418	3.000	
MoreLessBusSnow	Often	Rarely	0.03763
	3.500	3.000	
MoreLessBusWind	Daily	Occasionally	0.0423
	3.345	3.000	
MoreLessBusWind	Daily	Rarely	0.03446
	3.345	2.913	
MoreLessBus30	Daily	Occasionally	0.03681
	3.200	2.776	
MoreLessBus30	Daily	Rarely	0.03486
	3.200	2.682	

Tab 4.17 T-Test between Different Bus Use Frequency Group

Aspect	Group1	Group2	p-value
MoreLessUBahnRain	Daily	Rarely	0.03885
	3.785	2.818	
MoreLessUBahnRain	Often	Rarely	0.02693
	3.889	2.818	
MoreLessUBahnWind	Daily	Occasionally	0.0351
	3.538	3.182	
MoreLessUBahn30	Daily	Often	0.03032
	3.495	3.028	
MoreLessUBahn30	Daily	Occasionally	0.01924
	3.495	3.030	
MoreLessUBahn0	Daily	Rarely	0.01983
	3.570	2.545	
MoreLessUBahn0	Often	Rarely	0.02653
	3.528	2.545	
MoreLessUBahn0	Occasionally	Rarely	0.02547
	3.545	2.545	

Tab 4.18 T-Test between Different U-Bahn Use Frequency Group

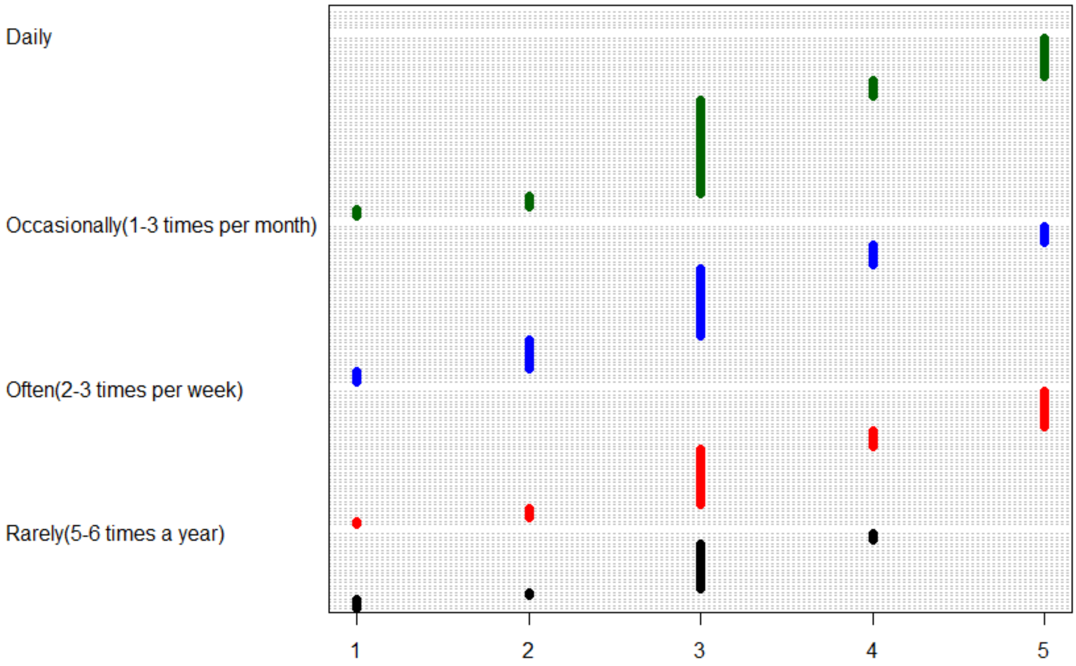

Fig 4.34 Use More or Less Bus in Rainy Days by Use Frequency of Bus

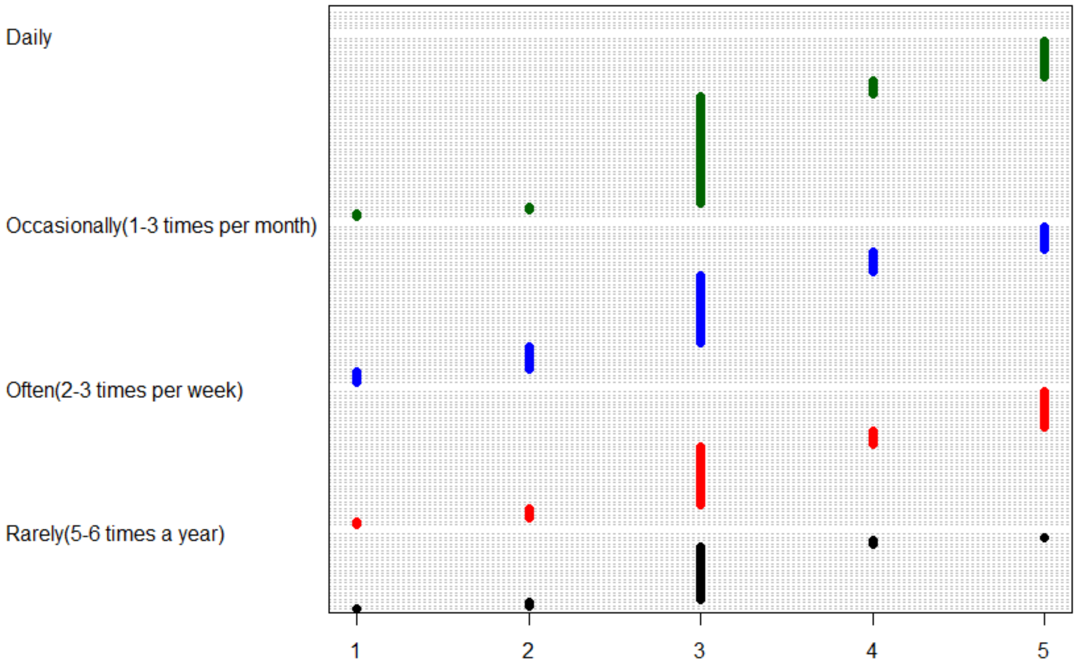

Fig 4.35 Use More or Less Bus in Snowy Days by Use Frequency of Bus

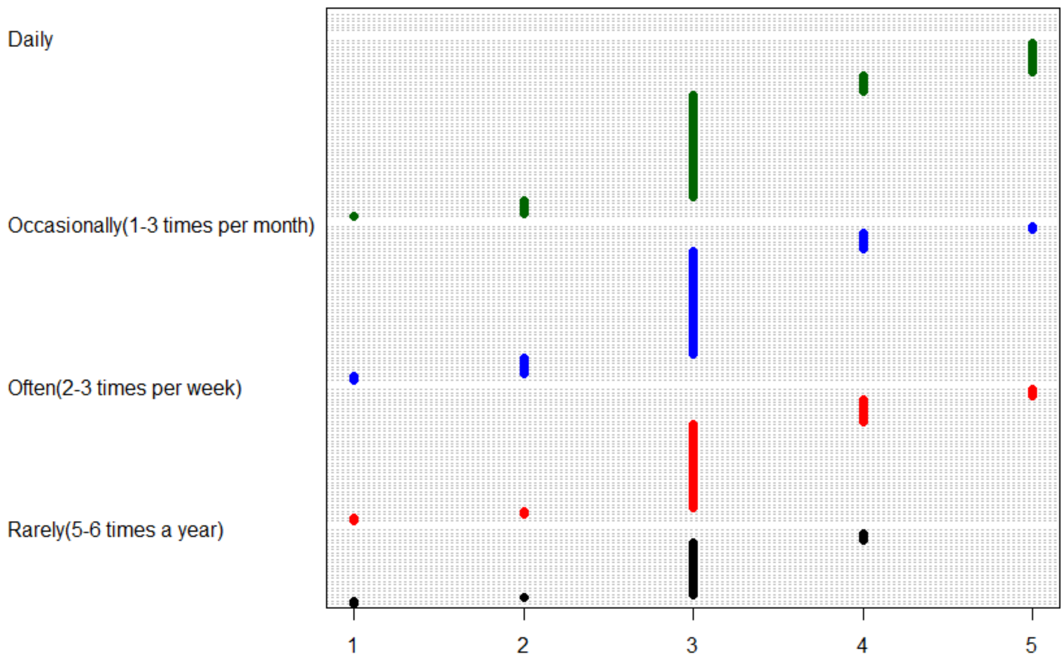

Fig 4.36 Use More or Less Bus in Windy Days by Use Frequency of Bus

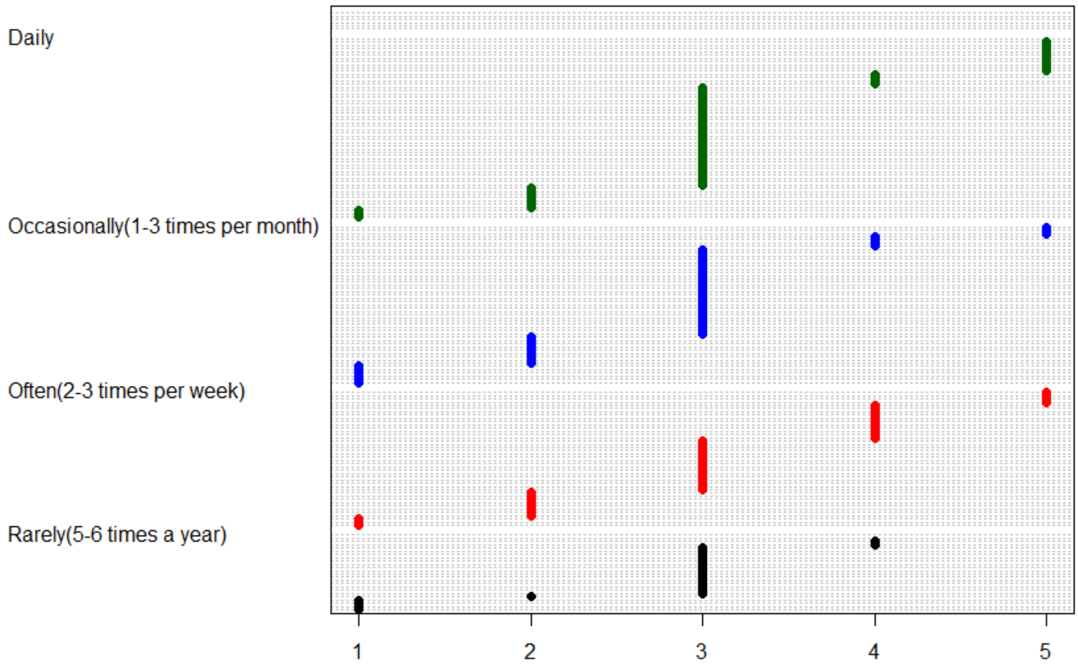

Fig 4.37 Use More or Less Bus in Hot Days by Use Frequency of Bus

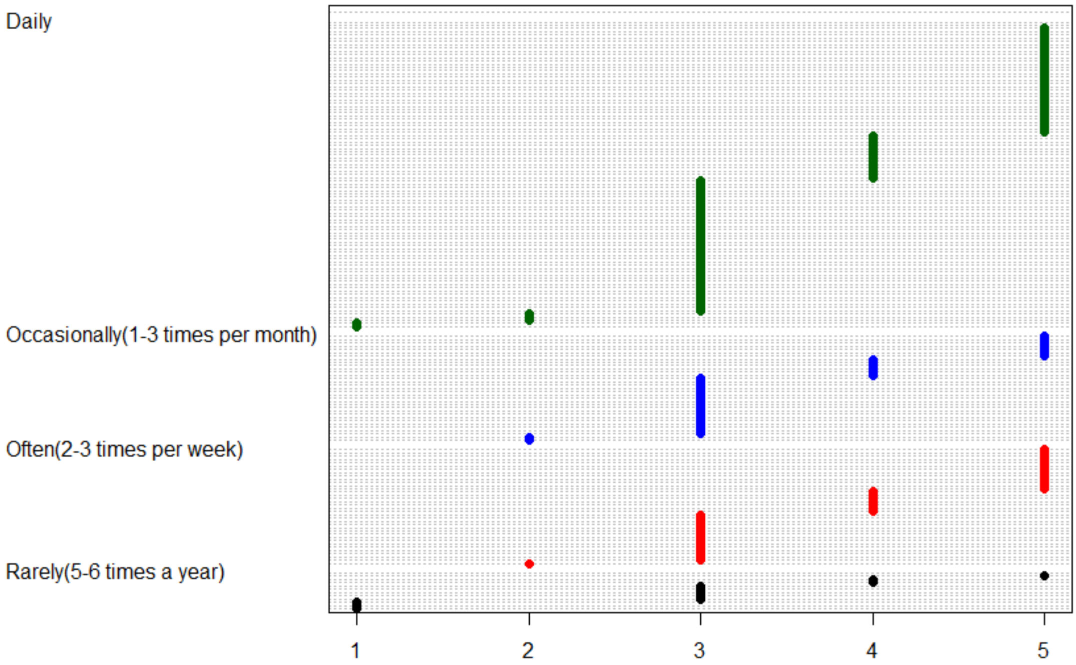

Fig 4.38 Use More or Less U-Bahn in Rainy Days by Use Frequency of U-Bahn

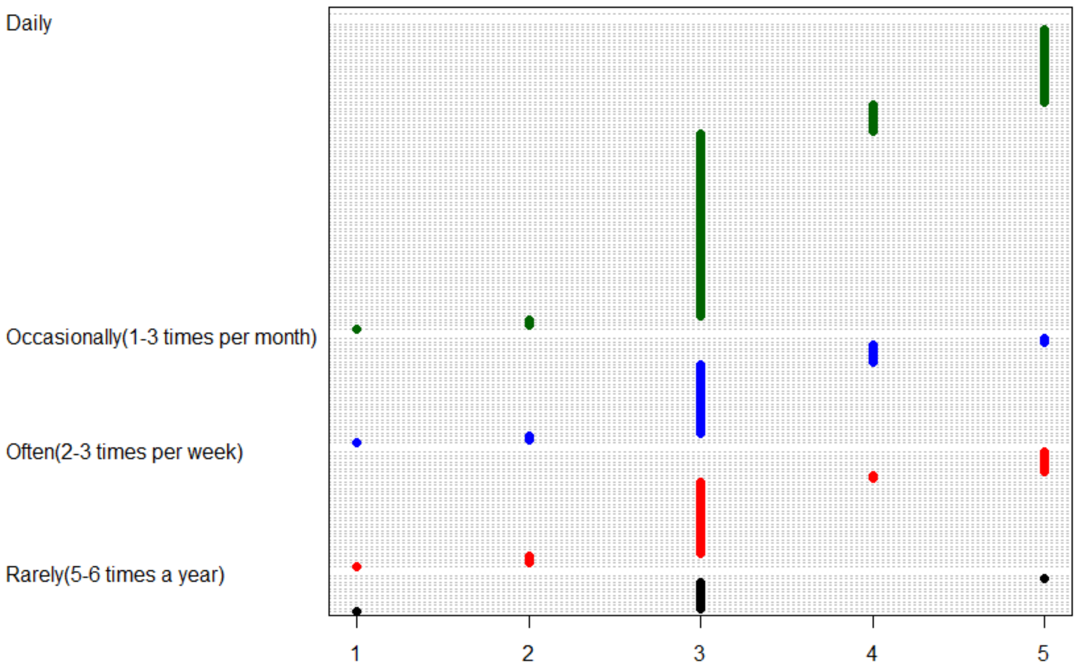

Fig 4.39 Use More or Less U-Bahn in Windy Days by Use Frequency of U-Bahn

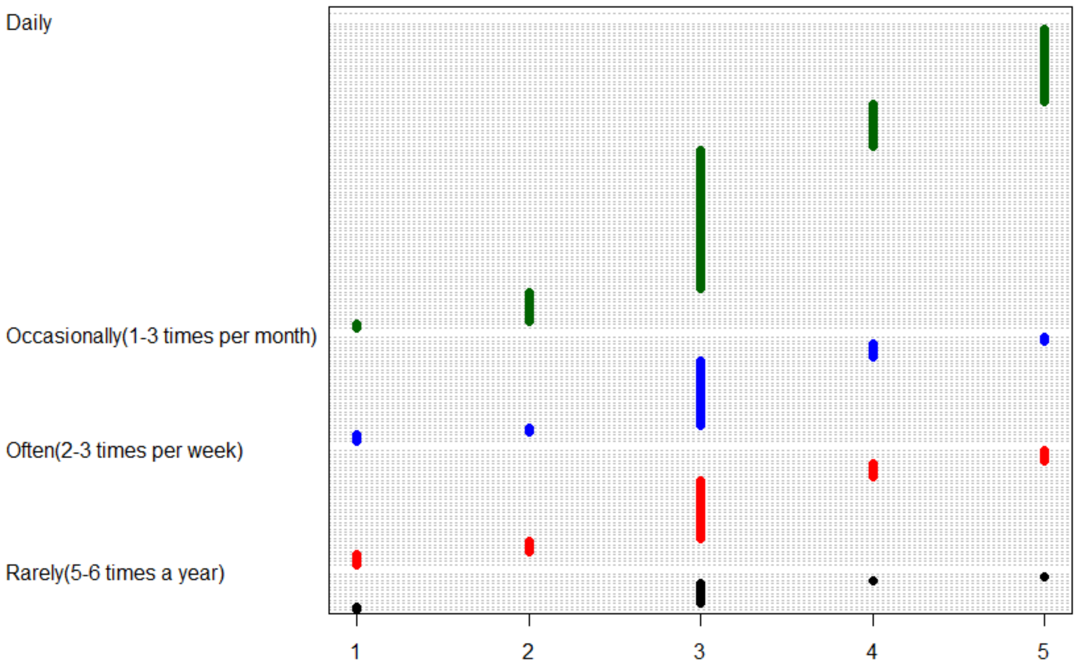

Fig 4.40 Use More or Less U-Bahn in Hot Days by Use Frequency of U-Bahn

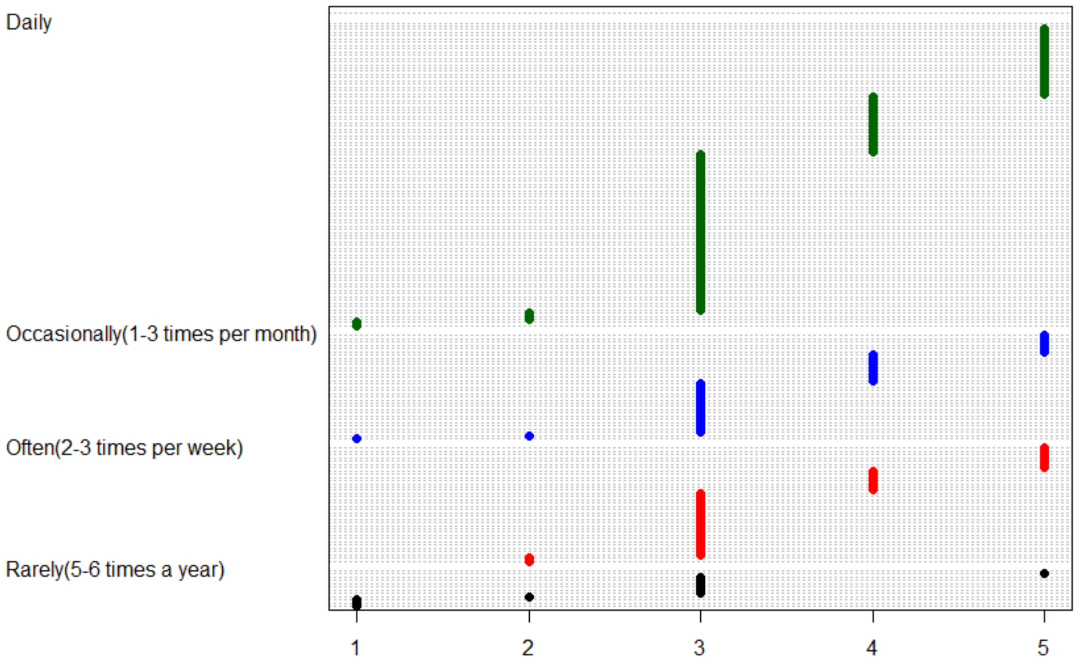

Fig 4.41 Use More or Less U-Bahn in Cold Days by Use Frequency of U-Bahn

5 Model development

5.1 Factor analysis

Factor analysis was developed early in the twentieth century by Karl Pearson and Charles Spearman to gain insight into psychometric measurements, specifically the directly unobservable variable intelligence [JOHNSON and WICHERN, 1992]. The objective of factor analysis is to reduce the number of P variables to a smaller set of K (< P) variables and to describe the relationship among original variables in terms of a few unobservable factors.

According to WASHINGTON et al. [2003], factor analysis model could be formulated by expressing the Xi's as linear functions,

$$x_1 - \mu_1 = l_{11}F_1 + l_{12}F_2 + \cdots + l_{1m}F_m + \varepsilon_1$$

$$x_2 - \mu_2 = l_{21}F_1 + l_{22}F_2 + \cdots + l_{2m}F_m + \varepsilon_2$$

$$\vdots$$

$$x_p - \mu_p = l_{p1}F_1 + l_{p2}F_2 + \cdots + l_{pm}F_m + \varepsilon_p \quad (5.1)$$

in matrix notation the model is given as,

$$(x - \mu)_{p\times 1} = L_{p\times m}F_{m\times 1} + \varepsilon_{p\times 1} \quad (5.2)$$

where F is factor, l_{ij} is the factor loading. The ε is associated only with the Xi, and the random errors and factor loadings are unobservable or latent.

The above models have p + m unknowns and p equations, and we cannot get a unique solution if we don't have additional information. To solve this problem, additional restrictions are imposed. There are two kinds of factor rotation method, and through these two methods, we could obtain two types of factor analysis model, orthogonal and oblique. The aim of the rotations is to transfer each factor loading as close to 0 or 1 as possible. If factor loadings are close to 1, it means this factor has a big influence on variable Xi. Smaller factor loadings represent smaller influence.

First, factor analysis is performed on the importance of bus service. We try with 3 factors and delete those incomplete data using

```
> myfactanal1 <- factanal(na.omit(mydata[,13:46]), factors=3)
```

In followed tables loadings below 0.3 are shown as blank and loadings above 0.6 are shown in bold.

We could find in Tab. 5.1 that the third factor explains only 7.8% of the variance. We keep variables with loading above 0.5 and remove the rest ones and do factor analysis again using

```
> myfactanal3 <- factanal (na.omit (mydata [,c (13, 16, 19, 21, 22, 23, 24, 27, 28, 29, 30, 31, 32, 33, 34, 37, 38, 45)]), factors=3)
```

We find the third factor could explain 13.7% of the variance and try to do factor analysis with 4 factors. The fourth factor explains 10.5% of variance so we conclude that using 4 factors is more suitable in this case. The result is shown in Tab. 5.2.

A similar process is repeated for the importance of U-Bahn service and satisfaction of bus and U-Bahn. We keep the variables with loading above 0.5 in factor analysis of the importance of U-Bahn and the result is shown in Tab. 5.4. For satisfaction of bus service, we keep variables with loadings above 0.55 and find 4 factors could be used in this case. The result is shown in Tab. 5.6.

For satisfaction of U-Bahn service, we do factor analysis with 4 factors and all factors could explain at least 10% of the variance, we keep all the variables and the result is shown in Tab. 5.7.

In Tab 5. 2, Tab 5. 4, Tab 5. 6 and Tab 5. 7 the author gives the factor interpretation for each factor in the last row of the tables. Service production reflects service frequency, punctuality and waiting time during peak and off-peak hour. Quality of service is related to cleanliness and safety on board and in vehicles.

	Factor 1	Factor 2	Factor 3
IBCleanHygieBoard	0.585	0.309	
IBVehiclCrowd		0.362	
IBVehiclModern	0.350		
IBSafeForPassengBoard	**0.612**		
IBNumbOfSeat	0.445		
IBTemperBoardSummer	0.480		
IBTemperBoardWinter	0.504		
IBTemperBoardSpring	0.392		
IBIlluminaInVehicl	0.533		
IBCleanHygieStop	0.513		
IBSafeForPassengStop	**0.641**		
IBStopIllumina	0.510		
IBPercentaStopWiShelter	0.477		
IBProtectShelterFrRain	0.486		
IBTemperStopSummer			**0.907**
IBTemperStopWinter			**0.904**
IBTemperStopSpring			**0.735**
IBWaitTimeStopOffPeak		**0.672**	
IBWaitTimeStopPeak		**0.739**	
IBServPunctu	0.349	**0.601**	
IBServFrequenOffPeak		**0.631**	
IBServFrequenPeak		**0.736**	
IBTravSpeed		0.393	
IBWalkDistanTransfer		0.462	
IBWaitTimeStopTransfer	0.320	0.577	
IBClearTimeTableStop	0.557	0.317	
IBTimeTableAPP	0.463		
IBInfoScreenVehicl	0.449		
IBNetworkCoverage	0.430	0.413	
IBDistanStopHome		0.415	
IBCurrenTicketPrice	0.398		
IBVariabiliTicketTyp	0.496		
IBDriverKind	0.524		
IBDrivStyle	0.478		
SS loadings	**5.832**	**4.366**	**2.666**
Proportion var	**0.172**	**0.128**	**0.078**
Cumulative var	**0.172**	**0.300**	**0.378**

Tab 5.1 Factor analysis of IB with noise

	Factor 1	Factor 2	Factor 3	Factor 4
IBCleanHygieBoard	0.563			
IBSafeForPassengBoard	**0.816**			
IBTemperBoardWinter	0.405			
IBIlluminaInVehicl	0.467			
IBCleanHygieStop	0.479			0.321
IBSafeForPassengStop	**0.833**			
IBStopIllumina	0.463			
IBTemperStopSummer		**0.917**		
IBTemperStopWinter		**0.909**		
IBTemperStopSpring		**0.739**		
IBWaitTimeStopOffPeak			**0.769**	
IBWaitTimeStopPeak			**0.846**	
IBServPunctu				**0.742**
IBServFrequenOffPeak			0.370	0.464
IBServFrequenPeak			0.494	0.458
IBWaitTimeStopTransfer	0.306			0.492
IBClearTimeTableStop	0.443			0.500
IBDriverKind	0.329			
SS loadings	**3.127**	**2.478**	**1.977**	**1.894**
Proportion var	**0.174**	**0.138**	**0.110**	**0.105**
Cumulative var	**0.174**	**0.311**	**0.421**	**0.526**
Factor interpretation	Safety	Temperature	Waiting time	Punctuality

Tab 5.2 Factor analysis of IB without noise

	Factor 1	Factor 2	Factor 3
IUCleanHygieBoard	**0.612**		
IUVehiclCrowd	0.406		
IUVehiclModern	0.432		
IUSafeForPassengBoard	**0.605**		
IUNumbOfSeat	0.429		
IUTemperBoardSummer	0.486		
IUTemperBoardWinter	0.588		
IUTemperBoardSpring	0.415		
IUIlluminaInVehicl	0.538		
IUCleanHygieStop	0.583		
IUSafeForPassengStop	**0.654**		
IUStopIllumina	0.553		
IUTemperStopSummer			**0.832**
IUTemperStopWinter			**0.884**
IUTemperStopSpring			**0.750**
IUWaitTimeStopOffPeak		**0.752**	
IUWaitTimeStopPeak		**0.756**	
IUServPunctu	0.363	**0.659**	
IUServFrequenOffPeak		**0.707**	
IUServFrequenPeak		**0.810**	
IUTravSpeed		0.537	
IUWalkDistanTransfer		0.478	
IUWaitTimeStopTransfer		**0.604**	
IUClearTimeTableStop	**0.602**	0.330	
IUTimeTableAPP	0.533		
IUInfoScreenVehicl	0.464		
IUNetworkCoverage	0.398	0.479	
IUDistanStopHome	0.335	0.410	
IUCurrenTicketPrice	0.358		
IUVariabiliTicketTyp	0.502		
IUDriverKind	0.525		
SS loadings	**5.695**	**4.899**	**2.509**
Proportion var	**0.184**	**0.158**	**0.081**
Cumulative var	**0.184**	**0.342**	**0.423**

Tab 5.3 Factor analysis of IU with noise

	Factor 1	Factor 2	Factor 3
IUCleanHygieBoard	**0.635**		
IUSafeForPassengBoard	**0.700**		
IUTemperBoardWinter	0.495		
IUIlluminaInVehicl	0.537		
IUCleanHygieStop	**0.632**		
IUSafeForPassengStop	**0.737**		
IUStopIllumina	0.552		
IUTemperStopSummer			**0.834**
IUTemperStopWinter			**0.909**
IUTemperStopSpring			**0.734**
IUWaitTimeStopOffPeak		**0.779**	
IUWaitTimeStopPeak		**0.771**	
IUServPunctu	0.399	**0.635**	
IUServFrequenOffPeak		**0.715**	
IUServFrequenPeak		**0.783**	
IUTravSpeed		0.500	
IUWaitTimeStopTransfer	0.324	0.554	
IUClearTimeTableStop	**0.609**		
IUTimeTableAPP	0.519		
IUVariabiliTicketTyp	0.467		
IUDriverKind	0.495		
SS loadings	**4.310**	**3.708**	**2.286**
Proportion var	**0.205**	**0.177**	**0.109**
Cumulative var	**0.205**	**0.382**	**0.491**
Factor interpretation	Quality of service	Service production	Temperature

Tab 5.4 Factor analysis of IU without noise

	Factor 1	Factor 2	Factor 3
SBCleanHygieBoard	**0.638**		
SBVehiclCrowd	0.555	0.325	
SBVehiclModern	0.531		
SBSafeForPassengBoard	0.598		
SBNumbOfSeat	0.575		
SBTemperBoardSummer	0.426	0.306	
SBTemperBoardWinter	0.596		
SBTemperBoardSpring	**0.632**		
SBIlluminaInVehicl	**0.628**		
SBCleanHygieStop	0.517		
SBSafeForPassengStop	0.501	0.327	
SBStopIllumina	0.471		0.352
SBPercentaStopWiShelter			0.415
SBProtectShelterFrRain			0.495
SBTemperStopSummer			**0.877**
SBTemperStopWinter			**0.821**
SBTemperStopSpring	0.309		**0.632**
SBWaitTimeStopOffPeak		**0.695**	
SBWaitTimeStopPeak		**0.737**	
SBServPunctu		**0.680**	
SBServFrequenOffPeak		**0.752**	
SBServFrequenPeak		**0.784**	
SBTravSpeed		0.473	
SBWalkDistanTransfer	0.386	0.373	
SBWaitTimeStopTransfer		0.580	
SBClearTimeTableStop	0.378	0.374	
SBTimeTableAPP	0.427	0.353	0.332
SBInfoScreenVehicl	0.364	0.355	
SBNetworkCoverage	0.303	0.389	
SBDistanStopHome	0.398		
SBCurrenTicketPrice		0.308	
SBVariabiliTicketTyp	0.349		
SBDriverKind	0.552		
SBDrivStyle	**0.618**		
SS loadings	**5.960**	**4.899**	**3.230**
Proportion var	**0.175**	**0.144**	**0.095**
Cumulative var	**0.175**	**0.319**	**0.414**

Tab 5.5 Factor analysis of SB with noise

	Factor 1	Factor 2	Factor 3	Factor 4
SBCleanHygieBoard		0.527		
SBVehiclCrowd	0.310	0.528		
SBSafeForPassengBoard		0.427		
SBNumbOfSeat		0.370	0.399	
SBTemperBoardWinter			**0.769**	
SBTemperBoardSpring			**0.866**	
SBIlluminaInVehicl		0.352	0.500	
SBTemperStopSummer				**0.940**
SBTemperStopWinter				**0.763**
SBTemperStopSpring			0.337	0.577
SBWaitTimeStopOffPeak	**0.716**			
SBWaitTimeStopPeak	**0.751**			
SBServPunctu	**0.661**			
SBServFrequenOffPeak	**0.762**			
SBServFrequenPeak	**0.780**			
SBWaitTimeStopTransfer	0.546			
SBDriverKind		**0.728**		
SBDrivStyle		**0.716**		
SS loadings	**3.312**	**2.390**	**2.160**	**1.977**
Proportion var	**0.184**	**0.133**	**0.120**	**0.110**
Cumulative var	**0.184**	**0.317**	**0.437**	**0.547**
Factor interpretation	Service production	Driver behavior	Temperature Onboard	Temperature at stop

Tab 5.6 Factor analysis of SB without noise

	Factor 1	Factor 2	Factor 3	Factor 4
SUCleanHygieBoard			**0.644**	
SUVehiclCrowd			0.386	
SUVehiclModern				
SUSafeForPassengBoard			**0.658**	
SUNumbOfSeat		0.366	0.329	0.345
SUTemperBoardSummer				0.472
SUTemperBoardWinter				**0.745**
SUTemperBoardSpring				**0.810**
SUIlluminaInVehicl				0.560
SUCleanHygieStop			**0.669**	
SUSafeForPassengStop			**0.639**	
SUStopIllumina		0.399	0.524	
SUTemperStopSummer		0.456		0.364
SUTemperStopWinter		0.416		0.364
SUTemperStopSpring		0.349		0.460
SUWaitTimeStopOffPeak	**0.689**			
SUWaitTimeStopPeak	**0.712**			
SUServPunctu	0.544		0.385	
SUServFrequenOffPeak	**0.798**			
SUServFrequenPeak	**0.749**			
SUTravSpeed	0.463	0.321		0.441
SUWalkDistanTransfer	0.337	0.440		
SUWaitTimeStopTransfer	0.528	0.427		
SUClearTimeTableStop		**0.725**	0.309	
SUTimeTableAPP		**0.690**		0.311
SUInfoScreenVehicl		**0.669**		
SUNetworkCoverage		0.420		
SUDistanStopHome		0.513		
SUCurrenTicketPrice	0.319			
SUVariabiliTicketTyp			0.382	
SUDriverKind		0.368	0.325	
SS loadings	**4.108**	**3.868**	**3.549**	**3.411**
Proportion var	**0.133**	**0.125**	**0.114**	**0.110**
Cumulative var	**0.133**	**0.257**	**0.372**	**0.482**
Factor interpretation	Service production	Information	Quality of service	Temperature

Tab 5.7 Factor analysis of SU

5.2 Ordered Logit Model

In this section, we try to find the most influential specific satisfaction factors on the overall satisfaction for bus and U-Bahn. As we mentioned before, ordered logit model will be a good choice since satisfaction is obviously ordered data.

Author deleted some instances, which were obviously unserious or against common sense. The dataset has been reduced from 177 respondents to 141 respondents. Then a logistic regression model named "lrm" in package "rms" is applied. Comments for developing satisfaction model for U-Bahn are lying below as an example.

```
> install.packages("rms")
> library ("rms", lib.loc="~/R/win-library/3.4")
>lrmSU<-
lrm(SU~SUCleanHygieBoard+SUVehiclCrowd+SUVehiclModern+SUSafeForPassengBoard+
SUNumbOfSeat+SUTemperBoardSummer+SUTemperBoardWinter+SUTemperBoardSpring
+SUIlluminaInVehicl+SUCleanHygieStop+SUSafeForPassengStop+SUStopIllumina+SUTem
perStopSummer+SUTemperStopWinter+SUTemperStopSpring+SUWaitTimeStopOffPeak+S
UWaitTimeStopPeak+SUServPunctu+SUServFrequenOffPeak+SUServFrequenPeak+SUTra
vSpeed+SUWalkDistanTransfer+SUWaitTimeStopTransfer+SUClearTimeTableStop+SUTime
TableAPP+SUInfoScreenVehicl+SUNetworkCoverage+SUDistanStopHome+SUCurrenTicket
Price+SUVariabiliTicketTyp+SUDriverKind, data=na.omit(mydataSU))
```

In this model, we use all variables designed in the questionnaire. The initial result is shown in Fig. 5.1. We could find some variables are significant and some are not. To obtain a better model, we delete those insignificant variables (P-Value> 0.05) and build a new model with left variables. The result is shown in Fig. 5.2. A similar process is repeated when developing satisfaction model for bus and related results are shown in Fig. 5.3 and Fig. 5.4.

In the satisfaction model for U-Bahn, the most influential specific satisfaction is waiting time at stations during peak hours (with coefficient 1.1727), followed by travel speed (with coefficient 0.6560), temperature at stations in summer times (with coefficient 0.4925) and Vehicles' modernity (with coefficient 0.4276).

In the satisfaction model for bus, the most influential specific satisfaction is network coverage of bus line (with coefficient 0.6832), followed by walk distance to next line when transfer (with coefficient 0.5849), travel speed (with coefficient 0.5196), clear timetable information at stops (with coefficient 0.5036) and driving style (with coefficient 0.4706).

All coefficients are positive, it means the more passengers are satisfied with these specific aspects, the more satisfied they will be with the overall bus or U-Bahn service.

These influential factors also provide clues to public transport operators about how to increase the overall satisfaction and ridership of public transport.

Travel speed is important in both bus and U-Bahn service. What’s more, as a rapid transit, a lot of commuters choose to travel with U-Bahn during rush-hour, it makes waiting time at stations during peak hours much more important than other aspects. Vehicles in old mode and in new mode are both running in the Munich U-Bahn systems, and new vehicles provide better illumination, more space for standing passengers and have air conditioner systems. It could be concluded from the satisfaction model that if the rate of the vehicle in new mode is increased, the overall satisfaction for U-Bahn will be obviously increased.

When it comes to bus, network coverage of bus line and walk distance to next line when transfer are most important variables, it makes sense because unlike U-Bahn, bus service is more related to every neighborhood, shopping place or workplace, so the accessibility and convenience is much more important than other aspects of bus service. Compared with U-Bahn, drivers’ skills and behavior are more influential since bus is more dependent on driver’s operation. Finally, clear timetable information at stops is also a significant aspect. In all U-Bahn stations there are clear electronic screens which provide the information about the next vehicles, however, only some of the bus stops have similar facilities. Since traditional paper schedules are a little bit complicated and not so friendly to elder people, people with subnormal vision or people who have no idea about what time it is now, the overall satisfaction will be increased if more bus stops are equipped with electronic information screens.

```
Frequencies of Responses

 1  2  3  4  5
 4 10 34 63 28

                     Model Likelihood     Discrimination     Rank Discrim.
                        Ratio Test            Indexes           Indexes
obs            139   LR chi2     128.83    R2         0.651    C       0.866
max |deriv| 2e-12    d.f.            31    g          3.015    Dxy     0.733
                     Pr(> chi2) <0.0001    gr        20.384    gamma   0.771
                                           gp         0.163    tau-a   0.508
                                           Brier      0.051

                       Coef     S.E.   Wald Z Pr(>|Z|)
y>=2                    -6.1777 1.4955 -4.13  <0.0001
y>=3                    -8.4132 1.5395 -5.47  <0.0001
y>=4                   -11.0720 1.6417 -6.74  <0.0001
y>=5                   -15.0760 1.9256 -7.83  <0.0001
SUCleanHygieBoard        0.2641 0.2408  1.10  0.2727
SUVehiclCrowd           -0.2297 0.2337 -0.98  0.3257
SUVehiclModern           0.4788 0.2543  1.88  0.0598
SUSafeForPassengBoard   -0.0242 0.2945 -0.08  0.9344
SUNumbOfSeat            -0.0658 0.2550 -0.26  0.7963
SUTemperBoardSummer     -0.1799 0.2089 -0.86  0.3894
SUTemperBoardWinter      0.1947 0.3077  0.63  0.5270
SUTemperBoardSpring      0.3722 0.3676  1.01  0.3113
SUIlluminaInVehicl       0.0668 0.2798  0.24  0.8113
SUCleanHygieStop        -0.0913 0.2631 -0.35  0.7285
SUSafeForPassengStop     0.0558 0.3843  0.15  0.8845
SUStopIllumina          -0.1823 0.3002 -0.61  0.5437
SUTemperStopSummer       1.2024 0.3365  3.57  0.0004
SUTemperStopWinter      -0.6100 0.3222 -1.89  0.0583
SUTemperStopSpring      -0.2685 0.3416 -0.79  0.4318
SUWaitTimeStopOffPeak   -0.1340 0.3307 -0.41  0.6854
SUWaitTimeStopPeak       1.4532 0.3504  4.15  <0.0001
SUServPunctu             0.1135 0.2667  0.43  0.6705
SUServFrequenOffPeak     0.1321 0.3265  0.40  0.6859
SUServFrequenPeak       -0.1575 0.3393 -0.46  0.6426
SUTravSpeed              0.6705 0.3014  2.22  0.0261
SUWalkDistanTransfer    -0.1856 0.3071 -0.60  0.5456
SUWaitTimeStopTransfer   0.2022 0.3126  0.65  0.5176
SUClearTimeTableStop    -0.4058 0.2832 -1.43  0.1519
SUTimeTableAPP           0.5788 0.3163  1.83  0.0672
SUInfoScreenVehicl      -0.2302 0.2401 -0.96  0.3376
SUNetworkCoverage        0.3304 0.2463  1.34  0.1797
SUDistanStopHome        -0.0235 0.2290 -0.10  0.9184
SUCurrenTicketPrice     -0.3193 0.2608 -1.22  0.2207
SUVariabiliTicketTyp     0.5398 0.2474  2.18  0.0291
SUDriverKind            -0.1593 0.2222 -0.72  0.4735
```

Fig 5.1 Initial Result of the Satisfaction Model for U-Bahn

```
Frequencies of Responses

 1  2  3  4  5
 4 10 34 63 28

                      Model Likelihood      Discrimination     Rank Discrim.
                         Ratio Test            Indexes            Indexes
Obs              139   LR chi2     101.08   R2         0.557   C       0.848
max |deriv| 3e-08      d.f.             4   g          2.380   Dxy     0.696
                       Pr(> chi2) <0.0001   gr        10.800   gamma   0.715
                                            gp         0.142   tau-a   0.483
                                            Brier      0.054

                    Coef     S.E.   Wald Z Pr(>|Z|)
y>=2                -4.4684 1.1283 -3.96  <0.0001
y>=3                -6.2863 1.1221 -5.60  <0.0001
y>=4                -8.7159 1.2252 -7.11  <0.0001
y>=5               -12.1222 1.4533 -8.34  <0.0001
SUVehiclModern       0.4276 0.1968  2.17  0.0298
SUTemperStopSummer   0.4925 0.1806  2.73  0.0064
SUWaitTimeStopPeak   1.1727 0.2061  5.69  <0.0001
SUTravSpeed          0.6560 0.2203  2.98  0.0029
```

Fig 5.2 Final Result of the Satisfaction Model for U-Bahn

```
Frequencies of Responses

 2  3  4  5
15 40 60 13

                       Model Likelihood     Discrimination    Rank Discrim.
                          Ratio Test           Indexes           Indexes
Obs            128    LR chi2      92.80    R2       0.567    C       0.855
max |deriv| 8e-08     d.f.            34    g        2.506    Dxy     0.711
                      Pr(> chi2) <0.0001    gr      12.258    gamma   0.712
                                            gp       0.385    tau-a   0.472
                                            Brier    0.148

                         Coef     S.E.   Wald Z Pr(>|Z|)
y>=3                     -8.4945 1.7563 -4.84  <0.0001
y>=4                    -11.3803 1.8904 -6.02  <0.0001
y>=5                    -15.3625 2.1526 -7.14  <0.0001
SBCleanHygieBoard          0.0026 0.2532  0.01  0.9917
SBVehiclCrowd              0.1523 0.3040  0.50  0.6165
SBVehiclModern            -0.1727 0.2979 -0.58  0.5621
SBSafeForPassengBoard     -0.3890 0.2939 -1.32  0.1855
SBNumbOfSeat               0.2634 0.2897  0.91  0.3633
SBTemperBoardSummer        0.1913 0.2158  0.89  0.3754
SBTemperBoardWinter        0.0711 0.3470  0.20  0.8376
SBTemperBoardSpring        0.2189 0.3564  0.61  0.5391
SBIlluminaInVehicl        -0.0405 0.3751 -0.11  0.9140
SBCleanHygieStop           0.6456 0.3005  2.15  0.0317
SBSafeForPassengStop      -0.6121 0.4114 -1.49  0.1368
SBStopIllumina             0.0345 0.2787  0.12  0.9015
SBPercentaStopWiShelter    0.1366 0.3667  0.37  0.7094
SBProtectShelterFrRain     0.3831 0.3641  1.05  0.2926
SBTemperStopSummer        -0.4924 0.3578 -1.38  0.1688
SBTemperStopWinter         0.0699 0.2958  0.24  0.8133
SBTemperStopSpring         0.1326 0.3135  0.42  0.6724
SBWaitTimeStopOffPeak      0.1158 0.3302  0.35  0.7259
SBWaitTimeStopPeak        -0.0515 0.3185 -0.16  0.8716
SBServPunctu              -0.2765 0.2883 -0.96  0.3375
SBServFrequenOffPeak       0.2047 0.3386  0.60  0.5454
SBServFrequenPeak          0.4186 0.3657  1.14  0.2523
SBTravSpeed                0.4032 0.2900  1.39  0.1644
SBWalkDistanTransfer       0.4696 0.3353  1.40  0.1613
SBWaitTimeStopTransfer    -0.0730 0.3254 -0.22  0.8224
SBClearTimeTableStop       0.6040 0.2861  2.11  0.0348
SBTimeTableAPP             0.0524 0.3194  0.16  0.8697
SBInfoScreenVehicl         0.0972 0.2615  0.37  0.7101
SBNetworkCoverage          0.5023 0.2756  1.82  0.0684
SBDistanStopHome           0.0212 0.2600  0.08  0.9351
SBCurrenTicketPrice        0.1672 0.2550  0.66  0.5121
SBVariabiliTicketTyp      -0.1253 0.3082 -0.41  0.6842
SBDriverKind              -0.2262 0.2924 -0.77  0.4392
SBDrivStyle                0.4798 0.3148  1.52  0.1275
```

Fig 5.3 Initial Result of the Satisfaction Model for Bus

```
Frequencies of Responses

 2  3  4  5
15 40 60 13

                        Model Likelihood     Discrimination    Rank Discrim.
                           Ratio Test           Indexes           Indexes
obs            128     LR chi2      71.48    R2       0.470    C       0.830
max |deriv| 6e-10      d.f.             5    g        2.024    Dxy     0.660
                       Pr(> chi2) <0.0001    gr       7.565    gamma   0.661
                                             gp       0.342    tau-a   0.438
                                             Brier    0.161

                       Coef     S.E.   Wald Z Pr(>|Z|)
y>=3                    -6.9729 1.2500 -5.58  <0.0001
y>=4                    -9.5301 1.3888 -6.86  <0.0001
y>=5                   -13.0843 1.6288 -8.03  <0.0001
SBTravSpeed              0.5196 0.2245  2.31  0.0207
SBWalkDistanTransfer     0.5849 0.2423  2.41  0.0158
SBClearTimeTableStop     0.5036 0.1733  2.91  0.0037
SBNetworkCoverage        0.6832 0.2114  3.23  0.0012
SBDrivStyle              0.4706 0.1925  2.45  0.0145
```

Fig 5.4 Final Result of the Satisfaction Model for Bus

6 Conclusion

A satisfaction survey for bus and U-Bahn in Munich has been conducted to investigate the most influential specific satisfactions on the overall satisfaction for bus and U-Bahn in Munich respectively. The questionnaire consists of three parts, personal information, judgment of the importance and satisfaction for several aspects in bus and U-Bahn service, and the influence of weather on bus and U-Bahn ridership. The survey started from July 2017, and it lasted two months. Author waited along S-Bahn stations and invited passengers to take part in the survey randomly during peak hours and off-peak hours on weekdays and weekends. Finally, the author collected 191 questionnaires and 177 of them were valid. Two statistical methods (factor analysis and ordered logit modeling) have been applied. In the satisfaction model for U-Bahn, the most influential specific satisfaction is waiting time at stations during peak hours, followed by travel speed, temperature at stations in summer times and Vehicles' modernity. In the satisfaction model for bus, the most influential specific satisfaction is network coverage of bus line, followed by walk distance to next line when transfer, travel speed, clear timetable information at stops and driving style. In addition, the impact of adverse weather on the ridership of bus and U-Bahn has also been estimated through the statistical test. Gender, age, ownership of driving license and car, use frequency of bus and U-Bahn were found to have an influence on the ridership in adverse weather.

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List of abbreviations

SC/D	Customer Satisfaction/ Dissatisfaction
ÖPNV	Öffentlicher PersonenNahVerkehr

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Declaration concerning the Master’s Thesis

I hereby confirm that the presented thesis work has been done independently and using only the sources and resources as are listed. This thesis has not previously been submitted elsewhere for purposes of assessment.

Munich, November 8th, 2017

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Yiwei Zuo