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MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

Bc. Markéta Jirmanová

Study programme (field/specialization) of the student:

master's degree – DS – Transportation Systems and Technology

Theme title (in Czech): **Optimalizace Metody vyhodnocení kvality provozu spojů veřejné hromadné dopravy**

Theme title (in English): **Optimization of the Quality of Public Transport Operation Evaluation Method**

Guidelines for elaboration

During the elaboration of the master's thesis follow the outline below:

- Quality of public transport definition
- Description of characteristics of the current state of the Method and search for other methods of evaluating the quality of operation
- Critical analysis of the current state of the method
- Optimization of the method based on the findings of the critical analysis and its calibration on case studies

Graphical work range: --

Accompanying report length: 55 pages

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[1] BANISTER, David. The Sustainable Mobility Paradigm. Transport Policy. 2008, č. 15, s.73-80. ISSN 0967-070X.

[2] SVÍTEK, Miroslav a Michal POSTRÁNECKÝ. Města budoucnosti. NADATUR, 2018. ISBN 978-80-7270-058-5

Master's thesis supervisor: **Ing. Vojtěch Novotný, Ph.D.**

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a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule

b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

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I confirm assumption of master's thesis assignment.

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Student's name and signature

Prague 01.července 2022

FACULTY OF
TRANSPORTATION
SCIENCES
CTU IN PRAGUE

Master's thesis

Optimization of the Quality of Public Transport Operation Evaluation Method

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Transport systems and technology
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May 15, 2023

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Declaration

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Abstrakt

Celkový nárůst mobility obyvatel v poslední době vyvolal větší poptávku po udržitelné mobilitě, která je pro budoucí rozvoj měst nezbytná. Vzhledem k narůstajícím kongescím ve městech, způsobených vysokým počtem automobilům, je důležité zaměřit se na městskou hromadnou dopravu, která je vhodnou a udržitelnou alternativou k individuální automobilové dopravě. Cílem této práce je optimalizovat parametry Metody vyhodnocení kvality provozu veřejné dopravy, která byla vyvinuta v roce 2017 a může se stát důležitým nástrojem při zavádění preferenčních opatření a celkovém zkvalitnění provozu MHD. Tato optimalizace byla provedena na základě vyhodnocení souboru reálných dopravních dat ze 107 mezizastávkových úseků ve 4 různých městech. Nakonec byla implementována optimalizovaná Metoda vyhodnocení kvality provozu veřejné dopravy a výsledky byly porovnány s verzí roku 2017, s cílem, aby se Metoda vyhodnocení kvality provozu veřejné dopravy opět přiblížila využití v praxi.

Klíčová slova Preference veřejné dopravy, chytré město, kvalita veřejné dopravy, cestovní doba, výkonnost veřejné dopravy

Abstract

The recent overall increase in the populations mobility has created a greater demand for sustainable mobility, which is essential for the future development of cities. Given the increasing congestion in cities caused by the high number of cars, it is important to focus on public transport, which is a suitable and sustainable alternative to individual car transport. The aim of this thesis is to optimize the parameters of the Public Transport Quality of the Service Evaluation Method, which was developed in 2017 and can become an important tool in the implementation of priority measures and the overall improvement of public transport operations. This optimization was carried out on based on the evaluation of a set of real traffic data from 107 inter-stop sections in 4 different cities. In the end, it was implemented by the optimized Level of Service of Public Transport Operation Evaluation Method for evaluating the quality of public transport operations and the results were compared with the 2017 version, with the aim that the Level of Service of Public Transport Operation Evaluation Method was again closer to being used in practice.

Keywords Public Transport Priority, Smart city, Public Transport Quality, Travel Time, Service Performance

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[2] Decisive Travel Time
[3] Travel Speed Index
[4] Reliability Index
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Introduction

The overall increase in urban population mobility has recently created a greater demand for sustainable mobility, which is essential for future urban development. Given the increasing congestion in cities caused by the high number of cars, it is important to focus on public transport, which is a suitable and sustainable alternative to individual car transport. From this point of view, it is necessary to convince residents to use public transport more than cars in order to avoid traffic congestion. The support and prioritisation of public transport is a cornerstone of sustainable urban mobility planning (Sustainable Urban Mobility Plans), where it plays a crucial role, particularly in terms of reducing greenhouse gas emissions and thus meeting the goals of the European Green Deal. [6] In order to make public transport competitive with cars, it is required to offer the level of public transport quality needed in addition to the financial advantage. [7]

There are many indicators that can describe the quality of public transport given the availability of data collection from real traffic. In 2017 Ing. Vojtěch Novotný, Ph.D. created The Quality of Public Transport Operation Evaluation Method (QPTOEM). This method is based on evaluating the reliability of public transport and travel speed - two important objective indicators of the quality of public transport operations, which can be evaluated from real traffic data. In this way, it should be possible to identify problematic inter-stop sections on the road and propose their possible improvements, thereby improving the quality of public transport and which would lead to more people using this mode of transportation. Following the development of this method, the PREFOS Research Group was established at the Czech Technical University in Prague, Faculty of Transportation Sciences, which deals not only with development and the implementation of this method, but also with research on the public transport priority in general. Within this research group, this thesis was also created, which deals with the optimization of the QPTOEM.To optimize the QPTOEM, more than a hundred inter-stop sections from four different cities are evaluated, using statistical methods to achieve the best possible result of the thesis, aiming to modify the QPTOEM to correspond as closely as possible to real traffic.

Chapter **1**

Quality of Public Transport Operations as an Important Part of Public Transport Quality

There are many different ways of looking at the quality of public transport and how to evaluate it. Currently, a very popular view of the quality of public transport and mobility in general is from a Smart City perspective.The term Smart City refers to a city that effectively uses modern technology and data collection to manage and operate the city in a way that creates synergies between different sectors with consideration to energy consumption and the quality of life of the citizens in that city. For such a city, the most economical, environmentally friendly, sustainable and space-efficient way is to keep mobility to a minimum, so the focus is on relocating targets rather than making public transport more cost-effective. [8] Of course, this is not always possible, which is why shared transport in all its forms, such as bike-sharing, car-sharing or public transport, is encouraged. Given the characteristics of a Smart City, public transport that is very well integrated with other mobility systems such as bike sharing, transfer terminals, etc. is advantageous, and such synergies are close to integrated regional transport systems, for example. Travel, where necessary for residents, should be as short as possible, thus reducing the economic losses caused by 'wasted' time on transport. [9] The type of vehicles used is also related to the reduction of energy consumption. A quality public transport system should use the most efficient (electric) vehicles currently available that do not pollute the environment either by emissions or noise. [8]

Anyway, from a Smart City perspective, these are rather goals that can be achieved in the future. Currently, the evaluation of the quality of public transport operations has many variations and, given the broadness of this topic, there are a number of parameters that can be evaluated in this regard. First of all, it is important to distinguish whether the quality of public transport is from the perspective of the passengers or the operator. From the operator's point of view, quality public transport is as efficient as possible, but the least economically demanding, which includes both fuel costs and, for example, staff wages, etc. At the same time, quality public transport should generate minimal losses for the operator so that it is subsidised as minimally as possible. However, due to the increasing mobility of the population and the large number of private cars, which are very inefficient, this takes up a lot of space and generally reduces the quality of life in cities, public transport is nowadays highly promoted. It is therefore necessary that the public transport service is of high quality, especially from the passengers' point of view, as this is what will convince them to choose public transport over the car. Public transport quality indicators can be divided, for example, into performance and service quality indicators [10]:

- Quality of service indicators (or "soft" indicators) - this set of indicators is used for surveying the user opinion about specific aspects of the public transport service and describing it in a qualitative manner (e.g. satis-faction about punctuality, travel time, safety, ticket price, comfort, company image, etc.). [10]
- Performance indicators (or "hard" indicators) - this set of indicators describes the performance of public transport in a quantitative manner (e.g. travel time, reliability etc.). [10]

Soft indicators or tools are a range of instruments that aim to persuade individuals to voluntarily change their travel behaviour towards greater sustainability. Soft tools aim to change behaviour by changing attitudes, perceptions of the objective environment and the consequences associated with the use of different modes of transport, and by strengthening the capacity to use public and non-motorised modes of transport. Such tools are used in a wide range of variations (in the form of mobility plans for employees, school mobility plans, personal planning services or information campaigns promoting public transport) and usually accompany infrastructure and pricing instruments.[7]

A number of studies confirm the effect of soft motivational tools. For example, in Japanese cities, there has been an average 17 % reduction in car trips and a 15 % to 35 % reduction in CO2 emissions. Conversely, public transport use has increased by up to 50 % [11]. The magnitude of the effect of soft instruments varies according to the specific type of instrument and for different target groups [12]. Impacts are larger for groups undergoing life changes and with poorly developed travel habits. In some cities, however, soft tools have not led to the intended changes [13]. The evidence on the extent to which these changes are sustained is also mixed, to say the least. While in Kassel and Nuremberg, Germany, the changes lasted beyond two years after the programme was implemented, in the English cities of Nottingham and Leeds, changes in travel behaviour were not sustained. [7]

However, economic indicators and indicators of the quality of public transport have a much greater influence on the choice of mode of transport, and travel time is closely related to this, which is influenced by the proximity of transport infrastructure. In particular, the choice of transport mode depends on the distance of the residence from the nearest public transport stop [14] and its interval. The length of the public transport interval has a lower, but nevertheless an order of magnitude comparable effect to the duration of a public transport journey. This means that the share of public transport in the modal split is more affected when the travel time is reduced or increased by one minute than when the interval of the nearest public transport service is changed by the same length. [7]

Utility-based models of travel time also rely on the importance of travel time, particularly the Random Utility Model, RUM [15]. In addition to mode choice, these types of models are used to explain individuals' decisions about whether, when, and where to travel. An individual compares the utility of an alternative according to the extent to which that alternative satisfies his or her individual needs or desires. He or she then ranks the alternatives by utility and chooses the alternative providing the greatest utility. The random utility model assumes that the choice reflects a rational process of optimizing the benefits that the individual can achieve. One of the three factors influencing mode choice in the random utility model is assumed to be the characteristics of the alternatives from which the individual chooses; in the case of mode choice, this is most often the time taken to travel by each mode to a given destination and the associated monetary costs. The reliability or flexibility of the transport mode is also considered, but measuring these characteristics is often difficult. [16]

In general terms, there are six key areas or requirements that must be met for the public transport system to be perceived as attractive and of a high quality by the public transport passenger (Figure 1.1). Of these six areas, travel speed and reliability are indicators of the quality of service. [1]

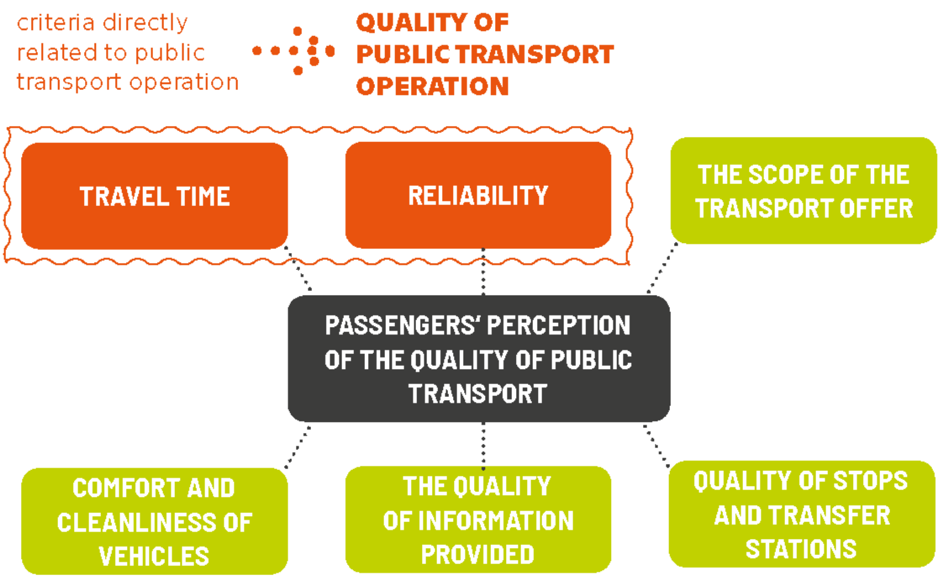


Figure 1.1: Diagram of the overview of public transport quality parameters from the passengers' point of view. The highlighted parameters are key to the QPTOEM.[1]

The passenger expects to be transported between the origin and destination of his/her journey in a reasonable (acceptable) time at a reasonable (acceptable) speed, which is in principle more convenient than travelling by car. He also expects to reach his destination on time, regardless of external circumstances. Here, it should also be taken into account that even relatively small delays are more perceived in the case of public transport travel, because, unlike travelling by car, the passenger can easily compare the journey time or the arrival time to the destination with the timetable - therefore punctuality is very important. Travel speed and reliability are essentially qualitative parameters of public transport operations. [1]

If a trip takes significantly longer by transit than by other modes, or if actual trip time ranges so widely as to be unpredictable, people may choose not to take the transit and cities will miss out on opportunities to reduce congestion and spur development. Also reliability affects how passengers perceive waiting times. If the waiting time and travel time vary significantly, or are routinely much longer than the scheduled time, passengers build this time into their trips, and transit becomes less useful for them. to eliminate sources of delay. In this case, this includes delays caused by congestion and stopping at intersections, but also dwell time at stops, which includes passenger boarding, entering and exiting the stop, speed of door opening, etc. In the Twin Cities, the transit agency estimates that the majority of transit runtimes on a major corridor are when transit vehicles are not moving as can be seen in Figure 1.2. [2]

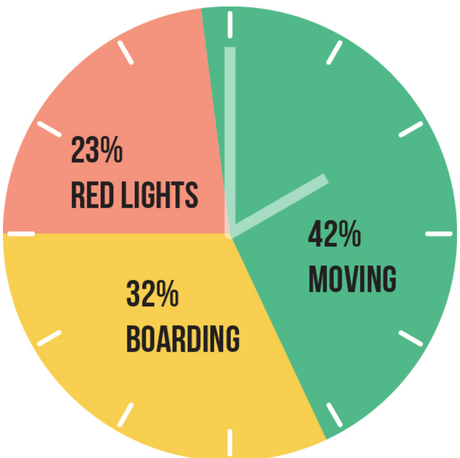


Figure 1.2: Round trip highly affected by the traffic. [2]

However, reliability and travel speed are not only important indicators for the choice of means of transport, but can also significantly influence the economic costs of public transport for the operator. As can be seen in Figures 1.3 and 1.4, for example, for a 70-minute bus turnaround, 7 buses are needed at a 10-minute interval. If 10 minutes of travel time is saved, only 6 buses are needed to serve the section, or the interval can be reduced to 8.5 minutes, making the option of travelling by bus more attractive. From the operator's point of view, saving one bus service can mean reduced operating costs as the purchase price, staff costs etc. play a big part.

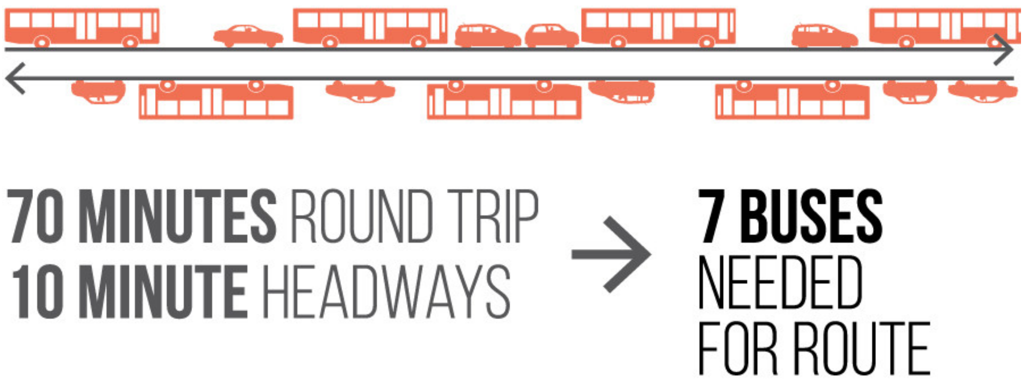


Figure 1.3: Changing number of vehicles needed for the area service after saving 10 minutes of the route. [2]

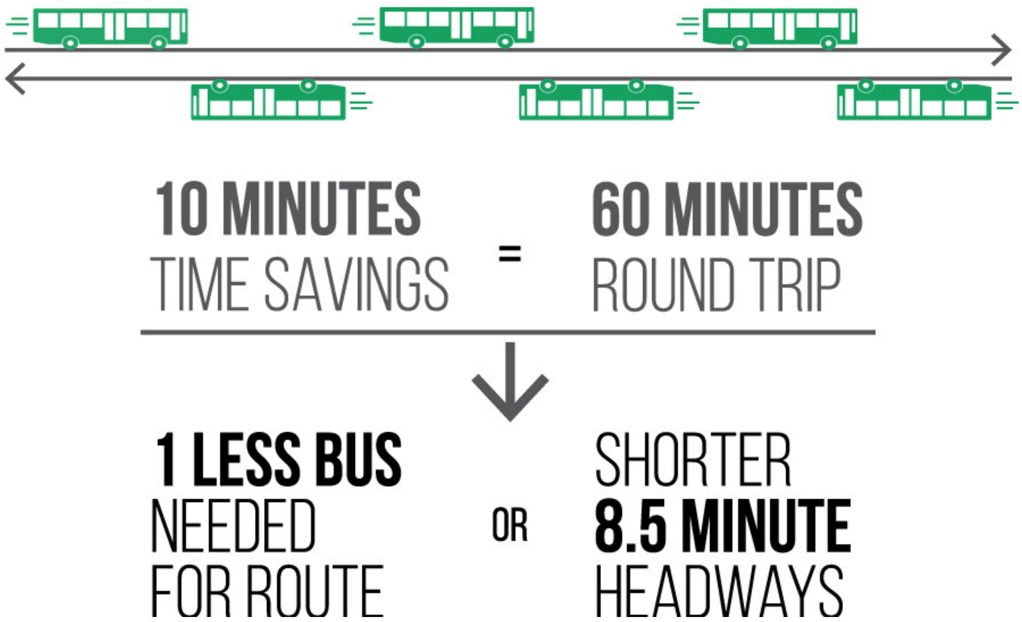


Figure 1.4: Graph showing that majority of transit runtimes on a major corridor are when transit vehicles are not moving. [2]

Chapter 2

The Quality of Public Transport Operation Evaluation Method (QPTOEM) principles and default version

As mentioned in Chapter 1, the quality of public transport operations is an important part of the evaluation of the quality of public transport. The shortest possible travel time of public transport vehicles and their reliability are not only an important aspect for the choice of travel mode for passengers, but can also lead to a reduction in the cost of public transport operations for the operator. On the basis of these requirements, in 2017 Ing. Vojtěch Novotný, Ph.D. defined the QPTOEM.[1]

The method is based on a quantitative evaluation of qualitative parameters of public transport operations, travel speed and reliability (Figure 1.1) and on the basis of (commonly available) data on the operation of individual connections in a given section. The evaluation is designed for the inter-stop section, as this is usually the smallest section for which measurable data (tracking of departure and arrival at the stop) is available. Each inter-stop section is then rated on a scale of 1 "excellent" - 5 "unacceptable". A data structure that contains both the arrival and departure time of the service at the stop is usually more suitable for a more accurate evaluation (the travel time or speed is evaluated and the effect of the length of stay of the service at the stop is removed). On the contrary, a data structure providing only the time of departure of the connection from the stop and working with travel time more relevantly reflects the customer quality sensing (see Chapter 1). [1]

2.1 Reliability of public transport operations

A reliable inter-stop section is considered to be one where public transport services achieve the same journey times throughout the day, regardless of the time of day or changes in traffic. This can be seen in Figures 2.1 and 2.2, which show plots of two different inter-stop sections. In Figure 2.1, it is possible to see a segment that is considered to be relatively reliable because the travel time is the same during the day, but is higher than the schedule throughout the day.[1]

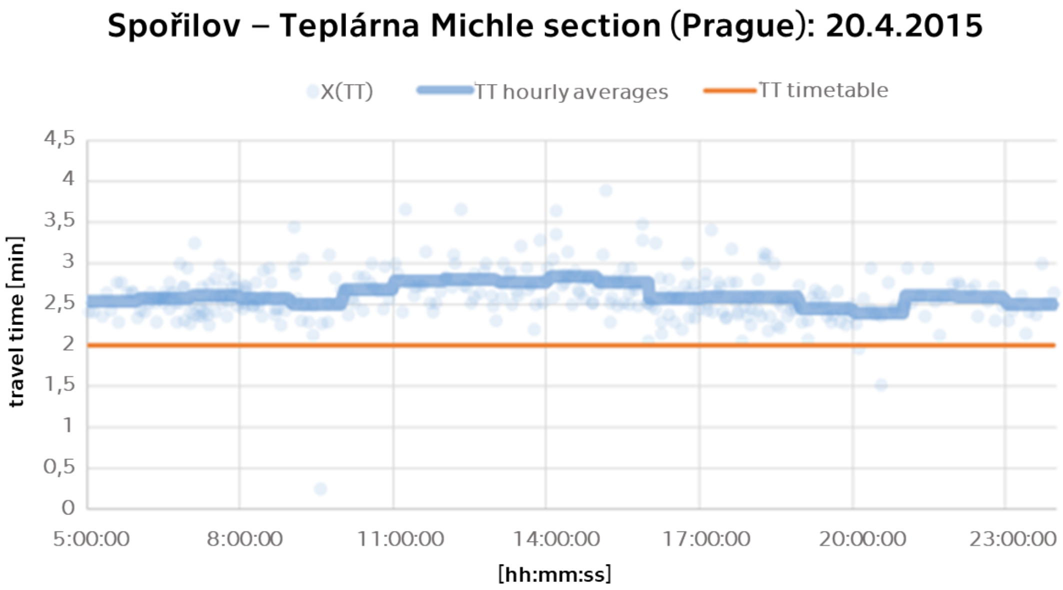


Figure 2.1: Graph of travel time (hourly average) versus time of day. Model for working days for the section Spořilov - Teplárna Michle (Prague).[1]

Conversely, Figure 2.2 shows an example of a section where, although the average hourly travel time is on schedule for some parts of the day, this section cannot be considered reliable because there is a large variance in travel times throughout the day. Therefore, it cannot be considered correct to determine the reliability of public transport operations in relation to the timetable travel times.[1]

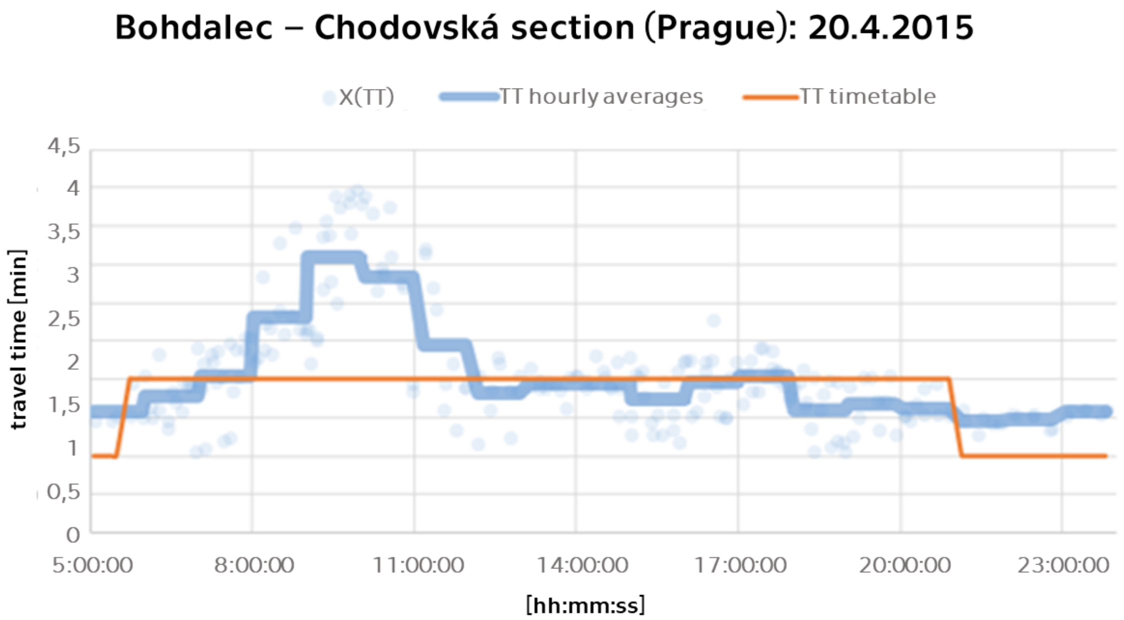


Figure 2.2: Graph of travel time (hourly average) versus time of day. Model for working days for the Bohdalec - Chodovská (Prague) section.[1]

To determine the level of reliability of a section, a reliability index is defined in the QPTOEM. Since a reliable section is one where the same travel time is achieved throughout the day regardless of the time of day, the reliability index is mathematically described as the standard deviation of the travel times (TT[7]), as can be seen in the following Equation 2.1.

$$i(rel_{A-B}) = \frac{\sigma_{TT}}{s} \cdot 1000 = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}[x_{TT} - E(X_{TT}]^2}}{s} \cdot 1000 \tag{2.1}$$

Since the variance in travel times is more likely to be greater for longer sections, this standard deviation is relativised by the length of the section. The multiplication by 1000 is to make the numbers easy to read and not too small. For the reliability index, it is therefore known that the higher the reliability index, the worse the quality of public transport operations.[1]

[7]Travel Time

2.2 Travel speed in inter-stop sections

The second important parameter of the QPTOEM is travel time, or in the case of the method, travel speed. This is very easy to measure and well quantifiable, but it is necessary to determine exactly what the travel speed can be compared to. For this purpose, it is proposed to find the ideal travel speed, i.e. the highest average travel speed at which a public transport vehicle can pass a given stopping point without unnecessary delays. How to determine such a travel speed? It is suggested to use the timetable time, but as already mentioned, the timetable is artificially set to match the speeds achieved in reality, not to reflect the best travel time that can be achieved on the section. For this purpose, the so-called decisive travel speed is used in the QPTOEM. This is verbally defined as “the highest speed that can be regularly achieved” [1], i.e. it is very close to the ideal speed.

Mathematically, it is described as a ten percent quantile of all travel speeds, as can be seen in Equation 2.2. This value was determined based on the data available at the time the method was developed.[1]

$$V(TT_{A-B}; dec) = 0,06 \cdot \frac{s_{A-B}}{Q_{10}(t_{TT;A-B})} \tag{2.2}$$

The calculated decisive travel speed is then used in the calculation of the travel speed index. This is defined as the level reached of the decisive travel speed by the average travel speed of the section. Mathematically, it is therefore the ratio of the decisive travel speed to the average travel speed in the section, as shown in Equation 2.3.[1]

$$i(V_{TT;A-B}) = \frac{V(TT_{A-B;avg})}{V(TT_{A-B;dec})} \tag{2.3}$$

2.3 Level of Service of Quality of public transport operations

The Reliability Index and the travel speed index are used to determine the final Level of Service. The overall Level of Service is evaluated on an integer scale of 1 ("excellent") - 5 ("unacceptable"). This value is obtained by first fuzzifying the two indices, after which the numeric value of the linguistic variable is assigned. Based on this, the overall Level of Service is then evaluated using logic rules from the numerical values of the two indices, as can be seen in the diagram in Figure 2.3.

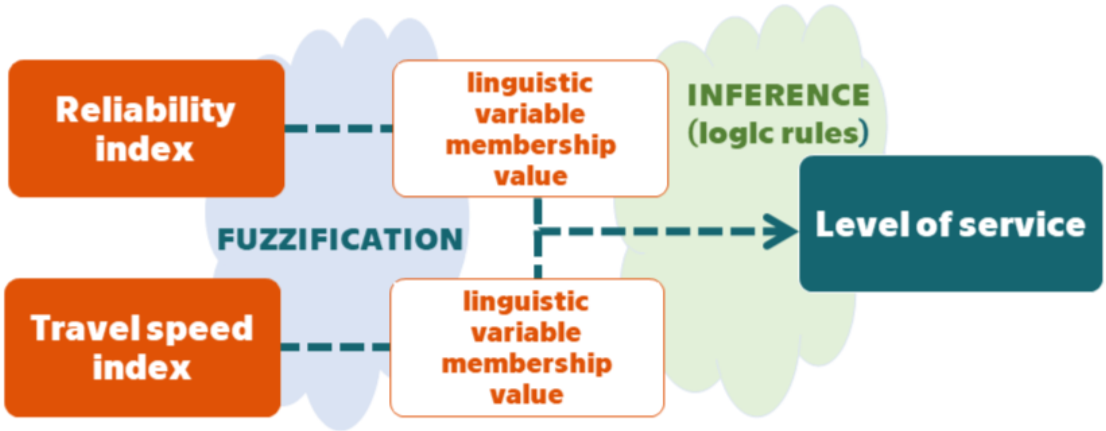


Figure 2.3: Diagram of the procedure for evaluating the overall Level of Service from the travel speed and reliability indices.[1]

Based on the qualitative evaluation of the reliability and travel speed indices, the overall value of the level of service of the inter-stop section is then calculated. This evaluation is performed using fuzzy sets and a series of logical rules. In simplified terms, this is determined by the larger percentage of membership in the sum of the two indices. Thus, if the reliability index was 75 % related to the value "low" and 25 % related to the value "unacceptable", and the travel speed index was 50 % related to the value "low" and also 50 % related to the value "unacceptable", the overall Level of Service will decide between the values "unacceptable" and "low". This will be determined by the sum of the percentages, i.e. an overall 125 % value of "low" and a 75 % value of "unacceptable" means that the overall Level of Service will have a value of "low".[1]

For each index, a membership function was created for the qualitative evaluation of public transport quality. This function assigns to a given index value a measure of membership to a particular qualitative evaluation. The membership graphs can be seen in Figures 2.4 and 2.5. For example, a reliability index value of 1.35 would correspond to a 75 % “low” and 25 % “unacceptable” value according to the membership function, as can be seen in Figure 2.4.

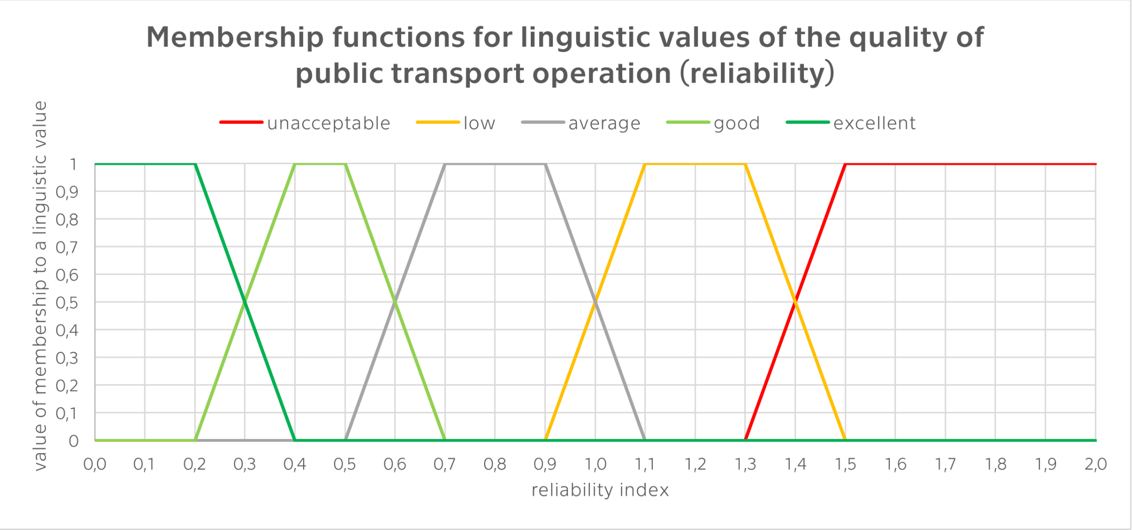


Figure 2.4: Linguistic membership function to determine the Level of Service for the reliability index. [1]

Similarly, a travel speed index value of 0.55 corresponds 50 % to the value “unacceptable” and 50 % to the value “low” (Figure 2.5).

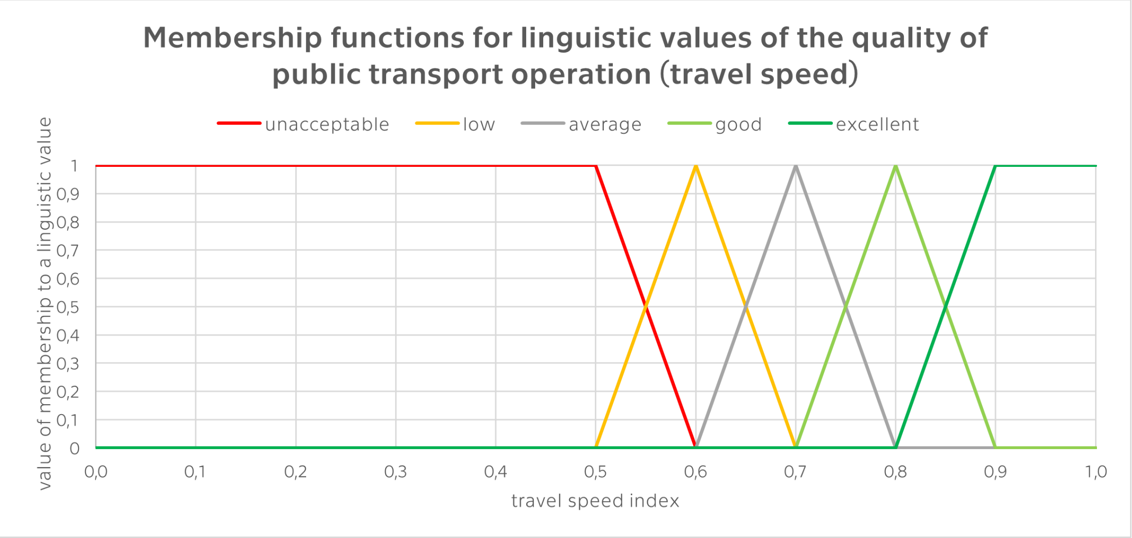


Figure 2.5: A linguistic membership function for determining the Level of Service for a travel speed index.[1]

The Level of Service are divided into 5 categories: excellent, good, insufficient, low and unacceptable. For clarity, each of these categories also has a numerical value from 1 to 5, where 1 corresponds to “excellent” and 5 to “unacceptable”.

This rating was chosen for clarity and readability for the general public and also corresponds in part to the already used rating of traffic volume and road passability for car drivers. At the same time, the overall value of both aspects, reliability and travel speed, is included in this single figure. In addition, by extracting the necessary data accurately from mass transit vehicle traffic data, an automated Level of Service evaluation can also be achieved.[1]

Chapter **3**

Pilot testing and ciritical analysis of the QPTOEM

In 2017, the method was defined on the basis of only a small amount of data and usually using only expert estimates. An important aspect of the optimization is the use of a larger and more variable data sample than when the QPTOEM was defined in 2017. This data from a total of 107 inter-stop sections and 4 different cities was first evaluated with the 2017 version of the QPTOEM. For this purpose, an evaluation sheet was created in the Power BI software. These results were plotted and linear trends were evaluated for each of the indicators (Level of Service for Reliability Index, travel speed index and Overall Level of Service). These trends were used not only to identify specific problems, but also, after optimization, to verify whether the QPTOEM now met the requirements and how it affected the results. A summary of the case studies can be seen in Table 3.1.

Table 3.1: A summary of the case studies.

City	Location	Number of inter-stop sections
Brno	Česká - Zelný trh	4
Brno	Gajdošova - Tomkovo nám.	7
Brno	Mendlovo nám. - Konečného nám.	7
Brno	Soukenická - Vsetínská	6
Budapest	Déli pályaudvar	2
Budapest	Erszébet híd	4
Budapest	Kéleti pályaudvar	2
Prague	Karlovarská	3
Prague	Libuš	6
Prague	Opatovská	10
Prague	Pod Jezerkou - Chodovská	6
Prague	Spořilov - Želivského	12
Pilsen	Line 16 (Doubravka - Sídliště Bory)	38

The pilot study was carried out after data from real public transport operations became available. This study was mainly important to validate the parameters of the QPTOEM. A total of 107 inter-stop sections of bus or tram networks were selected from 4 different cities. Data processing was also a challenging task as each city had a different source and format of raw data that needed to be preprocessed before being used in the QPTOEM evaluation.

3.1 Data processing - QPTOEM version 2017

In the optimization, the 2017 version was first evaluated for all inter-stop sections for accurate identification of the problem areas of the QPTOEM. The results of the 2017 evaluation also served as the basis for the subsequent optimization and were important for the final comparison of the optimized new version of the QPTOEM.

There was a different source data format for each city. This data had to be initially edited into a uniform format, which was then used as a source for the evaluation of individual inter-stop sections. The key information is the departure/arrival time from/to the stop. Other information is the starting and ending stops, the line number or service number to identify the correct data. Python was mainly used to modify the data into the appropriate format to provide the required information. Subsequently, obviously erroneous data, such as negative, too short or unusually long journey times, had to be filtered out. This was all done manually and by expert estimation thanks to local knowledge of the sections. Possible outliers (e.g. 12 minutes long travel time in a given section) were verified according to outliers and closures and possibly also filtered out if they were faulty measurements. For easier evaluation, detailed analysis and presentation of the results of the 2017 version of the QPTOEM, Power BI software was used to create a an evaluation sheet for each inter-stop section. With the Power BI software, the evaluation could be semi-automated and made more effective; for each inter-stop section it was only necessary to slightly modify the input data. Whole process of data processing can be seen in Figure 3.1.

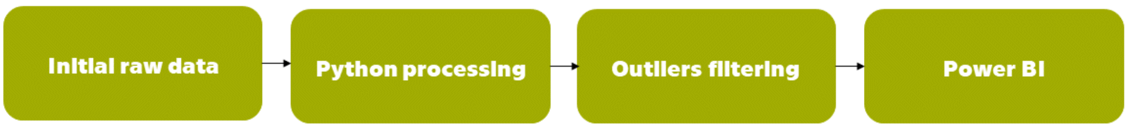


Figure 3.1: Initial data processing scheme.

For each inter-stop section an evaluation sheet is created, which has 4 pages. The first two pages contain the basic information about the section and the basic evaluation, therefore they are called the Basic Evaluation Sheet. The third and fourth pages contain a detailed description and evaluation of the section, the so-called Advanced Evaluation Sheet.

Basic Evaluation Sheet

On the first page of the evaluation sheet (Figure 3.2) it is possible to find basic data and parameters about the given inter-stop section. This information includes the name of the case study, the section ID (A is for one direction and B is the opposite direction) and the outlying stops. Under this heading is the length of the segment, the start and end date of the measurement, the number of measurements (number of connections that have passed through the segment in total), what percentage of the inter-stop segment the vehicle is travelling on a dedicated lane, the data source or provider, and the data structure (departure-to-departure or departure-to-arrival). The next row shows the basic results of the QPTOEM implementation such as Level of Service, the values of the two indices (reliability index and travel speed index), the decisive travel time and speed, and the delay distribution, which is calculated against the timetable and divided into intervals according to the length of the delay.

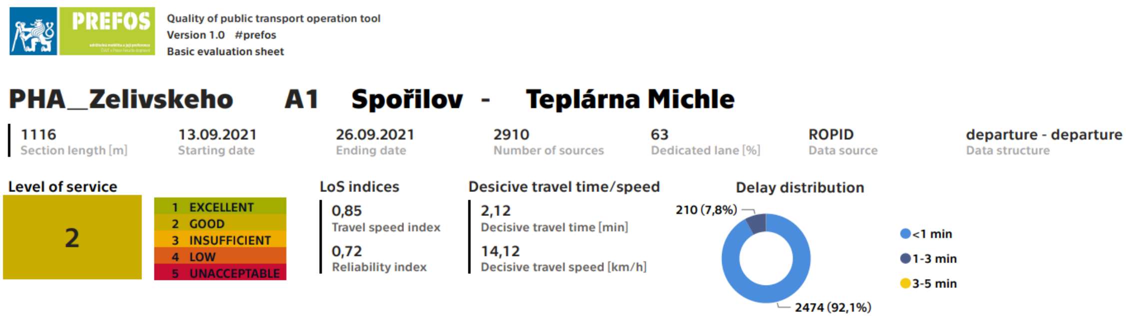


Figure 3.2: Screenshot of the information about the Spořilov - Teplárna Michle inter-stop section from the Basic Evaluation Sheet.

On the first page it is also possible to find a more detailed analysis using the travel time model of working days. Only weekday data is used for this model, as weekend data is of a different nature. Two graphs are produced for this model, as can be seen in Figure 3.3. The first graph shows the average travel times of public transport vehicles in hourly slices. On the x-axis is the hour of the day and on the y-axis is the travel time. The second graph shows the percentage comparison of these average hourly slices with the decision travel time, that is, by what percentage is the average travel time in a given hourly slice higher or lower than the decisive travel time. Below these graphs, you can find the average travel time, the travel speed, and the percentage comparison of the average travel time to the decisive travel time for the full day, the worst hourly slice, and the best hourly slice.

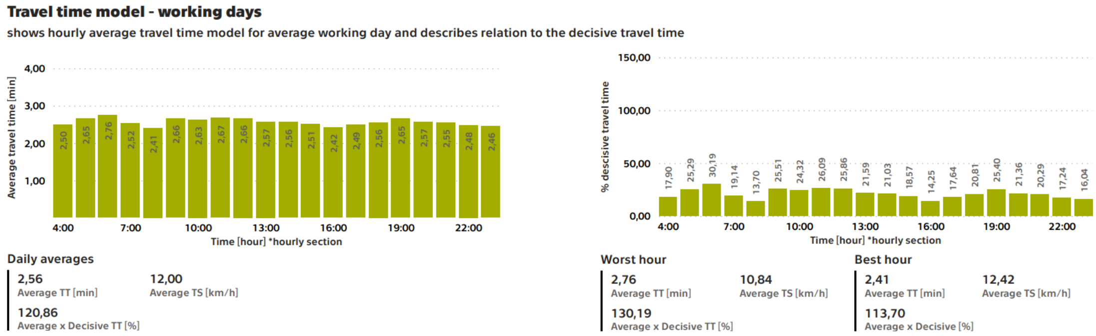
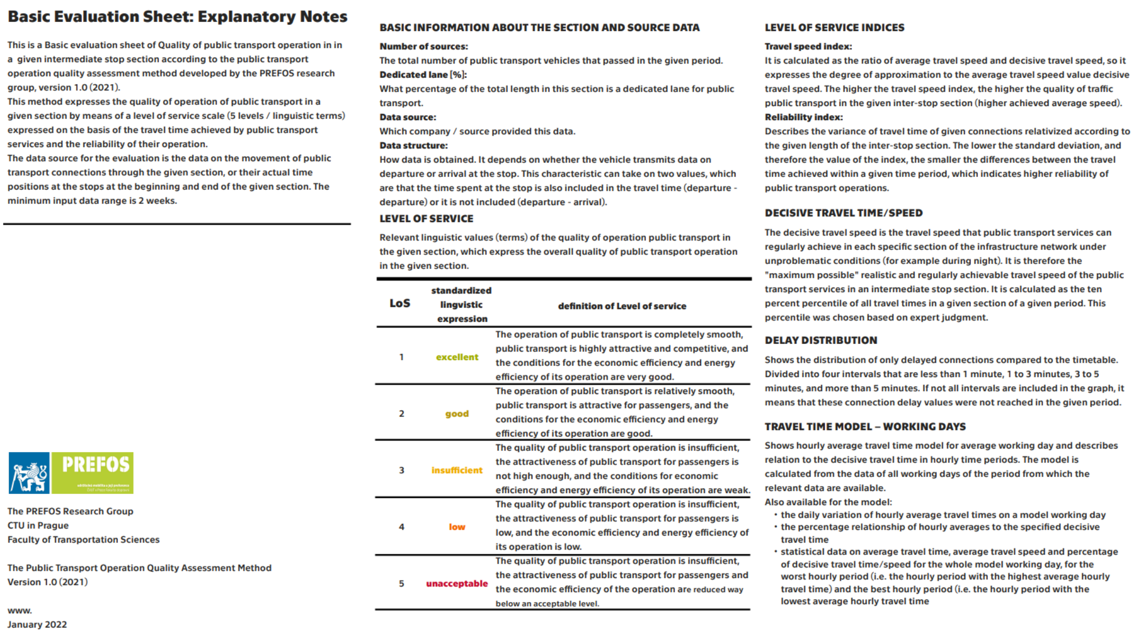


Figure 3.3: Screenshot of travel time model of working days for the Spořilov - Teplárna Michle inter-stop section in the Basic Evaluation Sheet.

The second page of the Basic Evaluation Sheet contains only notes that explain and describe in detail the variables used in the evaluation as seen in Figure 3.4.



Basic Evaluation Sheet: Explanatory Notes

This is a Basic evaluation sheet of Quality of public transport operation in in a given intermediate stop section according to the public transport operation quality assessment method developed by the PREFOS research group, version 1.0 (2021).
This method expresses the quality of operation of public transport in a given section by means of a level of service scale (5 levels / linguistic terms) expressed on the basis of the travel time achieved by public transport services and the reliability of their operation.
The data source for the evaluation is the data on the movement of public transport connections through the given section, or their actual time positions at the stops at the beginning and end of the given section. The minimum input data range is 2 weeks.

The PREFOS Research Group
CTU in Prague
Faculty of Transportation Sciences

The Public Transport Operation Quality Assessment Method
Version 1.0 (2021)

www.
January 2022

BASIC INFORMATION ABOUT THE SECTION AND SOURCE DATA

Number of sources:
The total number of public transport vehicles that passed in the given period.
Dedicated lane [%]:
What percentage of the total length in this section is a dedicated lane for public transport.
Data source:
Which company / source provided this data.
Data structure:
How data is obtained. It depends on whether the vehicle transmits data on departure or arrival at the stop. This characteristic can take on two values, which are that the time spent at the stop is also included in the travel time (departure - departure) or it is not included (departure - arrival).

LEVEL OF SERVICE

Relevant linguistic values (terms) of the quality of operation public transport in the given section, which express the overall quality of public transport operation in the given section.

LoS	standardized lingvistic expression	definition of Level of service
1	excellent	The operation of public transport is completely smooth, public transport is highly attractive and competitive, and the conditions for the economic efficiency and energy efficiency of its operation are very good.
2	good	The operation of public transport is relatively smooth, public transport is attractive for passengers, and the conditions for the economic efficiency and energy efficiency of its operation are good.
3	insufficient	The quality of public transport operation is insufficient, the attractiveness of public transport for passengers is not high enough, and the conditions for economic efficiency and energy efficiency of its operation are weak.
4	low	The quality of public transport operation is insufficient, the attractiveness of public transport for passengers is low, and the economic efficiency and energy efficiency of its operation is low.
5	unacceptable	The quality of public transport operation is insufficient, the attractiveness of public transport for passengers and the economic efficiency of the operation are reduced way below an acceptable level.

LEVEL OF SERVICE INDICES

Travel speed index:
It is calculated as the ratio of average travel speed and decisive travel speed, so it expresses the degree of approximation to the average travel speed value decisive travel speed. The higher the travel speed index, the higher the quality of traffic public transport in the given inter-stop section (higher achieved average speed).
Reliability index:
Describes the variance of travel time of given connections relativized according to the given length of the inter-stop section. The lower the standard deviation, and therefore the value of the index, the smaller the differences between the travel time achieved within a given time period, which indicates higher reliability of public transport operations.

DECISIVE TRAVEL TIME/SPEED

The decisive travel speed is the travel speed that public transport services can regularly achieve in each specific section of the infrastructure network under unproblematic conditions (for example during night). It is therefore the "maximum possible" realistic and regularly achievable travel speed of the public transport services in an intermediate stop section. It is calculated as the ten percent percentile of all travel times in a given section of a given period. This percentile was chosen based on expert judgment.

DELAY DISTRIBUTION

Shows the distribution of only delayed connections compared to the timetable. Divided into four intervals that are less than 1 minute, 1 to 3 minutes, 3 to 5 minutes, and more than 5 minutes. If not all intervals are included in the graph, it means that these connection delay values were not reached in the given period.

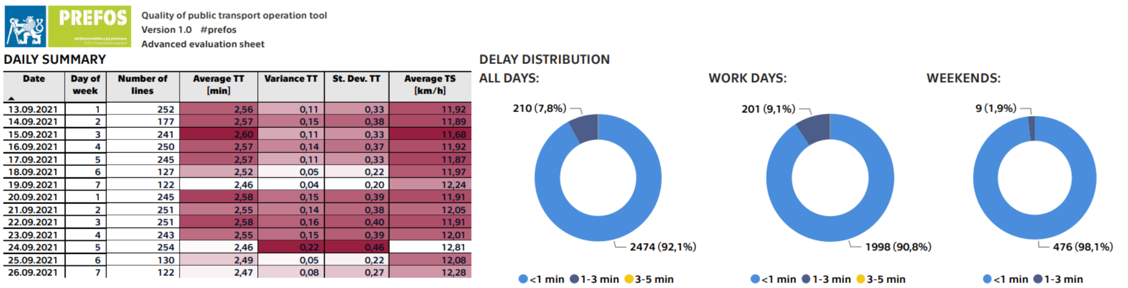
TRAVEL TIME MODEL – WORKING DAYS

Shows hourly average travel time model for average working day and describes relation to the decisive travel time in hourly time periods. The model is calculated from the data of all working days of the period from which the relevant data are available.
Also available for the model:
- the daily variation of hourly average travel times on a model working day
- the percentage relationship of hourly averages to the specified decisive travel time
- statistical data on average travel time, average travel speed and percentage of decisive travel time/speed for the whole model working day, for the worst hourly period (i.e. the hourly period with the highest average hourly travel time) and the best hourly period (i.e. the hourly period with the lowest average hourly travel time

Figure 3.4: Screenshot of the second page of the Basic Evaluation Sheet.

Advanced Evaluation Sheet

There are a total of three tables on the first page of the Advanced Evaluation Sheet. The first one is a daily summary where you can see for each day of the measurement the number of connections, the average travel time, the variance and standard deviation of the travel time and the average travel speed. In addition, all statistical variables have variable underlining, with darkest red being the worst results and white being the best results. Next to this daily summary table, you can see ring charts of the delay distribution for all days, weekdays only and weekends only. These are only values of delays against the timetable not against the decisive travel time. The daily summary table and ring charts are seen in the Figure 3.5.



Date	Day of week	Number of lines	Average TT [min]	Variance TT	St. Dev. TT	Average TS [km/h]
13.09.2021	1	252	2,56	0,11	0,33	11,92
14.09.2021	2	177	2,57	0,15	0,38	11,89
15.09.2021	3	241	2,60	0,11	0,33	11,68
16.09.2021	4	250	2,57	0,14	0,37	11,92
17.09.2021	5	245	2,57	0,11	0,33	11,87
18.09.2021	6	127	2,52	0,05	0,22	11,97
19.09.2021	7	122	2,46	0,04	0,20	12,24
20.09.2021	1	245	2,58	0,15	0,39	11,91
21.09.2021	2	251	2,55	0,14	0,38	12,05
22.09.2021	3	251	2,58	0,16	0,40	11,91
23.09.2021	4	243	2,55	0,15	0,39	12,01
24.09.2021	5	254	2,46	0,22	0,46	12,81
25.09.2021	6	130	2,49	0,05	0,22	12,08
26.09.2021	7	122	2,47	0,08	0,27	12,28

Figure 3.5: Screenshot of a daily summary table and delay distribution charts for the Spořilov - Teplárna Michle inter-stop section in Prague.

The second table is the average travel time table, where one can see the average travel times in each hourly slice, of each working day. Like the characteristics in the previous table, they are again underlined, making it easy to identify outliers and gaps in the measurements. The last table is the hourly summaries, where the average travel time and average travel speed for each hourly slice for all days are expressed. Finally, on this page there are also delay diagrams for all days, weekdays and weekends separately. An example of a table of average travel times and a table of hourly summaries for the Spořilov - Teplárna Michle inter-stop section in Prague can be seen in Figure 3.6.

AVERAGE TRAVEL TIME [min]

Time [hour]	13.09.2021	14.09.2021	15.09.2021	16.09.2021	17.09.2021	18.09.2021	19.09.2021	20.09.2021	21.09.2021	22.09.2021	23.09.2021	24.09.2021	25.09.2021	26.09.2021
4	2,47	2,55	2,51	2,49	2,45	2,55	2,41	2,52	2,47	2,56	2,43	2,47	2,73	2,45
5	2,66	2,64	2,82	2,74	2,69	2,57	2,38	2,69	2,53	2,52	2,71	2,53	2,56	2,50
6	2,70	2,76	2,74	2,85	2,85	2,51	2,57	2,78	2,66	2,68	2,87	2,68	2,56	2,53
7	2,53	2,53	2,68	2,63	2,56	2,47	2,47	2,47	2,37	2,51	2,55	2,40	2,40	2,38
8	2,51	2,33	2,53	2,38	2,56	2,43	2,51	2,57	2,46	2,23	2,34	2,20	2,47	2,53
9	2,68	2,79	2,81	2,57	2,52	2,49	2,43	2,62	2,56	2,62	2,63	2,79	2,58	2,49
10	2,66	2,25	2,69	2,55	2,61	2,50	2,59	2,65	2,75	2,98	2,58	2,51	2,47	2,54
11	2,71		2,71	2,59	2,54	2,60	2,45	2,71	2,55	2,66	2,72	2,84	2,56	2,56
12	2,73		2,83	2,51	2,67	2,46	2,50	2,68	2,58	2,62	2,71	2,66	2,49	2,51
13	2,59		2,57	2,49	2,72	2,44	2,44	2,66	2,52	2,71	2,59	2,34	2,52	2,52
14	2,52		2,53	2,59	2,62	2,40	2,37	2,62	2,61	2,59	2,61	2,37	2,38	2,50
15	2,58		2,55	2,53	2,51	2,48	2,50	2,48	2,53	2,58	2,34	2,49	2,50	2,60
16	2,47	2,44	2,54	2,35	2,44	2,83	2,46	2,18	2,57	2,53	2,40	2,22	2,57	2,45
17	2,49	2,62	2,48	2,63	2,32	2,41	2,45	2,60	2,43	2,49	2,45	2,35	2,41	2,36
18	2,50	2,55	2,58	2,60	2,60	2,44	2,40	2,60	2,59	2,59	2,81	2,21	2,34	2,49
19	2,62	2,78	2,53	2,66	2,54	2,65	2,48	2,68	2,84	2,68	2,52	2,68	2,56	2,47
20	2,52	2,70	2,59	2,55	2,61	2,62	2,54	2,57	2,47	2,59	2,52	2,56	2,51	2,48
21	2,29	2,63	2,48	2,46	2,56	2,52	2,41	2,91	2,60	2,50	2,51	2,54	2,44	2,24
22	2,49	2,53	2,39	2,58	2,56	2,69	2,36	2,52	2,42	2,47	2,36	2,48	2,63	2,36
23	2,31	2,59	2,46	2,51	2,46	2,24	2,40	2,51	2,33	2,59	2,38	2,45	2,30	2,32

HOURLY SUMMARIES

Time	Average travel time [min]	Average travel speed [km/h]
4	2,50	11,99
5	2,62	11,48
6	2,73	11,16
7	2,51	12,30
8	2,42	12,89
9	2,63	11,51
10	2,61	11,63
11	2,64	11,43
12	2,62	11,52
13	2,56	11,85
14	2,53	12,07
15	2,51	12,14
16	2,44	12,82
17	2,48	12,52
18	2,54	12,03
19	2,63	11,57
20	2,56	11,78
21	2,51	12,17
22	2,49	12,09
23	2,42	12,50

Figure 3.6: Screenshot of a table of average travel times for the Spořilov - Teplárna Michle inter-stop section in Prague.

On the last page you can find graphs of average travel times for hourly slices for each day of the week separately (Figure 3.7). This makes it possible to see any differences in weekend or weekday traffic.

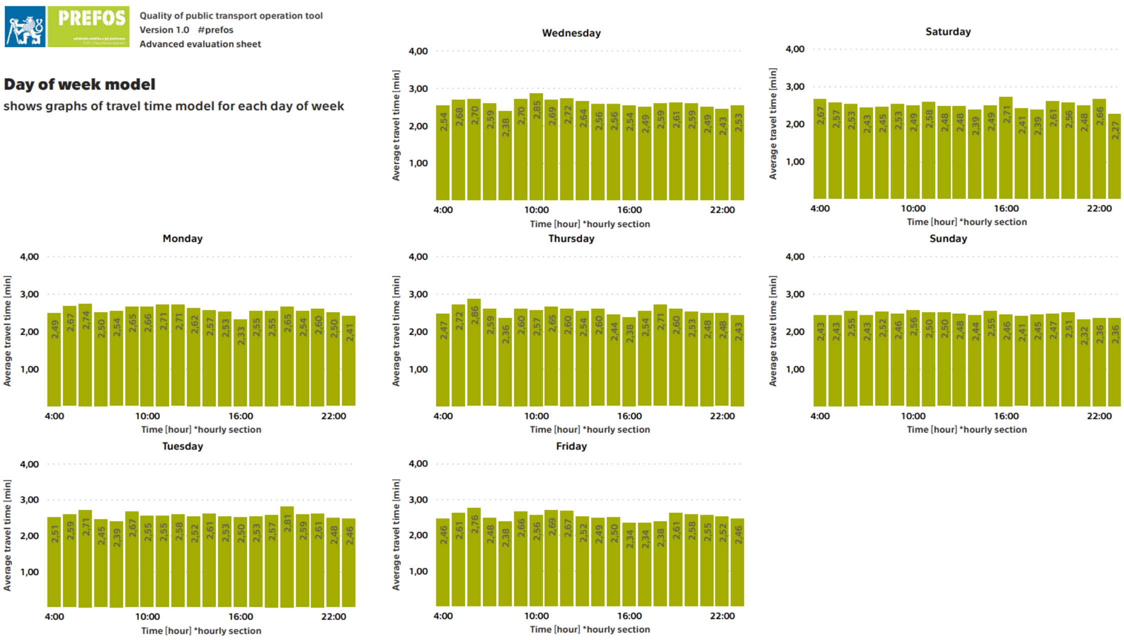


Figure 3.7: Screenshot of the second page of Advanced Evaluation Sheet with graphs of hourly slices for the Spořilov - Teplárna Michle inter-stop section in Prague.

3.2 Inter-stop sections evaluation - the QPTOEM version 2017

For the optimization of the QPTOEM, inter- stop sections from the cities of Prague, Pilsen, Brno and Budpaest were selected based on good data availability, sufficient extent of the transport network and also good local knowledge. This made it possible to select inter-stop sections where the quality of public transport operations is already subjectively known (frequent delays of connections or, on the contrary, very good transit) and thus to select equally excellent sections, unacceptable and average ones. An overview of the case studies can be seen in the table in the begining of this chapter in Table 3.1.

3.2.1 Brno

Brno is the second largest city in the Czech Republic, but with a population of 379,466 it is still far behind the capital Prague. [17] The backbone public transport network here consists of tram lines and is supplemented by buses. The diagram of public transport in Brno can be seen in Figure 3.8. 4 case studies were examined here, namely Česká - Zelný trh, Gajdošova - Tomkovo náměstí, Mendlovo náměstí - Konečného náměstí and Soukenická - Vsetínská. In total, there are 24 inter-stop sections.

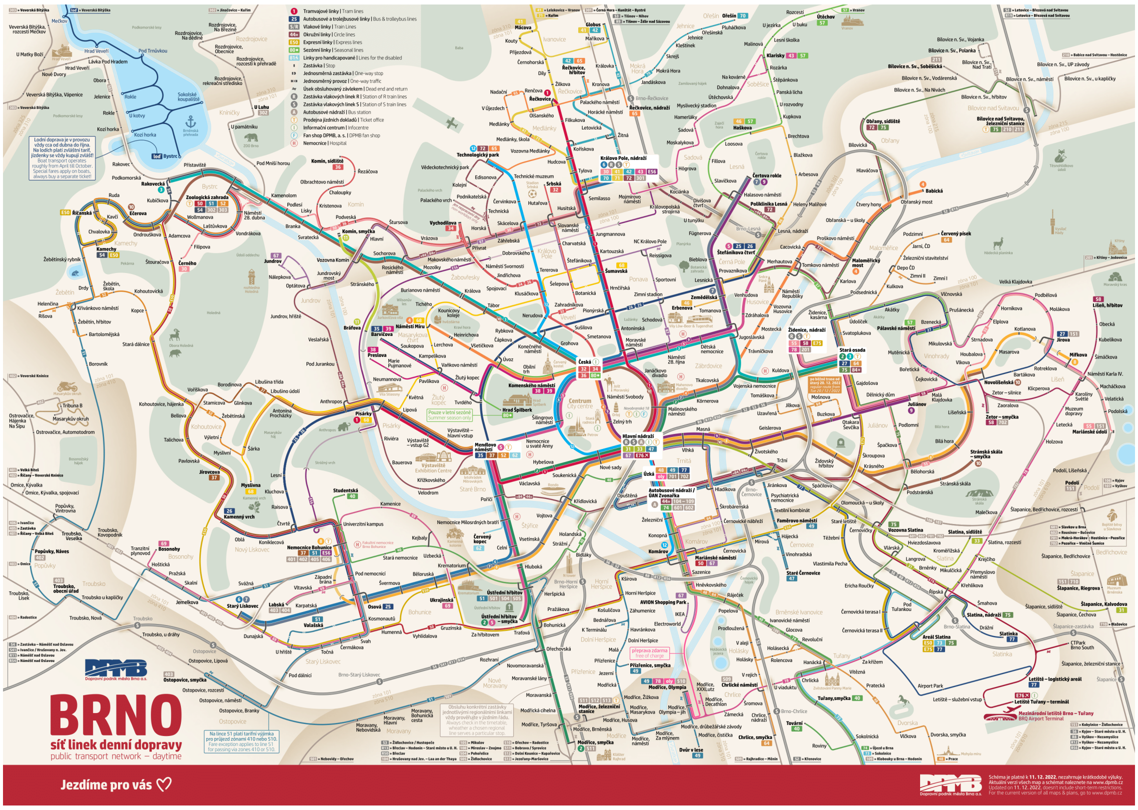


Figure 3.8: Diagram of public transport lines in Brno.[3]

Česká - Zelný trh case study

The Česká - Zelný trh case study has only 4 inter-stop sections with a total length of about 600 metres (Figure 3.9). However, an interesting feature of this section is that between the stops Česká, Náměstí Svobody and Zelný trh a pedestrian zone passes through, so it is possible to detect the influence of pedestrians on the operation of public transport vehicles.

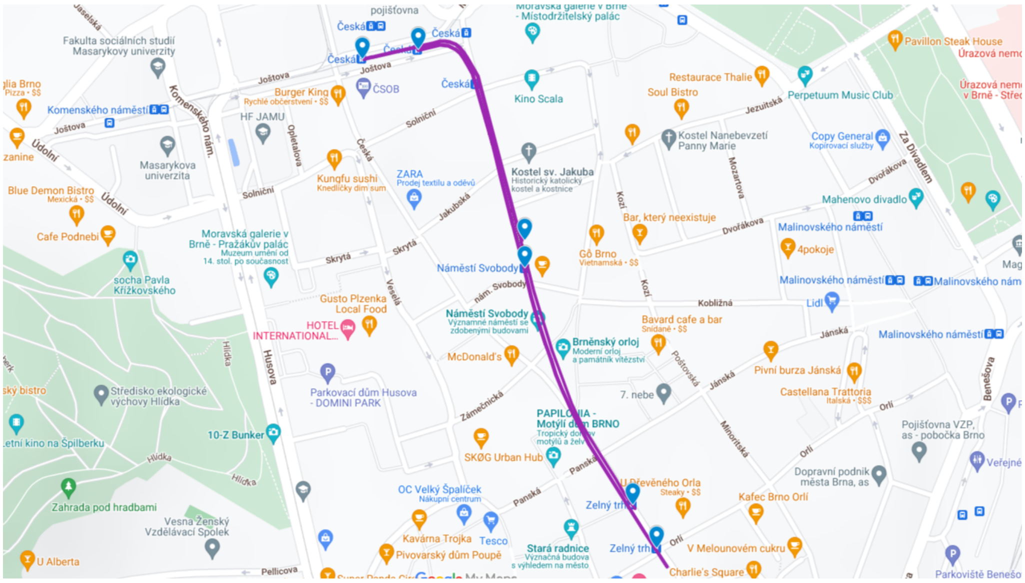


Figure 3.9: Diagram of the route with marked stops plotted on the map for the Česká - Zelný trh case study in Brno.

Gajdošova - Tomkovo náměstí case study

The Gajdošova - Tomkovo náměstí case study has 6 inter-stop sections with a total length of over 2000 metres(Figure 3.10). The stops along the route are Gajdošova, Stará osada, Židenice, kasárna and Tomkovo náměstí. This section is very busy with car traffic and there are no dedicated lanes, therefore there is a lot of interaction between public transport vehicles and cars.

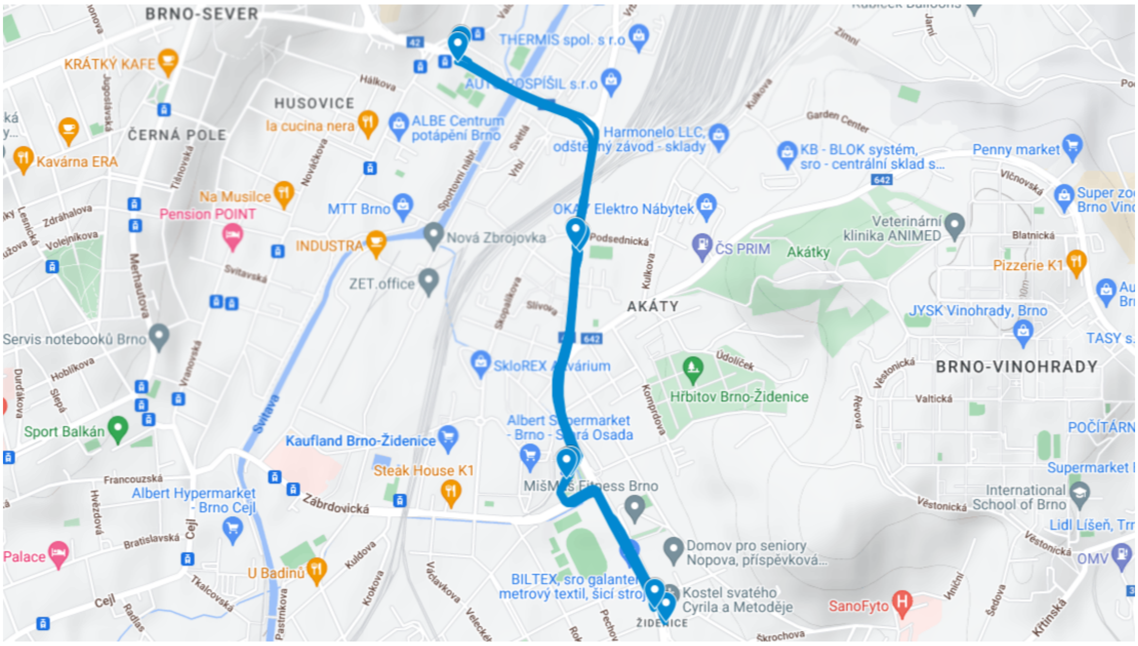


Figure 3.10: Diagram of the route with marked stops plotted on the map for the Gajdošova - Tomkovo náměstí case study in Brno.

Mendlovo náměstí - Konečného náměstí case study

Mendlovo náměstí - Konečného náměstí case study has 7 inter-stop sections with stops at Konečného náměstí, Čápkova, Úvoz, Tvrdého and Mendlovo náměstí as can be seen in Figure 3.11. The total length of the section is approximately 1900 metres. For a significant length of several inter-stop sections, there is a dedicated lane for public transport vehicles.

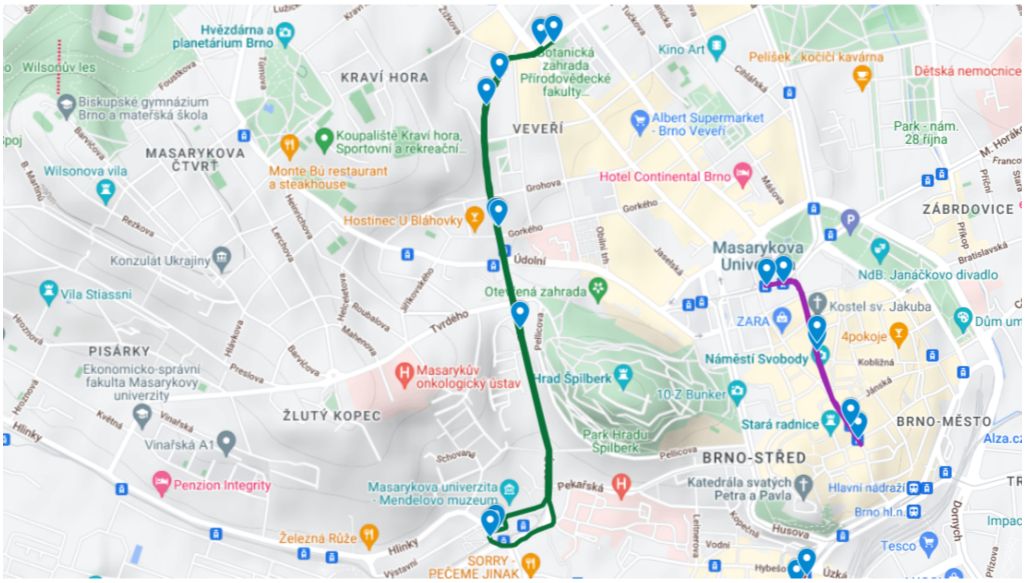


Figure 3.11: Diagram of the route with marked stops plotted on the map for the Mendlovo náměstí - Konečného náměstí case study in Brno.

Soukenická - Vsetínská case study

Soukenická - Vsetínská case study also has a total of 6 inter-stop sections with a length of 1200 metres. A diagram with marked stops can be seen in Figure 3.12. All stops on the route (Soukenická, Křídlovická, Vojtova and Vsetínská) and the inter-stop sections are on a dedicated lane for public transport vehicles.

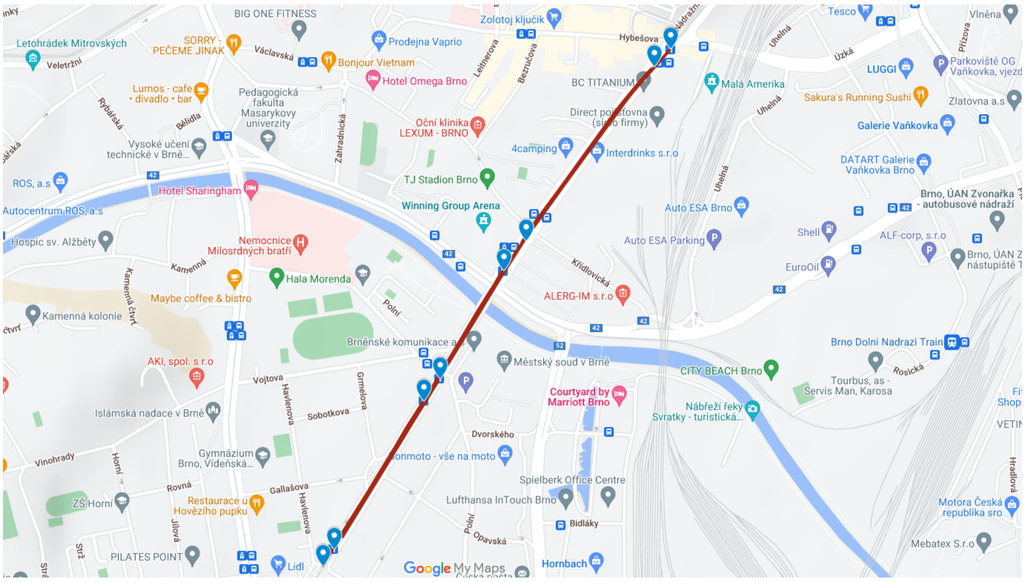
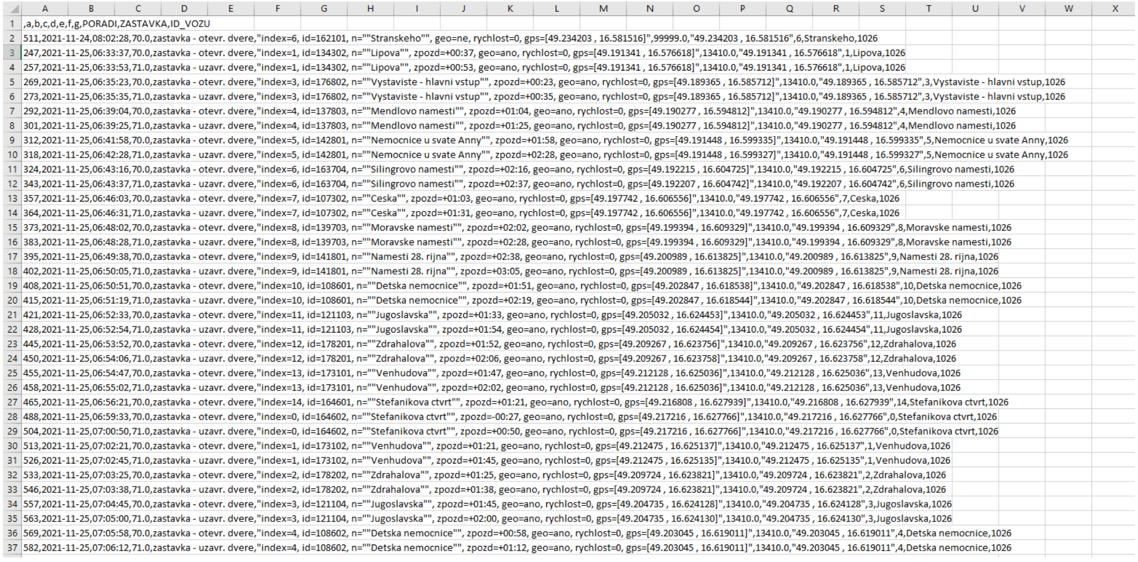


Figure 3.12: Diagram of the route with marked stops plotted on the map for the Soukenická - Vsetínská case study in Brno.

Data source and format in Brno

In Brno, the data is not used directly for this purpose by the transport company (Dopravní podnik města Brna, a.s.). Therefore, raw data with all information sent to the system from public transport vehicles was provided directly from the transport company. Therefore, the data had to be filtered and processed using Python due to their large volume. The arrival and departure from the stop is signalled by a command to open and close the doors (the data after this filtering can be seen in Figure 3.13), then the data was filtered based on the information of the starting and following stop. After this filtering, the data was ready for analysis using QPTOEM in the departure-arrival format.



```
1 ,a,b,c,d,e,f,g,PORADI,ZASTAVKA,ID_VOZU
2 511,2021-11-24,08:02:28,70.0,zastavka - otevr. dvere,"index=6, id=162101, n=""Stranskeho"", geo=ne, rychlost=0, gps=[49.234203 , 16.581516]",99999.0,"49.234203 , 16.581516",6,Stranskeho,1026
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4 257,2021-11-25,06:33:53,71.0,zastavka - uzavr. dvere,"index=1, id=134302, n=""Lipova"", zpozd=+00:53, geo=ano, rychlost=0, gps=[49.191341 , 16.576618]",13410.0,"49.191341 , 16.576618",1,Lipova,1026
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6 273,2021-11-25,06:35:35,71.0,zastavka - uzavr. dvere,"index=3, id=176802, n=""Vystaviste - hlavni vstup"", zpozd=+00:35, geo=ano, rychlost=0, gps=[49.189365 , 16.585712]",13410.0,"49.189365 , 16.585712",3,Vystaviste - hlavni vstup,1026
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9 312,2021-11-25,06:41:58,70.0,zastavka - otevr. dvere,"index=5, id=142801, n=""Nemocnice u svate Anny"", zpozd=+01:58, geo=ano, rychlost=0, gps=[49.191448 , 16.599335]",13410.0,"49.191448 , 16.599335",5,Nemocnice u svate Anny,1026
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```

Figure 3.13: Screenshot of data provided in Brno. Important is the column "zastavka - otevr./uzavr. dvere", which indicates the opening and closing of the door at the stop, according to which Brno calculates the time of arrival and departure to the stop.

Results of the evaluation in Brno

In the table in Figure 3.14 can be seen the results of the 2017 QPTOEM evaluation for Brno. The resulting Level of Service is highlighted according to the resulting value, green is for the best values and red is for the worst.

City	Location	Section	Level of service	Section Length [m]	Decisive travel time [min]	Travel speed index	Reliability index	Average travel time [min]	Data structure
Brno	Česká - Zelný trh	A1	3	277	0,67	0,76	0,96	0,96	D-A
Brno	Česká - Zelný trh	A2	1	359	1,15	0,91	0,51	1,28	D-A
Brno	Česká - Zelný trh	B1	3	330	0,8	0,75	1,07	1,17	D-A
Brno	Česká - Zelný trh	B2	1	300	0,97	0,91	0,4	1,08	D-A
Brno	Gajdošova - Tomkovo nám.	A1	4	644	1,25	0,65	2,07	2,54	D-A
Brno	Gajdošova - Tomkovo nám.	A2	4	709	1,77	0,63	4,36	4,4	D-A
Brno	Gajdošova - Tomkovo nám.	A3	4	849	1,4	0,63	2,29	3,47	D-A
Brno	Gajdošova - Tomkovo nám.	B1	3	554	1,27	0,74	0,84	1,86	D-A
Brno	Gajdošova - Tomkovo nám.	B2a	3	382	0,88	0,73	0,8	1,31	D-A
Brno	Gajdošova - Tomkovo nám.	B2b	2	328	0,7	0,87	0,66	0,84	D-A
Brno	Gajdošova - Tomkovo nám.	B3	3	815	1,37	0,78	1,48	2,21	D-A
Brno	Mendlovo - Konečného nám.	A1	4	297	0,88	0,74	1,75	1,36	D-A
Brno	Mendlovo - Konečného nám.	A2	1	407	0,7	0,89	0,24	0,8	D-A
Brno	Mendlovo - Konečného nám.	A3	2	1156	3,13	0,82	0,81	4,13	D-A
Brno	Mendlovo - Konečného nám.	B1	4	250	0,77	0,67	1,29	1,23	D-A
Brno	Mendlovo - Konečného nám.	B2	1	495	0,82	0,87	0,28	0,97	D-A
Brno	Mendlovo - Konečného nám.	B3a	4	350	1	0,72	1,73	1,59	D-A
Brno	Mendlovo - Konečného nám.	B3b	2	905	2,12	0,78	0,66	2,83	D-A
Brno	Soukenická - Vsetínská	A1	1	528	0,67	0,83	0,21	0,81	D-A
Brno	Soukenická - Vsetínská	A2	2	317	0,75	0,89	0,56	0,86	D-A
Brno	Soukenická - Vsetínská	A3	1	408	0,65	0,91	0,15	0,72	D-A
Brno	Soukenická - Vsetínská	B1	2	509	0,8	0,82	0,82	1,07	D-A
Brno	Soukenická - Vsetínská	B2	4	349	0,87	0,66	1,35	1,47	D-A
Brno	Soukenická - Vsetínská	B3	1	388	0,62	0,91	0,19	0,68	D-A

Figure 3.14: Table of results of evaluation of the 2017 version of the QPTOEM in Brno.

3.2.2 Budapest

Budapest was chosen because it is a foreign city and compared to other foreign cities there is a good knowledge of the local situation and the availability of public transport bus operation data. A total of 8 inter-stop sections in 3 different locations have been selected. The location Blaha Lujza tér - Keleti Pályaudvar was chosen because of frequent congestion but buses are routed on a dedicated lane for almost the whole inter-stop section. A diagram can be seen in Figure 3.15.

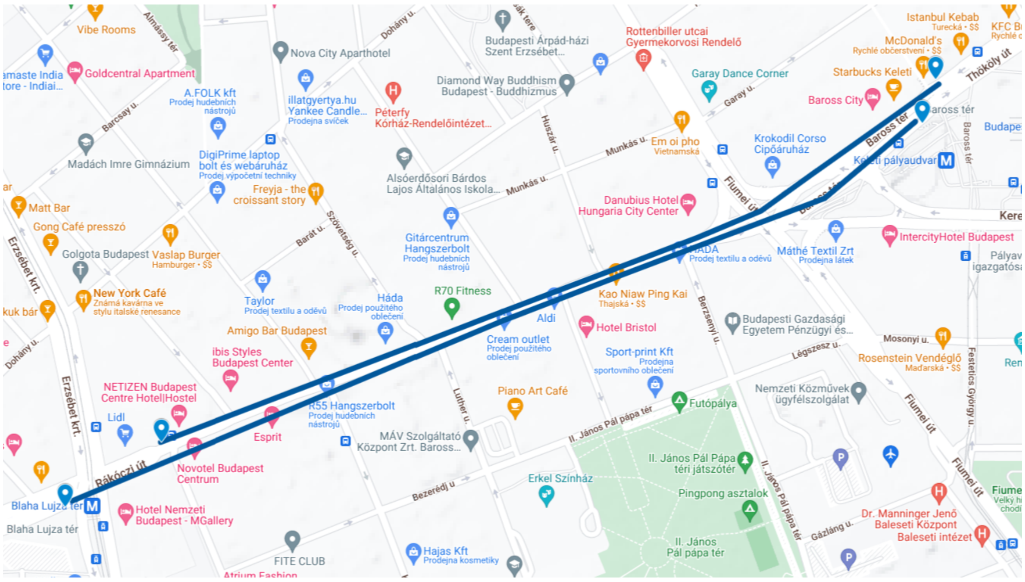

Figure 3.15: Diagram of the route with marked stops plotted on the map for the Blaha Lujza tér - Keleti Pályaudvar location in Budapest.

The location over the Erszébet híd bridge was chosen again because of the dedicated lane. The Ferenciek tér, Március 15. tér and Döbrentei tér stops are located here and a diagram of this site can be seen in Figure 3.16.

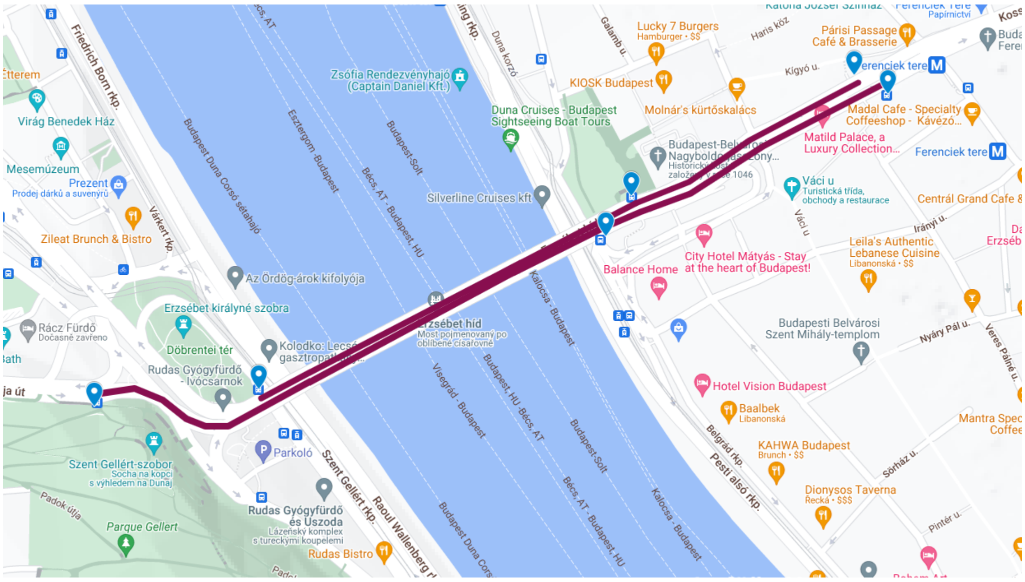

Figure 3.16: Diagram of the route with marked stops plotted on the map for the Erszébet híd location in Budapest.

The last location (Figure 3.17) from Déli pályaudvar station to Széll Kálmán tér was chosen precisely because of the large amount of congestion and at the same time the minimal movement of public transport buses on the dedicated lane.

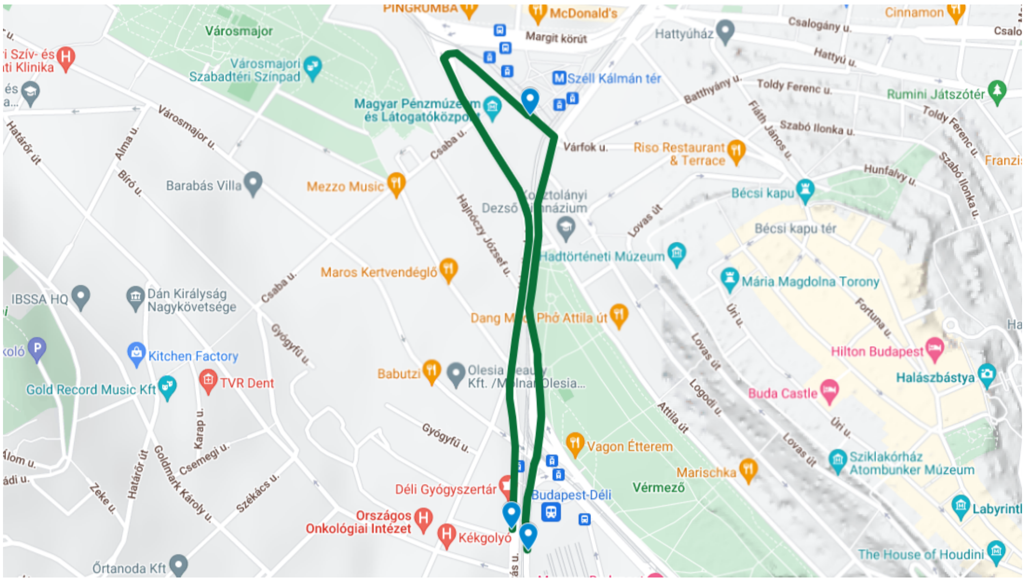

Figure 3.17: Diagram of the route with marked stops plotted on the map for the Déli pályaudvar - Széll Kálmán tér location in Budapest.

Data source and format in Budapest

In Budapest, the data is not provided directly by the transport company (BKK FUTÁR - Centre for Budapest Transport), but is publicly available via an API[8] server. From this server it was possible to download line by line information with arrival and departure information from the stops, the ID of the stop and the order of the stop on the route. A sample of this data is shown in Figure 3.18. According to these parameters, the data was also filtered and processed to be used for analysis using QPTOEM.

[8]Application Programming Interface

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5	2074406	133E	VĂˇsĂˇrcs	1	20220202	02.02.2022 7:21	02.02.2022 7:21	NULL	NULL		BKK_5185				
6	684609	139	DĂ©li pĂ	1	20220121	21.01.2022 5:02	21.01.2022 5:02	21.01.2022 5:03	21.01.2022 5:04		BKK_3011				
7	1569977	108E	VĂˇsĂˇrcs	1	20220128	28.01.2022 14:35	28.01.2022 14:35	28.01.2022 14:35	28.01.2022 14:35		BKK_3052				
8	222198	112	BosnyĂˇk	1	20220117	17.01.2022 16:28	17.01.2022 16:28	17.01.2022 16:25	17.01.2022 16:25		BKK_5033				
9	2074407	133E	FĹ‘tĂ©r	2	20220202	02.02.2022 7:23	02.02.2022 7:23	NULL	NULL		BKK_5185				
10	684610	139	KirĂˇlyhĂ	2	20220121	21.01.2022 5:03	21.01.2022 5:03	21.01.2022 5:05	21.01.2022 5:05		BKK_3011				
11	1569978	108E	FĹ‘tĂ©r	2	20220128	28.01.2022 14:37	28.01.2022 14:37	28.01.2022 14:37	28.01.2022 14:37		BKK_3052				
12	222199	112	Tisza IstvĂ	2	20220117	17.01.2022 16:30	17.01.2022 16:30	17.01.2022 16:27	17.01.2022 16:27		BKK_5033				
13	2074408	133E	MolnĂˇr V	3	20220202	02.02.2022 7:26	02.02.2022 7:26	NULL	NULL		BKK_5185				
14	684611	139	Tartsay Vi	3	20220121	21.01.2022 5:04	21.01.2022 5:04	21.01.2022 5:05	21.01.2022 5:05		BKK_3011				
15	1569979	108E	ApollĂł ut	3	20220128	28.01.2022 14:39	28.01.2022 14:39	28.01.2022 14:39	28.01.2022 14:39		BKK_3052				
16	222200	112	Amerikai	3	20220117	17.01.2022 16:32	17.01.2022 16:32	17.01.2022 16:29	17.01.2022 16:29		BKK_5033				
17	2074409	133E	Miskolci u	4	20220202	02.02.2022 7:28	02.02.2022 7:28	NULL	NULL		BKK_5185				
18	684612	139	BAH-csom	4	20220121	21.01.2022 5:06	21.01.2022 5:06	21.01.2022 5:06	21.01.2022 5:06		BKK_3011				
19	1569980	108E	MolnĂˇr V	4	20220128	28.01.2022 14:40	28.01.2022 14:40	28.01.2022 14:40	28.01.2022 14:40		BKK_3052				
20	222201	112	ZuglĂł vas	4	20220117	17.01.2022 16:34	17.01.2022 16:34	17.01.2022 16:31	17.01.2022 16:31		BKK_5033				
21	2074410	133E	BosnyĂˇk	5	20220202	02.02.2022 7:32	02.02.2022 7:32	NULL	NULL		BKK_5185				
22	684613	139	MuskotĂ	5	20220121	21.01.2022 5:07	21.01.2022 5:07	21.01.2022 5:07	21.01.2022 5:07		BKK_3011				
23	1569981	108E	Cinkotai Ă	5	20220128	28.01.2022 14:42	28.01.2022 14:42	28.01.2022 14:42	28.01.2022 14:42		BKK_3052				
24	222202	112	ZuglĂł vas	5	20220117	17.01.2022 16:35	17.01.2022 16:35	17.01.2022 16:32	17.01.2022 16:32		BKK_5033				
25	2074411	133E	Tisza IstvĂ	6	20220202	02.02.2022 7:34	02.02.2022 7:34	NULL	NULL		BKK_5185				
26	684614	139	FehĂ©rlĂ	6	20220121	21.01.2022 5:09	21.01.2022 5:09	21.01.2022 5:08	21.01.2022 5:08		BKK_3011				
27	1569982	108E	BosnyĂˇk	6	20220128	28.01.2022 14:45	28.01.2022 14:45	28.01.2022 14:45	28.01.2022 14:45		BKK_3052				
28	222203	112	StefĂˇnia	6	20220117	17.01.2022 16:37	17.01.2022 16:37	17.01.2022 16:34	17.01.2022 16:34		BKK_5033				
29	2074412	133E	ZuglĂł vas	7	20220202	02.02.2022 7:36	02.02.2022 7:36	NULL	NULL		BKK_5185				
30	684615	139	Dayka GĂ	7	20220121	21.01.2022 5:11	21.01.2022 5:11	21.01.2022 5:10	21.01.2022 5:10		BKK_3011				

Figure 3.18: Screenshot of data provided in Budapest.

Results of the evaluation in Budapest

The results of the 2017 QPTOEM evaluation for Budapest can be seen in Figure 3.19. The resulting Level of Service is higlighted according to the resulting value, green is for the best values and red is for the worst.

City	Location	Section	Level of service	Section Length [m]	Decisive travel time [min]	Travel speed index	Reliability index	Average travel time [min]	Data structure
Budapest	Déli pályaudvar	A1	3	781	2	0,79	0,78	2,73	D-A
Budapest	Déli pályaudvar	B1	2	1050	2	0,71	0,64	2,97	D-A
Budapest	Erszébet híd	A1	4	250	0,67	0,67	2,66	1,19	D-A
Budapest	Erszébet híd	A2	4	414	0,93	0,66	1,18	1,63	D-A
Budapest	Erszébet híd	B1	3	312	0,97	0,8	1,49	1,36	D-A
Budapest	Erszébet híd	B2	3	554	1	0,76	0,82	1,45	D-A
Budapest	Keleti pályaudvar	A1	2	780	1,57	0,87	0,46	3	D-A
Budapest	Keleti pályaudvar	B1	3	862	2,1	0,7	1,04	3,25	D-A

Figure 3.19: Table of results of evaluation of the 2017 version of the QPTOEM in Budapest.

3.2.3 Prague

Prague is the capital of the Czech Republic. With a population of 1,280,299, it is also the largest city and the only one with more than 1 million inhabitants in the Czech Republic.[18] This also corresponds to the high mobility of the population and the largest transport network. The backbone of the public transport network is the 3 metro lines, which is complemented by a dense tram and bus network. Currently, only 1 trolleybus line is in operation. A diagram of the metro and tram lines can be seen in Figure 3.20. The size of Prague is also related to the high density of individual car traffic and the frequent interaction between public transport vehicles and cars.

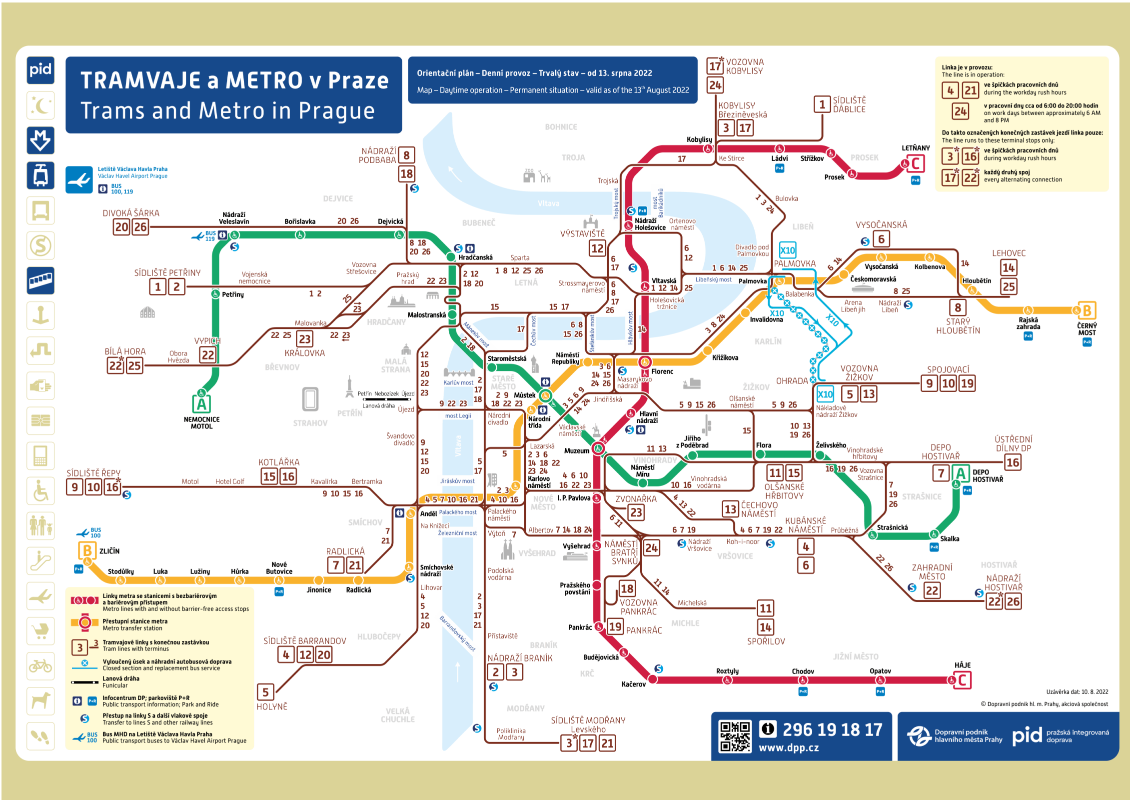

Figure 3.20: Metro and tram lines scheme in the public transport network in Prague.[4]

For the pilot study 5 areas were selected in Prague, namely the case studies Pod Jezerkou - Chodovská, Spořilov - Želivského, Karlovarská, Libuš and Opatovská. The case study Krymská - Náměstí Míru was also selected to test the data provided by buses and trams. In total, there are 40 inter-stop sections on the Prague public transport network.

Pod Jezerkou - Chodovská case study

This case study contains a total of 6 sections in both directions between the stops Pod Jezerkou, Michelská, Plynárna Michle and Chodovská. The total length is approximately 1,600 metres and on a large part of the route public transport buses travel in a dedicated lane. A diagram of the route plotted on the map can be seen in Figure 3.21.

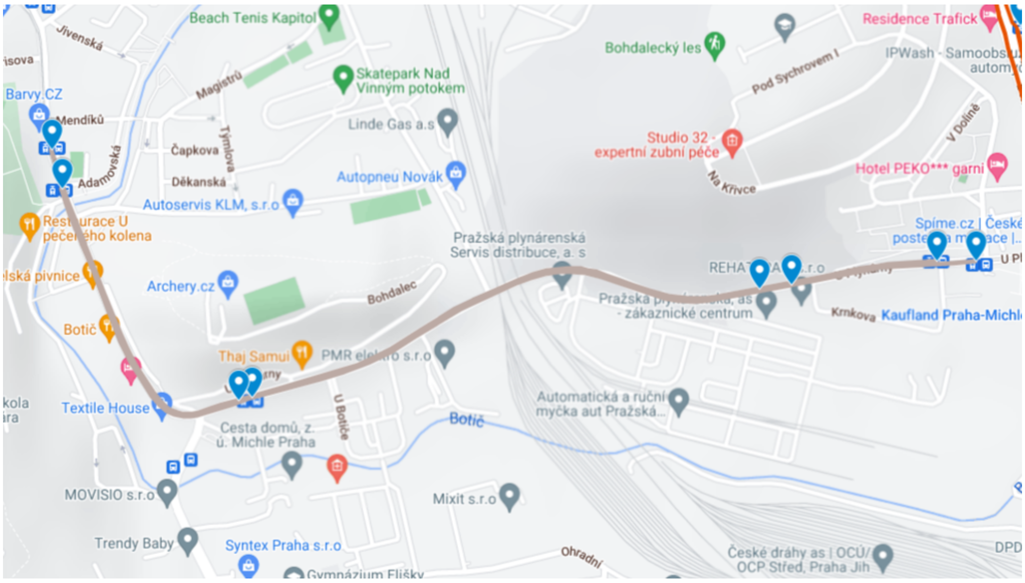

Figure 3.21: Diagram of the route with marked stops plotted on the map for the Pod Jezerkou - Chodovská case study in Prague.

Spořilov - Želivského case study

case study Spořilov - Želivského is the largest case study in Prague. It includes a total of 12 sections between the stops Spořilov, Teplárna Michle, Chodovská, Bohdalec, Slavia, Bělocerkevská, Želivského. This section is very variable, there are both short and very long inter-stop sections, at the same time there are sections with frequent delays and sections with almost trouble-free operation of public transport connections. The total length of the section is almost 4500 metres and its route is shown on the map in Figure 3.22.

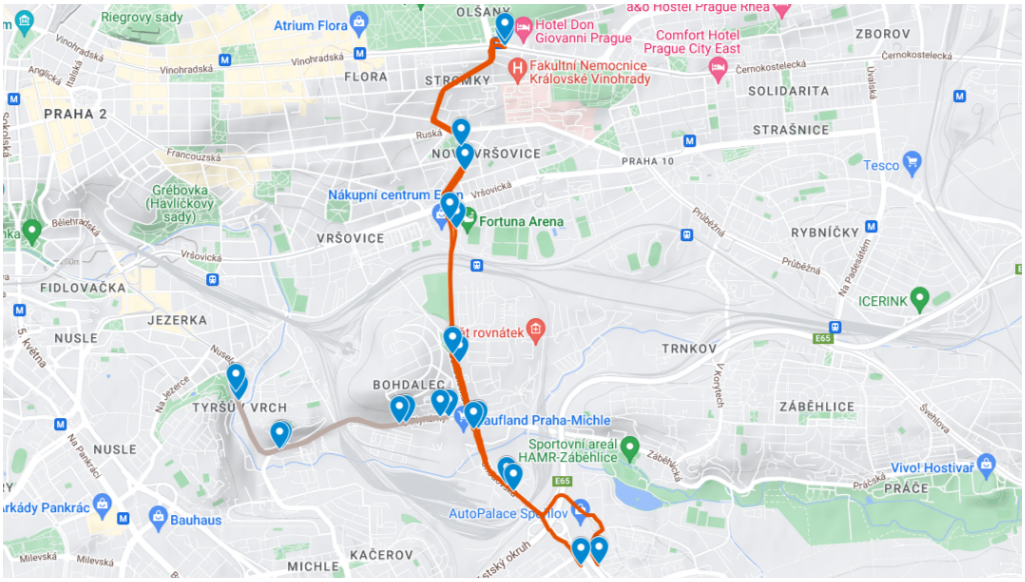

Figure 3.22: Diagram of the route with marked stops (orange) plotted on the map for the Spořilov - Želivského case study in Prague.

Karlovarská case study

Case study Karlovarská has only 3 inter-stop sections, only in one direction, with a total length of almost 2000 metres. On the route there are the stops Staré náměstí, Jiviny, Ruzyňský hřbitov and Bílá hora, which are highlighted in Figure 3.23. There are no dedicated lanes for public transport on this section, and a large part of the route runs along the congested Karlovarská road. The worse quality of public transport can be presumed here.

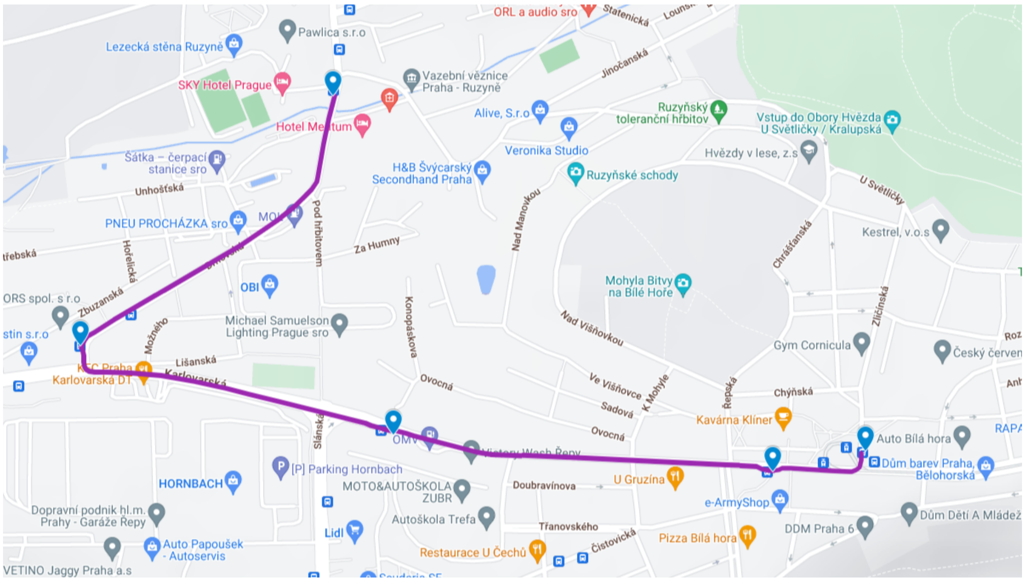

Figure 3.23: Diagram of the route with marked stops plotted on the map for the Karlovarská case study in Prague.

Libuš case study

In the Libuš area, a total of 6 sections are being evaluated with a length of approximately 1,200 metres. The stops along the route are U Zvoničky, Libuš, U Libušské sokolovny and Sídliště Písnice (Figure 3.24). Public transport buses do not drive in a dedicated lane along the entire route and the entire route is located on an important road for the area.

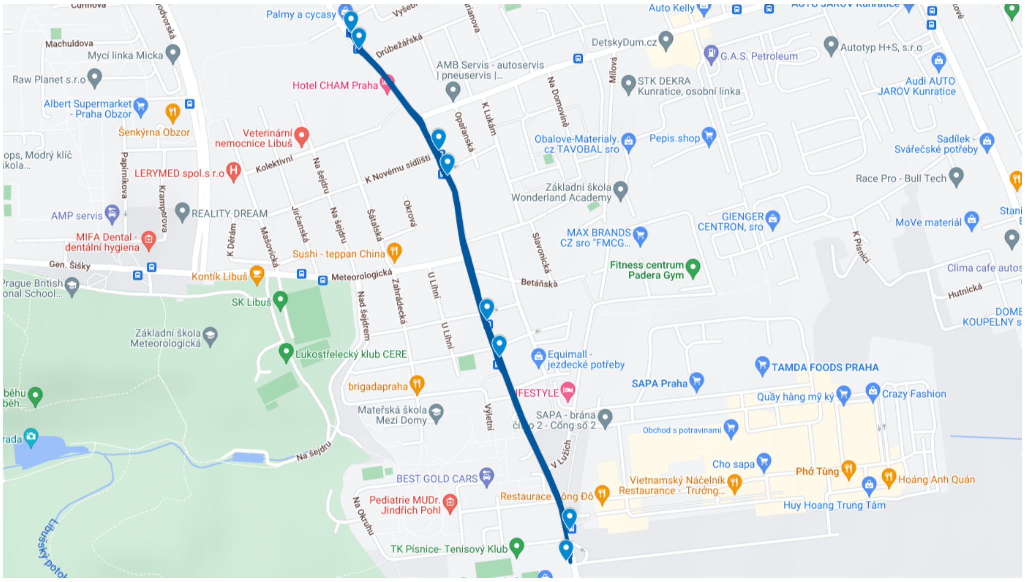

Figure 3.24: Diagram of the route with marked stops plotted on the map for the Libuš case study in Prague.

Opatovská case study

Case study Opatovská contains 10 inter-stop sections in both directions with the stops Opatov, Ke Kateřinkám, Metodějova, Háje, Horčičkova and Jižní město, the total length is approximately 3,000 m (Figure 3.25). In this case, the route of public transport buses is partly led in a dedicated lane in each inter-stop section, so the impact of this priority measure can be well studied.

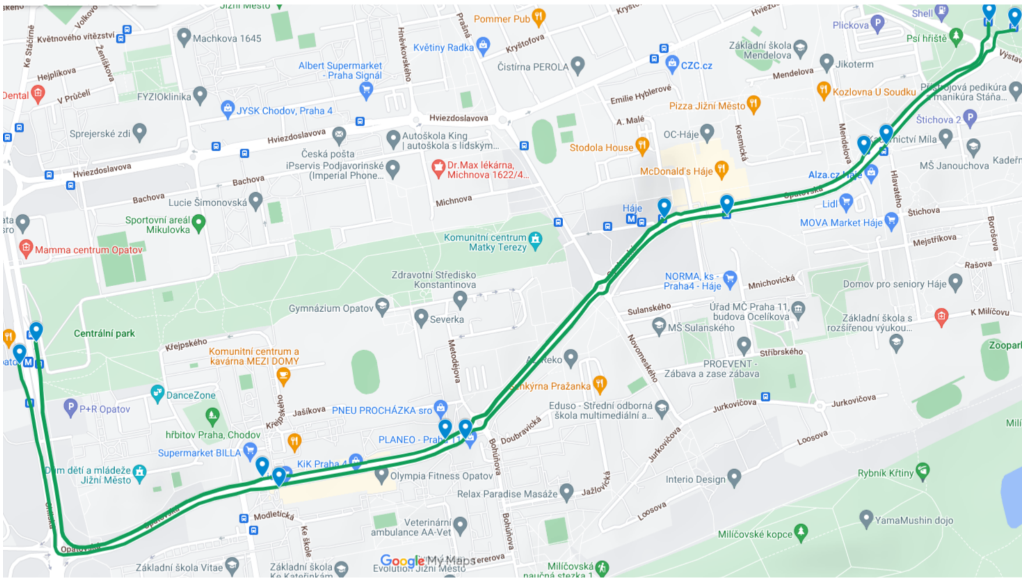

Figure 3.25: Diagram of the route with marked stops plotted on the map for the Opatovská case study in Prague.

Krymská - Náměstí Míru case study

Case study Krymská - Náměstí Míru was evaluated only for the purpose of comparing the functionality of data from bus and tram lines, it has no greater importance in the pilot study.

Data source and format in Prague

In March 2020, ROPID[9] joined private carriers in providing information on the live locations of their buses. This information is available to all Prague Integrated Transport passengers in the IDOS and PID[10] Lítačka applications. In autumn 2020, a new web application mapa.pid.cz was launched to display the current position and information about PID buses and trams. In connection with the launch of the Prague application the data was also linked and made available (only bus-related data for now) to other applications and developers. Timetables and location information from PID buses are provided and published by ROPID to the Prague data platform Golemio, which is being developed by and operated by Operátor ICT.[19]

The data provided for Prague study is very clear and easy to process. They are provided in departure - departure format. In addition to the necessary information such as departure time from the stops, date and line number, there is also the calculated travel time and its comparison with the timetable. A sample of the data for the inter-stop section Bohdalec - Chodovská can be seen in Figure 3.26. The data shows a large amount of information, from the left (Figure 3.26) - the date, line, connection, circulation, the start of the section (initial stop), the time according to the timetable at the initial stop (when the connection should have arrived there), the actual time at the initial stop (when the connection actually arrived there), the difference between these two times, the end of the section (final stop), the scheduled time at the final stop (when the service should have arrived there), the actual time at the end stop (when the service actually arrived there), again the difference of these two times, then the scheduled travel time, the actual travel time, the deviation of these times and the percentage deviation.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Datum	Linka	Spoj	Oběh	Počátek úseku	Čas JŘ	Čas skut.	Odchylka	Konec úseku	Čas JŘ	Čas skut.	Odchylka	Cest.doba JŘ	Cest.doba skut	Odchylka	
2	13. 9. 2021	213	89	213/4	Bohdalec	00:04	00:04:11	0 min. 11 s	Chodovská	00:05	00:05:40	0 min. 40 s	1 min.	1 min. 29 s	0 min. 29 s	48,33%
3	13. 9. 2021	136	172	136/19	Bohdalec	04:54	04:54:19	0 min. 19 s	Chodovská	04:55	04:55:43	0 min. 43 s	1 min.	1 min. 24 s	0 min. 24 s	40,00%
4	13. 9. 2021	213	58	213/4	Bohdalec	05:04	05:05:24	1 min. 24 s	Chodovská	05:06	05:06:31	0 min. 31 s	2 min.	1 min. 07 s	-0 min. 53 s	-44,17%
5	13. 9. 2021	136	1	136/1	Bohdalec	05:14	05:14:33	0 min. 33 s	Chodovská	05:16	05:16:11	0 min. 11 s	2 min.	1 min. 38 s	-0 min. 22 s	-18,33%
6	13. 9. 2021	213	196	213/13	Bohdalec	05:20	05:21:01	1 min. 01 s	Chodovská	05:22	05:22:20	0 min. 20 s	2 min.	1 min. 19 s	-0 min. 41 s	-34,17%
7	13. 9. 2021	213	174	213/11	Bohdalec	05:25	05:25:28	0 min. 28 s	Chodovská	05:27	05:27:49	0 min. 49 s	2 min.	2 min. 21 s	0 min. 21 s	17,50%
8	13. 9. 2021	136	21	136/3	Bohdalec	05:35	05:37:36	2 min. 36 s	Chodovská	05:37	05:40:02	3 min. 02 s	2 min.	2 min. 26 s	0 min. 26 s	21,67%
9	13. 9. 2021	213	39	213/3	Bohdalec	05:40	05:41:21	1 min. 21 s	Chodovská	05:42	05:42:01	0 min. 01 s	2 min.	0 min. 40 s	-1 min. 20 s	-66,67%
10	13. 9. 2021	213	159	213/10	Bohdalec	05:45	05:45:31	0 min. 31 s	Chodovská	05:47	05:47:44	0 min. 44 s	2 min.	2 min. 13 s	0 min. 13 s	10,83%
11	13. 9. 2021	136	41	136/5	Bohdalec	05:55	05:55:09	0 min. 09 s	Chodovská	05:57	05:56:43	-0 min. 17 s	2 min.	1 min. 34 s	-0 min. 26 s	-21,67%
12	13. 9. 2021	213	107	213/7	Bohdalec	06:03	06:04:30	1 min. 30 s	Chodovská	06:05	06:05:50	0 min. 50 s	2 min.	1 min. 20 s	-0 min. 40 s	-33,33%
13	13. 9. 2021	136	50	136/6	Bohdalec	06:11	06:11:43	0 min. 43 s	Chodovská	06:13	06:13:48	0 min. 48 s	2 min.	2 min. 05 s	0 min. 05 s	4,17%
14	13. 9. 2021	213	129	213/8	Bohdalec	06:16	06:16:36	0 min. 36 s	Chodovská	06:18	06:17:59	-0 min. 01 s	2 min.	1 min. 23 s	-0 min. 37 s	-30,83%
15	13. 9. 2021	136	61	136/7	Bohdalec	06:21	06:21:39	0 min. 39 s	Chodovská	06:23	06:23:43	0 min. 43 s	2 min.	2 min. 04 s	0 min. 04 s	3,33%
16	13. 9. 2021	213	24	213/2	Bohdalec	06:25	06:29:35	4 min. 35 s	Chodovská	06:27	06:31:48	4 min. 48 s	2 min.	2 min. 13 s	0 min. 13 s	10,83%
17	13. 9. 2021	136	81	136/9	Bohdalec	06:29	06:32:28	3 min. 28 s	Chodovská	06:31	06:34:10	3 min. 10 s	2 min.	1 min. 42 s	-0 min. 18 s	-15,00%
18	13. 9. 2021	213	219	213/16	Bohdalec	06:33	06:35:45	2 min. 45 s	Chodovská	06:35	06:37:44	2 min. 44 s	2 min.	1 min. 59 s	-0 min. 01 s	-0,83%
19	13. 9. 2021	136	72	136/8	Bohdalec	06:37	06:37:49	0 min. 49 s	Chodovská	06:39	06:39:47	0 min. 47 s	2 min.	1 min. 58 s	-0 min. 02 s	-1,67%
20	13. 9. 2021	213	198	213/13	Bohdalec	06:40	06:40:53	0 min. 53 s	Chodovská	06:42	06:42:02	0 min. 02 s	2 min.	1 min. 09 s	-0 min. 51 s	-42,50%
21	13. 9. 2021	136	90	136/10	Bohdalec	06:44	06:48:36	4 min. 36 s	Chodovská	06:46	06:49:56	3 min. 56 s	2 min.	1 min. 20 s	-0 min. 40 s	-33,33%
22	13. 9. 2021	136	99	136/11	Bohdalec	06:51	06:52:25	1 min. 25 s	Chodovská	06:53	06:54:03	1 min. 03 s	2 min.	1 min. 38 s	-0 min. 22 s	-18,33%
23	13. 9. 2021	213	60	213/4	Bohdalec	06:54	06:56:04	2 min. 04 s	Chodovská	06:56	06:57:59	1 min. 59 s	2 min.	1 min. 55 s	-0 min. 05 s	-4,17%
24	13. 9. 2021	136	186	136/21	Bohdalec	06:57	07:00:55	3 min. 55 s	Chodovská	06:59	07:02:12	3 min. 12 s	2 min.	1 min. 17 s	-0 min. 43 s	-35,83%
25	13. 9. 2021	213	41	213/3	Bohdalec	07:00	07:02:41	2 min. 41 s	Chodovská	07:02	07:04:41	2 min. 41 s	2 min.	2 min.	0 min.	
26	13. 9. 2021	136	194	136/23	Bohdalec	07:04	07:04:35	0 min. 35 s	Chodovská	07:06	07:05:58	-0 min. 02 s	2 min.	1 min. 23 s	-0 min. 37 s	-30,83%
27	13. 9. 2021	213	212	213/15	Bohdalec	07:07	07:07:56	0 min. 56 s	Chodovská	07:09	07:09:52	0 min. 52 s	2 min.	1 min. 56 s	-0 min. 04 s	-3,33%
28	13. 9. 2021	213	95	213/6	Bohdalec	07:14	07:14:13	0 min. 13 s	Chodovská	07:16	07:15:49	-0 min. 11 s	2 min.	1 min. 36 s	-0 min. 24 s	-20,00%
29	13. 9. 2021	136	237	136/33	Bohdalec	07:17	07:23:18	6 min. 18 s	Chodovská	07:19	07:25:41	6 min. 41 s	2 min.	2 min. 23 s	0 min. 23 s	19,17%
30	13. 9. 2021	213	77	213/5	Bohdalec	07:20	07:20:00	0 min.	Chodovská	07:22	07:22:03	0 min. 03 s	2 min.	2 min. 03 s	0 min. 03 s	2,50%
31	13. 9. 2021	213	176	213/11	Bohdalec	07:27	07:27:26	0 min. 26 s	Chodovská	07:29	07:29:41	0 min. 41 s	2 min.	2 min. 15 s	0 min. 15 s	12,50%
32	13. 9. 2021	136	198	136/24	Bohdalec	07:30	07:45:03	15 min. 03 s	Chodovská	07:32	07:46:08	14 min. 08 s	2 min.	1 min. 05 s	-0 min. 55 s	-45,83%

Figure 3.26: Screenshot of data provided in Prague for the inter-stop section Bohdalec - Chodovská.

[9]Regional Organiser of Prague Integrated Transport (*Regionální organizátor pražské integrované dopravy*)

[10]Prague Integrated Transport (*Pražská integrovaná doprava*)

Results of the evaluation in Prague

The results of the 2017 QPTOEM evaluation for Prague can be seen in Figure 3.27. The resulting Level of Service is higlighted according to the resulting value, green is for the best values and red is for the worst.

City	Location	Section	Level of service	Section Length [m]	Decisive travel time [min]	Travel speed index	Reliability index	Average travel time [min]	Data structure
Prague	Karlovarská	A1	3	673	1,17	0,71	1,08	1,89	D-D
Prague	Karlovarská	A2	4	593	1,14	0,67	2,44	2,18	D-D
Prague	Karlovarská	A3	4	701	0,9	0,68	2,04	1,95	D-D
Prague	Libuš	A1	4	331	0,9	0,72	1,81	1,44	D-D
Prague	Libuš	A2	3	412	1,07	0,72	1,3	1,64	D-D
Prague	Libuš	A3	3	434	0,68	0,64	0,87	1,19	D-D
Prague	Libuš	B1	3	314	0,6	0,71	0,77	0,92	D-D
Prague	Libuš	B2	4	377	1	0,68	1,77	1,75	D-D
Prague	Libuš	B3	3	446	0,95	0,8	0,71	1,27	D-D
Prague	Opatovská	A1	2	935	1,93	0,81	0,44	2,48	D-D
Prague	Opatovská	A2	1	430	0,93	0,88	0,39	1,08	D-D
Prague	Opatovská	A3	1	794	1,68	0,86	0,3	1,98	D-D
Prague	Opatovská	A4	3	390	0,97	0,79	0,76	1,29	D-D
Prague	Opatovská	A5	2	411	0,62	0,85	0,45	0,76	D-D
Prague	Opatovská	B1	2	421	1,77	0,86	0,66	2,1	D-D
Prague	Opatovská	B2	1	477	0,97	0,88	0,39	1,13	D-D
Prague	Opatovská	B3	1	686	1,55	0,89	0,32	1,79	D-D
Prague	Opatovská	B4	2	424	1,13	0,8	0,69	1,48	D-D
Prague	Opatovská	B5	1	914	1,15	0,81	0,34	1,49	D-D
Prague	Pod Jezerkou - Chodovská	A1	2	498	1,07	0,85	0,42	1,28	D-D
Prague	Pod Jezerkou - Chodovská	A2	1	848	1,15	0,85	0,21	1,39	D-D
Prague	Pod Jezerkou - Chodovská	A3	4	281	0,73	0,76	1,69	1,14	D-D
Prague	Pod Jezerkou - Chodovská	B1	2	533	1,12	0,85	0,57	1,39	D-D
Prague	Pod Jezerkou - Chodovská	B2	1	820	1,23	0,87	0,29	1,46	D-D
Prague	Pod Jezerkou - Chodovská	B3	2	271	0,47	0,77	0,57	0,65	D-D
Prague	Spořilov - Želivského	A1	2	1116	2,12	0,85	0,72	2,56	D-D
Prague	Spořilov - Želivského	A2	4	396	0,98	0,66	1,56	1,79	D-D
Prague	Spořilov - Želivského	A3	4	456	1,08	0,7	1,79	1,88	D-D
Prague	Spořilov - Želivského	A4	3	883	1,7	0,82	1,51	2,23	D-D
Prague	Spořilov - Želivského	A5	3	403	1	0,74	1,05	1,46	D-D
Prague	Spořilov - Želivského	A6	4	1208	2,52	0,71	5,24	4,51	D-D
Prague	Spořilov - Želivského	B1	2	654	1,23	0,86	0,5	1,47	D-D
Prague	Spořilov - Želivského	B2	2	486	1	0,83	0,49	1,27	D-D
Prague	Spořilov - Želivského	B3	3	504	1,25	0,73	0,98	1,85	D-D
Prague	Spořilov - Želivského	B4	3	881	1,58	0,78	1,31	2,24	D-D
Prague	Spořilov - Želivského	B5	3	514	1,32	0,77	0,87	1,84	D-D
Prague	Spořilov - Želivského	B6	3	865	2,05	0,82	1,16	2,61	D-D

Figure 3.27: Table of results of evaluation of the 2017 version of the QPTOEM in Prague.

3.2.4 Pilsen

Pilsen is one of the largest cities in the Czech Republic, with a total of 168,733 inhabitants.[20] The transport network in Pilsen is not very large, the backbone network consists of tram lines supplemented by buses and trolleybuses (Figure 3.28). However, Pilsen has been trying to modernise and develop its public transport network for a long time, which is why a number of priority measures have been implemented. The line 16 corridor is currently under development, and there is an interest in monitoring the quality of public transport on this line. It is why the entire route of this trolleybus line has been selected for case study in Pilsen.

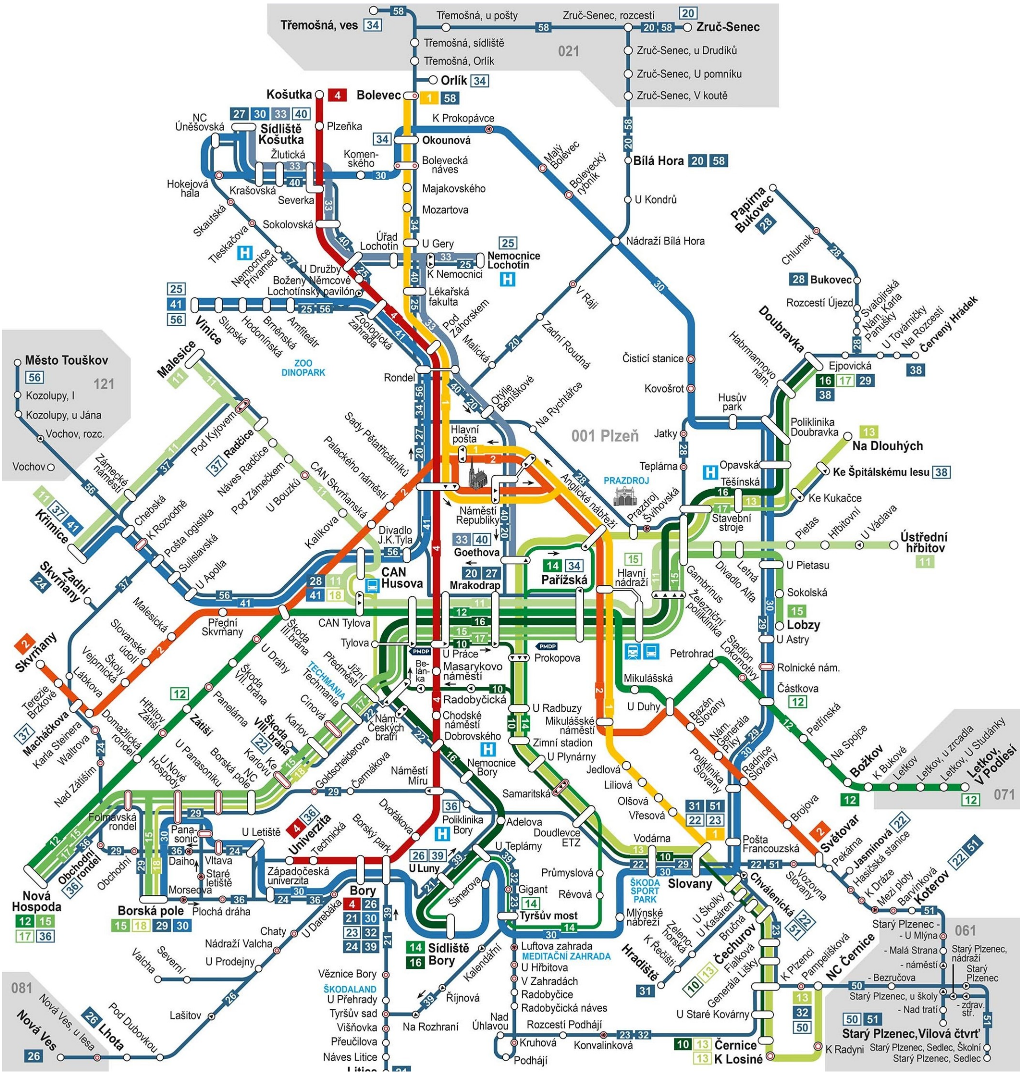

Figure 3.28: Diagram of public transport lines in Pilsen.[5]

Case study trolleybus line 16

Line 16 is the backbone trolleybus line of Pilsen public transport. It connects large residential areas with the city centre, public transport interchanges, medical facilities, offices, employers and commercial areas. It is the busiest trolleybus line in Pilsen. It has a total of 21 stops on its route and contains 38 intermediate stop sections, with a total length of over 8,000 metres. A diagram of the line can be seen in Figure 3.29.

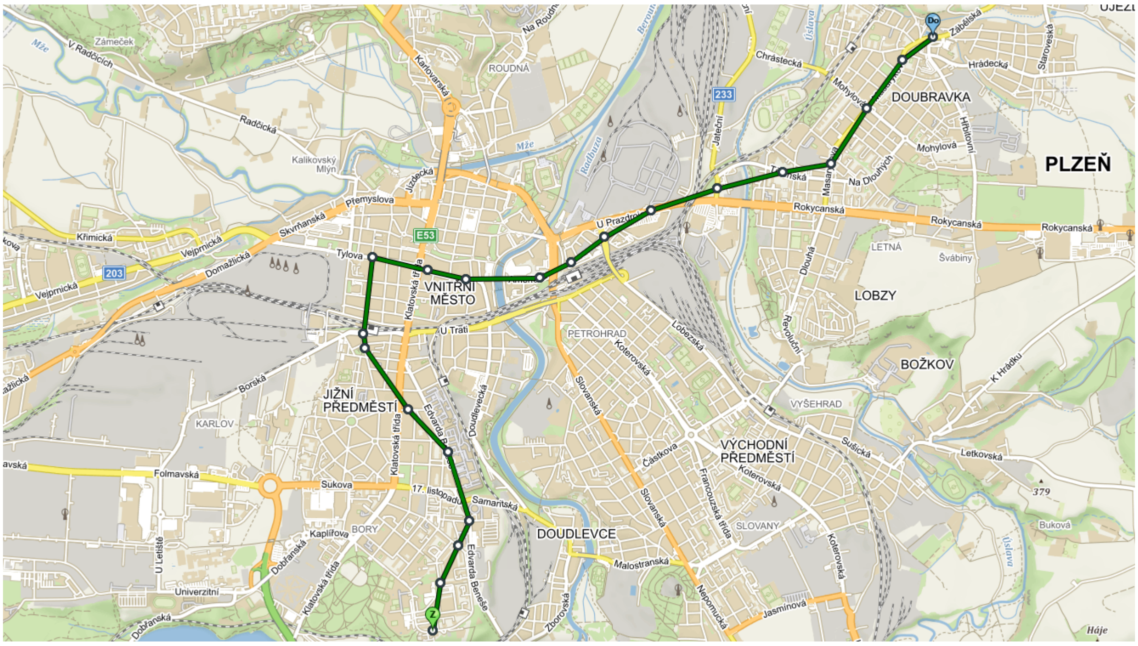

Figure 3.29: Diagram of the route with marked stops plotted on the map for the trolleybus line 16 in Pilsen.

Data source and format in Pilsen

Pilsen public transport company (Plzeňské městské dopravní podniky, a.s.) have their own private software for obtaining RealTime data from public transport vehicles. This data is not provided publicly, but for the purpose of this thesis data was provided directly by Pilsen public transport company. Pilsen public transport company already uses the QPTOEM to monitor the operation of their vehicles, but in a slightly modified version that better captures the nature of the Pilsen transport network, for example using a different determination of the decisive travel time.

Because they process the data themselves, the data is again clear and only the most important information is provided. The data is provided in a departure-arrival format, so the travel time is not affected by the vehicle standing at the bus stop. An example of the data can be seen in Figure 3.30.

	A	B	C	D	E	F	G	H	I	J
1	ident	Kurz	Č. vozu	Doba v zastávce	Čas začátku	Čas konce	Celková jízdní doba	V jízdě	RCA	
2	1676	4	2527	00:00:00	30.9.20 23:42:01	30.9.20 23:43:16	00:01:15	00:01:15	395	
3	1675	9	2590	00:00:00	30.9.20 23:29:59	30.9.20 23:31:07	00:01:08	00:01:08	458	
4	1674	8	2588	00:00:00	30.9.20 23:00:29	30.9.20 23:01:39	00:01:10	00:01:10	456	
5	1673	5	2589	00:00:00	30.9.20 22:53:02	30.9.20 22:54:09	00:01:07	00:01:07	457	
6	1672	7	2584	00:00:00	30.9.20 22:43:28	30.9.20 22:44:29	00:01:01	00:01:01	452	
7	1671	4	2527	00:00:00	30.9.20 22:30:39	30.9.20 22:31:47	00:01:08	00:01:08	395	
8	1670	3	2587	00:00:00	30.9.20 21:58:59	30.9.20 22:00:03	00:01:04	00:01:04	455	
9	1669	5	2589	00:00:00	30.9.20 21:46:00	30.9.20 21:47:10	00:01:10	00:01:10	457	
10	1668	7	2584	00:00:00	30.9.20 21:35:02	30.9.20 21:36:07	00:01:05	00:01:05	452	
11	1667	8	2588	00:00:00	30.9.20 21:24:53	30.9.20 21:26:07	00:01:14	00:01:14	456	
12	1666	4	2527	00:00:00	30.9.20 21:14:32	30.9.20 21:15:37	00:01:05	00:01:05	395	
13	1665	9	2590	00:00:00	30.9.20 21:03:07	30.9.20 21:04:22	00:01:15	00:01:15	458	
14	1664	3	2587	00:00:00	30.9.20 20:50:10	30.9.20 20:51:27	00:01:17	00:01:17	455	
15	1663	5	2589	00:00:00	30.9.20 20:36:59	30.9.20 20:38:13	00:01:14	00:01:14	457	
16	1662	7	2584	00:00:00	30.9.20 20:23:59	30.9.20 20:25:03	00:01:04	00:01:04	452	
17	1661	8	2588	00:00:00	30.9.20 20:14:07	30.9.20 20:15:22	00:01:15	00:01:15	456	
18	1660	4	2527	00:00:00	30.9.20 20:04:21	30.9.20 20:05:35	00:01:14	00:01:14	395	

Figure 3.30: Screenshot of data provided in Pilsen for the line 16.

The data provides a large amount of information, from the left it is the identification number, the vehicle identification number, the time spent at the stop (this is 0 seconds, because the system does not evaluate it), the start time (the time when he left the stop), the end time (the time when he arrived at the next stops) and total travel time. Each data set is for a specific inter-stop section and line.

Results of the evaluation in Pilsen

The results of the 2017 QPTOEM evaluation for Pilsen can be seen in Figure 3.31. The resulting Level of Service is underlined according to the resulting value, green is for the best values and red is for the worst.

City	Location	Section	Level of service	Section Length [m]	Decisive travel time [min]	Travel speed index	Reliability index	Average travel time [min]	Data structure
Pilsen	Line 16	A1	1	530	1,22	0,93	0,65	1,35	D-A
Pilsen	Line 16	A2	1	405	0,98	0,9	0,31	1,1	D-A
Pilsen	Line 16	A3	1	275	0,98	0,9	0,45	1,1	D-A
Pilsen	Line 16	A4	2	700	1,15	0,82	0,42	1,46	D-A
Pilsen	Line 16	A5	1	425	0,97	0,9	0,31	1,09	D-A
Pilsen	Line 16	A6	3	645	1,37	0,76	1,05	1,95	D-A
Pilsen	Line 16	A7	3	260	0,8	0,8	1,73	1,08	D-A
Pilsen	Line 16	A8	4	480	1,17	0,76	2,98	1,93	D-A
Pilsen	Line 16	A9	4	350	0,88	0,66	1,39	1,49	D-A
Pilsen	Line 16	A10	2	290	0,7	0,83	0,75	0,88	D-A
Pilsen	Line 16	A11	3	510	0,8	0,71	0,9	1,26	D-A
Pilsen	Line 16	A12	2	300	1,27	0,87	0,76	1,49	D-A
Pilsen	Line 16	A13	1	360	0,97	0,92	0,26	1,06	D-A
Pilsen	Line 16	A14	3	580	1,1	0,69	0,81	1,72	D-A
Pilsen	Line 16	A15	3	480	1,2	0,74	0,98	1,73	D-A
Pilsen	Line 16	A16	1	550	1	0,91	0,18	1,11	D-A
Pilsen	Line 16	A17	2	450	1,13	0,85	0,65	1,38	D-A
Pilsen	Line 16	A18	1	570	0,67	0,86	0,24	0,8	D-A
Pilsen	Line 16	A19	1	390	0,75	0,91	0,21	0,83	D-A
Pilsen	Line 16	A20	2	300	1,03	0,83	0,84	1,28	D-A
Pilsen	Line 16	B1	1	538	1,17	0,87	0,35	1,37	D-A
Pilsen	Line 16	B2	1	355	0,92	0,9	0,36	1,03	D-A
Pilsen	Line 16	B3	2	550	0,77	0,83	0,44	0,97	D-A
Pilsen	Line 16	B4	1	357	1,02	0,91	0,31	1,13	D-A
Pilsen	Line 16	B5	3	528	1,45	0,73	1,02	2,12	D-A
Pilsen	Line 16	B7	1	674	1,2	0,87	0,35	1,4	D-A
Pilsen	Line 16	B8	2	491	1,12	0,84	0,61	1,37	D-A
Pilsen	Line 16	B9	3	425	1,5	0,76	1,22	2,09	D-A
Pilsen	Line 16	B10	4	249	0,72	0,7	1,98	1,16	D-A
Pilsen	Line 16	B11	4	532	1,43	0,77	3,3	2,34	D-A
Pilsen	Line 16	B12	4	157	0,63	0,68	3,46	1,1	D-A
Pilsen	Line 16	B14	2	618	1,5	0,8	0,74	1,96	D-A
Pilsen	Line 16	B15	2	573	1,25	0,78	0,61	1,67	D-A
Pilsen	Line 16	B16	1	543	1,1	0,91	0,29	1,23	D-A
Pilsen	Line 16	B17	2	375	1,03	0,88	0,44	1,19	D-A
Pilsen	Line 16	B18	2	341	0,77	0,87	0,66	0,91	D-A
Pilsen	Line 16	B19	3	457	0,97	0,8	0,83	1,29	D-A
Pilsen	Line 16	B20	2	343	1,1	0,86	1,06	1,33	D-A

Figure 3.31: Table of results of evaluation of the 2017 version of the QPTOEM in Pilsen.

3.2.5 Level of Service evaluation results - QPTOEM version 2017

After evaluating the results of the QPTOEM, the reliability index and travel speed index values were further converted to Level of Service values for each index so that these values could be compared to each other and also compared to the overall Level of Service value. These values were further sorted by distance and based on this, plotted in the graph in Figure 3.32.

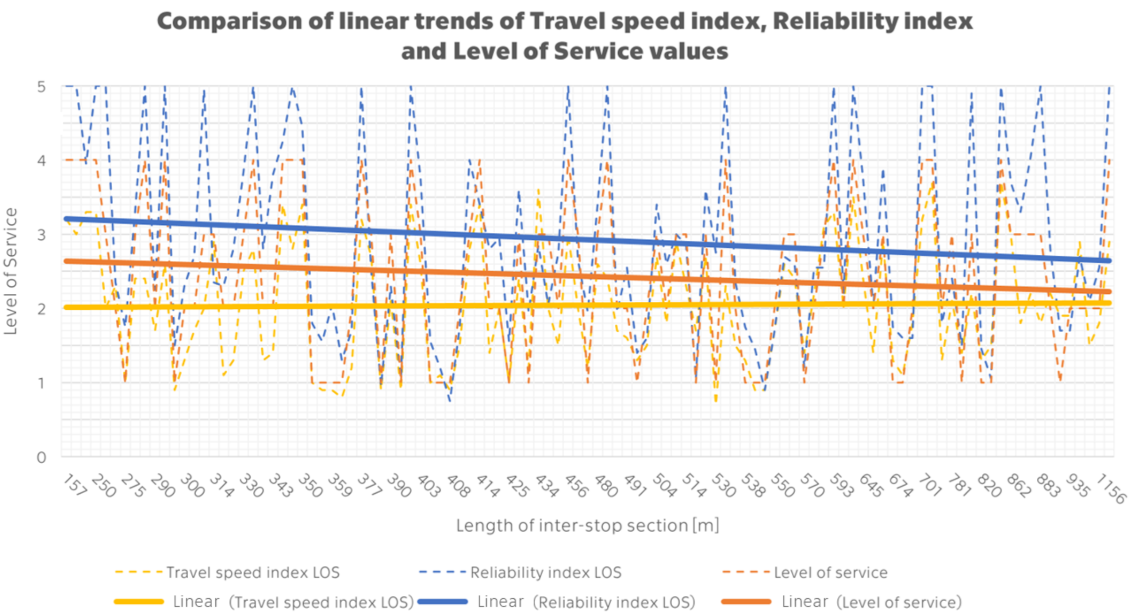

Figure 3.32: Graph showing the results of the evaluation of the overall Level of Service, Level of Service travel speed index and Level of Service reliability index of the 2017 version of the QPTOEM.

The graph shows the results of the evaluation of the inter-stop sections of the 2017 version of the QPTOEM, ordered by the length of the inter-stop section from shortest to longest. The length of the inter-stop section is shown on the x-axis and the y-axis is the Level of Service value, the maximum of this value corresponds to the maximum of the Level of Service, i.e. 5. The yellow dashed line shows the Level of Service values of the travel speed index, the blue dashed line shows the Level of Service values of the reliability index, and the orange line shows the total Level of Service values. The solid lines show the linear trends of each variable. This graph will be relevant for further analysis of the QPTOEM.

3.3 Critical analysis of the 2017 version of the QPTOEM

The first part of the critical analysis of the QPTOEM consisted in studying the processes and procedures used and then identifying possible weaknesses. The aim is to make the QPTOEM more relevant to the actual data, universally applicable and intuitively evaluable.

As there was not enough data available when the QPTOEM was established, the focus should be on evaluating variables that were initially determined by expert estimation, as they are directly dependent on the input data, and also on variables whose meaning was more difficult to understand when studying the QPTOEM. Specifically, these are in 4 areas:

- **inaccurate evaluation of the decisive travel time:**
  It is a problem here because the decisive travel speed was suggested by expert estimation based on a small amount of data. Other statistical options for determining the critical travel time should be explored, these may be, for example, focusing on night services when traffic is low, or other percentile values.

- **inaccurate prescription of linguistic membership functions:**
  The prescriptions of the linguistic membership functions, as well as the decisive travel speed, were determined on the basis of expert estimation. However, this expert estimate was based on data in only one traffic network. The values of these membership functions may be different for different sizes/types of traffic networks with different local conditions, so this possibility needs to be verified on different networks.

- **using both time and speed in the calculations:**
  The method now uses not only a time but also speed for calculation. This is because the speed makes it possible to compare two different lengths, since the length factor is included in the speed. However, for better and easier data handling, it would be advisable to use only time data that are directly detectable, without further partial calculations, which reduces the probability of error in the index calculations. The comparison of speeds can be done separately after the calculation of the indices.

- **non-intuitive qualitative evaluation of indices**
  The method now goes against each other in assigning a qualitative evaluation to each index, that is, for one index it goes in the direction of "the smaller the value, the better" and for the other index it is the opposite "the higher the value, the better". To make the results more intuitive to work with and more readable, it would be useful to explore the possibility of unifying these recalculations. The possibility of reversing the fraction when calculating the travel speed (time) index and then redefining the membership function for this index is suggested.

Only the time should be taken into account, since in the case of all calculations in the QPTOEM it is equivalent to the speed and is directly obtainable from urban data. The inversion of the fraction for the travel speed (time) index is due to the same comparison with the reliability index, i.e. the “bigger the worse” representation.

The second part of the critical analysis was based directly on the pilot study evaluation graph in Figure 3.33. For the validation of the QPTOEM, uniformly inter-stop sections that are known from practice to be problematic and problem-free were selected. Based on this, two assumptions can be made in the evaluation of the QPTOEM:

- all trends should be parallel to the X-axis
- the overall Level of Service trend should be around 2.5

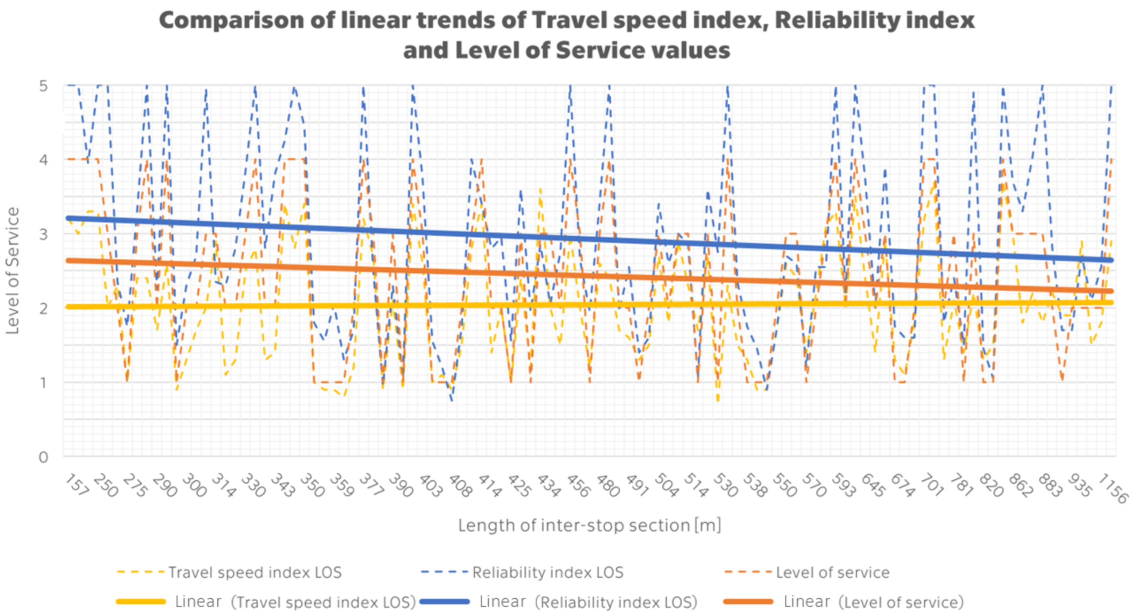

Figure 3.33: Graph showing the results of the evaluation of the overall Level of Service, Level of Service travel speed index and Level of Service reliability index of the 2017 version of the QPTOEM.

However, this graph shows that only the travel speed index satisfies the assumption of parallelism with the X-axis. The overall Level of Service has an improving character with the length of the inter-stop section, which should not be the case given that the inter-stop sections selected were uniformly problem and non-problem inter-stop section. However, the same trend (parallel to the trend of the overall Level of Service) characterizes the reliability index. This could indicate another 3 problematic areas:

- **too much influence of the reliability index on the overall Level of Service**

- **possibly inaccuracy in the calculation of the reliability index**
- **bad influence of short inter-stop sections**

Those 3 problematic areas together with the 4 problematic areas found while studying the QPTOEM are giving togehter 7 key areas which should be focused on during the optimization process.

Chapter **4**

Calibration of the QPTOEM according to the findings of the 2017 version evaluation and critical analysis

The 7 key findings from the critical analysis were further combined into 4 more specific areas that covered these findings and were further optimized:

- decisive travel time/speed (in 2017 there was insufficient data for an optimal determination, redetermination needed)
- the reliability index (too high influence on the overall Level of Service, influence of the length of the inter-stop section, optimization needed)
- the calculation using both travel time and speed (simplification without using travel speed, which is equivalent to travel time)
- linguistic membership functions (in 2017 there was insufficient data for an optimal determination, optimization needed)

This calibration should result in a new optimised version of the method. Based on the findings of the critical analysis, it was determined to start by using only travel time and not travel speed for all calculations, as travel time is directly obtainable from the data, for travel speed this has to be further calculated (urban public transport positioning systems do not directly provide travel speed information), as well as the travel speed index was renamed to travel time index. First, the evaluation of the decisive travel time had to be modified because it affects the travel time index and also the overall Level of Service. Subsequently, the reliability index (RI) was adjusted and the effect of the length of the inter-stop section was studied. Then, the travel time index (TTI) was modified to make its evaluation more intuitive and unified with the reliability index. After adjusting both indices, the linguistic membership functions were optimized and calibrated. The whole optimization and calibration procedure is illustrated in Figure 4.1. Mathematical optimizations and calibrations were consulted with the laboratory LAMbDA (Laboratory of Applied Mathematics in Transportation and Logistics).

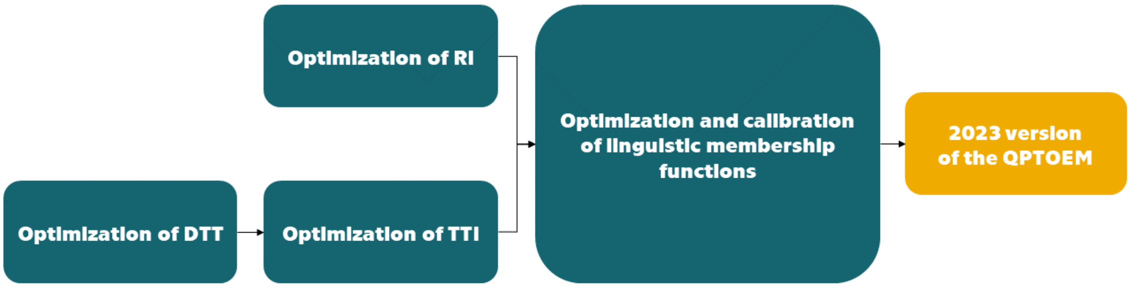

Figure 4.1: Diagram of optimization and calibration procedure of the QPTOEM.

4.1 Redetermination of decisive travel time/speed

First of all, it was necessary to start with the redetermination decisive travel time, because its value has an impact on the value of the travel time index and consequently on the resulting Level of Service value. The problem with decisive travel time/speed is, that in 2017 there was insufficient data for an optimal determination. In the current version of the QPTOEM, as defined, the value of the decisive time is determined as a ten percentile of all travel times (Equation 4.1).

$$V(TT_{A-B}; dec) = 0,06 \cdot \frac{s_{A-B}}{Q_{10}(t_{TT;A-B})} \tag{4.1}$$

In Pilsen, where the QPTOEM is already being tested in a slightly modified version, they have determined that the decisive travel time will be calculated as the average of the travel times travelled during the night hours. This would also be a general option, but even the operation of public transport vehicles during night hours does not guarantee the best possible travel time without measurement failures or various other abnormalities (e.g. a change in weather can significantly affect travel time even during night hours).

The first value used for testing was the average of the 2.5% percentile of each day. The 2.5 % value is based on statistical values because 5 % is the average error in the measurement data set. However, it was necessary to divide this value from both two sides (both large and small extremes), so both the bottom and top will have an error of 2.5 %. In addition, although we calculate the average value from several travel times, the measurement errors are eliminated. Still, most of these low travel time values are achieved by public transport vehicles during night hours. The new critical travel time was therefore determined according to Equation 4.2, where “n” is the number of measuring days.

$$t(TT_{A-B}; dec) = \frac{1}{n}\sum_{i=1}^{n} Q_{2.5}(t_{day;A-B}) \tag{4.2}$$

This calculation method was applied to all inter-stop sections and processed using Python. Firstly, it was only compared to the original values of the critical travel time, as can be seen in Figure 4.2. In this case, the new value of the critical travel time was overall less than the original value, which was expected due to the use of a lower percentile value.

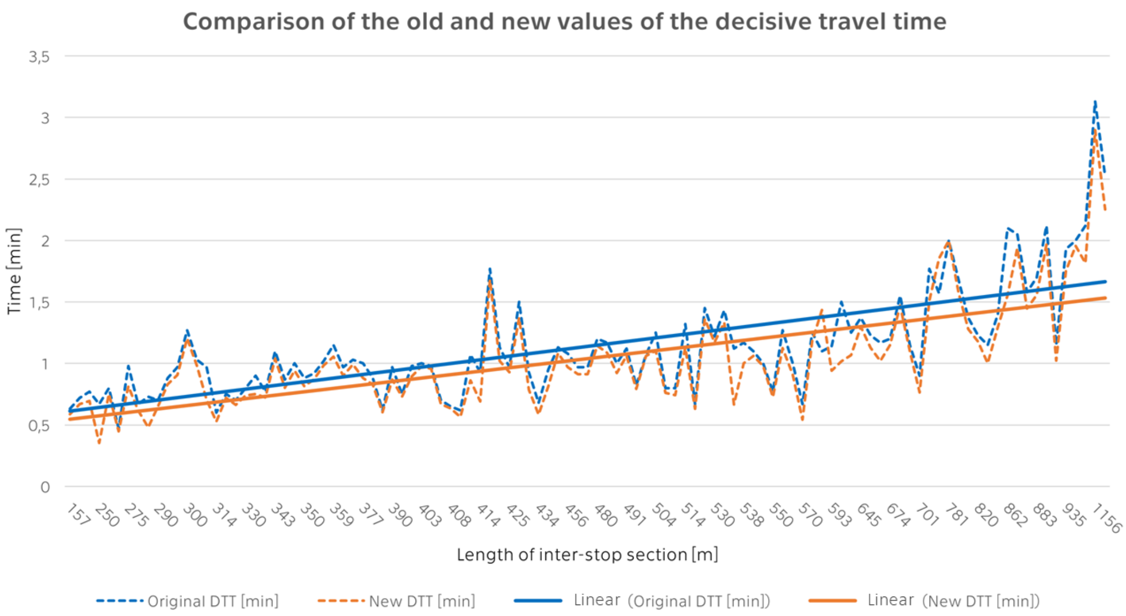

Figure 4.2: Graph comparing the old and new values of the decisive travel time (DTT).

To verify that this method of calculating the decisive travel time is effective, the travel speed index, the Level of Service of the travel speed index and the overall Level of Service were then recalculated. Finally, these results were plotted in a graph (Figure 4.3) which, shows the dependence of the Level of Service value on the length of the inter-stop section. The Level of Service value is calculated here for the new travel speed index value, the original reliability index value, and the total value. A linear trend has also been formed for each of these parameters. Compared to the original graph, a horizontal flattening of the overall Level of Service can be seen here, thus a reduction in the effect of the reliability index. This was one of the aims to be achieved, for this reason this method of evaluating the decisive travel time was adopted as a new evaluation option for the QPTOEM.

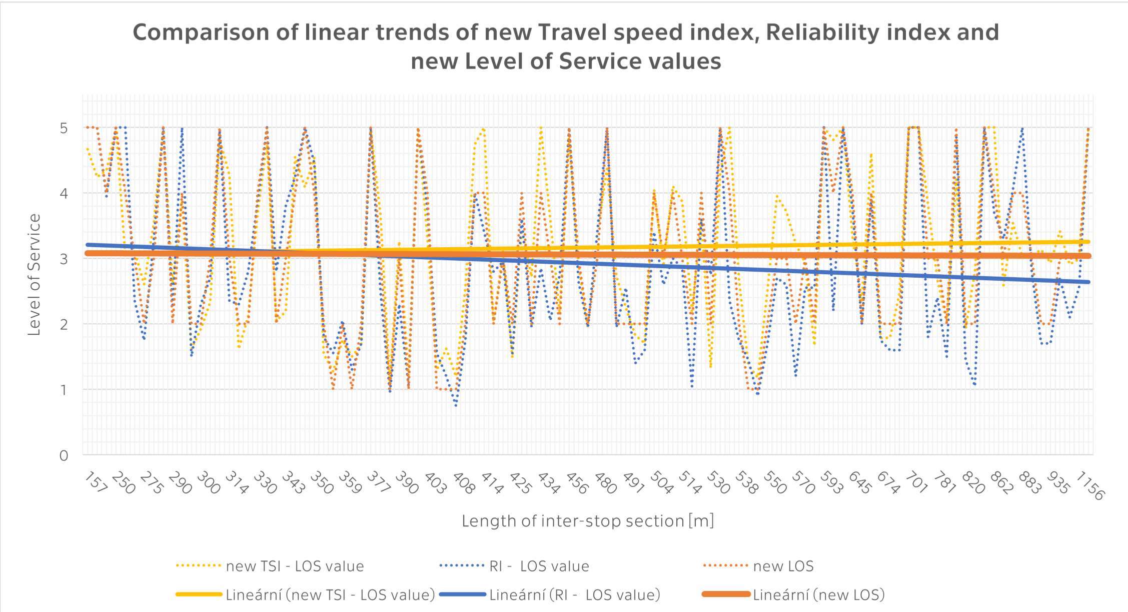

Figure 4.3: Graph comparing linear trends of new travel speed index (TSI), reliability index (RI) and new Level of Service (LOS) values

4.2 Optimization of the reliability index

Based on the evaluation of the 2017 version of the QPTOEM findings, it was possible that short inter-stop sections have a negative effect on the Level of Service value and, in general, that the reliability index has a high effect on the overall Level of Service value. Due to the character of the calculation of the reliability index, there is a possibility that the relativisation to the distance of the inter-stop section in the calculation of the reliability index is incorrectly set up, where this recalculation is now only done by dividing by the length of the section. To analyse the exact reliability index problem, it was also plotted on a graph (Figure 4.4).

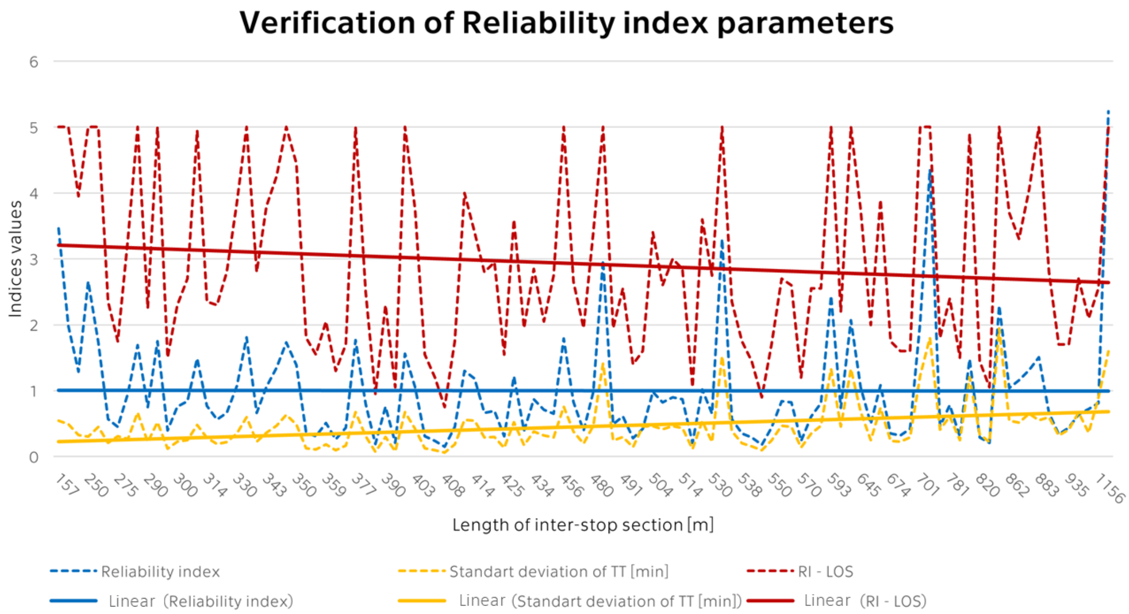

Figure 4.4: Graph comparing linear trends of reliability index parameters.

This graph shows the travel time standard deviation values, the reliability index values and the Level of Service reliability index values as a function of the length of the inter-stop segment. What is important in this graph is not the comparison and differences between the values of each parameter, but their trends. After displaying the linear trends, the graph shows that the Level of Service of the reliability index improves with the length of the inter-stop segment the standard deviation of the travel times deteriorates, which was expected, but interestingly the trend of the reliability index value is horizontal, which indicates that it is not the calculation of the reliability index that is wrong, but the linguistic membership function is.

4.3 Change from travel speed index to travel time index

Since the purpose of the method is not only the identification of bottlenecks in the network, but also its clarity and comprehensibility for non-experts, the QPTOEM of calculating the travel speed index was modified before the final optimization of the linguistic membership functions. In the first place, the original travel speed index should be calculated only from travel times, since the index value will be the same when calculated from the two variables, due to the mathematical relationship of conversion between time and speed, but we already know the travel time directly from the data and do not need to convert it further to speed. Therefore, the travel speed index has been anchored as the TRAVEL TIME INDEX (TTI). However, the travel speed can still be used as a universal tool when comparing individual sections with each other, as the speed already has the distance of the section embedded in it.

For better clarity, it is also suggested that the two indices work on the principle that the smaller the index value, the better the qualitative evaluation. For the reliability index this is true, in addition, due to the mathematical prescription already determined, the application to the travel time index. Thus, the principle of calculating the travel time index has been reversed and is now as a ratio of the critical travel time to the average travel time, the change in calculation is indicated in Equation 4.3.

$$i(V_{TT;A-B}) = \frac{V(TT_{A-B;avg})}{V(TT_{A-B;dec})} => i(TT_{A-B}) = \frac{TT_{A-B;dec}}{TT_{A-B;avg}} \tag{4.3}$$

However, this change in calculation results in high index values and after applying the mathematical formula for the linguistic affiliation function, the Level of Service index of travel time grows to values over 10 in some cases. This can cause the travel time index to be overweighted in the case of the calculation of the overall Level of Service of the inter-stop section, since the overall Level of Service is calculated as the average of the Level of Service values for the two indices (Equation 4.4) and the worst case qualitative evaluation of "unacceptable" corresponds to a value of 5. Therefore, a maximum mathematical Level of Service value of 5 has been embedded for the two indices to avoid too much influence from either index. Thus, once the calculated mathematical value is higher than 5, only the value 5 is counted for the calculation of the overall Level of Service (for the overall Level of Service it is sufficient that the state is "unacceptable", there is no need to know how much "unacceptable" it is).

$$LOS = \frac{i_{LOS}(TT_{A-B}) + i_{LOS}(rel_{A-B})}{2} \tag{4.4}$$

4.4 Optimization of both linguistic membership functions

Problem with both linguistic memebership functions was caused by insufficient data for an optimal determination in 2017. First of all, the values of the membership functions of the two indices were compared. The difference between them is that the index linguistic membership function for the travel speed index has evenly distributed intervals for each index value, and at the same time there are no horizontal parts, where for the longer interval of the index value there is a 100 % membership to one qualitative evaluation other than "unacceptable" or "excellent" as can be seen in the Figure 4.5.

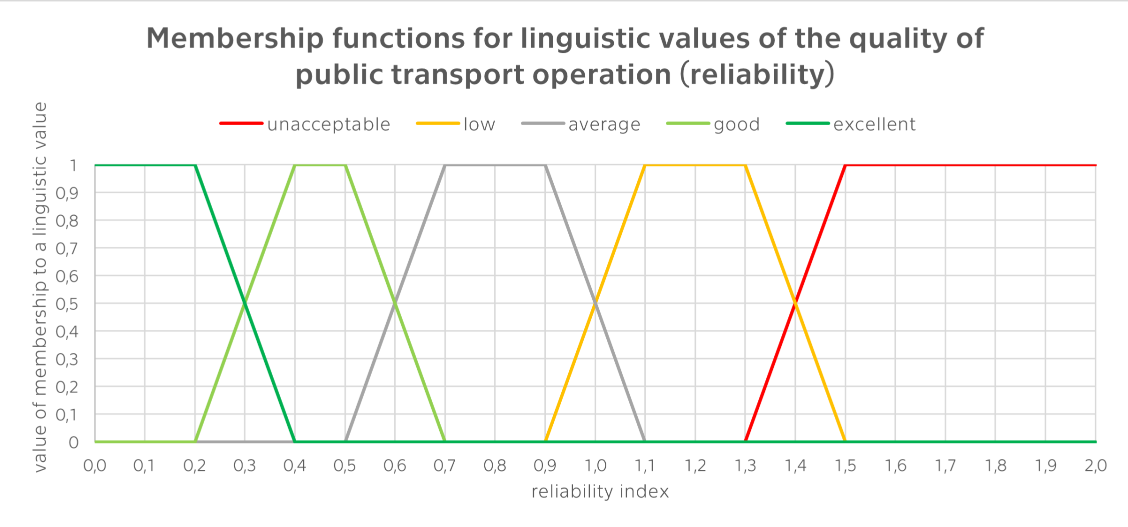

Figure 4.5: Linguistic membership function to determine the Level of Service for the reliability index. [1]

This assumption was verified by creating a mathematical rewrite for the membership function for the travel speed index. Given that for the reliability index, unlike the travel speed index, the smaller the value the better, the transcript was created in the form of Equation 4.5.

$$RI_{LOS} = \frac{RI - a}{b} + 1 \tag{4.5}$$

The variable a indicates the beginning of a change in the affiliation values, or the value of the reliability index, which is no longer 100 % "excellent" and is starting to approach "good". The value b indicates the width of the interval over which the membership value of a given qualitative evaluation increases linearly from 0 % to 100 %, or vice versa. This formula was then applied to the reliability index values with random values of a and b. Since the exact Level of Service values were not necessary to compare, the trend that the values were important. After applying this formula, the trend appeared to be horizontal, indicating a proper adjustment of the membership function.

After the optimization of both indices, the values of the membership functions still had to be optimized, since these values no longer corresponded to the real operating conditions. For the final optimization, a graph similar to Figure 4.3 was used. This graph shows the Level of Service values for the two indices and the overall Level of Service and the trends of these values that are most important for the result. The final optimization is based on the assumption that all inter-stop sections are evenly distributed, so there are approximately the same number of good inter-stop sections as bad ones. Thus, the trend value of the overall Level of Service should be around 2.5. Similarly, the trend for both indices should be as horizontal as possible. To achieve this goal, the values of the parameters a and b in the linguistic membership function prescriptions for the two indices were adjusted. The resulting graph after optimization can be seen in Figure 4.6.

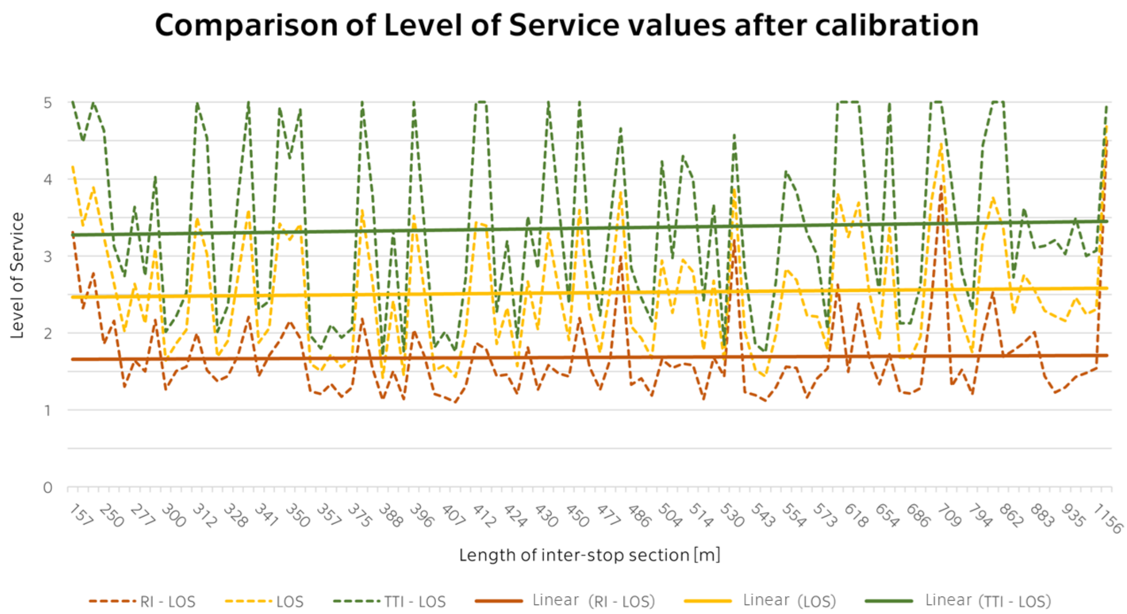

Figure 4.6: Graph of comparison of Level of Service values after calibration (TTI - travel time index, RI - reliability index, LOS - level of service).

After calibrating the linguistic membership functions, the resulting mathematical prescription for the linguistic membership functions was according to Equations 4.6 and 4.7.

$$RI_{LOS} = \frac{RI - 0}{1,5} + 1 \tag{4.6}$$

$$TTI_{LOS} = \frac{TTI - 0,97}{0,22} + 1 \tag{4.7}$$

For the reliability index, the origin of the intervals finally came out directly at the reliability index value of 0 and the width of the intervals was 1.5. For the travel time index the best optimized value for parameter a came out to be 0.97 and for parameter b

0.22. The resulting plots of the linguistic membership functions are shown in Figure 4.7 and Figure 4.8.

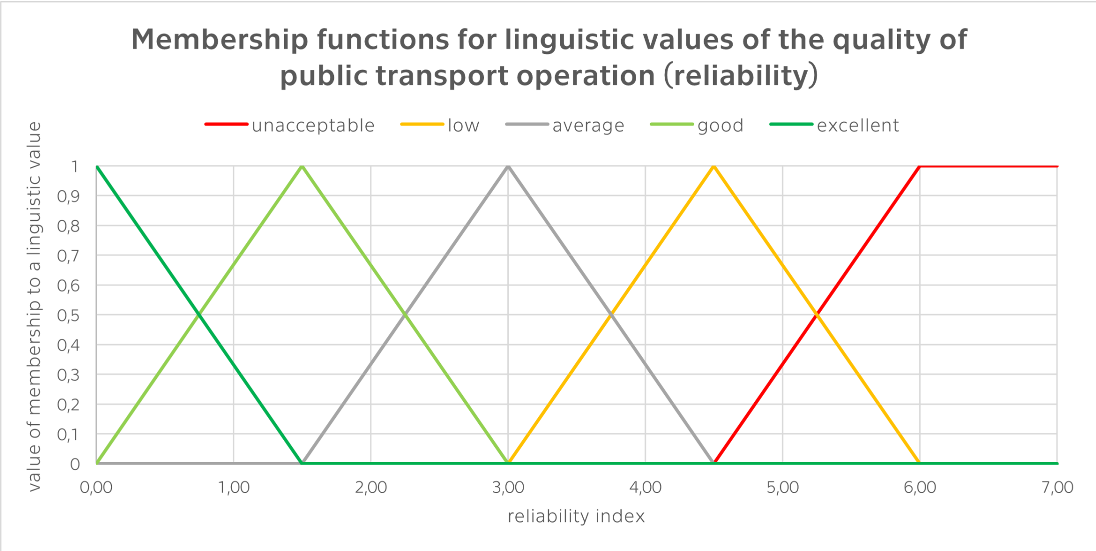

Figure 4.7: New linguistic membership function to determine the Level of Service for the reliability index.

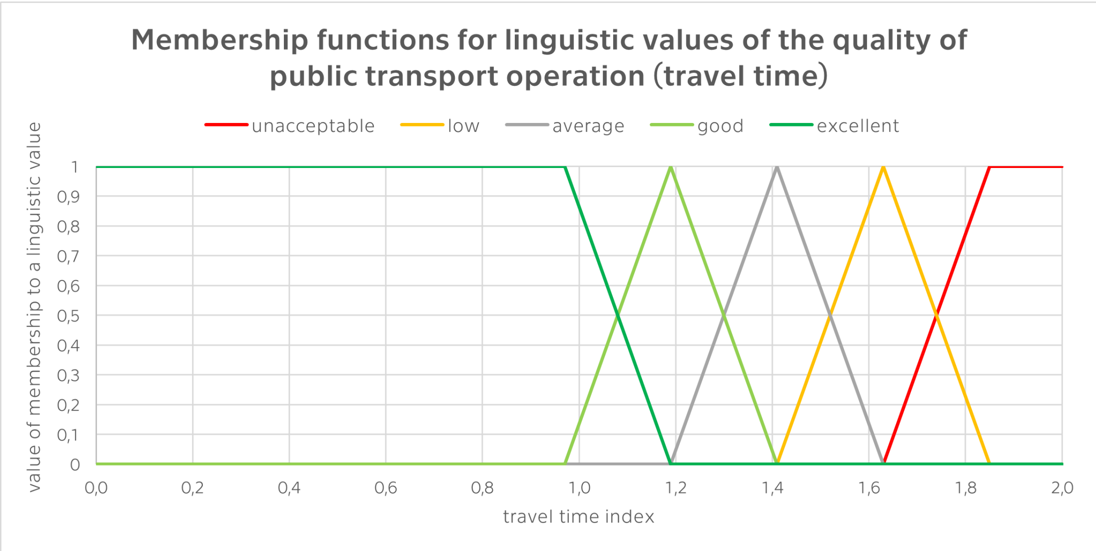

Figure 4.8: New linguistic membership function to determine the Level of Service for the travel time index.

Due to the simplicity and versatility of this optimization, it can then be used for each transport network separately. Since the character of the traffic is different for each city and its transport network, it is possible to calibrate the values of the membership functions individually directly to the nature of the respective public transport network when implementing the method in this way. In the end, this calibration could be automated later by derivations and no longer needs to be done manually using an Excel spreadsheet.

4.5 QPTOEM 2023: new version and comparison with the 2017 version

As already mentioned, the new version of the method should be individually calibratable for each urban public transport network based on historical data. This calibration is done by expertly estimating the two parameters a and b in the prescription function, which converts the reliability index and travel time index values into linguistic Level of Service values. For the inter-stop sections used for calibration, the function prescription was calculated according to Equations 4.8 and 4.9.

$$RI_{LOS} = \frac{RI - 0}{1,5} + 1 \tag{4.8}$$

$$TTI_{LOS} = \frac{TTI - 0,97}{0,22} + 1 \tag{4.9}$$

The basis for calibration to a specific network is to monitor the linear trends of both indices and the overall Level of Service. In this particular case, all trends should be horizontal and, in addition, the values of the overall Level of Service should be around 2.5, since the inter-stop sections for this purpose were selected systematically to have the same number of problem and non-problem inter-stop sections.

A comparison of the results of the 2017 QPTOEM and the 2023 QPTOEM can be seen in the tables in Figures 4.9 - 4.12.The grey shaded cells are the results for the original 2017 version and the white shaded cells are for the new 2023 version. In the last column is the change in the overall Level of Service value (old version - new version of the method), “+1” means an improvement of 1 and “-1” means a deterioration of 1.

City	Location	Section	Section Length [m]	Decisive travel time OLD [min]	Decisive travel time NEW [min]	Travel speed index OLD	Travel time index NEW	Reliability index	LOS TSI 2017	LOS TTI 2023	RI LOS 2017	RI LOS 2023	LOS 2017	LOS 2023	LOS distance (2023 - 2017)
Brno	Česká - Zelný trh	A1	277	0,67	0,62	0,76	1,55	0,96	3,02	3,64	3,30	1,64	3	3	0
Brno	Česká - Zelný trh	A2	359	1,15	1,06	0,91	1,21	0,51	1,02	2,10	2,05	1,34	1	2	-1
Brno	Česká - Zelný trh	B1	330	0,80	0,74	0,75	1,58	1,07	3,16	3,77	3,85	1,71	3	3	0
Brno	Česká - Zelný trh	B2	300	0,97	0,91	0,91	1,19	0,40	1,02	2,01	1,50	1,27	1	2	-1
Brno	Gajdošova - Tomkovo nám.	A1	644	1,25	1,07	0,65	2,38	2,07	5,00	5,00	5,00	2,38	4	4	0
Brno	Gajdošova - Tomkovo nám.	A2	709	1,77	1,51	0,63	2,91	4,36	5,00	5,00	5,00	3,91	4	4	0
Brno	Gajdošova - Tomkovo nám.	A3	849	1,40	1,29	0,63	2,68	2,29	5,00	5,00	5,00	2,53	4	4	0
Brno	Gajdošova - Tomkovo nám.	B1	554	1,27	1,13	0,74	1,65	0,84	3,17	4,10	2,70	1,56	3	3	0
Brno	Gajdošova - Tomkovo nám.	B2a	382	0,88	0,83	0,73	1,58	0,80	3,28	3,77	2,50	1,53	3	3	0
Brno	Gajdošova - Tomkovo nám.	B2b	328	0,70	0,66	0,87	1,27	0,66	1,67	2,36	2,80	1,44	2	2	0
Brno	Gajdošova - Tomkovo nám.	B3	815	1,37	1,28	0,78	1,73	1,48	3,80	4,44	4,90	1,99	3	3	0
Brno	Mendlovo nám. - Konečného nám.	A1	297	0,88	0,83	0,74	1,64	1,75	3,53	4,03	5,00	2,17	4	3	1
Brno	Mendlovo nám. - Konečného nám.	A2	407	0,70	0,67	0,89	1,19	0,24	1,25	2,01	1,20	1,16	1	2	-1
Brno	Mendlovo nám. - Konečného nám.	A3	1156	3,13	2,90	0,82	1,43	0,81	2,42	3,07	2,55	1,54	2	2	0
Brno	Mendlovo nám. - Konečného nám.	B1	250	0,77	0,70	0,67	1,77	1,29	3,74	4,63	3,95	1,86	4	3	1
Brno	Mendlovo nám. - Konečného nám.	B2	495	0,82	0,79	0,87	1,22	0,28	1,55	2,15	1,40	1,19	1	2	-1
Brno	Mendlovo nám. - Konečného nám.	B3a	350	1,00	0,94	0,72	1,69	1,73	3,71	4,27	5,00	2,15	4	3	1
Brno	Mendlovo nám. - Konečného nám.	B3b	905	2,12	1,97	0,78	1,44	0,66	2,51	3,13	2,80	1,44	2	2	0
Brno	Soukenická - Vsetínská	A1	528	0,67	0,63	0,83	1,28	0,21	1,73	2,42	1,05	1,14	1	2	-1
Brno	Soukenická - Vsetínská	A2	317	0,75	0,72	0,89	1,19	0,56	1,28	2,01	2,30	1,37	2	2	0
Brno	Soukenická - Vsetínská	A3	408	0,65	0,63	0,91	1,14	0,15	0,97	1,76	0,75	1,10	1	1	0
Brno	Soukenická - Vsetínská	B1	509	0,80	0,76	0,82	1,40	0,82	2,52	2,97	2,60	1,55	2	2	0
Brno	Soukenická - Vsetínská	B2	349	0,87	0,80	0,66	1,84	1,35	4,08	4,93	4,25	1,90	4	3	1
Brno	Soukenická - Vsetínská	B3	388	0,62	0,60	0,91	1,13	0,19	0,88	1,71	0,95	1,13	1	1	0

Figure 4.9: Table of results of comparison evaluation of the 2017 version and the 2023 version of the QPTOEM in Brno, first part.

City	Location	Section	Section Length [m]	Decisive travel time OLD [min]	Decisive travel time NEW [min]	Travel speed index OLD	Travel time index NEW	Reliability index	LOS TSI OLD	LOS TTI NEW	RI LOS OLD	RI LOS NEW	LOS 2017	LOS 2023	LOS distance (2023 - 2017)
Prague	Karlovarská	A1	673	1,17	1,02	0,71	1,85	1,08	3,81	5,00	3,90	1,72	3	3	0
Prague	Karlovarská	A2	593	1,14	0,94	0,67	2,32	2,44	4,77	5,00	5,00	2,63	4	4	0
Prague	Karlovarská	A3	701	0,90	0,77	0,68	2,55	2,04	5,00	5,00	5,00	2,36	4	4	0
Prague	Libuš	A1	331	0,90	0,75	0,72	1,91	1,81	3,75	5,00	5,00	2,21	4	4	0
Prague	Libuš	A2	412	1,07	0,86	0,72	1,90	1,30	3,48	5,00	4,00	1,87	3	3	0
Prague	Libuš	A3	434	0,68	0,58	0,64	2,04	0,87	4,29	5,00	2,85	1,58	3	3	0
Prague	Libuš	B1	314	0,60	0,53	0,71	1,75	0,77	3,48	4,53	2,35	1,51	3	3	0
Prague	Libuš	B2	377	1,00	0,88	0,68	1,99	1,77	4,29	5,00	5,00	2,18	4	4	0
Prague	Libuš	B3	446	0,95	0,81	0,80	1,56	0,71	2,52	3,68	2,05	1,47	3	3	0
Prague	Opatovská	A1	935	1,93	1,75	0,81	1,41	0,44	2,22	3,02	1,70	1,29	2	2	0
Prague	Opatovská	A2	430	0,93	0,79	0,88	1,37	0,39	1,39	2,83	1,95	1,26	1	2	-1
Prague	Opatovská	A3	794	1,68	1,58	0,86	1,26	0,30	1,52	2,30	1,50	1,20	1	2	-1
Prague	Opatovská	A4	390	0,97	0,87	0,79	1,48	0,76	2,48	3,33	2,30	1,51	1	2	-1
Prague	Opatovská	A5	411	0,62	0,57	0,85	1,34	0,45	1,84	2,70	1,75	1,30	2	2	0
Prague	Opatovská	B1	421	1,77	1,68	0,86	1,25	0,66	1,57	2,27	2,80	1,44	2	2	0
Prague	Opatovská	B2	477	0,97	0,91	0,88	1,24	0,39	1,42	2,23	1,95	1,26	1	2	-1
Prague	Opatovská	B3	686	1,55	1,47	0,89	1,22	0,32	1,34	2,13	1,60	1,21	1	2	-1
Prague	Opatovská	B4	424	1,13	1,02	0,80	1,45	0,69	2,36	3,19	2,95	1,46	2	2	0
Prague	Opatovská	B5	914	1,15	1,02	0,81	1,46	0,34	2,28	3,21	1,70	1,23	1	2	-1
Prague	Spořilov - Želivského	A1	1116	2,12	1,82	0,85	1,41	0,72	1,72	3,00	2,10	1,48	2	2	0
Prague	Spořilov - Želivského	A2	396	0,98	0,89	0,66	2,00	1,56	4,53	5,00	5,00	2,04	4	4	0
Prague	Spořilov - Želivského	A3	456	1,08	0,97	0,70	1,94	1,79	4,26	5,00	5,00	2,19	4	4	0
Prague	Spořilov - Želivského	A4	883	1,70	1,56	0,82	1,43	1,51	2,38	3,11	5,00	2,01	3	3	0
Prague	Spořilov - Želivského	A5	403	1,00	0,98	0,74	1,49	1,05	3,15	3,38	3,75	1,70	3	3	0
Prague	Spořilov - Želivského	A6	1208	2,52	2,25	0,71	2,00	5,24	4,41	5,00	5,00	4,49	4	5	-1
Prague	Spořilov - Želivského	B1	654	1,23	1,13	0,86	1,30	0,50	1,63	2,52	2,00	1,33	2	2	0
Prague	Spořilov - Želivského	B2	486	1,00	0,92	0,83	1,38	0,49	2,13	2,84	1,95	1,33	2	2	0
Prague	Spořilov - Želivského	B3	504	1,25	1,10	0,73	1,68	0,98	3,24	4,23	3,40	1,65	3	3	0
Prague	Spořilov - Želivského	B4	881	1,58	1,45	0,78	1,55	1,31	2,95	3,62	4,05	1,87	3	3	0
Prague	Spořilov - Želivského	B5	514	1,32	1,13	0,77	1,63	0,87	2,83	4,00	2,85	1,58	3	3	0
Prague	Spořilov - Želivského	B6	865	2,05	1,93	0,82	1,35	1,16	2,15	2,72	3,30	1,77	3	2	1

Figure 4.10: Table of results of comparison evaluation of the 2017 version and the 2023 version of the QPTOEM in Prague, first part.

City	Location	Section	Section Length [m]	Decisive travel time OLD [min]	Decisive travel time NEW [min]	Travel speed index OLD	Travel time index NEW	Reliability index	LOS TSI OLD	LOS TTI NEW	RI LOS OLD	RI LOS NEW	LOS 2017	LOS 2023	LOS distance (2023 - 2017)
Budapest	Déli pályaudvar	A1	781	2,00	2,00	0,79	1,37	0,78	2,67	2,80	2,40	1,52	3	2	1
Budapest	Déli pályaudvar	B1	1050	2,00	1,96	0,71	1,52	0,64	3,27	3,49	2,70	1,43	2	2	0
Budapest	Erszébet híd	A1	250	0,67	0,35	0,67	3,36	2,66	4,37	5,00	5,00	2,77	4	4	0
Budapest	Erszébet híd	A2	414	0,93	0,69	0,66	2,35	1,18	4,29	5,00	3,40	1,79	4	3	1
Budapest	Erszébet híd	B1	312	0,97	0,71	0,80	1,93	1,49	2,87	5,00	4,95	1,99	3	3	0
Budapest	Erszébet híd	B2	554	1,00	0,91	0,76	1,59	0,82	3,10	3,83	2,60	1,55	3	3	0
Budapest	Keleti pályaudvar	A1	780	1,57	1,85	0,87	1,62	0,46	4,77	3,95	1,80	1,31	2	3	-1
Budapest	Keleti pályaudvar	B1	862	2,10	1,55	0,70	2,09	1,04	3,54	5,00	3,70	1,69	3	3	0

Figure 4.11: Table of results of comparison evaluation of the 2017 version and the 2023 version of the QPTOEM in Budapest, first part.

City	Location	Section	Section Length [m]	Decisive travel time OLD [min]	Decisive travel time NEW [min]	Travel speed index OLD	Travel time index NEW	Reliability index	LOS TSI OLD	LOS TTI NEW	RI LOS OLD	RI LOS NEW	LOS 2017	LOS 2023	LOS distance (2023 - 2017)
Pilsen	Line 16	A1	530	1,22	1,17	0,93	1,15	0,65	0,96	1,83	2,75	1,43	1	2	-1
Pilsen	Line 16	A10	290	0,70	0,65	0,83	1,35	0,75	2,05	2,74	2,25	1,50	2	2	0
Pilsen	Line 16	A11	510	0,80	0,74	0,71	1,70	0,90	3,65	4,30	3,00	1,60	3	3	0
Pilsen	Line 16	A12	300	1,27	1,20	0,87	1,24	0,76	1,48	2,22	2,30	1,51	2	2	0
Pilsen	Line 16	A13	360	0,97	0,90	0,92	1,18	0,26	0,85	1,94	1,30	1,17	1	2	-1
Pilsen	Line 16	A14	580	1,10	1,43	0,69	1,20	0,81	3,60	2,05	2,55	1,54	3	2	1
Pilsen	Line 16	A15	480	1,20	1,14	0,74	1,51	0,98	3,06	3,48	3,40	1,65	3	3	0
Pilsen	Line 16	A16	550	1,00	0,98	0,91	1,13	0,18	0,99	1,75	0,90	1,12	1	1	0
Pilsen	Line 16	A17	450	1,13	1,08	0,85	1,27	0,65	1,81	2,38	2,75	1,43	2	2	0
Pilsen	Line 16	A18	570	0,67	0,54	0,86	1,48	0,24	1,63	3,30	1,20	1,16	1	2	-1
Pilsen	Line 16	A19	390	0,75	0,73	0,91	1,14	0,21	0,96	1,76	1,05	1,14	1	1	0
Pilsen	Line 16	A2	405	0,98	0,96	0,90	1,15	0,31	1,09	1,81	1,55	1,21	1	2	-1
Pilsen	Line 16	A20	300	1,03	0,98	0,83	1,30	0,84	1,95	2,52	2,70	1,56	2	2	0
Pilsen	Line 16	A3	275	0,98	0,81	0,90	1,35	0,45	1,09	2,74	1,75	1,30	1	2	-1
Pilsen	Line 16	A4	700	1,15	1,10	0,82	1,33	0,42	2,12	2,62	1,60	1,28	2	2	0
Pilsen	Line 16	A5	425	0,97	0,93	0,90	1,17	0,31	1,10	1,93	1,55	1,21	1	2	-1
Pilsen	Line 16	A6	645	1,37	1,30	0,76	1,50	1,05	2,97	3,42	3,75	1,70	3	3	0
Pilsen	Line 16	A7	260	0,80	0,75	0,80	1,44	1,73	2,59	3,12	5,00	2,15	3	3	0
Pilsen	Line 16	A8	480	1,17	1,09	0,76	1,77	2,98	3,94	4,66	5,00	2,99	4	4	0
Pilsen	Line 16	A9	350	0,88	0,81	0,66	1,83	1,39	4,09	4,90	4,45	1,93	4	3	1
Pilsen	Line 16	B1	538	1,17	1,00	0,87	1,37	0,35	1,46	2,81	1,75	1,23	1	2	-1
Pilsen	Line 16	B10	249	0,72	0,67	0,70	1,74	1,98	3,79	4,48	5,00	2,32	4	3	1
Pilsen	Line 16	B11	532	1,43	1,33	0,77	1,76	3,30	3,89	4,57	5,00	3,20	4	4	0
Pilsen	Line 16	B12	157	0,63	0,59	0,68	1,87	3,46	4,27	5,00	5,00	3,31	4	4	0
Pilsen	Line 16	B14	618	1,50	1,02	0,80	1,93	0,74	2,35	5,00	2,20	1,49	2	3	-1
Pilsen	Line 16	B15	573	1,25	1,18	0,78	1,41	0,61	2,51	3,01	2,55	1,41	2	2	0
Pilsen	Line 16	B16	543	1,10	1,06	0,91	1,16	0,29	1,06	1,86	1,45	1,19	1	2	-1
Pilsen	Line 16	B17	375	1,03	0,99	0,88	1,20	0,44	1,34	2,05	1,70	1,29	2	2	0
Pilsen	Line 16	B18	341	0,77	0,72	0,87	1,26	0,66	1,54	2,31	2,80	1,44	2	2	0
Pilsen	Line 16	B19	457	0,97	0,91	0,80	1,41	0,83	2,48	3,01	2,65	1,55	3	2	1
Pilsen	Line 16	B2	355	0,92	0,87	0,90	1,18	0,36	1,07	1,96	1,80	1,24	1	2	-1
Pilsen	Line 16	B20	343	1,10	1,04	0,86	1,28	1,06	1,73	2,41	3,80	1,71	2	2	0
Pilsen	Line 16	B3	550	0,77	0,73	0,83	1,34	0,44	2,06	2,66	1,70	1,29	2	2	0
Pilsen	Line 16	B4	357	1,02	0,99	0,91	1,15	0,31	0,97	1,80	1,55	1,21	1	2	-1
Pilsen	Line 16	B5	528	1,45	1,36	0,73	1,56	1,02	3,16	3,67	3,60	1,68	3	3	0
Pilsen	Line 16	B7	674	1,20	1,15	0,87	1,22	0,35	1,43	2,12	1,75	1,23	1	2	-1
Pilsen	Line 16	B8	491	1,12	1,06	0,84	1,29	0,61	1,82	2,45	2,55	1,41	2	2	0
Pilsen	Line 16	B9	425	1,50	1,37	0,76	1,52	1,22	2,82	3,52	3,60	1,81	3	3	0

Figure 4.12: Table of results of comparison evaluation of the 2017 version and the 2023 version of the QPTOEM in Pilsen, first part.

The results from the tables in Figures 4.9 - 4.12 can also be seen in the graph in Figure 4.13. There, the values and linear trends of both the new and old total Level of Service are shown. It also shows the value and linear trend of the reliability index, which remains the same for both versions. It can be seen from this display that the new Level of Service values (version 2023) correspond better with the reliability index values (they have the same trend direction).

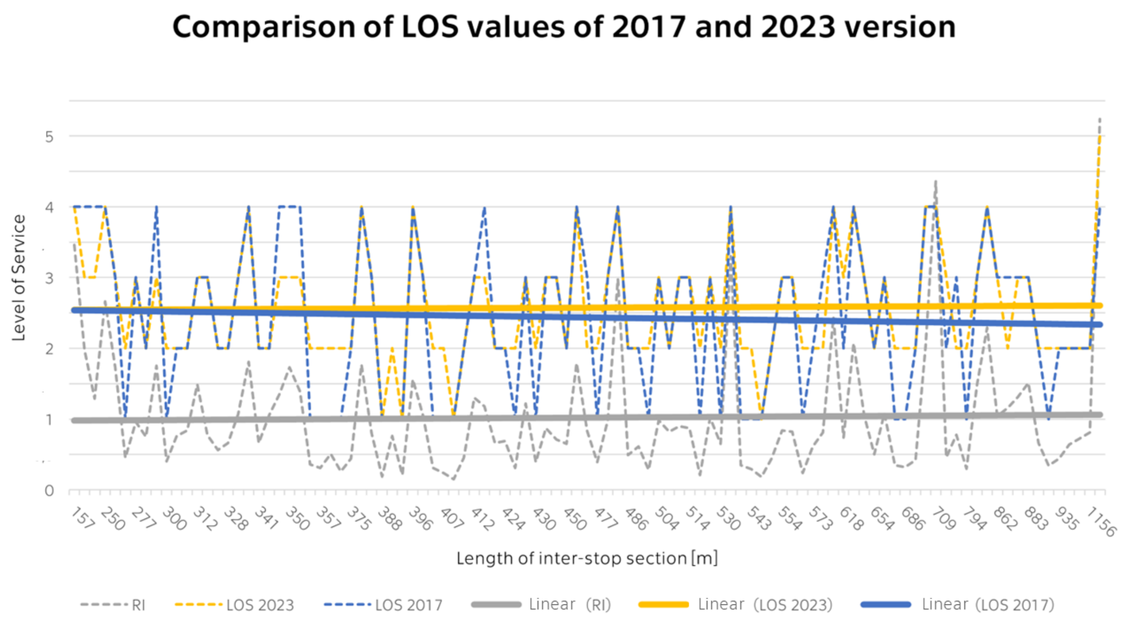

Figure 4.13: Graph of results of comparison evaluation of the 2017 version and the 2023 version of the QPTOEM in Pilsen.

In general, all the objectives of this sub-optimization were met and solved for a more effective use of the method in practice, as can be seen in Table 4.1. However, there is still a great amount of potential room for improvement of the method.

Table 4.1: Results of the optimization.

Problematic area	**Fixed**	**Solution**
The decisive travel time	✓	Redetermined by different statististical method
The reliability index	✓	Problematic was the linguistic membership function
The calculation using both travel time and speed	✓	Travel speed index changed to travel time index
Linguistic membership functions	✓	New method - optimized linguistic functions unique for traffic network

4.6 Possible future directions of QPTOEM development

The QPTOEM 2023 version is different from the original 2017 version in terms of calculation, in particular in the determination of the critical travel speed and the travel time index. A significant innovation is the individual calibration of the linguistic membership functions according to a given traffic network. This calibration is based on the trends of the Level of Service of reliability index, the Level of Service of travel time index and the overall Level of Service. The values of these variables are plotted against the length of the segment, and the values of the reliability index are plotted in the same way to see the effect of distance on the network. The aim of the calibration is then to parallel the trend of the reliability index and the trends of the individual Level of Service variables.

However, during the process of determining the new version of the QPTOEM, other development opportunities were discovered that need to be explored before being put into practice, such as:

- outliers identification in the data and data filtering
- determining in hourly slices
- switching to real-time mode when evaluating the QPTOEM and monitoring long-term trends

4.6.1 Outlier identification and data filtering

When evaluating the 2017 version of the method, there were occasional deviations in the evaluation sheets in the monitored data that had to be subsequently removed because they had a negative impact on the resulting Level of Service value and were outliers, not regular delays on the link. For example, in Prague in the Spořilov - Želivského case study there was an important football match near this area at the time of measurement. For this reason, there were exceptionally large delays on bus routes, as can be seen in the table in Figure 4.14. This observation led to the possibility of using automatic data filtering to identify these outliers.

AVERAGE TRAVEL TIME [min]

Time [hour]	13.09.2021	14.09.2021	15.09.2021	16.09.2021	17.09.2021	18.09.2021	19.09.2021
4	2,78	2,50	2,43	2,40	2,60		
5	3,03	2,82	2,60	3,10	2,93	2,47	3,18
6	2,96	3,24	3,12	3,27	2,73	2,62	2,49
7	3,62	3,29	4,72	3,76	3,08	2,85	2,76
8	3,80	4,40	3,84	5,05	5,33	3,07	2,96
9	4,03	3,63	4,01	5,15	4,15	3,08	2,93
10	3,48	3,84	3,00	3,37	3,64	3,04	3,08
11	3,26		6,50	3,28	3,73	3,19	3,11
12	3,59		5,92	3,83	3,11	2,88	3,08
13	3,02		4,54	3,67	3,73	2,82	2,99
14	3,71		6,06	3,61	5,57	3,33	3,04
15	3,80		4,49	7,54	6,87	2,60	3,28
16	3,62	5,08	6,42	6,39	5,97	3,06	3,01
17	3,96	4,35	8,87	17,44	4,02	2,75	3,08
18	3,30	3,70	4,47	5,49	3,41	2,69	3,02
19	3,18	2,84	3,12	3,82	2,72	2,68	3,15
20	3,03	2,83	3,54	3,28	2,50	2,90	3,03
21	2,68	2,74	2,92	3,93	2,70	2,73	3,09
22	2,47	2,71	2,73	2,97	2,74	2,86	2,89
23	2,51	2,68	2,63	2,78	2,74	2,78	2,83

Figure 4.14: Part of the results of filtering outliers from measured data.

For this purpose, a filtering the QPTOEM in the form of a band was created, whereby it is evaluated how far some values are outside this band and the values to be filtered are determined accordingly. So the prerequisite for this QPTOEM is to set the center of the strip and the width of the strip. If the percentage of values that exceed the value of this band exceeds a certain threshold, this is a regular occurrence, hence the values must be retained for the resulting Level of Service to be valid. If the percentage is low, the values can be deleted and these are outliers.

To set the bandwidth and values, the standard deviation value was first used. In this case, any multiple of the standard deviation would determine the width of the interval from the mean travel time of the entire measurement. In this interval, the values of the hourly slices would be used for simplicity. However, when testing any multiple of the standard deviation from the mean, the percentage did not match reality, or for travel times of inter-stop sections where some sections should be deleted, the percentage bound did not match. Therefore, this option was dropped as the multiplication of the standard deviation is too individual for each inter-stop section. So the next step was to set the distance from the mean as a multiple of the mean and determine the boundary based on that. In this case, the boundary was very close, however, for some of the inter-stop sections it still did not fit, so finally it was determined to evaluate the percentage of data not from the hourly slices, but from the total data. In this case, the boundary was already very close and after several attempts to set the correct value of the strip width and rechecking with real data, this boundary was estimated to be 1.5 %, with a strip distance of 1.5 times the average travel time value of all measured values for that inter-stop section. This means that for each inter-stop section separately the average travel time of all values was calculated, which could be for example 80 seconds. This value was then multiplied by 1.5 times, so in this case 120 seconds, and this value was added and subtracted from the average. This produced a range of values for the calculation of outliers which in this case would be from -40 seconds to 200 seconds, the negative lower bound in this case does not matter. Thus, after the evaluation, it would show how many travel times in a given inter-stop section exceeded 200 seconds and what percentage of the total data. Part of the resulting table just for the final values from the testing can be seen in Figure 4.15.

Out[3]:

	fln	percentage error	num section
0	BI_PHA_Karlovarská_A1_Staré-náměstí-Jiviny-Vyh...	1.453634	29
1	BI_PHA_Karlovarská_A2_Jiviny-Ruzyňský-hřbitov-...	4.628633	43
2	BI_PHA_Karlovarská_A3_Ruyzňský-hřbitov-Bílá-ho...	4.505495	41
3	BI_PHA_Libuš_A1_U-Zvoničky-Libuš-Vyhodnoceni_o...	1.211632	30
4	BI_PHA_Libuš_A2_Libuš-U-Libušské-sokolovny-Vyh...	0.645161	16
5	BI_PHA_Libuš_A3_U-Libušské-skolovny-Sídliště-P...	0.150414	6
6	BI_PHA_Libuš_B1_Libuš-U-Zvoničky-Vyhodnoceni_o...	0.041017	1
7	BI_PHA_Libuš_B2_U-Libušské-sokolovny-Libuš-Vyh...	0.613246	15
8	BI_PHA_Libuš_B3_Sídliště-Písnice-U-Libušské-so...	0.101574	4
9	BI_PHA_Opatovská_A1_Opatov-Ke-kateřinkám-Vyhod...	0.000000	0
10	BI_PHA_Opatovská_A2_Ke-Kateřinkám-Metodějova-V...	0.028588	1
11	BI_PHA_Opatovská_A3_Metodějova-Háje-Vyhodnocen...	0.000000	0
12	BI_PHA_Opatovská_A4_Háje-Horčičkova-Vyhodnocen...	0.063045	6
13	BI_PHA_Opatovská_A5_Horčičkova-Jižní-Město-Vyh...	0.268620	11
14	BI_PHA_Opatovská_B1_Ke-Kateřinkám-Opatov-Vyhod...	0.000000	0
15	BI_PHA_Opatovská_B2_Metodějova-Ke-Kateřinkám-V...	0.029438	1

Figure 4.15: Part of the results of filtering outliers from measured data.

In the resulting filtering, this would then mean that all sections that have more than 1.5 % of data outside the filter band are regular outages and do not need to be filtered as they are regular events on the section. All those below 1.5 % need to be deleted as they are outliers that could have a negative impact on the resulting Level of Service value. However, these values were only tested for the Prague case studies, as it has the largest number of sections. These values are also likely to be unique for each data set from a different city and different length of measurement. Therefore, these possibilities for filtering and eliminating outliers need to be further researched.

4.6.2 Hourly slices and real time solution options

Since the method is now only able to perform a historical evaluation for an overall monitoring period, it offers the possibility of evaluating at a lower time interval, for example in hourly slices, in order to monitor the changes in Level of Service values during the day. However, it does not make sense in the current calculation to calculate a reliability index in this respect, as one hour is too short an interval for such an evaluation. Therefore, for the time being only the travel time index has been used in the evaluation, in which due to calibration the results are poor. The results of the attempt to evaluate the hourly slices can be seen in Figure 4.16. This evaluation was based only on data from Pilsen. In the table, the rows show the individual inter-stop sections and the columns show the results for each hour of the day. The specific Level of Service values are underlined by value, with the best (1) and worst (5) inter-stop sections in white and red accordingly.

LOS TTI version 2023	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Adelova - Nemocnice Bory	2	3	4	4	4	3	3	3	3	3	4	4	4	3	3	3	3	3	3	2
Adelova - U Teplárny	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Dobrovského - Nemocnice Bory	3	3	4	4	4	3	4	3	3	3	4	4	4	4	3	3	3	3	3	3
Dobrovského - Nám. Českých Bratří	3	3	5	5	5	5	5	4	4	4	5	5	5	5	3	3	3	3	3	3
Doubravka - Habrmannovo náměstí	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4
Gambrinus - Hlavní nádraží	2	3	3	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2
Gambrinus - Stavební stroje	2	4	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	3	2
Habrmannovo náměstí - Doubravka	5	5	5	5	5	4	4	4	4	5	5	5	5	5	4	4	4	4	4	4
Habrmannovo nám. - Pol. Doubravka	2	3	5	5	4	5	4	4	4	4	5	5	5	5	4	3	3	3	2	2
Hlavní nádraží - Pařížská	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	5
Hlavní nádraží - Železniční poliklinika	5	5	5	5	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5
Jižní Předměstí - Dobrovského	3	3	4	5	4	4	5	4	4	5	5	5	5	5	3	3	2	2	3	3
Jižní Předměstí - Tylova	3	3	3	4	3	3	3	3	3	4	5	5	5	4	3	3	3	3	3	3
Mrakodrap - Pařížská	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	4
Mrakodrap - U Práce	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Nemocnice Bory - Adelova	5	4	4	5	4	5	4	5	4	5	5	5	5	5	5	4	4	4	5	4
Nemocnice Bory - Dobrovského	3	3	4	3	3	3	3	3	3	3	3	4	4	4	4	3	3	3	3	3
Nám. Českých Bratří - Jižní Předměstí	4	5	4	5	4	4	4	4	4	5	5	5	5	5	4	4	4	4	4	4
Opavská - Poliklinika Doubravka	3	3	4	5	4	4	4	4	4	5	5	5	5	5	4	3	3	3	3	3
Opavská - Těšínská	3	4	4	4	4	4	3	3	3	4	4	4	4	4	4	3	3	3	3	3
Pařížská - Hlavní nádraží	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	5
Pařížská - Mrakodrap	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Pol. Doubravka - Habrmannovo nám.	5	5	5	4	4	4	4	4	4	4	4	4	5	4	4	4	4	4	4	4
Poliklinika Doubravka - Opavská	4	4	4	5	5	5	5	4	5	5	5	5	5	5	5	4	4	4	4	4
Stavební stroje - Gambrinus	2	3	3	3	3	3	3	3	3	3	3	4	4	3	3	3	3	3	3	2
Stavební stroje - Těšínská	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Sídliště Bory - U Luny	4	3	3	3	3	3	3	3	3	4	3	3	3	3	4	4	3	4	3	3
Tylova - Jižní Předměstí	3	4	4	5	4	4	3	3	3	4	5	5	5	4	3	3	3	3	3	3
Tylova - U Práce	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4
Těšínská - Opavská	3	3	3	4	3	3	3	3	3	3	3	4	4	4	4	4	3	3	3	3
Těšínská - Stavební stroje	3	3	3	4	3	3	3	3	3	3	4	4	4	3	3	3	3	3	3	3
U Luny - Sídliště Bory	3	4	3	4	3	3	3	3	3	3	3	3	3	4	4	3	3	3	3	3
U Luny - U Teplárny	3	3	4	4	3	3	3	3	3	3	4	4	4	4	4	3	3	3	3	3
U Práce - Mrakodrap	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
U Práce - Tylova	4	5	5	5	5	5	4	4	4	5	5	5	5	5	5	4	5	4	4	3
U Teplárny - Adelova	3	3	4	5	4	3	4	3	3	4	5	5	5	4	4	3	3	3	3	3
U Teplárny - U Luny	3	3	4	4	3	3	3	3	3	3	4	4	4	4	3	3	3	3	3	3
Železniční poliklinika - Gambrinus	3	3	3	4	4	4	4	5	5	5	5	5	5	5	4	3	3	3	3	2

Figure 4.16: The results of the attempt to evaluate the hourly slices.

Although the results in absolute numbers are worse for the individual inter-stop sections, which does not correspond to the real situation in the inter-stop sections, it is still possible to identify the individual traffic peaks of the day. In this respect, for further development, it will be necessary to optimize both index values and to think about the exact interpretation of the results of the hourly sections.

The issue of hourly slices is also related to the collection of continuous real-time data. The aim of the method is to make the best possible use of it in practice, and real-time monitoring is part of this. However, this will still require optimizing the data collection and the initial data processing, as well as taking into account other statistical pitfalls that may arise. In the case of long-term data collection and evaluation, it is then possible to identify trends in the quality of public transport operations and thus prevent a major traffic collapse in public transport (it is then possible to focus on a section, for example, at the stage when the Level of Service is 3, not only when it is regularly 5).

Conclusion

Public transport is an essential part of meeting the Green Deal and sustainable transport goals. For this reason, people need to be encouraged more to use public transport services as a substitute for individual car journeys. The key to competitive public transport is its quality, and in particular the quality of public transport operations, which has a major influence on mode choice. For this reason, in 2017, a method to evaluate the quality of public transport operations was proposed by Ing. Vojtěch Novotný, Ph.D.

The QPTOEM evaluates the quality of public transport operations based on two important indicators for both passengers and service providers - travel speed and travel reliability. Each of these indices describes indicator. The values of both indices are then converted into qualitative values from 1 to 5 (1 - 'excellent', 5 - 'unacceptable'). Using logic rules, they are then evaluated on the overall quality of public transport operations, again on a scale of 1 to 5 called the Level of Service.

However, the calculations in the method were evaluated on a small amount of data, so the calculations needed to be verified and calibrated on a larger amount of data, which was the subject of this thesis. Data from 4 cities from 107 inter-stop sections were used and the 2017 version was subjected to critical analysis. Based on this critical analysis, potential problem areas that could affect the incorrect evaluation of Level of Service were evaluated:

- decisive travel time/speed (in 2017 there was insufficient data for an optimal determination, redetermination needed)
- the reliability index (too high influence on the overall Level of Service, influence of the length of the inter-stop section, optimization needed)
- the calculation using both travel time and speed (simplification without using travel speed, which is equivalent to travel time)
- linguistic membership functions (in 2017 there was insufficient data for an optimal determination, optimization needed)

These areas were analysed in detail and optimised using statistical methods to make the method more relevant to reality and more applicable in practice. The result is an optimized method (the QPTOEM version 2023) that is more applicable to real traffic as it is individually calibrated for each traffic network, which was the main purpose of this thesis. The final overview and solution of the problems can be seen in Table 4.2.

Table 4.2: Results of the optimization.

Problematic area	**Solution**	**Need for further development**
The decisive travel time	Redetermined by different statistical method	Try more statistical methods
The reliability index	Problematic was the linguistic membership function	-
The calculation using both travel time and speed	Travel speed index changed to travel time index	-
Linguistic membership functions	New method - optimized linguistic functions unique for traffic network	Test on more traffic networks

However, there is still room for further calibration and shifting of the QPTOEM in different areas, such as identifying outliers in the data or converting the method to real-time mode to evaluate the data and track different trends in the quality of public transport in the inter-stop sections.

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Appendix **A**

List of acronyms

API Application Programming Interface

DTT Decisive Travel Time

LOS Level of Service

PID Prague Integrated Transport (*Pražská integrovaná doprava*)

QPTOEM Quality of Public Transport Operation Evaluation Method

RI Reliability Index

ROPID Regional Organiser of Prague Integrated Transport (*Regionální organizátor pražské integrované dopravy*)

TT Travel Time

TTI Travel Time Index

TSI Travel Speed Index