Acta Polytechnica CTU Proceedings **41**:8–14, 2023
https://doi.org/10.14311/APP.2023.41.0008

LEVEL OF SERVICE OF PUBLIC TRANSPORT OPERATION – PILOT STUDY

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Abstract. Smart transport planning based on the use of available data while supporting sustainable transport modes is an integral part of the Smart city concept. This article presents a critical analysis of the Level of Service of Public Transport Operation Assessment Method, which is based on two indicators – the reliability index and the travel speed index. The method is applied to a larger sample of data from several different cities, it makes it possible to evaluate the possible shortcomings of the method, since the method has not yet been applied to such a large number of case studies.

Keywords: Public transport priority, smart city, level of service.

1. Introduction

The overall increase in urban population mobility has recently created a greater demand for sustainable mobility, which is essential for future urban development and meeting the goals of EU Green Deal 2050 [1–3]. Considering the capacity of city roads to be filled with cars, it is important to focus on urban public transport, which is a suitable and sustainable alternative to individual car transport [2, 4]. From the sustainable development point of view, there is a need to identify an efficient modal-split and to increase the share of other modes of transport, whereas use of private cars must be reduced [5]. Considering the options for other modes of transport around the city, public transport must be the backbone of sustainable urban mobility [6, 7]. The role of public transport today is not simple, as high road traffic volumes have a negative impact on its speed and reliability. From the passenger's point of view, the main criteria required by customers or potential users is the travel time, reliability or the cleanliness of the cars [8]. We can further divide public transport quality indicators into subjective and objective [9]. Subjective factors such as the cleanliness and comfort of the indicator are not so easy to assess, and it is necessary to directly ask the opinion of the passengers [10]. Objective indicators are those that can be determined from the collected data, these indicators are conclusive, for example travel time, adherence to timetables (reliability), delays and others. These objective indicators have a great influence on the use of public transport, as they have a very high influence when deciding whether a passenger will drive their own car or use public transport.

2. Quality of public transport operation and its assessment method

In the past, the evaluation of public transport operation was often limited to the evaluation of parameters related to the economics (the so-called circulating or technical speed), or the evaluation of the delay of the connection in reaching the destination. Achievement of travel speed and reliability was often expressed in terms of whole lines, not in terms of individual sections, and the achieved values were compared with the timetable data, which by its very nature (timetable for whole minutes, artificially extended travel times in sections with regular congestion, etc.) is not a completely objective evaluation.

The development of ICT and the real-time positioning of public transport vehicles have brought new data sources and new possibilities for their processing – whether for the purposes of public transport network operation management (for example [12]) or transport planning (for example [13]). Although there have been other ways of evaluating public transport operations (for example [14] or [9]), most of them work with a more global view and cannot be used as an analytical tool for evaluating individual sections.

In 2017, The Quality of Public Transport Operation Assessment Method was created as a response to the lack of an objective data-based method for evaluating the quality of traffic and identifying problematic locations or sections in terms of public transport operation on urban roads (e.g. trams, buses/trolleybuses) [11]. The aim of the method is to provide transport engineers with an analytical tool to assess the operation of public transport across the network and to identify sections where public transport operations need to be improved through the implementation of priority measures and thereby improving the quality of public transport and which would lead to more people using

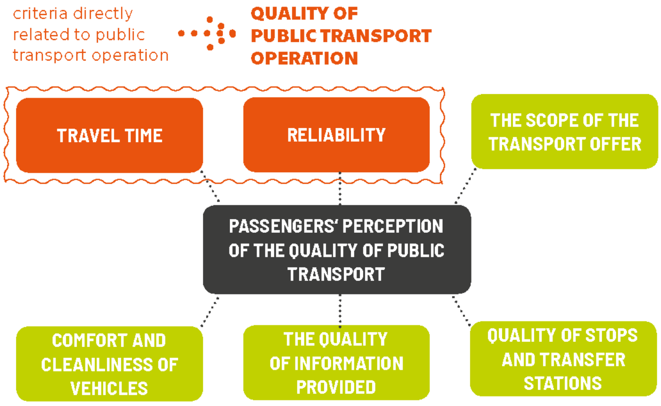

FIGURE 1. Quality of public transport operation and its relation to passengers' perception of the quality of public transport [11].

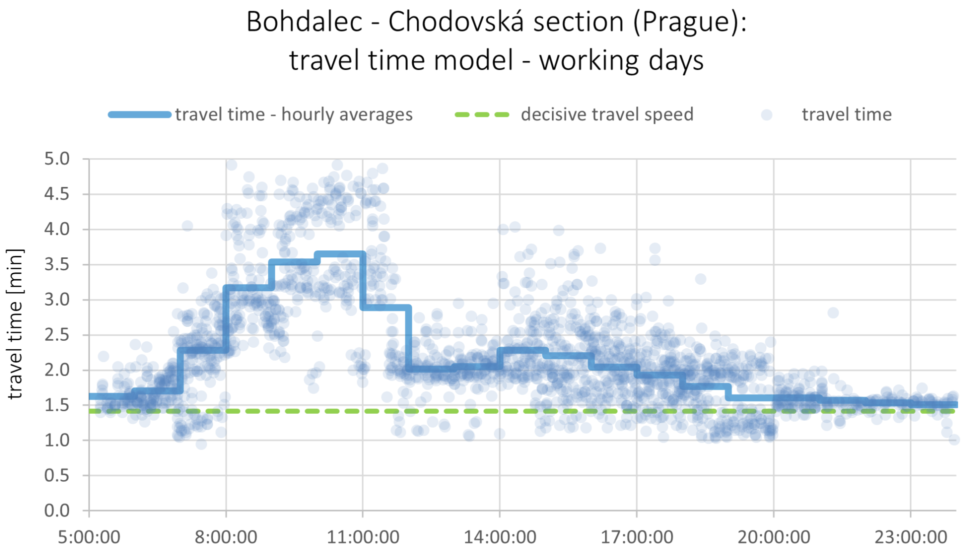

FIGURE 2. Same travel time achieved throughout the day – a section with reliable public transport service [11].

this mode of transportation.

The method is generally based on assessment of travel speed and reliability of public transport in intermediate stop sections, which basically corresponds to the passengers' perception of the quality of public transport operation (see Figure 1).

The Method is based on level-of-service theory and uses objective data-based evaluation of travel speed and reliability [11]. In order to maintain objectivity, both parameters are evaluated only on the basis of the available data on the movement of public transport services in a given inter-stop section, respectively their time positions in the stops. The evaluation of these parameters is then aggregated into an overall level of service for unambiguous evaluation and easy presentability. In this context, the method can form one part of the implementation of the smart city concept [9].

2.1. Reliability evaluation

For public transport to be considered reliable, it needs to have the same travel time regardless of the time of day or traffic situation. This means that in the case of a graphical display, the values for each travel time should form a horizontal line as seen in Figure 2, on the contrary, in case of unreliable operation, the graph will show high deviations from the average, as seen in Figure 3. For interest, the graphs also show the travel time according to the timetable (usually given in whole minutes), which illustrates the inapplicability of evaluating timetable compliance in individual intermediate stop sections.

For the purposes of the method, the reliability of the operation is expressed by the reliability index. This is now calculated as the standard deviation divided by the length of the segment (a longer segment will tend to greater deviations, therefore it would not be objective without the length of the segment), the whole multiplied by 1000, for the sake of clarity of the index.

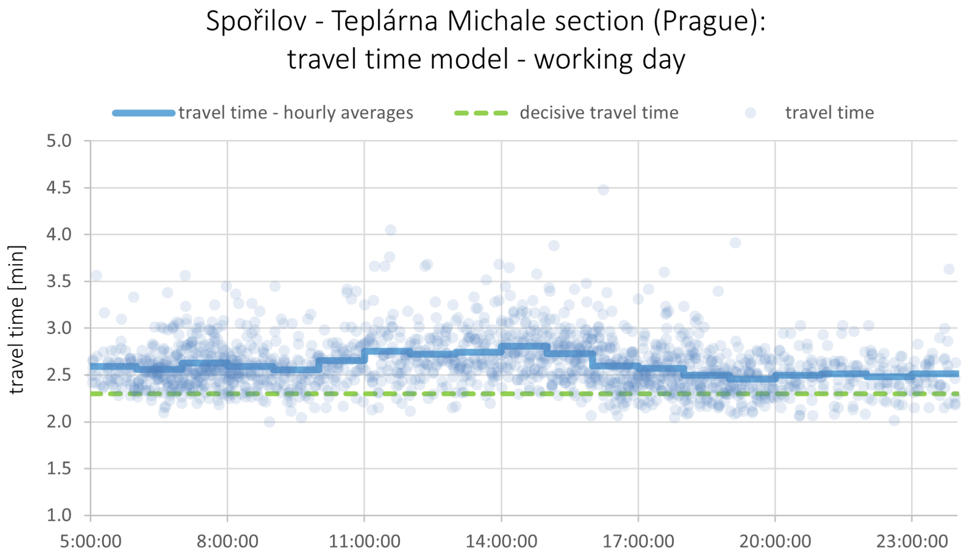

Figure 3. Typical evolution of travel times affected by the traffic situation – a section with unreliable public transport operation [11].

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

2.2. Travel speed evaluation

The second indicator that the method uses is travel speed. In this case, it is necessary to determine the so-called decisive travel speed, which is determined as a ten percent percentile (10 % percentile was determined using small sample of data) (2). This should be the highest most often achievable speed that the vehicle can drive, i.e. the speed that the vehicle should ideally achieve when passing freely through the section. This decisive speed is then used to determine the travel speed index by dividing the average travel speed by the decisive speed (3).

$$V\left(rel_{A-B;dec}\right) = 0.06\,\frac{s_{A-B}}{Q_{10}\left(t_{cest;A-B}\right)} \tag{2}$$

$$i\left(v_{cest;A-B}\right) = \frac{V\left(cest_{A-B;avg}\right)}{V\left(cest_{A-B;dec}\right)} \tag{3}$$

2.3. Final level of service of public transport operation

For both indices, a linguistic value is subsequently determined according to their calculated numerical value. Each index has a so-called function for the linguistic values of the quality of public transport. For the reliability index, a linguistic value of 100 % "excellent" corresponds to a value of 0.2. Furthermore, as the numerical value of the reliability index increases, the linguistic value deteriorates up to the value "unacceptable", which for 100 % corresponds to a reliability index of 1.5 and higher, as can be seen on Figure 4.

For the travel speed index, the situation is the opposite, as can be seen in Figure 5. If the travel speed index is higher than 0.9, its linguistic value is 100 % "excellent", then the lower it is, the worse the linguistic value. If it falls below 0.5, its value is 100 % "unacceptable".

From these two linguistic values, the total value of the service level of the given section is then obtained by logical rules. Simplistically, the sum of all affiliations of the two indices is made and whichever linguistic value prevails in the sum of affiliations is the overall Level of Service. Further, it is only converted to integer values, where "unacceptable" corresponds to a value of 5 and "excellent" corresponds to a value of 1.

3. Testing the method – a pilot study

However, The Level of Service of Public Transport Operation Assessment Method was originally tested on a small sample of data [11]. The logical next step was to pilot test the method on a larger sample of data and subject it to critical analysis based on the results.

Pilot testing was carried out on a total of 107 interstop sections of tram or bus services in 4 cities (Prague, Brno, Pilsen and Budapest). The sections were selected to form a representative sample – tram and bus sections, sections with and without a dedicated carriageway (e.g. a separate tramway or bus lane), sections with regular congestions and, for example, tram sections in the pedestrian zone.

3.1. Obtaining input data

Due to the different data acquisition systems in the cities, it was necessary to first adjust and unify the input data for the evaluation. This was done using

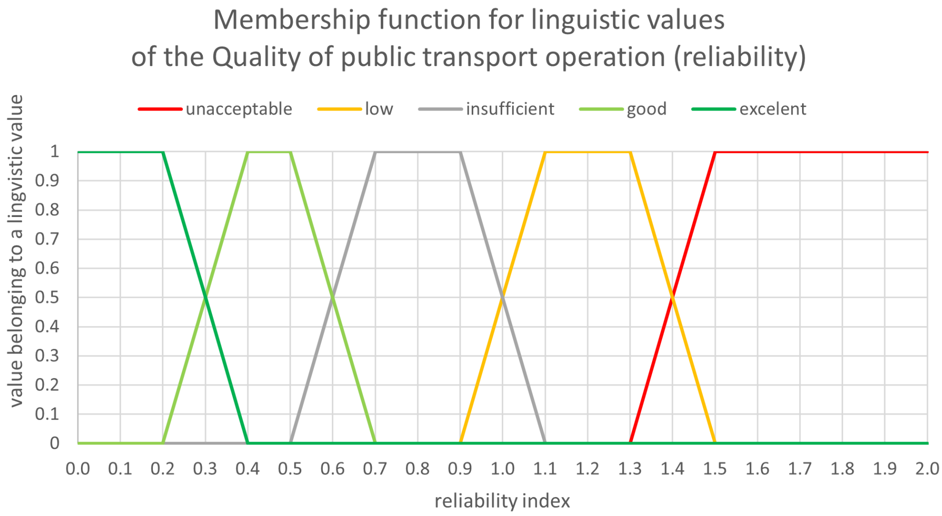

Figure 4. Reliability index and membership function for linguistic values of the quality of public transport traffic [11].

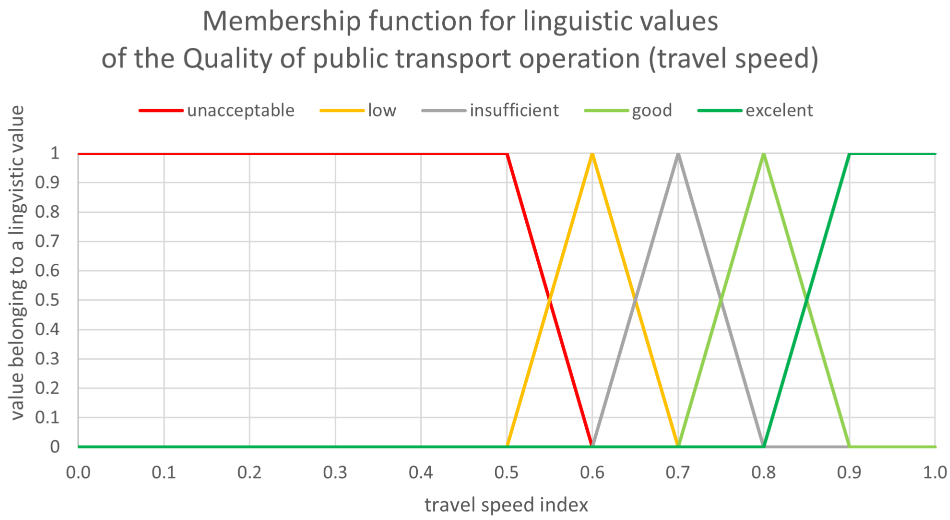

Figure 5. Travel speed index and membership function for linguistic values of the quality of public transport traffic [11].

Python. In order to apply the data to the method, it is necessary to know mainly the time and date of arrival and departure from both stops of one section. Data from cities can have two formats, according to which vehicles report either only arrival or only departure from the stop (arrival – departure, arrival – arrival), therefore the driving time is extended by the time of standing at the stop, or the vehicle reports both, therefore it is possible to get the exact value of the driving time in the section (departure – arrival). A 2-week sample of data was processed from each section.

3.2. Using power BI software to evaluate level of service

In order to evaluate such a large number of sections, it was necessary to create at least a partially automated evaluation of the Level of Service. For this purpose, was used software Power BI and was created an evaluation sheet for each section separately. This sheet contains basic information about the given section so that it is possible to better imagine the traffic situation on the given section (Figure 6). Only working days are used to display graphs in the travel time model. Thanks to this, it is possible to better recall the traffic situation and clearly see the impact of rush hours on the operation of public transport buses. To identify various extraordinary events in traffic or other inconsistencies in the used data, a table is used that shows the average travel time in hourly sections for each day separately. Thanks to the gradual coloring from the darkest red (longest travel time) to white (shortest travel time), it is possible to see different fluctuations during the day and the trend of travel times for each day separately (Figure 7). Likewise, it is possible to detect data inconsistency using hourly slice charts for each day. It is also possible to find here a comparison of the delay in the section compared to

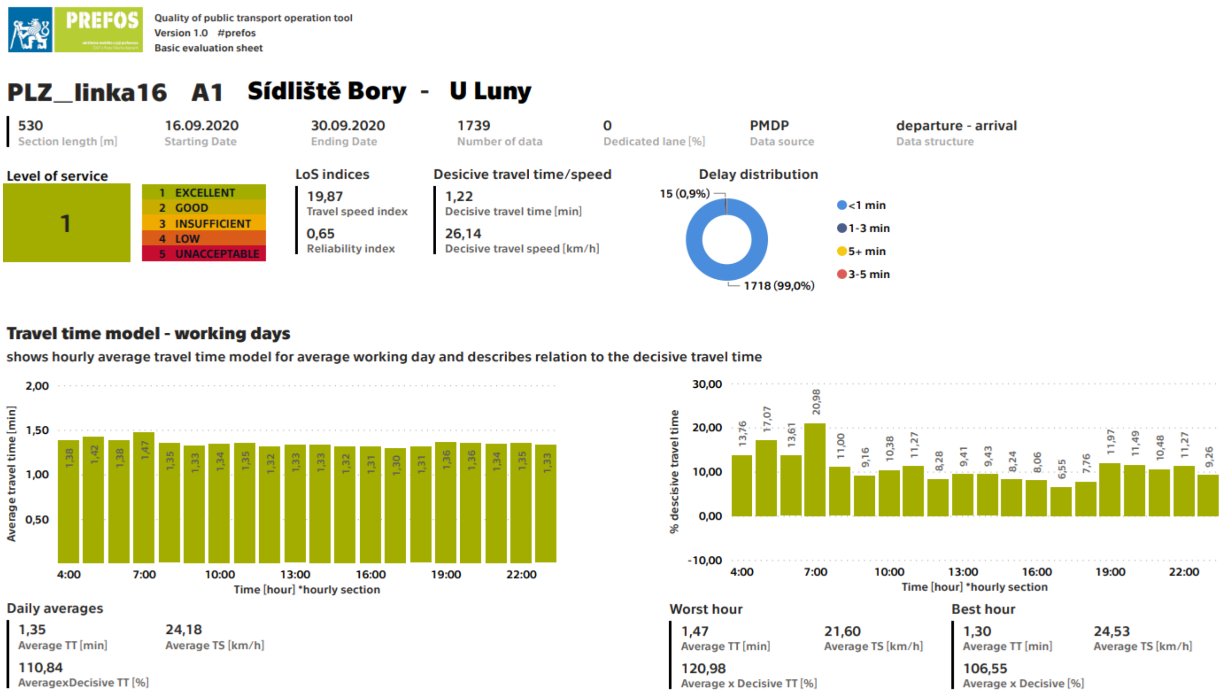

Figure 6. Travel speed index and membership function for linguistic values of the quality of public transport traffic [11].

AVERAGE TRAVEL TIME [min]

Time [hour]	26.04. 2021	27.04. 2021	28.04. 2021	29.04. 2021	30.04. 2021	01.05. 2021	02.05. 2021	03.05. 2021	04.05. 2021	05.05. 2021	06.05. 2021	07.05. 2021	08.05. 2021	09.05. 2021	10.05. 2021	11.05. 2021	12.05. 2021	13.05. 2021	14.05. 2021
5	1,01	1,15	1,21	1,11	1,00	0,93	0,77	1,08	1,03	1,04	0,93	1,00	0,78	0,93	1,07	1,04	0,93	1,17	0,98
6	1,12	1,14	1,16	1,03	1,14	1,02	1,03	1,29	1,18	1,25	1,27	1,13	1,23	0,84	1,20	1,23	1,14	1,31	1,34
7	1,40	1,25	1,13	1,21	1,29	0,88	1,01	1,38	1,41	1,50	1,31	1,21	1,08	1,06	1,42	1,51	1,18	1,40	1,25
8	1,62	1,52	1,88	1,64	1,37	1,01	1,12	1,98	1,74	1,72	1,92	1,20	0,97	1,42	1,93	1,79	1,74	1,70	1,44
9	1,44	1,12	1,94	1,47	1,69	1,20	0,97	1,78	1,37	1,50	1,82	1,39	1,14	1,22	1,75	1,71	1,37	1,56	1,57
10	1,50	1,49	1,51	1,29	1,73	1,05	1,24	1,51	1,35	1,24	1,45	1,38	1,53	1,15	1,27	1,29	1,39	1,40	6,51
11	1,38	1,51	1,40	1,34	1,51	1,36	1,29	1,65	1,38	1,53	1,21	1,37	1,30	1,24	1,57	1,38	1,24	1,56	3,29
12	1,33	1,65	1,48	1,45	1,28	0,99	1,23	1,41	1,37	1,48	1,40	1,49	1,25	1,11	1,36	1,98	1,67	1,34	1,59
13	1,48	1,24	1,48	1,33	1,76	1,18	0,99	1,27	1,30	1,57	1,11	1,45	1,08	1,26	1,38	1,26	1,22	1,15	1,00
14	1,18	1,49	1,33	1,62	2,47	1,09	1,12	1,71	1,68	1,29	1,66	1,81	1,28	1,42	1,57	1,60	1,38	1,32	
15	1,57	1,68	1,45	1,81	2,61	1,10	1,51	1,63	1,80	2,02	2,23	2,56	0,98	1,18	1,70	1,83	2,03	1,00	
16	1,27	1,15	1,54	1,26	3,51	1,10	0,88	2,06	1,74	2,15	2,00	2,11	1,26	1,16	1,43	1,42	2,16	2,06	
17	1,23	1,22	1,39	1,41	3,01	1,10	1,16	1,23	1,33	1,40	1,38	1,40	1,09	1,24	1,51	1,38	1,28	2,44	
18	1,04	1,23	1,23	1,05	1,48	1,37	1,28	1,19	1,15	1,20	1,22	1,05	1,27	1,18	1,16	1,14	1,15	1,23	
19	1,25	1,09	1,20	1,14	1,09	1,12	1,04	1,17	1,07	1,36	1,14	1,17	1,11	1,45	1,04	1,17	1,09	1,19	
20	0,98	1,17	1,12	1,27	1,02	1,11	1,22	1,17	1,11	1,21	1,10	1,10	1,03	1,06	1,12	0,93	1,00	1,04	
21	1,03	1,13	1,01	1,03	0,99	1,08	0,95	1,15	1,13	1,05	0,95	0,96	0,90	1,01	1,16	1,13	1,30	1,17	
22	1,04	0,89	1,26	1,04	1,21	1,04	1,30	0,92	1,02	1,04	0,96	1,21	1,36	0,96	1,20	1,48	1,32	1,00	
23	1,62	1,55	0,93	1,03	1,50	1,07	1,27	1,02	0,92	1,05	1,00	0,92	1,28	0,95	1,18	0,97	0,91	0,84	

Figure 7. A table used for identifying various extraordinary events in traffic or other inconsistencies in the used data.

the timetable. Since the driving time according to the timetable can be artificially adjusted, it is then possible to see whether this value has really been artificially extended or whether it is close to the ideal driving time.

4. Results and critical analysis of the pilot study

After evaluating the level of service for all of 107 sections, the results were confronted with both expert expectations and the behaviour of the travel speed and reliability indices depending on the type and characteristics of the section.

Most of the sections that were selected and evaluated correspond to the assumptions of the level of service if there were no traffic abnormalities on the measured days. However, the analysis opened some questions or pointed to the need to calibrate the method:

- Determination of decisive travel speed is the 10 percent quantile really appropriate?
- Too much influence of the reliability index on the resulting level of service, especially for short sections.
- The need to refine the calibration of the linguistic function of affiliation.

4.1. Determination of decisive travel time/speed

Now the decisive travel time/speed is determined as the ten percent percentile of all measured travel times.

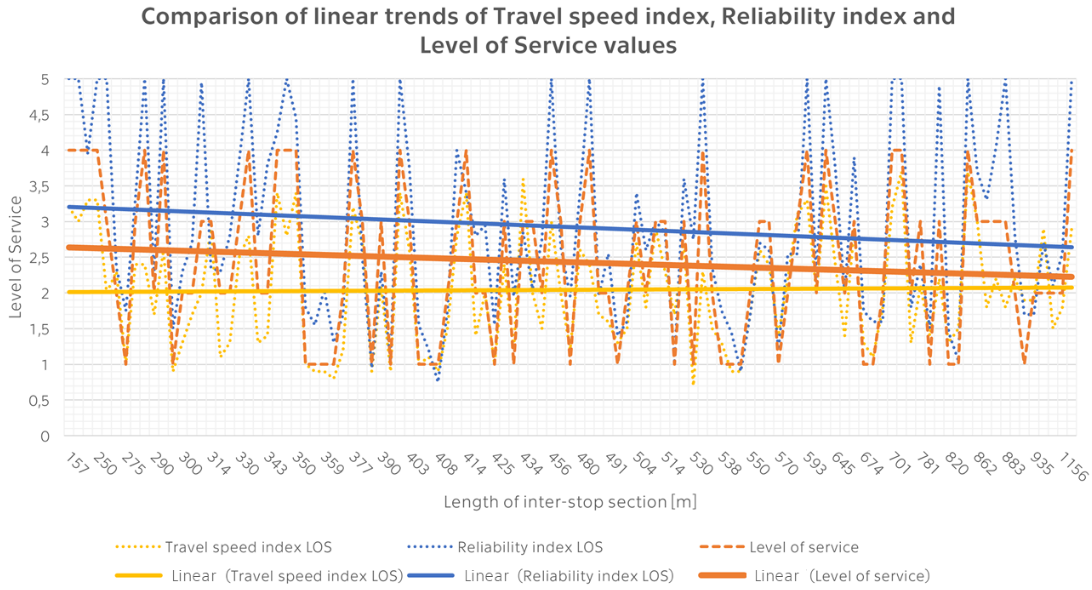

Figure 8. Graph of index dependence on section length and their linear trends.

Anyway, this value was created as an estimate based on a small sample of data, so it is now necessary to verify that this value is closest to the ideal travel time. One of the main factors that could influence the determination of the decisive travel time/drive is the time span of the data used. If values are used that do not include night connections, such as the time span 8:00–20:00, the value of the decisive travel time on a section loaded with individual car traffic is likely to be significantly higher than if the night lines that go after almost ideal conditions.

Likewise, the total number of connections per day could have a decisive travel time value, or it is possible that a minimum number of connections per day will need to be determined for which the mathematical evaluation formula will be relevant.

4.2. Short sections and excessive influence of the value of the reliability index on the Level of Service

The problem of short sections and too much influence on the overall level of service can be seen in the following graph. For the purposes of this graph, both indices (reliability index and travel time index) were recalculated to the numerical value "Level of service", from which the average of these two values is used to determine the overall level of service of the entire section, these values are displayed on the y-axis, the length of individual sections is then displayed on the x-axis. When displaying trends, ideally, the curve should be horizontal, thus the length of the section would not affect the Level of Service. As can be seen on the graph (Figure 8), the trend of the overall Level of Service is decreasing, so the longer the section, the better the Level of Service. At the same time, the Level of Service trend curve has the same slope as the reliability index trend curve, on the contrary, the travel speed index curve is almost horizontal, from which it can be concluded that the reliability index has a greater influence on the overall Level of Service of the section compared to the travel speed index.

4.3. Linguistic functions of affiliation

Like decisive travel time, the linguistic affiliation functions were created based on small amount of data. This is not a significant problem when evaluating the method, however, due to the possibility of evaluation on a larger sample of data, it would be good to focus on specific linguistic functions and verify whether these values correspond to reality.

5. Conclusion

Thanks to the evaluation of 107 sections and the implementation of The Level of Service of Public Transport Operation Assessment Method on real data in 4 different cities, it was verified that the Method could be a suitable evaluation tool for identifying problem sections on the network where the quality of public transport operation is insufficient. And therefore, where it would be appropriate to make preferential measures for public transport, or to optimize the operation of public transport in another way. The calibration and correction of the identified problems in this work is another important step towards the practical use of The Level of Service of Public Transport Operation Assessment Method and the improvement of the quality of public transport.

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