TARIFF SYSTEMS AND DISTANCE MEASUREMENT OF PUBLIC PASSENGER TRANSPORT STOPS

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Resume

The development of IT technologies in the systems of tickets sales facilitates the charging and differentiating the fare amounts versus distance, as well as in the systems of public transport on short distances, in the urban, suburban and regional transport. The essence of the transport activity consists in covering a distance and a part of cost components and thereby the total costs, increase with the distance covered by means of transport. In a similar way the calculation of fares depending on distances may be considered as the most appropriate from the point of view of transport as a service. Inaccuracies and deviations during the distance measurements have various results, which further on may have effect on analyses, comparisons, correctness during the fare calculations, as well as settlements related to public financing of the public transport. An independent and precise distance measurement is indispensable to eliminate the impact of the measurement method on distances.

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1 Introduction

An efficient urban and regional transport creates increasingly great challenges together with the increasing number of rides, commuting to cities from longer and longer distances, transport congestion, limitations of the land, which may be used for transport purposes and the necessity for environmental protection of cities. Hence the need for development of public transport systems, competitive for individual motorization. Apart from qualitative factors, prices are an extremely important element of the assessment and competitiveness of the urban and regional public transport. Their amounts are affected by very many factors, economic, social and political ones. The services of urban and regional public transport are a mass in nature and are widely available, hence a tariff method of price shaping is used. The public transport tariffs are expected to ensure the assumed income, however, on the other hand they are a significant part of the policy carried out by cities, not only in the field of urban mobility, but in the field of funds redistribution between various social groups, as well.

The occurring effects of suburbanization, city sprawl and localization of various functions and activities outside their boundaries, cause on the one hand that suburban areas are covered by the urban public transport services and on the other hand a share of regional nature transport, when serving daily commuting to work. The integration of such systems is a natural course of events and this also means the application of tariff regulations previously characteristic of regional transport, also in the urban transport and vice versa.

Various solutions may be encountered in the field of public financing of passenger public transport. The urban public transport is widely financed from the public funds, apart from tariff revenues. The financing is related to the interference of public authorities in the scope of provided services and prices, including entitlements to concessionary travelling. As a result, the services of urban public transport are provided within their scope, i.e. city areas and lines with low occupancy, in non-rush hours and on holidays on a level, which would not be possible, if the ticket revenues would entirely have to cover the costs. In the case of regional transport, the public interference is generally smaller and a share of market decisions higher, however, in this case various systems of public financing are used as well, starting from financing the income lost on the sales of concessionary tickets up to subsidies to the performed operational work.

Despite the fact that the tariff revenues obtained in the urban public transport are only a part of those needed to finance the provided services, the level of prices in the urban public transport and the rules of their differentiation are the subject of great interest of the public and of medial activity. Prices affect the image of public transport, the transport policy of cities is evaluated from their angle, as well. It is important, because the social perception and the image shaped by the media ultimately decides about the demand for services of the urban and regional public transport.

The adopted principles of differentiation, including the type of adopted tariff, the scope of persons entitled to concessionary and free travelling and the differentiation depending on the number of services, i.e. prices of multi-ride and season tickets, have a special place in discussions and assessments of prices in the public transport.

The paper is aimed at comparing the price differentiation rules in the urban and regional public transport and showing against this background theoretical and practical principles of section-based tariffs application, including the measurement of inter-stop distances. It is necessary to draw attention to the fact that distance tariffs, despite their numerous advantages and widespread use in the passenger transport on longer distances, as well as in the cargo transport, so far were not common in the urban public transport. This resulted from a mass nature of services and the necessity of simplifications in the sales systems. However, together with the dissemination of IT and systems of fare charging, it is now necessary to consider this method of price differentiation, because it best links not only increasing costs of transport with the increasing distance and fare, but the service measured by the covered distance with its price, as well. This does not mean switching only to this type of tariff in the tariff systems used in cities, but as an option to be chosen by the service users. The implementation of such a system requires, among other things, to perform properly the distance measurements, so as to avoid inaccuracies and thereby incorrectness in the fare charging. The methods of inter-stop distances measurement will be presented in the paper and the adoption of uniform rules in this field excludes situations, in which the performance of measurements by various methods can result in different results and related subsequent misunderstandings. In addition, the results of carried out measurements can also be used in other areas of the urban transport management, including the calculation of the remuneration, to which the carrier is entitled for the services provision.

2 The hitherto state of research

The public transport, including the urban public transport, has an important place in the research on cities functioning and development, in the economics of the public sector and transport. Hence, there are numerous studies on financing of the urban transport, including issues related to the demand for services and prices. In particular, the research and publications focus on issues related to the impact of various factors on the size of demand for urban transport services, including the relationships of the price elasticity of the demand [1-14]. A factor, which additionally intensifies the research now, is the use of IT and glocalization technologies in the transport management, including the sales of services; on the one hand they enable access to many data, e.g. the volume of transport, but also inter alia solutions in the field of price differentiation, which only a decade or two ago were not possible. It is also important that the public financing of urban transport, as well as appropriate price differentiation, causes changes in the share of transport work and limits the external effects of transport, including those related to road accidents [15]. The tariff systems are also expected to be effective, so that together with the public funds it would be possible to finance the purchases of ecological means of public transport [16]. Therefore, studies into the price differentiation are important [17-21], as well as the comparative studies on their amounts, which consider a diversified economic potential of cities [22]. Based on that it is visible that, in big cities in Europe, the study carried out altogether for 100 big cities in different countries, a uniform (fixed) or zone tariff prevails in the urban public transport [22]. With respect to single tickets a uniform tariff occurred in 57.3% of cases, a zone tariff in 33.3% and a section-based tariff in 9.4% of cases. The situation was quite similar for monthly tickets, 60.4%, 36.6% and 3% of cases, respectively [22]. The occurrence frequency of various tariff solutions in big cities in Europe and a widespread use, for many years, of uniform or zone tariffs, cause that publications focus on them, e.g. in the field of the very zones designing [23-24].

In publications on prices it is also possible to distinguish those which describe, in the form of algorithms, the selection procedures for fare collection systems [25], showing methods and models possible to use, including mathematical models to search for solutions of selected decision problems, e.g. comparisons of fare and revenues of entities in the case of distance or zone tariffs [26], or searching, at a known tariff structure and various proceeding strategies, for the cheapest connections [27]. The methodologies of procedure are important both for the service users and for carriers, for whom the fares paid by passengers are the revenues on sales of services.

However, it is necessary to consider that the developed models may frequently not contain parameters or relationships between variables, which makes their practical use under the current conditions difficult or impossible. It is necessary to be aware of many factors, e.g. economic, social and time, when the changes and implementations occur, which ultimately translates into various limitations, difficult to define in mathematical formulae as well as of neglecting certain factors and limitations in the developed models. Therefore, the heuristic methods, including the most popular Delphi and brainstorming method, are frequently advised for solutions searching. Hence, as a result, the searching for a solution requires knowledge, experience and skills to identify causalities, to analyze and assess a wide range of possible solution variants. Prices are not the only field of mathematical methods use in the public transport, their application in practice covers now most decision problems occurring in the organization itself and in the provision of urban public transport services [28].

Despite the multitude of publications, a shortage is still perceived in the field of studies on the relationships between prices and the travel distance in the urban transport. Making the fare dependent on the distance, hence section-based tariffs, were and are widely used only in the longer-distance transport due to carrying out in the past sales by carriers at their own points and now, with the development of IT technologies and with their use, they can be applied in a broader range. However, there are now no analyses on the use of section-based tariffs in the urban public transport, this gap is to be filled by this paper. As it has been stated [29]: "… rather less well-developed literature on the relationship between public transport prices and distance (…), there has to our knowledge been little practical work on bringing these two concepts together". Few papers can be mentioned among published and available results of studies [30-34].

The digitisation of payments is the main trend in the passenger transport and it is very frequently perceived as a condition for improving the effectiveness of provided services. The technology used for digital payments in the passenger transport is permanently developing [35-36]. It is also possible to add that the price differentiation depending on distances is not the only one; the differentiation e.g. depending on affiliation to various social groups, like children and youth, pupils and students, retired persons and persons above an indicated age, is widely applied, or on the number of services, like single tickets and multi-ride or season tickets. In this way the ticket prices of urban public transport take into account social elements and via low unit prices, in the case of season tickets converted to a ride, elements of motivation and shaping the share of transport tasks division [21-22, 37]. Tariffs can also be used to extract the consumer's surplus when there are a lot of connections supplied, so that a law of large number applies in the estimation of the consumer's willingness to pay [38].

In addition, understanding the expectations of price fairness and of accessibility of urban and regional public transport services, which also are appearing in publications related to the urban transport prices, it is possible to notice that the increase in services availability is achieved by public financing, subsidies to the cost of services provision and/or entitlements to concessionary travels and the price differentiation for various social groups. It is also possible to show certain doubts, whether by means of urban or regional transport prices the welfare and social policy should be carried out, or is it a task of other public institutions, while the public transport should focus primarily on the effective use of resources and provision of high quality services. The pursuit of justice, understanding at the same time various meanings of this term, is obtained just by application of tariffs, which on the one hand reflect the relationships in the costs of transport, consisting in increased costs at transport on longer distances and on the other hand, create a system, in which a person travelling a shorter distance would pay less than that who travels a longer distance.

3 Tariff types used in the urban and regional public transport

Adopting the method of considering the travel distance as the criterion, three basic types of tariffs may be mentioned [18-19, 37]:

- uniform,
- zone,
- distance.

In the uniform tariff the ticket price does not depend on the distance of a ride; the price is the same in a specific network, in which it is binding, in a city or in an indicated area. The advantage of this tariff consists in the price list simplification and thereby in facilitation of the tickets purchase and hence the use of public transport services. In addition, an easy determination of the fare amount enables passengers to make comparisons between costs related to various methods of movement. At the same time the tariff is relatively simple for the carriers themselves; the lack of differentiation depending on the distance reduces the number of sold ticket types, which is major facilitation, in particular when paper tickets are used and the sales are carried out using the rules of outsourcing, at external points of sales. In addition, the tickets inspection is easier, because it is not necessary to check if a zone or distance has been exceeded, as it is the case for other tariff types. Identical prices of tickets for all the passengers, irrespective of the travelled distance, are the basic drawback of this tariff system. That means that passengers travelling only a short distance, for example one or two stops, pay the same amount as passengers travelling a distance of a dozen or so stops, which causes that persons travelling a short distance have a feeling that the paid fare is too high. This tariff solution may be the reason for dodging, when travelling a short distance, hence the price is perceived as high and a probability of inspection low due to a short time of travel [39], or entirely giving up travel in favour of a walk. Apart from simplicity of this tariff system, an opinion may be encountered as well that its application in cities results from a limited impact of residents on spatial management and the location of places of residence and such activities as work, education and purchases, hence persons living at longer distances should not be burdened with high costs of commuting.

In its nature the uniform tariff is a solution, in which single tickets are binding, which next results in a pressure to create direct connections. Willing to avoid that, this system is modified, enabling transfers, thus, in the uniform tariff systems it is frequently possible to use various lines for a specified time, within the area covered by the uniform tariff. This allows avoiding situations in which many direct connections are created with a low frequency of journeys, at the same time characterised by a non-uniform occupancy on the entire route length [37].

The zone (area) tariff consists in dividing a given area into various zones, where their boundaries may be determined in various ways. Such solutions are used, where the zone boundaries are universally known, e.g. within a region or metropolitan area the zone boundaries

***Table 1** Comparison of various tariff types*

Tariff type	Advantages	Disadvantages
Uniform	- very simple and easy to use for passengers, - one face value of a normal single ticket facilitated the development of sales systems, in particular in the case of paper tickets, a possibility to use external points of sale, - easy tickets inspection, there is no problem of zone crossing,	- no differentiation depending on the travel distance, as a result rides on short distances are relatively expensive, which can encourage to travel without a valid ticket or to give up riding on short distances, - no price differentiation depending on the distance causes that it is not good to use as the only tariff in large metropolitan areas or in big cities, - the offered tickets are single tickets, in the case of multi-ride travels the necessity to buy the next tickets causes that direct connections are expected, which is unfavourable from the transport organization point of view,
Zone	- relatively simple and easy in use and allowing in areas with a large number of lines to link the amount of fare with the travelled distance, - a small number of tickets face values does not complicate the tariff information and sales systems, - the ease of defining and identifying the tariff zones in a situation, where these are boundaries of districts, cities, or other administrative units,	- the issue of a too high fare in the situation of starting a ride before the boundary of a tariff zone and finishing behind it, the necessity to apply an option with a time validity of the ticket, hence the ticket entitles to travel within the zone or during a certain time, - the necessity to apply zone exceptions in situations where the line route goes beyond the zone boundaries, but there are no stops there, or only one stop and the route returns, - in the case of a larger number of zones, the necessity to mark the ride start on the ticket, - the adoption of administrative units as zone boundaries can result in the diversification of zone areas; the adoption of notional boundaries can cause difficulties in the tariff zone identification, in particular for persons using the public transport occasionally, - in the case of time zone determination (time tariff), not the best link with the travel distance; depending on the line route, time of day, or day of a week, the travel time on the same distance can differ even a few times,
Section-based	- making the amount of fare dependent on the travel distance, for passengers a possibility of lower fares as compared to other tariff types during the rides on short distances, in the case of long distances the degression of tariff rates, - the tariff application even only as an option in the urban transport systems facilitates the integration of tariff solutions with the regional transport systems,	- multitude of ticket face values or paid fares requires passengers to determine the place of destination during the ticket purchase, or the carriers to apply systems for fares calculation, which use IT systems and solutions of check-in and check-out type, - more difficult ticket sales, in particular in external sales networks, multitude of face values can also increase the costs of sales for paper tickets, - a relatively more complex price list, in particular where there are many distance sections and the fare degression systems may discourage persons, who use the public transport occasionally, from the use of services, as well, - more difficult tickets inspection due to a possibility of exceeding a specific distance section.

may be determined by administrative boundaries of cities or other administrative units; there may also be a solution in which the area is divided into zones determined by administrative boundaries of the city - urban and suburban. In addition, district boundaries may be the zones or other spatial boundaries, e.g. rivers or express roads passing through cities and dividing them in this way, the crossing of a zone boundary occurs on bridges or flyovers. Another approach is also used, the city center is the central zone and the others are determined as rings that surround it, hence the next zone comprises districts surrounding the city center, then peripheral districts and suburban areas next. The zones can also have a honeycomb shape, i.e. the form of neighboring hexagons, as shapes filling the entire surface and having relatively short boundaries in relation to the surface. In such cases the size of zones may be freely changed and the price diversification achieved in this way. The advantage of zone systems is creation of a relatively simple system, in which even in a complicated network of lines and connections, the fare depends on the travelled distance. The situations, in which a ride starts before a zone boundary and ends on the stop after the boundary crossing, is a drawback of zone systems, which according to general rules may mean the necessity of a higher fare, due to the fact that the zone boundary was crossed during the ride. To avoid higher fares in such situations, the zone systems are modified by e.g. allowing alternative travelling with individual ticket types also for some time. As a result, passengers during a short ride can cross the zone boundary, which has been determined in space, however, they will not pass this boundary in the time dimension, hence they will not have to pay an increased fare. The zones are determined in space, as indicated areas, however, it is also possible to consider that time tickets belong to zone solutions, where zones, for which they are valid, are determined by the ticket validity period since validation. In addition, other approaches may be encountered, in which the differentiation depending on time is classified as section-based tariffs.

Zone tariffs make the fare dependent on the distance, which results in a fare growing with the increasing travelled distance, but for simplification it is not the distance of e.g. each covered kilometer, but the amount of fare is determined for certain distance ranges, given in meters or in kilometers, or measured by the number of stops. The adopted distance ranges may be identical or diversified, in a similar way the fares versus distance may be proportional, albeit degressive fares are frequently applied. The adopted distance ranges, i.e. the length of sections, are conditioned locally, by the expanse of the area and the length of the transport line routes; however, it is necessary to consider that the adoption of overly long distance ranges results in reduced differentiation depending on the distance, for example within the range of 10 to 20 km the person travelling 11 km pays the same fare, as the person travelling 19 km. Table 1 presents a comparison of uniform, zone and section-based tariffs.

The actual distances are determined by measurements between consecutive stops and arithmetical rounding should be performed only after summing up distances between stops on a given route. It is also necessary to emphasize situations, where between the same two stops one can travel by various lines on various routes, hence also distances, which can result in a different amount of fare. Thus, there may appear situations where the distance, according to which the fare is calculated, is not a real distance, but a tariff distance. It is worth considering, to what extent the additional cases of entering should be taken into account, e.g. to serve a housing estate, for persons, who do not get on or off; this is an additional elongation of the route, which also increases the amount of fare. The applied prices can be aimed at competing with moving by private cars, hence it is worth considering the tariff setting on as short as possible route, on which private cars move.

4 Section-based tariffs in the system of urban, regional and national tariffs

The section-based tariffs in the systems of urban transport were not often used in the past. This resulted from the mass nature of such transport, ticket sales at various external points, where the possibilities of information provision as well as sales of a significant tickets range were limited and also difficulties for passengers to determine the distance, on which they are travelling and hence what face value of the ticket should be bought. Therefore, in systems of paper tickets in the urban public transport, the situations, where the section-based tariff was used, were rare. It is necessary to consider that in the urban public transport there is only a part of persons, who use the services systematically and who have knowledge about the system. Part of passengers use the services occasionally, thus for them prices, with a large range of differentiation, are a problem. The implementation of solutions using the IT, including systems with the localization of means of transport on a current basis, took off from passengers the necessity of acquiring the information independently; this is carried out using algorithms in various sales programs and applications. The situation was and is different in the systems of longer-distance public transport, where the sales were carried out at own points of sales, ticket windows or by vehicle drivers, hence the use of section-based tariff was widespread.

It is indisputable that the section-based tariff in the best way, among the tariffs used, reflects the costs of the service provision, because the costs of transport services depend in a major part on the mileage of means of transport. In addition, in the section-based tariff ticket prices are not averaged, those for short distances are cheaper than those for longer distances. Hence, in the case of travelling a distance of one or two stops prices are low, or at least lower than those for longer distances, which eliminates the very feeling on injustice, which appears in such situations in the uniform or zone tariffs and it does not motivate to walk or to travel without paying the fare as well, assuming that the risk is then relatively low, since the lack of ticket or paying the fare in another way may be justified that the inspection started too early from the moment of entering the vehicle by the passenger and due to that he/she has not paid a relevant fare. In addition, the risk of inspection during a ride on a short distance is smaller due to a shorter travel time, than if distances are longer. Hence in the section-based tariff systems, by making the ticket price dependent on the distance, a feeling of fair prices is experienced and there is no field for losing passengers or revenues on sales of these services on short distances, as well.

The tariff, which makes the fare directly dependent on the distance, by its congruence with tariffs used in the transport provided on longer distances, both bus and railway transport, creates a good starting point for the introduction of integrated tariff systems in the urban and regional transport. This is important especially in the processes of suburbanization and daily commuting from suburban areas to city centers.

The implementation of a section-based tariff requires measuring distances between the consecutive stops on the routes and adopting the so-called tariff distances between them. It should be emphasized that the tariff distances for various reasons not necessarily must correspond to the actual distances; there may be situations, where for a number of reasons a means of transport covers a longer distance, e.g. diversions due to road repairs or temporary difficulties and closures and the price is calculated according to the original distance. Moreover, the service users expect the route to be as short as possible, while there may be situations, where the route of a given line for a number of reasons not necessarily reflects the shortest one.

5 Request and methods of measuring the bus-stop distances of mass passenger transport lines

5.1 Request for measuring in Slovakia

The need for measuring the real bus-stop distances of mass passenger transport lines is a result of Act No. 56/2012 Coll. of the National Council of the Slovak Republic on Road Transport as amended and the Decree of the Ministry of Transport and Construction of the Slovak Republic No. 124/2012 Coll. as amended, which implements related provisions of the above-mentioned act. The transport regulation of bus service for the regular bus transport, except for the city bus transport, includes the list of all the bus stops of the bus service with their tariff numbers and tariff distance from the departure bus stop. The tariff distance serves as a basis for calculation of the basic passenger fare, payment for carriage of luggage, domestic animals and bus consignments. The bus-stop tariff distance of the bus service is determined by a real distance of a bus stop from the departure bus stop in kilometres rounded up. The real distance is measured by a specific measuring instrument under Art. 7 Sec. 4 of the Decree No. 124/2012 Coll. according to the road passport or digital maps.

From the given options, measuring in the real road network with a bus is the most accurate way of determining the real bus-stop distance. The measurement must be performed in compliance with Act No. 157/2018 Coll. of the National Council of the Slovak Republic on Metrology and amendment to some acts (Art. 28 Sec. 2). The results from measuring are the basis for establishing the tariff distances of each bus stop of respective mass passenger transport lines, for processing the transport regulations of bus service, the whole network of City Public mass transport or suburban bus services.

The Department of Road and Urban Transport at the University of Zilina in Zilina is an intellectual property owner of measurement methodology for distances called "Measuring methodology for distances by the measurement and reporting instrument Correvit" (Number of methodology: 01/2002/KCMD). This methodology was validated and approved by the Slovak Metrological Institute Bratislava and it is recommended to be used for a specified purpose.

The methodology gives a general procedure for ***measurement of distances*** via the Correvit system. Based on the fact that its text is generally formulated, it can also be used in the other types of measurement (as for the road vehicle driving performances) that are realized on the same principle with using the Correvit system [40]. In accordance with its version, the speed, time, acceleration, deceleration, track or any dynamical vehicle driving tests can be measured without problems. The second methodology of the Department of Road and Urban Transport is called "The measuring methodology for real bus-stop distances of mass passenger transport lines" (Number of methodology: 02/2002/KCMD). This methodology was validated and approved by the Ministry of Transport, Posts and Telecommunications and it is recommended to be used for a specified purpose. It gives the principles and procedures for measurement of ***real distances***, the results of which constitute the basis for determination of tariff distances between the bus stops on the transport lines. Both methodologies are used for measurements in the Slovak Republic.

5.2 Research methods

The following measurement instruments and metres, or some of their similar character, are used for measurements of the bus-stop distances in compliance with texts of the above-mentioned methodologies. These are used for measuring the required quantities while providing necessary accuracy of measurement:

- Measuring and reporting instrument CORREVIT (s. no. of the microwave sensor: 21.0336); Manufacturer: CORRSYS DATRON, Sensorsysteme GmbH, P.O. Box 1349, 35523 Wetzlar, Germany
- Tape measure 50 m (STN 25 1150.2) - *specified measuring instrument;* Manufacturer KINEX, a.s., Bytca.
- Multimeter METEX INSTRUMENTS M 3860D.
- Level.

CORREVIT from Corrsys Datron (Figure 1 and 2) was used as a measuring and reporting instrument for measuring the real bus-stop distances. The operating principle of Correvit is a method of optical correlation. It does not require a strictly defined structure (such as a measuring grid located on the surface measured).

It operates with a random stochastic structure of a monitored object's surface (road surface, rail, belt of rolled steel, textile, paper and the like). Random non-repetitive distribution of lighter and darker points of the surface monitored means that the light signal reflected from the surface must be processed and assessed on the basis of statistical methods.

The system is used most frequently for measuring the driving dynamic performances of road vehicles since the measurement is contactless and it means that the results are not burdened by a drive slip and abrasion of tyres. For these reasons, the measurement can be performed on different surfaces (asphalt, concrete, snow, ice etc.) and in any terrain.

Depending on a type of sensor used (the so-called measuring head), the system makes it possible to determine the speed, track, acceleration, deceleration, vehicle performance while coasting and to monitor the angles of vehicle rolling and drifting.

This instrument consists of three basic components: a microwave optical sensor (Figure 1), an evaluation and control unit and a control panel of service and display unit (Figure 2). By means of the level and measure tape, the horizontal plane and prescribed height of the optoelectronic sensor were set, which are necessary for the instrument to function properly.

The main part of the CORREVIT system is developed by an efficient and precise optoelectronic sensor, not only designed for tasks solutions at measurement of dynamic characteristics of the road transport, but it has greater applications as well, such as measuring the distances, driving time and the like. It enables touch-less scanning of the vehicle's speed in the longitudinal direction from 0.5 to 400 km.h^{-1} with accuracy of ± 0.5 % and is confirmed by the calibration protocol.

A microwave optical sensor provides accurate, reliable and contactless measurement of the speed and length via using technology based on the Doppler effect. The unit detects relative motion between the unit itself and the testing surface by a planar antenna, which emits two radio beams in an angle of 45°. After reaching the surface, the beams are reflected back to the antenna. The resulting dual frequency (equal to difference of received and transmitted frequencies) is directly related to the speed.

This dual beam planar system enhances the accuracy by automatic compensation of errors caused by the surface unevenness. The signal received is converted to required quantity via RISC - a board central processing unit and then sent to relevant outputs. Thanks to effective working range from 300 mm to 1200 mm, the microwave optical sensor may be used in applications demanding greater distances without the loss of accuracy. The basic data on the measuring instrument used are given in Table 2.

Prior to measurement of the bus-stop distances, the measuring and reporting instrument CORREVIT from

Figure 1 *Attachment of the microwave optical sensor*

Figure 2 *Evaluation and control unit (left) and control panel (right)*

Table 2 *Basic specific data on Correvit*

Measuring range	
Test range	0,5 - 400 km/h
Location	300 - 1200 mm from the Earth's surface
Speed accuracy	< 1% of the test value
Distance accuracy	< 0.5% (>2 00 m)
Reproducibility	< 0.25% (the test distance 200 m)
Inputs/outputs	
Pulse output	compatible with TTL
Analogue output	0 ... 10 V, proportional to the speed
Serial interface	compatible with PC, RS 232
Pulse input	compatible with TTL
Transmission frequency	24.125 GHz (± 50 MHz)
Transmission power	< + 25 dBm, (source 5mW)
Light beam angle	2 x 45° ± 10° lengthwise
Light beam angle	90° ± 7.5° transverse
Power supply	9 - 32 V DC, 10 W
Operating parameters	
Operating temperature	- 20 °C to + 60 °C
Protection	Sensor head IP65
Shocks	6 ms
Vibrations	10 ... 150 Hz
Dimensions	
Sensor	166 mm x 44 mm x 108 mm
Evaluation unit	170 mm x 45 mm x 125 mm
Weight	
Sensor	550 g
Evaluation unit	800 g
Length of cables	5 m

Table 3 *Distances measured and deviations of the measuring instrument on the standard and calibrated track of 1,000 m*

Order number	Distance measured by Correvit [m]	Deviation from the standard track [%]
1	1,002.16	0.216
2	1,001.96	0.196
3	1,002.58	0.258
4	1,004.21	0.421
5	1,003.71	0.371
6	1,003.46	0.346
7	1,002.87	0.287
8	1,003.18	0.318
		0.302

Corrsys Datron was verified in a certified and accredited calibration laboratory, resulting in a calibration certificate, which provides information on the speed of the sensor guaranteeing the quality and measurement accuracy of the device.

The calibration also involved verification of measurement for distances by Correvit. ZTS Elektronika SKS, s.r.o. Accreditation - Calibration Laboratory is an owner of certified measuring track 1 000 m long, which was measured by laser and geodetically by GEO3 Trencin, s.r.o. company. On this track, there were 8 measurements for distances performed and their results are shown in Table 3. The percentage deviation of each measurement from the standard (certified measuring section) and the overall average deviation of the measuring instrument Correvit of 0.302% were further calculated.

Based on the fact that in the most cases of measurements for distances by the CORREVIT system (especially when measuring the distances between the bus-stops of mass passenger transport lines) the conclusion of measurement results is based only on the sole independent measurement (from the economic reasons and after the client's agreement), the measurement uncertainty is expressed by a limit error of the CORREVIT system declared by the manufacturer, i.e. < 0.5% (see Table 1).

The manufacturer guarantees the measurement accuracy in terms of technical parameters of the measuring instrument CORREVIT, specified by calibration measurement.

5.3 Measuring the reals bus-stop distances - case study

The measurement itself for real bus-stop distances of mass passenger transport lines was performed *incrementally* for a certain journey section. It means that the beginning of measurement is in the departure bus stop (starting point) and the end is in the following, pre-determined measuring point of a transport line.

The vehicle started after being commanded by the head of measurement and was driving straightforwardly, if possible, on the track surveyed. The speed, driving mode and measurement conditions within measuring the bus-stop distances of mass passenger transport lines are compatible with operating conditions and are agreed prior to measurement itself. The driver ran and stopped the vehicle always at the pre-determined and agreed place, which was still at the same place of each bus stop, for example at the bus stop sign as in the real service.

After the vehicle was stopped in the respective measuring point by a control panel, the values measured, i.e. the distances between individual measuring points (bus stops), were stored in the measuring instrument's memory for further processing.

The measurement for the real bus-stop distances of mass passenger transport lines is usually performed by one measuring on the client's determined transport road, one-way from the departure bus stop to the end bus stop of the bus service and vice versa, due to different arrangement of the bus stops in the opposite way.

***Table 4** Examples of measurement results regarding the bus-stop distances*

O.N.	Note	Bus stop 1	Bus stop 2	Number of measurements by Correvit	Journey length (m)
1		SAD	Prievidza, tehelna	236	676.3
2		Prievidza, tehelna	Prievidza, Nestle	237	426.9
3		Prievidza, Nestle	Prievidza, aut.st.	238	1,115.4
4		Prievidza, aut.st.	Prievidza, L.Ondrejova	239	1,509.2
5	transition	Prievidza, L.Ondrejova	Prievidza, hotel Magura	240	2,566.1
6		Prievidza, hotel Magura	Prievidza, L.Ondrejova	241	1,857.7
7		Prievidza, L.Ondrejova	Prievidza, aut.st.	242	1,592.9
8		Prievidza, aut.st.	Prievidza, Prior	243	907.1
9		Prievidza, Prior	Prievidza, Necpalska	244	753.9
10	transition	Prievidza, Necpalska	Okruzna krizovatka - Prievidza, Necpalska	245	1,704.6
11		Prievidza, Necpalska	Prievidza, Prior	246	809.6
12		Prievidza, Prior	Prievidza, aut.st.	247	891.9
13		Prievidza, aut.st.	Prievidza, Necpalska	248	833.9
14		Prievidza, Necpalska	Nedozery-Brezany, zel.st.	249	4,764.0
15		Nedozery-Brezany, zel.st.	Nedozery-Brezany, Brezany, Jednota	250	560.7

For the data processing and evaluation, the software CeCallWinPro 1.09.001 was used. Here, the microwave system works as an all-inclusive system for the data collection and evaluation. Software's functions can store the testing parameters and corresponding description permanently, together with online display and evaluation (e.g. creation of graphs, tables). All the data measured may be stored and evaluated later in the off-line mode, as well. The data are given clearly in the form of a table with required parameters and these can be further handled meaningfully. The data being exported to the XLS were time, track, speed, acceleration or deceleration in a time period of each 0.1 second.

Within one of the real measurements of selected suburban transport lines in the area of the Self-governing Region of Trencin, there were 141 measurements performed. According to the methodology approved, the Protocol from the measurement results is being issued. The measurement results are given in a tabular form including all the selected bus-stop distances (sections) of mass passenger transport lines (Table 4).

When required by a client, the tariff distances for suburban or urban public passenger transport lines under Slovak legislation are defined, as well.

6 Discussion and summary

The transport services consist in changing place; hence, it is natural for the service users to pay for the covered distance. Moreover, part of costs depends on the distance, on which the transport is provided. Time tariffs are used in the urban transport practice, their advantage is the ease of use; in addition, to some extent they reflect the involvement of resources of the service provider, because some costs depend on time. It is possible to mention depreciation calculated based on the time and personnel costs, payroll, including the vehicle drivers, as well. The premises for their use resulted from the ease of price differentiation in that respect, however, for the service users it is the changing of location that is important and not being in a means of transport; the service users would prefer the service to be as short as possible. Contrary to other services or purchased products, in which processes of their creation are not attended, the movement consumes the time of service users, during the ride it is difficult to utilize this time in another way. Albeit in a situation, when during the travel the distance is covered all the time, the feeling of lost time is weaker than if people are waiting at stops or lose time during transfers. It should be added that in many cases the value of time for travelling and assessing it as lost, is many times higher, than the ticket price. Hence, considering the relationship between the costs and travel distances as well as the very subject of work in the transport services, which consists in the change of location, it is advisable to use tariffs making the fare dependant on the distance.

In the case of transport entities, the creation and updating on a current basis of a stop distances database is necessary and indispensable during the business running. These are the data necessary for timetables themselves, settlements of costs and various payments, if they depend on the distance. As a result of measurements, a database is obtained with actual distances; these figures should be updated, e.g. if a stop location is changed, if the traffic organization changes, or routes are corrected and changed. The actual distances may be used in price lists, containing information on the applied rates and may be the basis to calculate the fare. However, in some cases it is also possible to adopt the tariff distances, hence distances, which were intentionally corrected, so that as a result, the amount of fare for covering a specific section would change, as well. In particular this can be applied in situations where:

- between indicated stops various route variants exist, or various lines run along different routes, then different prices would be illogical, the more so if the route for a given line is chosen by the carrier,
- vehicles travel between stops on a longer distance, despite the fact that also a shorter one is possible, however, for various reasons the latter has not been chosen, for example it runs via dense development and there is no stop on the route, so the minimization of vehicles environmental impact is pursued,
- temporary diversions result from road closures due to repairs or other reasons.

Attention is drawn to the fact that measurements should be carried out precisely, in accordance with the adopted rules, because the obtained values are the basis for price calculation and deviations, if any, may be treated as a breach of consumer interests. It is also good to make measurements for possible routes, if any, so that at changes it would be not necessary to make measurements each time. As a result of measurements sufficient and known, accuracy is obtained, which would not necessarily be possible using maps.

The systems of e-tickets create great possibilities in the field of more innovative and flexible price differentiation and concessions defining, as well as promotions management. The use of IT technologies results in possibilities to introduce distance charging, i.e. section-based tariffs, without any difficulties for passengers. Various solutions can be used in this case, including also charging based on localization systems and defining the travel routes and distances from maps. This can be an alternative tariff for their calculation and its advantage consists in making the price dependent on the travelled distances, which may be important, in particular for the short-distance travels.

In recent times, there has been a higher demand for the measurements of tariff bus-stop distances of suburban bus transport in the Slovak Republic from the ordering parties of public transport services, namely the self-governing regions. This especially includes preparation of documents for procurement procedures for the next 10 years and the ordering party usually requires the real kilometres on the bus transport lines in the self-governing region or town. So, it is not only a tariff distance issue, which is very important for the passengers, but it is necessary to specify the transport performances, which enter the reimbursement of the economically substantiated costs and the adequate profit.

The distances of the bus stops were measured and determined by the Slovak state until 1990 through the Road Transport Institute. After 1990, the Slovak Republic did not appoint an independent organisation to take patronage over this professional activity. When building the new bus stops, determination of the tariff distances has been given to the hands of transport services suppliers, i.e. to the carriers. Here, it has led continuously to some disproportions and the measurement independence has lost. For instance, the transport performance for one carrier in the Self-governing Region of Kosice in the Slovak Republic is more than 12 million km per year and for the second one it is more than 14 million km. If the measurement accuracy of a properly determined transport performance is only 0.5 %, it is 140,000 km per year and 1,400,000 km per 10 years. When the economic price of performance is for example 1.6 EUR/km, it equals to a sum of EUR 2,240,000, which may not correspond to the transport performances provided.

In relation to the zone tariffs in the integrated transport systems, there is no problem with a correct tariff distance, if the zone tariff is used (in the Bratislava region for example), however, the integrated transport's organizer interests in the measurement for the real bus-stop distances of the bus transport lines due to fair funding for public passenger transport over the real performances realised. Given the size of the Slovak Republic, it could be effective that the Ministry of Transport and Construction of the Slovak Republic establish and fund one single information system of the bus stops of public passenger transport including the bus-stop distances with its regular update.

7 Conclusions

The essence of the transport activity consists in covering a distance and a part of costs components and thereby the total costs, increase with the distance covered by means of transport. In a similar way the calculation of fares depending on distances may be considered most appropriate from the point of view of transport as a service. Inaccuracies and deviations during the distance measurements have various results, which further on may have effect on analyses, comparisons, correctness during the fare calculations, as well as settlements related to public financing of the public transport. An independent and precise distance measurement is indispensable to eliminate the impact of the measurement method on distances.

In the urban and regional transport there are different approaches in differentiating the prices and considering the travel distances. In the case of uniform tariffs the distance does not differentiate the fare, in the zone tariff the fare goes up only after a tariff zone boundary crossing and for section-based tariffs the amount of fare increases with the increase in the covered distance. The development of systems, which enable automated calculation of fares, using e.g. automatic localisation, enables the application of section-based tariffs on a larger scale. In comparison to the uniform or zone tariffs their advantage consists in a lower fare at short-distance rides and a higher fare when travelling long distances. This is a premise of increasing the transport volume, because the feeling of overly high fare at short-distance rides is less strong, but on the other hand it is possible to apply higher prices at longer-distance travels, hence in a situation when the sensitivity to them is lowered. Obviously, in the systems, in which the uniform or zone tariffs have been used for many years, the section-based tariff may be one of tariff options, to be chosen by passengers.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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