PHD THESIS

IMPACTS ON SERVICE QUALITY OF STOCHASTIC PROCESSES OF URBAN PUBLIC PASSENGER TRANSPORT SYSTEM

By
DENKE, Zsolt
Transport engineer M.Sc.

Instructor: Prof. **KÖVES-GILICZE, Éva**

Budapest University of Technology and Economics
Faculty of Transportation Engineering
Department of Transport Operation

Budapest

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1. RESEARCH TASK AND METHODS

It is a worldwide phenomenon that more and more people are living in cities and towns. According to the World tendencies, two-third of the citizens in Hungary live in cities, eight of which have more than 100.000 inhabitants. Although the number of inhabitants in the main domestic cities have been decreasing in the last decade, the population in the surrounding suburban areas is growing due to suburbanisation.

The reason for urban sprawl is the generation of mobility by today's technical standards and deteriorating living standards in the cities, which people become more reactive to, responding by moving out of urban centres, if possible. Improving technical standards result in larger distances travelled. In transport systems, the total amount of time spent on changing locations (i.e. travelling) does not decrease in parallel with the increases in the speed of travel. Instead, it remains constant. The savings in time that result from using faster vehicles are spent not on other types of activities but more or longer distance travels. This is one of the reasons behind the changes in land-use, urban sprawl and concentration of the certain activities in one location (such as employment, shopping and leisure activities). Surveys show the increase of average daily trips and the travel distance and thus prove the theory, called "the constant of travel time budget".

Transportation negatively influences liveability and living standards of cities and urban areas. Urban transport is characterised by congestion on the roads, overcrowded vehicles in public transport in peak hours and long headways at less busy times of day. Journey time increases and road traffic safety declines, altogether the quality of transport diminishes. Urban transport causes serious environmental damages, such air and noise pollution, vibration, increasing land use of infrastructure, all of which result in rising social cost. All of these problems have lead to the necessity of forming of an environmentally sustainable transport system to improve the quality of urban life.

In urban public passenger transport system the modal share between public transport and private car use is determinate. Public transport considering its cost land use energy consumption and environmental impact is more favourable for society than private car use which provide better quality for its user considering its time-space availability speed and comfort. The key element is the appropriate modal share

between this two main transport mode for solves this problems and forming sustainable urban transport.
The environmentally sustainable development of urban transport systems is an internationally approved task of urban transport policy. For this reason, putting public passenger transport forward and moderation of further growth of private car use need to be implemented.
One of the tools of forming a sustainable urban transport system is the operation of a public passenger transport system with appropriate quality. However, the improvement of the quality indices of public transport is not in itself able to reverse the deteriorating trend of modal split. Due to advantages of private care use and some other, subjective, factors this can at the most slow down the trend of deterioration in public transport. That is why two-way, so-called pull and push measures are used, which simultaneously aim at both of the main motorised urban transport modes. The pull tools are to improve public transport's quality, while push measures aim making private car use less attractive.

Within sciences of transportation, the evolution of urban transport and, within that, the evolution of public transport as an individual area of science has occurred in the last few decades, so relating national and international literature are only a few decades old. Scientific discussion of urban public passenger transport is rooted in railway and road transport science's literature.
At the middle of the 20th century it was recognised that the principles of the transport processes with a determinist approach could only be examined in a limited way. Because of random factors in transport systems, certain events and processes occur with fluctuations. However, with the help of probability theory, the principles of a transport system can be modelled successfully.
It was in railway transportation, the most important transport mode until the second half of the 20th century, where probability theory applications have first been developed for planning infrastructure and carrying out traffic tasks. These have later been adapted in other transport modes as well. Two areas of the probability theory, mathematical statistics and queuing theory were used during the analysis. *Potthoff* established the examination of the random and stochastic character of railway operations. With his 5 volume and re-published work "Verkehrsströmungslehre",

which contains the formation of the stochastic concept of the transport technology, he founded the “Dresden School” of transport technology.

Potthoff and his followers, based on railway operations, developed the transport technology of all transport modes. In his book on urban public passenger transportation, *Rüger* demonstrates the stochastic character of traffic flows [11].

Transport processes have been studied in a stochastic approach by *Gilicze* and *Pálmai* since the end of 1960s, who have examined roundtrip time, characterising public transport processes, with methods of mathematical statistics [8]. These researches have been adopted in the field of timetable construction and traffic control.

In the EIPOS handbook of Dresden [5], *Hertel* demonstrated the general quality criteria of passenger transport systems, with which the aggregate comparable valuation of the quality could be performed. In the domestic literature *Gilicze* published the quality criteria of the passenger transport [7]. To focus her researches at one traffic subsystem, Gilicze discusses time-space quality criteria of public passenger transport and the measures to improving quality [9].

Quality and the ideas related to it, the quality loop and Total Quality Management (TQM) appeared in the lectures of *Hertel* and *Weigel* [13]. In domestic literature, a research group published a work about the expressions and phrases related to quality, in the editing of *Kondor* [10]. In the scope of Quattro project of the European Union, a general work on urban public transport’s quality was born, in which Monigl and his colleagues took part from Hungary. Within the project, besides the adaptation of the quality expressions for urban public transport, a private public passenger transport quality model was elaborated by the researchers [1]. On the topic of quality of the domestic public passenger transport, *Bősze* and *Jangel* from service providers (i.e. transport companies) published a work most recently.

Gilicze and *Pálmai* have elaborated a method for examining service disturbances of urban public transport systems, based on statistical examining of headway [4]. In their book, *Lányi* and *Klár* summarise disturbances to urban surface public transport, their effects, and the transportation engineering tools and traffic control simulation models used to lessen the consequences [6]. In Hungary, *Maklári* deals with the theoretical background and practical realisation of traffic light control of junctions, demonstrating through concrete examples the establishing and functioning of a system prioritising public transport. *Nagy* presented traffic control systems of surface lines of the Budapest Transport Company (BKV), including the Automatic Vehicle Monitoring (AVM) system used on the main bus lines and the Dispatcher Controlling System (DIR) controlling other bus, trolley-bus and the light rail lines. *Tóth* [12] in university study book on Road Traffic Informatics ("Közúti közlekedési informatika") summarises the controlling processes of road public passenger transport vehicles and the main features of state-of-the-art traffic control systems.

Measures for prioritising public transport are being presented through concrete examples and several numerical results from German towns by Fischer and his colleague's [2]. The Association of German Public Transport Service Providers presented the adaptation of information technology instruments through several German examples.

By comparing conventional bus stop bays and negative bus stop bays from the point of view of traffic operations, *Knoflacher* pointed out that the habits of people utilising forms of transportation can be affected, and for reasons of transportation policy should be affected, by "intelligent" transportation planning that put public transportation to the forefront.

In the research of stochastic systems, when description of relations of parts of complex systems is not any more possible with analytical mathematics methods that take into account probability, computer analysis can successfully be used. In a work of pioneering character of domestic science, *Dobay* dealt with computerised simulation of traffic on an urban bus line. In his book that discusses the simulation of road transportation's traffic-flow, *Vásárhelyi* mentions as one of the possible future stochastic simulation research works, the simulation of the movement of urban public passenger transport vehicles. Using object-oriented programming, *Horváth* simulated public passenger transport networks.

In my dissertation I examine the connections between the stochastic processes of the urban public transport system and its service quality. My research is restricted to processes that take place in surface subsystems (bus, trolley bus and light rail systems) that are partly or entirely disturbed by road traffic.

The goal of my dissertation is to present,

- That urban public passenger transport systems is limited stochastic system,

- That stochastic processes of urban public passenger transport system are consequences of disturbances,
- That service quality of urban public passenger transport is influenced by stochastic processes of the system,
- That disturbances decrease the quality of service of urban public transportation systems and these are felt by both passengers and operators through a set of quality parameters,
- What kind of measures can to be taken to decrease the stochastic character of urban public passenger transport, while at the same time increasing the level of service quality.

To reach these goals I conducted traffic surveys and researches. I evaluated the results of the traffic surveys with methods of mathematics statistics. The empirical distributions I approximated to theoretical distributions. I systematised the distributions of the processes that took place in the urban public passenger transport system. I analysed the basic processes of urban public passenger transport, used as a base to model the urban public passenger transport system with a probability theory approach. During modelling, I determined the location of disturbances that cause the stochastic character of the processes. I revealed the effect of stochastic processes on service quality of urban public passenger transport. I summarised in which quality criteria the effects of stochastic processes appear. I elaborated a method for the evaluation of stochastic urban public passenger transport processes. Finally, I systematised the measures that could be used to reduce stochastic effects while at the same time improving service quality.

2. NEW SCIENTIFIC RESULTS, THESISES

Theoretical Distributions \ Events		Relation											Remarks
		Frequency		Time									
				Roundtrip time									
		Arriving of vehicle	Arriving of passengers	Dwelling time at terminus	Travel time	Dwelling time at stop	Delay caused by disturbance	Headway	Combined headway	Multiple headway	Deviation from scheduled time	Speeds (e.g. travel speed, journey speed)	
Continuos	Normal			●	●	●		●		●		●	$\nu < 0{,}3..0{,}4$
	Erlang					●		●					$0{,}3..0{,}4 < \nu$ and $\nu < 0{,}65..0{,}8$
	Negative exponential					●[1]	●		●				$\nu > 0{,}65..0{,}8$
	Double mirrored exponential										●		$\nu > 1{,}0$ to all series of data
Discrete	Hyper-geometric	●											Finite observation period
	Binomial	●											Infinite observation period
	Poisson	●	●										

Legend: ● Connection between empirical and theoretical distributions proven by previous publications and by my personal traffic surveys.
ν Relative spread; quotient of spread and average

Table 1 Theoretical distribution describing empirical distribution of urban pubic passenger transport processes

1. Based on my traffic surveys, I concluded that the processes taking place in urban public passenger transport system are stochastic, and those processes are approximated by *normal* distribution, *Erlang* distribution, *negative exponential* distribution, *double mirrored exponential* distribution and *binomial* distribution. During my research I also found examples of *Poisson* and *Hyper-geometric* distributions in different publications.

   I systematised the theoretical distributions describing the events of the stochastic processes as (1) discrete distributions with a frequency relation to, and (2) continuous distributions with a time relation to the processes (Table 1).

Due to the overall impact of timetable constraints, spatial disturbances and travel demand, random occurrence in the processes of urban public passenger transport is restricted. Thus, the system is limited stochastic. The groupings of distributions described above provide a solid base for the stochastic simulation analysis of urban public transport system.

2. I prepared a probability theory model of the limited stochastic processes occurring in urban public passenger transport system. The model can be conceived as the basis for stochastic simulation analysis that can expose the usefulness and effectiveness of certain quality improving measures. I identified the components of the basic processes for service providers (roundtrip) and for passengers (journey). The time components of the basic processes, such as roundtrip time and journey time are probability variables. The developed model demonstrates the processes taking place at the stops (in which the two basic processes come together) and the linking processes as well.

   At the model the number of arriving passengers to the stop, the time order (travel time, headway, dwelling time at stop) and speed of vehicles as well as the number of carried passengers on vehicles are probability variables.

   Fluctuations in the time order of the vehicles are due to weather, to different driving styles and to the disturbances to traffic flow. Furthermore, the uneven arrival of passengers to the stops results in deviations from on-time travel as well. Based on traffic surveys, I concluded that deviations in passenger loading of vehicles result from the fluctuations in the number of passengers arriving to the stops, as well as fluctuations in the time order (headway, travel time) of the vehicles.

   The uneven headway heavily influences passenger loading of urban public passenger transport vehicles, which I described with regression curves. In most cases second-degree regression curve and regression line fitted best. However, even in case of equal headway, passenger loading is still heavily varied, which I explained with the random arrival of the passengers to the stops. Conclusively, the irregular, uneven passenger loading of the vehicles are caused by the combined effect of the uneven arrival of passengers to the stops and the stochastic arrivals of the vehicles.

3. I determined that there is a correlation between the stochastic processes and the service quality of urban public passenger transport systems. I demonstrated that the stochastic processes reduce the quality of service.

   I determined that the stochastic characteristic appears in the targeted service quality such as *headway*, *travel time* and *roundtrip time* criteria.

   I noted that within the targeted quality, the following criteria possess stochastic characteristics: *comfort* (exploitation of passenger space), *time availability* (headway, travel time), *punctuality* (headway and travel time) and *speed* (various speeds). To the competent authority, in the directly perceived quality, it is the *speed* (circulation speed) and the *cost-cover ratio* which present disturbances.
4. I developed a qualification system to evaluate delivered quality of urban public passenger transport system. I conducted statistical analysis to evaluate the different criteria of delivered quality such as; headway, travel time and speed.

   I noted the principles of changes of statistical characteristics of vehicle travel time along the routes. Data of the travel time, such as the spread and the range at measuring points, best resemble the $y = b \cdot x^a$ power curve (where: $0 < a < 1$ and $b > 0$). The spread and the range of the travel time along the route increases less than travel time itself, therefore data of the *relative spread* and the *irregularity indicator* of travel time (at measuring points), have a decreasing tendency, their data resemble the $y = b \cdot x^a$ hyperbola curve (where: $-1 < a < 0$ and $b > 0$). I suggest the calculation of the spread and the range of travel time. However, for the evaluation of disturbance levels and irregularities, I do not suggest calculating the relative spread and the irregularity indicator of the travel time.

   The stochastic characteristics of delivered quality along the routes can be compared to the statistical parameters of headway, travel time and speed. With this method the observed routes can be organised into absolute and relative sequences. Furthermore, within one observed route it is possible to determine the locations of disturbances and those locations where quality-improving measures should take place in order to reduce the disturbances. Beyond all, the method also enables us to evaluate the effectiveness of the intervening measures.

5. I made a systematised proposal for measures within and outside the competence of the service provider, aiming at enhancing service quality and reducing the disturbances of urban public transport.

   Measures outside the competence of the service provider consist of drawing up legal policies, adhering to legislation and measures of traffic engineering. I organised traffic engineering measures into station design, road and railway design and intersection design. Station design and road- and railway design is mutually connected. I determined, what kind of station design can be chosen in case of a certain road or rail design.

   Traffic control of urban public transport is the competence of the service provider. Traffic control of existing public transport networks can be conducted using different land- and satellite based telematic solutions. Beyond reducing the impacts caused by disturbances, the traffic control system is also capable of implementing data collection for the previously mentioned analysis.

3. USE OF RESULTS AND POSSIBILITIES FOR RESEARCH DEVELOPMENT

The growing spread of private car traffic forces urban public transport into increased competition. Improve quality of urban public passenger transport is one of the tools for urban public transport the successfully competition with the competing transport mode. I pointed out the correlation between the stochastic processes, caused by disturbances and the quality criteria of public passenger transport, which result in decreasing service quality. The elaborated method makes it possible for service provider to evaluate route-by-route the stochastic criteria of service quality, ranking of routes by their service quality and geographic location on each line of the disturbances resulting in reduced service quality.

The systematic measures give tools for service provider to reduce the disturbances. Measures of traffic engineering and telematics should be used in a combined way to achieve a more favourable effect, when a route or line undergoes a full revision. Effectiveness of the measures can be controlled by the method elaborated to evaluate the stochastic characters of service quality.

Further development on the subject of the dissertations possible in the field of evaluation methods of telematics and traffic engineering systems.

Case studies are worth conducting, in the field of effectiveness in improving service quality, of combined or separate measures of traffic control systems and strategies using different telematics tools and various traffic engineering measures.

Due to urban sprawl, a consequence of suburbanisation, short-distance trips, primarily the job motivated trips, take place in regional transportation systems that include suburban areas as well. Disturbances appearing in urban transport systems therefore becoming frequent in regional transport. As a consequence, research into the stochastic processes of urban public transport systems should be extended to regional transport systems as well.

In regional passenger transport systems, passenger flows are less concentrated both in time and space, in contrast with urban transport. As a result, the organisation of regional public passenger transport systems is different from that of a usual urban public passenger transport system.

- On the one hand, transport companies organise these services not in relations, but into directions or groups of services.
- On the other hand, headway is both longer and often irregular, due to the lack of regular interval timetable.

Therefore, in evaluation of delivered quality of regional transport the emphasis will probably move from statistical analysis of the headway to the analysis of travel time. The future establishment of transport associations makes possible the completion of such project in an institutional scope.

4. MAIN PUBLICATIONS IN THE AREA OF THE DISSERTATION

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