Changes of Passenger Preferences in Air Transportation

M. Baráth

BME, 1111 Budapest, Műegyetem rkp. 3.

Phone: +36 1 463 1037;
e-mail: marta.barath@mail.bme.hu

Abstract: Airlines and airport companies often conduct surveys of their passengers to get to know their present and latent needs. The purpose of this article is to reveal the differences between the preferences of business and leisure passengers in general and their recent changes in particular. The basis of this paper is a survey about passengers' travel preferences not taking into account carriers. In the article the preparation of the survey and the results of it are going to be discussed.

Keywords: air transportation, air passengers, market research

1. Introduction

The deregulation and liberalization of air traffic gave the opportunity for low cost airlines to appear on the market next to traditional airlines, which could convince those passengers who have lost confidence in the safety of travelling by air, since the 2001 September 11 attacks, to travel again due to their favourable prices [5]. The passengers' purpose of travel can be classified as business and leisure. Traditionally business passengers travel for commercial reasons quite often, timetable is vital to them in order to get to the meetings on time, and as long as their company pays for their travel, they do not regard price as a major factor. On the other hand, leisure passengers who travel on holiday or to visit friends or relatives once or twice a year are less sensitive to the convenience of departure time, however, they are quite concerned about the prices [1], [6]. On account of the financial crisis the needs of business passengers have changed. Companies had to reduce costs that influenced the frequency of trips and the allowed travel expenses. In spite of the fact that low cost airlines' target group are leisure passengers, they are obtaining bigger and bigger share on the market of business trips [4]. In the United States of America the price sensitivity of business passengers has risen so much that there is no significant difference between them and leisure passengers [7]. The same can be said about the Far East, where Chen and Wu examined the preferences of passengers flying between Taiwan and China [2]. In this article the author would like to examine the preferences of air passengers departing from Budapest.

2. The methodology of the survey

A one week survey has been carried out by the author at Budapest Liszt Ferenc International Airport to find out about the preferences of air passengers. Due to the limited capacity of the possibilities of information acquisition, instead of the whole basic population – who presently depart from Budapest by air – a sample has been selected. From the 1st of October, 2012 to the 7th of October, 2012 has been chosen as the time period for questioning. The permission for the survey has been granted by Budapest Airport Zrt. The preparation of the questionnaire was impeded by the fact that it had to meet two conditions. First, it had to be short enough to be completed as quickly as possible and also it still had to provide enough information. Therefore, only the most important questions could have been included, that is the main statistical information and the questions about the determining factors in the purchase of air tickets. In order not to distort the sample and to be able to ask the foreign passengers the questionnaire had also been translated into English. The time needed to fill it in was an important factor, as we queried passengers queuing for check-in. The explanation is that by the end of a long questionnaire the passengers would have become impatient which could result in getting unreliable or no answers at all. The estimated completion time of the questionnaire was 5 minutes but in reality, the time needed turned out to be 3 to 5 minutes.

As a second step the sampling had to be prepared. During the planning, the author strived to achieve a sample that is representative [9] regarding the area of Europe and also for the proportion of flights of traditional and low cost airlines. With these aims in mind, the author had to examine the timetable of Budapest Liszt Ferenc International Airport valid for the time period between 1 October and 7 October. A summary was created about the number flights and their properties such as destination, type of airlines (traditional or low cost) and the day of flight. Cities have been put into groups according to their geographical areas. Europe has been divided into seven parts: Germany, United Kingdom and Ireland, Northern Europe, Western Europe, Southern Europe, Southeast Europe and Eastern Europe and other. The author wished to divide Europe so that there would not be significant difference in the number of flights operating there. The number of flights of traditional and low cost airlines had to be separately summarized for every area. The planned sample has 500 elements, it has been divided according to the areas and the daily number of flights, taking into account the proportion of the number of flights of traditional and low cost airlines. Based on this, the number of people to be asked was allocated for each flight.

The survey was conducted by the author and two assistants from the 1st October to the 7th October between 4:30 a.m. and 5:00 p.m.. The method of selecting people was determined in a way that every fifth person shall be asked starting from the end of the queue. In case of no line for a certain flight, only those people could be inquired who happened to be there. If someone refused to answer then in case of a long line the next fifth person, otherwise the person standing before or after them was asked. In general, we can say that mainly families with small children and those travelling in large groups did not cooperate.

In the end, we managed to have 448 questionnaires completed. The results are distorted by the fact that passengers travelling on evening flights have not been asked, by the unwillingness of people to take part in the survey and also by the existence of language barriers. In some cases, there were only one or two people waiting for certain flights, therefore everyone had to be queried until the pre-set number of questionnaires were finished. The flights were departing in “units” (during certain time periods many flights were leaving at the same time) and the questions had to be asked at Terminal 2A and 2B sometimes simultaneously. Generally, the author was helped out by only one person in conducting the survey, therefore it was impossible in peak periods to carry out the survey as planned, which also distorts the results.

In order to examine passengers' needs, one type of the choice modelling, the contingent rating has been selected as a stated preference technique [3], [8]. The importance of factors of choosing a specific flight had to be graded from 1 to 5 by passengers, where 1 meant that the factor is of no relevance while 5 represented a key issue. In the questionnaire, 13 aspects had to be graded, however, in the article the author only deals with those 4 aspects in which regards business and leisure passengers’ preferences that differ widely in accordance with the literature so far.

3. The result of the survey

In Table 1, the distribution of the people questioned and the purpose of travel and other statistics can be seen.

Table 1.The distribution of the respondents

Gender	female	192	42.9%
	male	256	57.1%
Age-group	under 25	35	7.8%
	between 25-45	234	52.3%
	between 46-65	131	29.2%
	over 65	48	10.7%
Nationality	Hungarian	259	57.7%
	European	130	29.0%
	overseas	59	13.3%
Airline	traditional	231	51.5%
	low cost	217	48.5%
Purpose of travel	business	285	63.5%
	holiday	16	3.6%
	visiting a friend or family	68	15.4%
	studying	11	2.4%
	other	68	15.1%
Flight class	economy	434	96.8%
	business	14	3.2%

The distribution of the answers given to the 4 major questions can be seen regarding business passengers in Figure 1 and leisure passengers in Figure 2.

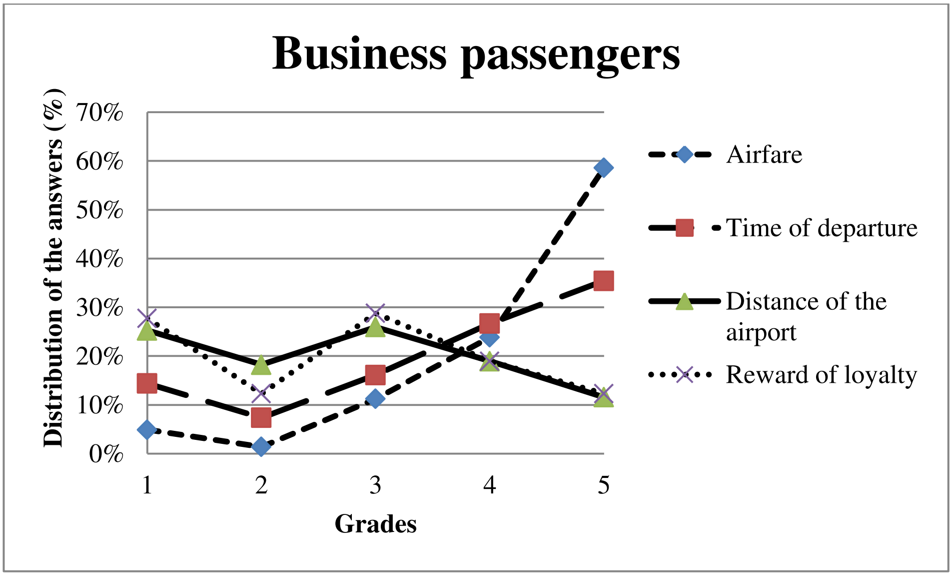

Figure 1.The distribution of the results obtained from business passengers

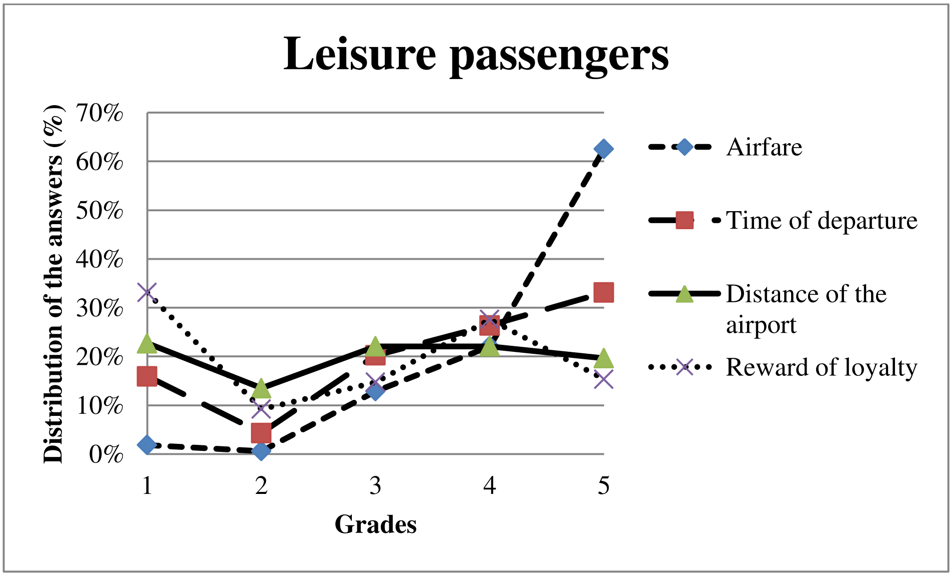

Figure 2.The distribution of the results obtained from leisure passengers

Based on the answers, what business passengers value the most are the airfare and the time of departure. Furthermore, 23.16% of business passengers consider price top priority over time of departure. The distance to the airport from the city center and the reward of loyalty are marginal for the majority business passengers. The results show also that price is of no importance only for a small minority of the people surveyed.

For the leisure passengers akin to the business passengers the airfare and the time of departure are the most important aspects. Yet, the top priority is airfare again. The distance to the airport from the city center and the reward of loyalty also play an important role for most leisure passengers.

It was concluded that, both types of passengers regard airfare as the most important aspect of selecting a flight.

In Figure 3, the distribution of answers can be observed grouped by the aspects of decision making, so that the replies of business and leisure passengers be more comparable this way.

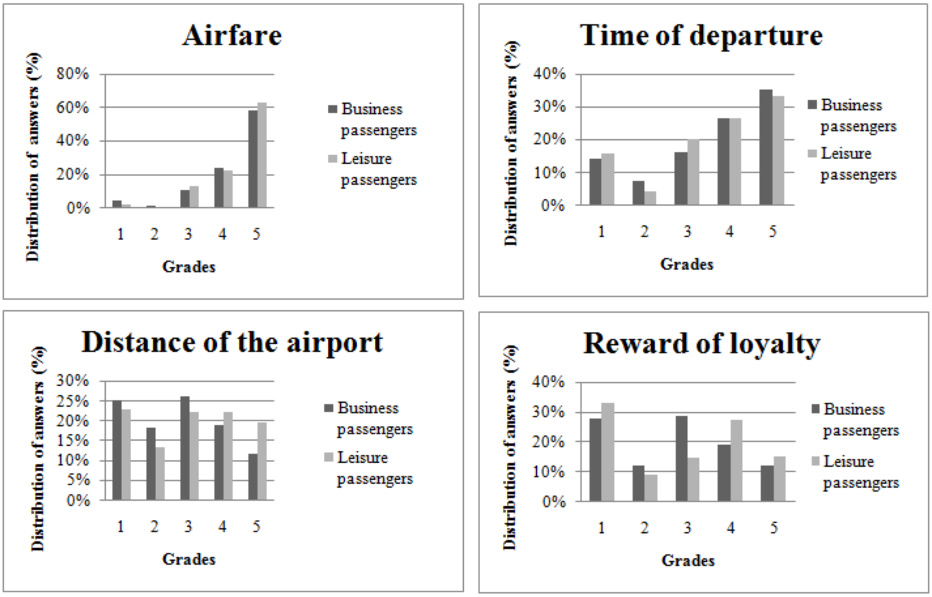

Figure 3.The distribution of the results according to categories

As we can see in the Figure 3, in the case of most marks only 2-4% difference can be observed between the answers of business passengers and leisure passengers. The smallest differences can be seen at the airfare and at the time of departure. Despite this, the distance to the airport from the city center was considered to be the most important factor by 8% more of the leisure passengers (mark 5), however, the reward of loyalty was considered slightly important (mark 3) by 14% more of the business passengers. The possible explanation behind this can be that the leisure passengers travel with bigger luggage, consequently, it is more important for them how far the hotel is.

Business passengers travel more often, therefore, they can use the frequent flyers' discounts more. As a result, we can state that in most cases the difference in the assessment of business and leisure passengers is negligible.

In Table 2, the average, standard deviation and median of the evaluations of the business passengers can be seen, and in Table 3 the same can be seen for leisure passengers.

Table 2.The average, standard deviation and median of the evaluations for business passengers

business	average	standard deviation	median
airfare	4.2982	1.0524	4.8919
time of departure	3.6140	1.5571	3.6875
distance of the airport	2.7579	2.0558	2.6454
reward of loyalty	2.7333	1.0259	2.5934

Table 3.The average, standard deviation and median of the evaluations for leisure passengers

leisure	average	standard deviation	median
airfare	4.4294	0.8720	4.5629
time of departure	3.5644	1.6431	3.6422
distance of the airport	3.0245	2.0056	2.7368
reward of loyalty	2.8282	2.2003	2.6344

Based on the averages for both business and leisure passengers the most important aspect is airfare. This is followed, in a decreasing order, by the time of departure, the distance to the airport from the city center and the reward of loyalty. Comparing the averages of the evaluation given to certain aspects by the two passenger types the difference is only a few tenths. Generally, leisure passengers value the aspects more relevant apart from time of departure, which seems to be crucial for business passengers.

Considering the standard deviations we can see that their value is high, especially on a five grade scale. Therefore it can be stated that the average does not represent the population adequately. Since the medians of the evaluation are near to the averages and the same order of priority can be set from them like from the averages, the author considers this priority order and the order of magnitude of the values acceptable.

The connection between the answers given for certain questions has been examined by using Pearson's correlation coefficients. In Table 4, the correlation coefficients based on the answers of business passengers can be seen, and in the Table 5 the same can be seen for leisure passengers.

Table 4.Pearson's correlation coefficients in the case of business passengers

business	airfare	time of departure	distance of the airport	reward of loyalty
airfare	1	-0.0362	0.0642	-0.0647
time of departure	-0.0362	1	**0.1689**	0.0689
distance of the airport	0.0642	**0.1689**	1	0.1076
reward of loyalty	-0.0647	0.0689	0.1076	1

Table 5.Pearson's correlation coefficients in the case of leisure passengers

leisure	airfare	time of departure	distance of the airport	reward of loyalty
airfare	1	0.0125	0.0850	0.0048
time of departure	0.0125	1	0.2293	0.0926
distance of the airport	0.0850	0.2293	1	**0.2320**
reward of loyalty	0.0048	0.0926	**0.2320**	1

In the case of both business and leisure passengers the correlation between the answers is about 0, therefore we can say that there is no connection between the aspects. The only exceptions could be in the case of leisure passengers the correlation between the distance of the airport and the reward of loyalty and also the correlation between the distance of the airport and the time of departure, which are considered as a weak connection with the approximate 0.2 values. Therefore, for those whom the distance of the airport was important, the time of departure and the reward of loyalty might also be important.

4. Summary

The appearance of low cost airlines and their market gaining and because of the effect of the financial crisis the preferences of air passengers have changed, the price sensitiveness of the passengers has grown. As we can see in the results of the survey the airfare is the most important factor for business as well as leisure passengers. Prior to the financial crisis it was a question of prestige for the companies that their employees travel on business class to meetings, however, nowadays many travel by low cost airlines to events abroad. It is also proved that although business passengers formed the majority of the travelers surveyed, 285, only 14 out of 448 actually travelled on business class. Based on the evaluations of those being asked in Budapest, the air passengers cannot be put into two significantly different groups. The business and the leisure passengers have very similar preferences according to the outcome of the survey. The price sensitivity of business passengers has risen and it is more important than the time of departure or the distance to the airport from the city center, therefore the market share of low cost airlines from the business flights might grow in the future.

Changes of business passenger preferences have a negative effect on traditional airlines, because their main source of income is the business passengers, who travel on business class. To minimize the losses, traditional airlines should reduce their costs as far as possible (for instance: by flight and crew planning optimization) and the airfare can be reduced by introducing some chargeable services. By way of illustration, business passengers typically travel with only hand baggage to one-day trips, therefore if they had to pay for the checked baggage, the airfare could be reduced by this amount. In airlines' communication campaigns it is recommended to draw attention to the discount airfare to the possibilities of reaching the city center from the airport, to their cost and needs of time, and to highlight the transfer services of airlines more. These options are usually better than the possibilities of reaching the city center from airports which have been used by low cost airlines.

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Application of GPS Technology to Evaluate the Quality of Public Transport

M. Bauer

Cracow University of Technology, ul. Warszawska 24, 31-155 Cracow, Poland
Phone: +48126282533, fax: +48126282535
e-mail: mbauer@pk.edu.pl

Abstract: This paper presents the importance of travel time researches in urban public transport. There were discussed the precision, scope and potential effects of the information, possible to get by different methods of measurements carried out with GPS receivers. Particular attention has been given to the author’s method of measurements. This method bases onto division of travel time (line or transport corridor) for detailed traffic processes: running time between two following stops, time of waiting for possibility of taking a position at the stop, alighting and boarding time and time of waiting for possibility to departure from stop. This kind of approach enables an overall evaluation of the public transport line quality. Application of the method was presented as an example of the public transport corridor in Cracow.

Keywords: urban public transport, GPS technology, measurements

1. Introduction

Operation of urban public transport requires constant quality control of provided services. It is only with complete knowledge about the condition of urban public transport when efficient continuous improvement activities can be carried out. For this reason, urban transport quality research should be conducted in a manner possibly continuous in order to enable evaluation of not only current quality indicators but also efficiency of measures taken [10]. The scope of measurements is diversified depending on the purpose of research results and intended accuracy of obtained data. Results of measurement may be used both for current evaluation of public transport system, verification of its offer, but also for planning future changes in line scheme [5]. Urban public transport quality measurements usually include [8], [11]:

- registration of occupancy of urban transport vehicles,
- measurement of duration of individual movement processes of urban transport vehicles on routes, such as: running time of a section between stops, travel time of transport corridor or the entire line, stopping time at stops,
- measurement of punctuality and regularity of running,
- registration of the number of alighting and boarding passengers,

- research of transport behaviours,
- research of passengers' preferences and satisfaction.

Measurements can be carried out in determined points of network which usually are bus or tramway stops and in vehicles servicing a line. The first ones have application mostly in research of general nature or in corridor studies. They enable to obtain information about numerous vehicles crossing measurement points in a relatively short time, however data about vehicles location between these points are lost. What is more, they are also prone to observation errors as an observer has little time to register measured variables, which is especially difficult in case of vehicle occupancy registration, in particular when more than one vehicle approach a public transport stop at the same time.

Whereas measurements carried out in urban transport vehicles allow to obtain accurate and reliable data on the change of vehicle location in time and space along with the size of passenger streams in a vehicle with an observer. Yet, they require involvement of a greater number of observers (in each vehicle) or engagement of advance measurement tools.

If the measurements of travel time can be efficiently used to improve the quality of transport services and at the same time to increase attractiveness of public transport largely depends on the quality and precision of the taken measurements. Quality and precision of obtaining data is dependent on the measurement devices applied. Various kinds of meters (including the very accurate ones, radio controlled) can be used both for measurements at network points and in urban transport vehicles. Currently however GPS receivers are gaining greater application as they enable to precisely control location of urban transport vehicle in time and space. As opposed to standard measurements carried out with the use of meters, the GPS receivers ensure reliable operation and great precision of obtained results.

2. Travel time measurements with application of manual GPS receivers

GPS technology is nearly created for measurements on vehicles, while its application in stationary network points is hardly efficient due to the loss of information on vehicle location [5], [7]. Two main types of GPS receivers used in urban transport vehicles measurements can be distinguished:

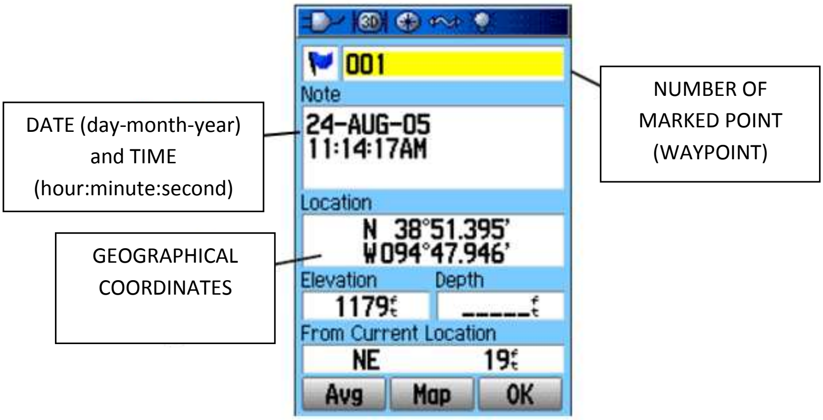
- **stationary receivers** ([3], built-in vehicle receivers), working without the need for an observer to interfere, being a part of vehicle equipment – useful for current, permanent registration of urban public transport system, particularly for schedule optimization,
- **manual receivers** [2], manned by measurers who additionally take measurements of vehicle occupancy; particularly important in corridor research and for individual lines, mostly useful in case of searching the reasons of disturbances on the public transport lines or corridors.

Measurements with the use of manual receivers usually require engagements of many people, yet especially in detailed research focused on reflecting movement processes they are as a rule more efficient than fully automated measurements (registering specified in advance scope of results). The greatest advantage of the latter in turn is nearly unlimited scope of obtained up-to-date information on many lines, restricted exclusively by the number of vehicles equipped with the measuring devices.

The paper focuses on the measurements carried out by observers equipped with manual receivers for road and sea navigation. Garmin GPSMAP62 receiver (also Garmin 60CSx, Garmin GPSMAP 62s) can serve as an example of such a device. It has a built-in button "mark" which can be used for marking all important moments and points of a journey (Figure 1).

Figure 1. Garmin GPSMAP 62 receiver [12]

Each pressing of the "mark" button causes immediate registration of the indicated point in time and space. This point is called "WAYPOINT". At this moment the number of indicated point is defined along with its geographical coordinates and current date and time (hour, minute, second). Application of this type of device for measurements in urban transport vehicles involves pressing the "mark" button at all previously defined essential moments of subsequent events on the line. The device allows to register time to an accuracy of one second, and to register distance to an accuracy of several meters. In case of settled routes it is fully sufficient. Example of information on the screen is shown on the Figure 2.


001

Note

24-AUG-05
11:14:17AM

Location

N 38°51.395'
W094°47.946'

Elevation 1179ft

Depth -----ft

From Current Location

NE 19ft

Figure 2. View of marked point on the screen of Garmin 60CSx receiver

What is important, thanks to regular connections with the satellite system, the probability of error of registration of moments and locations of events occurring on the route – is minimized. Exceptions are places of limited GPS signal reception, for instance in an area of intensive high urban development. In turn, the device's work in tunnels is basically restricted only to registering time. Nevertheless – except metro systems – such places are very scarce in city transportation networks.

Apart from the information registered with observers' "clicks", the device can automatically track route at time and space intervals set by the user [3]. On the basis of long experience it has been established that the most efficient registration is every 2 seconds, which on the one hand is sufficient to estimate the vehicle velocity and at the same time does not burden the device memory unduly.

3. Scope of information obtained during measurements

High measurement precision offered by the GPS system is unluckily not always used appropriately. Still, in many cities measurements are limited only to the departure times from subsequent public transport stops.

Such measurement method has been called **traditional method**. The result of measurements carried out in this manner are completion times of individual modules: **"between stops section" – "stop"** including running time and stopping time at the stop located at the end of this section, called: **stop-to-stop travel time** (Figure 3).

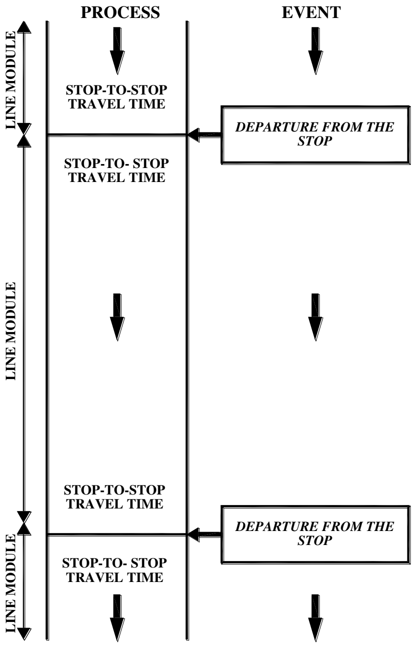


Figure 3. Moments of time registered in traditional method

Hence, these are not running times, even though they are so frequently called in Polish conditions, which is often the reason for erroneous interpretations of measurement results. On the grounds of times of departure from stop, one can establish the time span between individual stops forming the basis for constructing time tables and the values of stop-to-stop speeds, as well as calculate punctuality and regularity indicators. It is however not possible to indicate reasons for potential disorders on a line, as the information about the time between departures does not give any insight into the structure of travel time between following stops – how much time of it is the running time and how much is dwell time. As a result it is difficult to estimate if extended time of module completion on a line is caused by difficult traffic conditions on a section or if it is the effect of exceeding traffic capacity of a stop or increased numbers of alighting and boarding passengers.

Specification of traditional method is measurement involving registration of moments of opening and closing doors at bus stops. For the needs of this paper this method has been called **opened door method** (Figure 4).

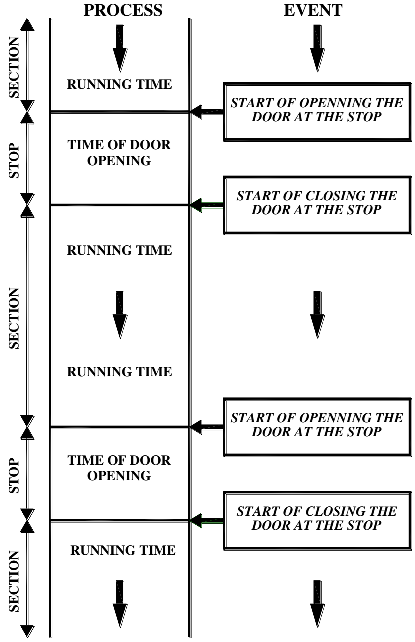


Figure 4. Moments of time registered in simple method

From the perspective of an observer on a vehicle, such measurement is also easy to carry out; the moments of door opening and closing are easy to capture. Situation gets slightly complicated when door opening is induced by a passenger, then the basic principle needs to be followed – at each public transport stop, the moment of the first door starting to open is registered and the moment of the last door starting to close. Nevertheless, further doubts arise, how to specify the time between vehicle door closing and the moment of their subsequent opening at the next bus stop? It is not a “pure” travel time as just after closing door the vehicle might still be at the stop for instance waiting for green signal (when stop is located nearside signalized intersection). A similar dilemma refers to the time between following registered moments of opening and closing door. It is not a “pure” dwell time as it is a common that buses stand with door open even though alighting and boarding have already finished. It seems that the most adequate term is “time of door opening” which, however, does not have any practical application. It can be acknowledged then that results obtained in such a way may serve to evaluate public transport line operations on a quite general level as they do not give any information about time loosing at stops.

In the **author’s method** of conducting measurements with the use of manual GPS receivers an approach has been presented which is based on accurate registration of events occurring at public transport stops, excluding time of passengers alighting and boarding and also the remaining time a vehicle spends at the stop (Figure 5).

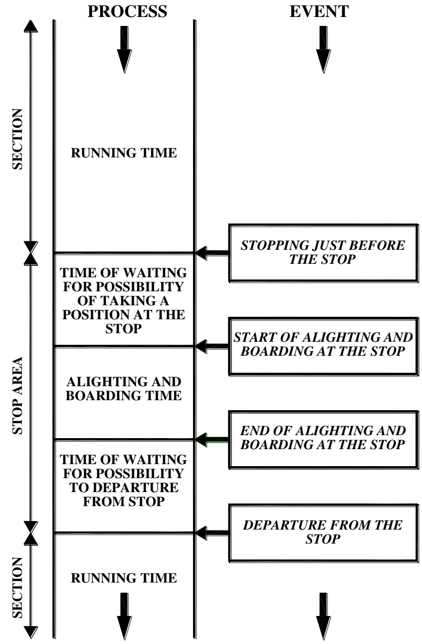


Figure 5. Moments of time registered in author’s method

In this method registration includes the moments of beginning and finishing of alighting and boarding passengers and also moments of departure from stops, which are registered independently from the moments of opening and closing of the vehicle door [1]. Additionally, registration also covers moments of stops just before the stops, in situations when a public transport vehicle is not able to take a position as the stop is occupied by another vehicle. Maximally, within one stop – four moments of event occurrences are registered and if a vehicle does not stop before the stop, these are only 3 moments. Still, thanks to use of a device with built in “mark” button it is not troublesome. As a result of application of the author’s method, one can isolate: time of waiting for the possibility of taking a position at the stop, dwell time (also called as: alighting and boarding time), time of waiting for the possibility to departure, and travel time of a section between two following stops. Such an approach entitles to draw binding conclusions on operation of a line and enables to identify the causes of potential disorders. Even if we have very detailed data, if it is needed, it is also possible to use the stop-to-stop approach, like in traditional method.

In the **extended author's method**, the group of moments registered at each stop includes additional moments of stopping and starting on the section (between public stop areas), for instance at the inlet of signalized intersection or in case of congestion at the section (Figure 6).

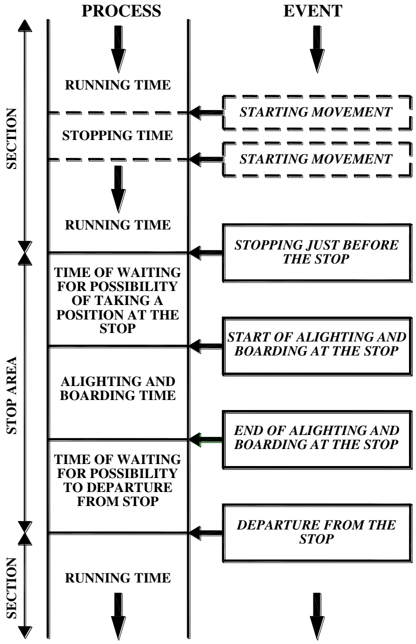


Figure 6. Moments of time registered in author's method

It gives the possibility to isolate time losses of public transport vehicles at the following elements (sections, stops) of the line or corridor. Comparison of travel times with and without losses can be helpful in analysis of introducing separated tramway tracks or bus lanes and priorities for public transport vehicles in traffic lights. Such a measurement method gives more accurate description of public transport operation.

Each measurement with participation of a human is at risk of errors. Most often they involve lack of "clicking" at a moment of occurrence of one of events, or too frequent marking events. Then results of automatic registration of vehicle trace come handy, thanks to them it is possible to complete the missing data (or removing excessive). The result of measurements is a set of public transport characteristics including duration of particular movement processes and reached velocities of a vehicle and transportation velocities. It is also possible to calculate various quality indicators, including punctuality and regularity indicators [9].

4. Exampled measurement results

Application of manual GPS receivers and the author's method of measurement gives the possibility to carry out very precise analyses of public transport corridor or an entire public transport line. This is the only way to accurately diagnose potential problem causes on a line.

Results of such studies form solid ground for taking specific actions. Nevertheless, due to the necessity to operate the device by a man, introduction of such research on a large scale is virtually impossible. In case of repeatable research it is necessary to install permanent receives, automatic, fixed in vehicles. In this chapter, the example of bus corridor evaluation is presented.

4.1. Description of public transport corridor

Trzech Wieszczów Avenue (shortly: ATW) is one of the most important transport corridors in Cracow. It is located on the western side of Cracow's close city centre, as a part of the second urban ring road. This corridor has significant meaning for individual and public transport. For the purposes of the paper, there were taken into consideration only results from the part of this corridor, from stop "Nowy Kleparz" to stop "Jubilat" (Figure 7).

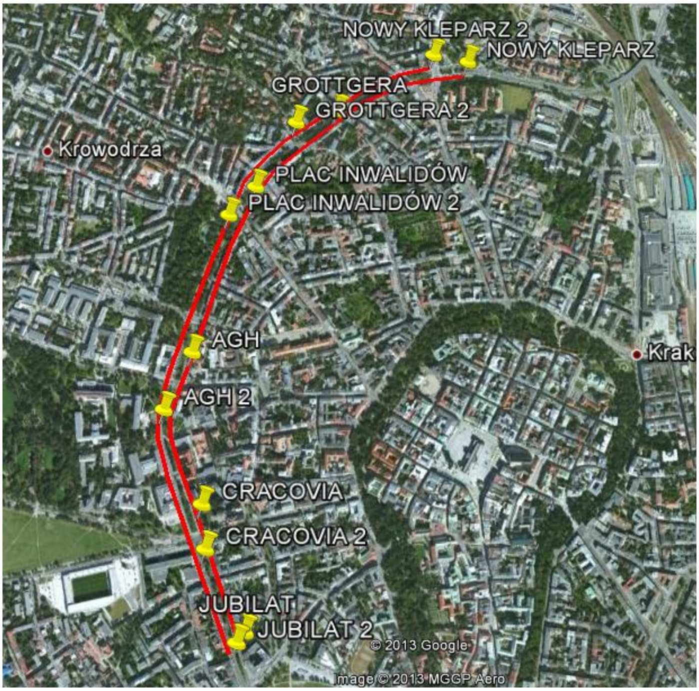


Figure 7. Public transport corridor: Trzech Wieszczów Avenue in Cracow

On the whole length of this part of corridor (2,4 [km]), right curb bus lanes were separated (both directions), but priorities for buses in traffic lights still in the planning. On the inlets of intersections, separated bus lanes are also used by all vehicles turning right. All stops are located far side signalized intersections, except stops "Grottgera" and "AGH" in South direction, located near side junctions. More than 40 urban buses (and about 70 private microbuses) use this corridor during one morning and afternoon peak hour, in one direction.

4.2. Measurements' results and their utility

Measurements were conducted on average working days, in the morning period (6:00-10:00 a.m.) in public transport buses operating at ATW, according to author's method. Observers in vehicles (with GPS receivers) on every stop on the corridor have been marking moments of:

- stopping just before the stop (only when all stop positions were occupied),
- start of alighting and boarding process,
- end of alighting and boarding process (even if door are still open),
- departure from the stop.

As the result of measurements, large group of waypoints and additional automatic traces was gathered. Exampled measurement results from only one bus, were presented on the Figure 8 (short figure – detailed view from stop AGH). Waypoints are marked by blue flags, black lines consist of automatic locations measured automatically with 2 seconds accuracy.

In general, 33 journeys were registered in each of two directions. On the basis of marked waypoints, for every module, was possible to calculate [2]:

- **running time [s]** (sometimes [min]) – defined as time interval between a bus is starting from one stop and stopping just before following stop,
- **time of waiting for possibility of taking a position at the stop [s]** – defined as time between the moment of stopping just before the stop and the moment of start of alighting and boarding at the stop,
- **alighting and boarding time [s]** – defined as time period between two moments of start and end of alighting and boarding passengers, even if door are still open,
- **time of waiting for possibility to departure [s]** – defined as time between the moment of end of alighting and boarding passengers to the moment of physical departure from the stop,
- **running speed [km/h]** – is the average speed bus achieve from leaving one stop to arriving at the next one's area,
- **stop-to-stop speed** – defined as the average speed of travel between moments a bus leaves two adjacent stops (includes running time and dwell time at the second at the section).

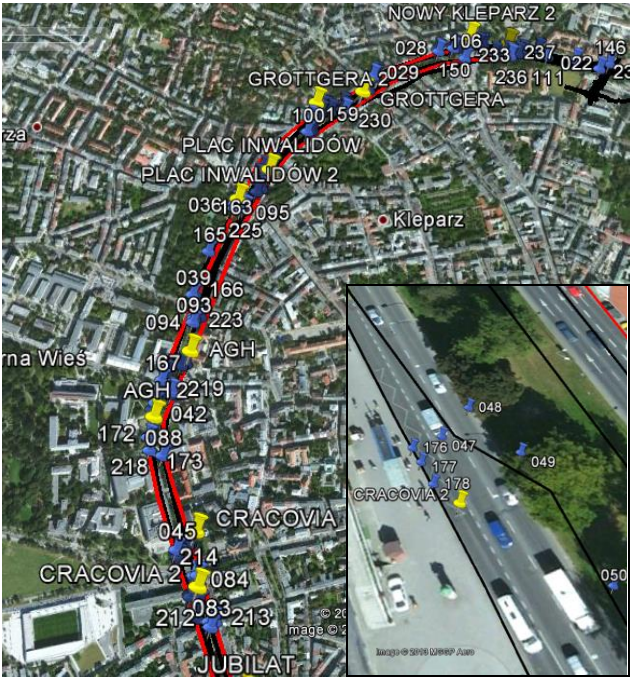


Figure 8. Example of measurement results collected by GPS receiver

The analysis was stared from the point of view general information about the corridor. On this level of accuracy – the results achieved through the application of author's method of measurement – are the same like in case of traditional method. Only moments of departure are used. Minimum and maximum and average values, standard deviations of running times and running speeds at several sections of the corridor are presented in the Table 1.

Table 1. Stop-to-stop travel times and speeds at the selected ATW sections

Section	Stop-to-stop travel time [s]				Stop-to-stop speed [km/h]			
	Min	Max	Average	St.dev	Min	Max	Average	St.dev
Direction: "Jubilat" – "Plac Inwalidów"								
Jubilat – Cracovia	66	152	**99**	22	9,2	21,3	**14,9**	3,4
Cracovia – AGH	60	142	**98**	23	12,9	30,6	**19,7**	4,6
AGH – Pl. Inwalidów	89	195	**128**	22	11,3	24,7	**17,6**	2,9
Pl. Inwalidów–Grottgera	58	216	**97**	33	6,0	22,3	**14,8**	4,3
Grottgera – N. Kleparz	80	210	**120**	25	9,3	20,3	**16,8**	3,0
Direction: "Plac Inwalidów" – "Jubilat"								
N. Kleparz – Grottgera	75	156	**103**	19	10,8	22,6	**16,9**	2,8
Grottgera–Pl. Inwalidów	87	183	**132**	23	8,5	17,8	**12,1**	2,2
Pl.Inwalidów – AGH	88	205	**143**	29	12,1	28,2	**18,2**	4,1
AGH – Cracovia	62	143	**99**	20	11,8	27,3	**17,7**	3,6
Cracovia – Jubilat	57	128	**72**	14	8,7	19,6	**16,0**	2,5

Although the benefits of bus lanes are commonly acknowledged, it could be seen, that on the analysed sections, stop-to-stop speeds are not satisfactory. Especially, on the stop-to-stop section “Grottgera” – “Plac Inwalidów” average stop-to-stop speed is only 12,1 [km/h]. On the sections: “Jubilat” – “Cracovia” and “Pl. Inwalidów” – “Grottgera” is less than 15 [km/h]. Several standard deviations of stop-to-stop speed are bigger than 4 [km/h] – they indicate a large dispersion of speeds. What are the reasons? What should the transport operator do to improve these results?

Credible answer on this question is possible only on the basis of more detailed approach, taking into consideration specified division for four processes on every stop-to-stop section. Basic characteristics of running times and running speeds at several sections are shown in the Table 2. Similarly, average values and standard deviations of processes take place in stops’ areas are presented in the Table 3.

On the slowest stop-to-stop section “Grottgera” – “Plac Inwalidów”, running speed is only 18,2 [km/h], even though buses use separated lane. But also very long alighting and boarding time on the stop “Plac Inwalidów” (34 [s]) has strong influence onto very low stop-to-stop speed. Because it is very important transfer point on the map of Cracow, this stopping time should be accepted.

Standard deviations indicate the occurrence of cases stopping buses just before the stops. At the bus stop “Pl. Inwalidów”, time of waiting for possibility of taking a position at the stop is the average of 5 [s]. This is too much, considering that such a loss of time are particularly criticized by passengers. On the other stops average values of time of waiting for possibility of taking a position at the stop are lower. Values of time of waiting for possibility to departure in some cases, are too long (8 [s]), while the acceptable value is 5 [s].

Table 2. Running times and running speeds at the selected ATW sections

Section	Running time [s]				Running speed [km/h]			
	Min	Max	Average	St.dev	Min	Max	Average	St.dev
Direction: “Jubilat” – “Plac Inwalidów”								
Jubilat – Cracovia	42	94	**67**	19	10,6	29,9	**22,5**	5,4
Cracovia – AGH	45	118	**70**	18	15,6	40,8	**27,7**	6,3
AGH – Pl. Inwalidów	68	110	**97**	22	14,0	32,3	**23,7**	5,1
Pl. Inwalidów–Grottgera	40	113	**75**	32	7,2	32,4	**20,0**	7,2
Grottgera – N. Kleparz	65	115	**93**	23	11,2	28,2	**21,9**	4,3
Direction: “Plac Inwalidów” – “Jubilat”								
N. Kleparz – Grottgera	51	140	**76**	20	12,1	33,2	**23,5**	5,2
Grottgera–Pl. Inwalidów	56	131	**89**	20	11,8	27,6	**18,2**	4,2
Pl.Inwalidów – AGH	67	164	**113**	27	15,1	37,1	**23,4**	6,3
AGH – Cracovia	48	113	**73**	18	15,0	35,3	**24,6**	5,7
Cracovia – Jubilat	31	71	**49**	12	15,7	36,0	**23,8**	5,3

Table 3. Stopping times at the selected ATW stops

Bus stop	Time of waiting for possibility of taking a position at stop [s]		Alighting and boarding time [s]		Time of waiting for possibility to departure [s]	
	Average	St. dev.	Average	St. dev.	Average	St. dev.
Direction: “Jubilat” – “Plac Inwalidów”						
Cracovia	**2**	7	**24**	13	**6**	3
AGH	**3**	9	**21**	11	**6**	4
Pl. Inwalidów	**5**	9	**20**	8	**7**	6
Grottgera	**3**	8	**14**	7	**5**	2
N. Kleparz	**3**	7	**18**	7	**8**	7
Direction: “Plac Inwalidów” – “Jubilat”						
Grottgera	**1**	5	**18**	6	**8**	6
Pl. Inwalidów	**1**	7	**34**	13	**8**	6
AGH	**3**	8	**20**	8	**7**	4
Cracovia	**2**	6	**18**	7	**7**	5
Jubilat	**1**	4	**13**	4	**8**	8

However, values of dwell time are most often on the sufficient level, can therefore be conducted that small values of stop-to-stop speeds should be increased by improvement of traffic conditions on the sections. Especially – on the inlets of signalized intersections, by separating lanes for vehicles turning right, outside the bus lanes.

5. Conclusions

Thanks to the implemented in the author’s method, time stratification into its components it is possible to specify the actual strengths and weaknesses of a researched line or its part. Occurrence of instances of waiting for the possibility to drive into a bus stop may prove low traffic capacity of the bus stop or excessive number of vehicles using the bus stop. In turn long times of waiting for the possibility to departure from a bus stop (after finishing passenger exchange) may result from the location of a bus stop at an entrance to traffic light cross road and lack of priority in the traffic lights, or they might result from frequent cases of selling tickets by drivers (when ticket machines are not available). Low speeds of running of a given section (extended running times) may by evidence of significant influence of other vehicle traffic on the movement of public transport vehicles or too liberal time tables forcing slower driving despite favourable traffic conditions. Indicating the sources of disorders creates the foundation for implementing efficient means of improvement such as separated lane, introducing traffic lights priority or correction of time table. Even exchange of fleet may be the cause for shortening dwell times for the same sizes of passenger streams. However, any actions must be based on reliable information about line conditions.

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Examination of a Railway Corridor Using a European Transport Model

Zs. Berki, F. Cselle

FŐMTERV Ltd. 1024 Budapest, Lövőház str. 37.
Phone: +36-1-3459746, fax: +36-1-3459550
email: berki@fomterv.hu, ferenc.cselle@fomterv.hu

Abstract: This paper describes some aspects of building of a European macro level freight transport model, which was part of a three step model system, designed to investigate the feasibility of a freight priority railway corridor bypassing Budapest.

Keywords: bypass, rail freight transport, feasibility study, European, strategic macro model

1. Background

The recent global transport policy efforts put considerable focus on enabling commercialisation of rail freight services and promote its competitiveness against road freight. This efforts lead to serious corridor investments based on underlying studies having large scale European Economic and Transport Models in background. However these investigations miss to catch a number of local issues and suffer from data gaps. Therefore in this paper, the authors focussed on showing, through a case study investigation, what local crosschecks and amendments needed before drawing conclusions from a global model. The most important words have to be capitalized in the title, according to the English conventions.

The Association of Hungarian Logistic Service Centers trusted the „V0 Magyarország" consortium (consisting of Főmterv Co. Ltd., Ákmi co. Ltd, COWI Magyarország Ltd. and Mott McDonald Hungary Ltd.) to carry out a feasibility study for „V0, the Budapest southern bypassing railway line", a freight oriented railway line, which bypasses Budapest. The bypass frees Budapest from the currently heavy freight traffic, and allows the southern main railway bridge (which currently is one of the major bottlenecks on the Hungarian railway infrastructure) to be used mainly, by passenger traffic. [1]

As Figure 1 shows, the international rail freight connections of the Hungarian economy comprise most of Europe, and are especially strong with the Central European economic region, the Balkan Peninsula and Eastern Europe.

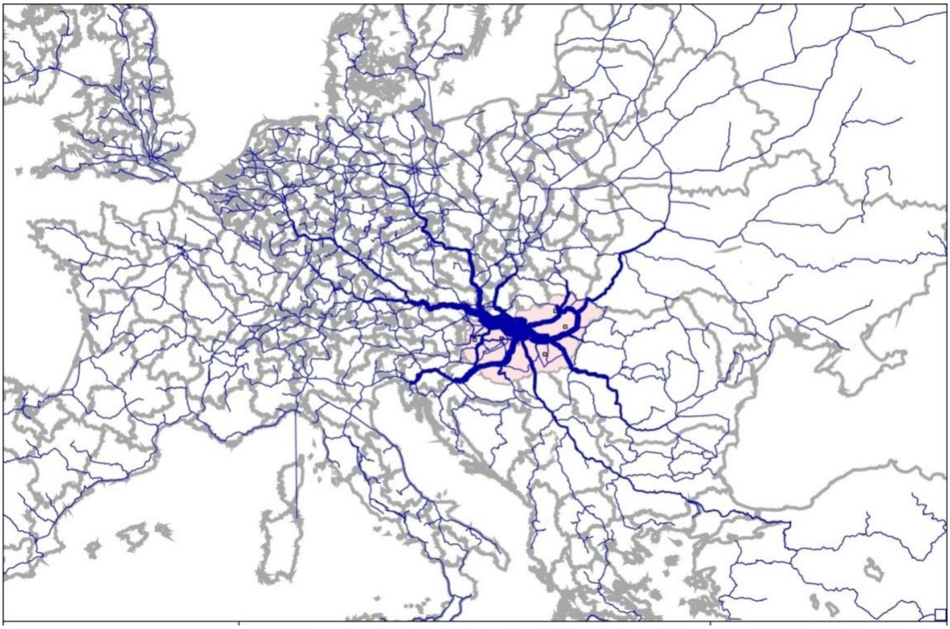

Figure 1. Rail freight connections of Hungary

With such a wide area of transport connections, the level of detail and complexity varies in the modelling of different aspects of the railway lines. Therefore a three step model approach has been adopted to support the analysis layers of the study to be able to examine all required aspects of the proposed railway development, with the appropriate detail. [2]

Figure 2. shows the model system used in the feasibility study.

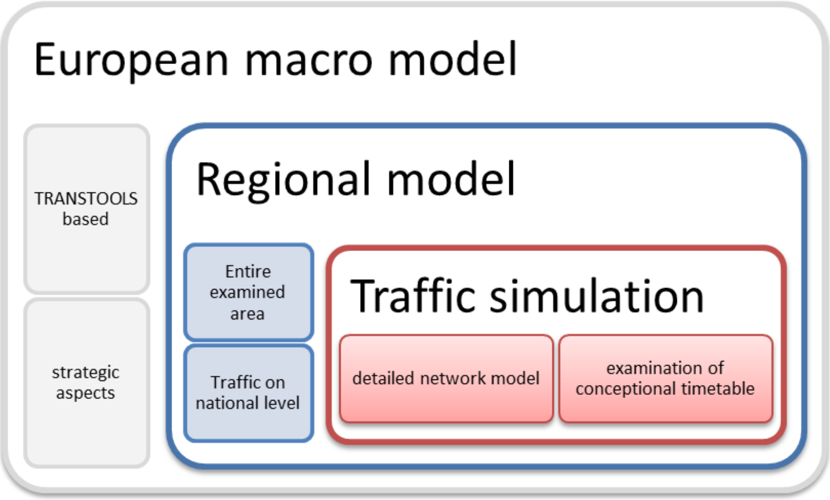

Figure 2. The model system used in the study

TRANSTOOLS was chosen as the base of the European macro level freight transport model. The macro level model had to:

- cover both the network and demand on NUTS3 level for entire Europe, based on TRANSTOOLS and ETIS+ data.
- be able to model the impacts of the planned transport development on the strategic level.

As TRANSTOOLS is a European level strategic model, it was necessary to adopt it to Hungarian country level, a level lower than it was originally designed, therefore its complexity had to be increased for the focus on country level impact assessment. This paper describes the changes made to the original model through the model building steps.

2. Some aspects of the macro level freight transport model

2.1. Aspects of the supply model

2.1.1. Network

Since TRANSTOOLS is a European level model, the network contains basically the TEN-T network, with some extensions. [3] For impact assessment purposes, the network model has been extended by some parts of the Hungarian network important in freight transportation or accessibility reasons. Figure 3. shows the network model used in the improved model.

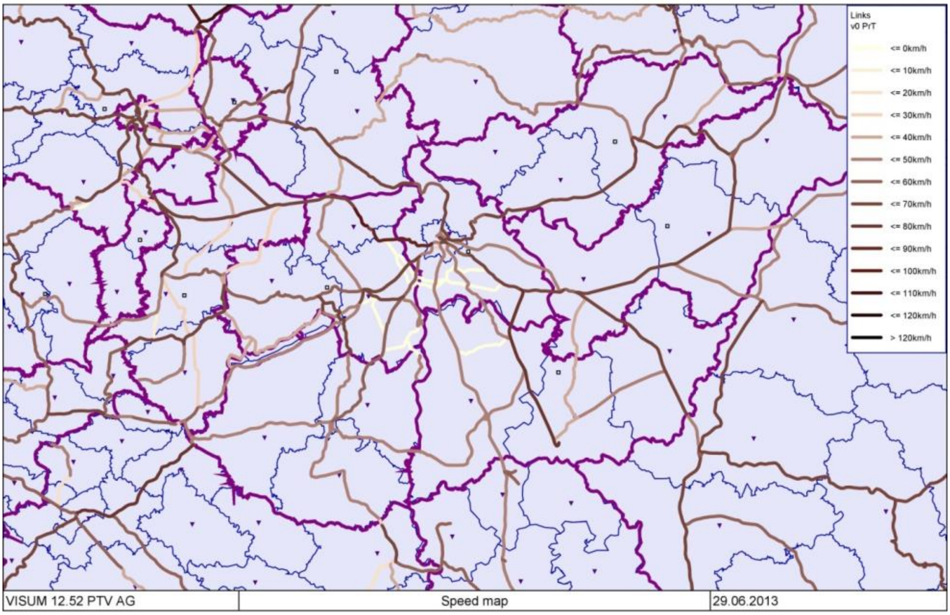

Figure 3. Railroad network used in the macro model

The network impedance was taken over from the original model, but speed set on the Hungarian network is based on the MAV PASS2 database of recorded runs of theHungarian Railways (MAV PASS2).

2.1.1. Zones

The original TRANSTOOLS model contains the freight data on NUTS2, regional level, which is completely sufficient on continental level, but is too aggregated to examine the impacts of a transport corridor within a single country, therefore a NUTS3 level zone system was adopted based on the ETIS+ data.

2.2. Aspects of the demand model

2.2.1. Connector system

With the new zone system, the original connectors had to be adapted to NUTS 3 level. To extend this, in the Hungarian zones 1-5 connectors are used for the transport system Rail. The sharing of traffic between the connectors is based on data from MAV PASS2 database, from which the loaded and unloaded amount of cargo was taken for each cargo stations per zone. The stations with less traffic than 5000 tons/year were left out, its traffic was added to the nearest main freight stations. The share of each connector gives its share of the overall traffic of the zone it is connecting to the network.

2.2.2. Demand matrices

The macro level model uses commodity flows, which are converted to vehicle flows for the assignment. This approach allows for more complex modelling of freight movements if needed (eg. transport chains), however this way to obtain the actual traffic flow on the network a conversion factor (commodity to vehicle) and a correction factor (the model does not contain empty runs) has to be used. The model uses the original 11 commodity group according to the NST/R 1 nomenclature, which are the following:

Table 1. Commodity groups in the macro model

NST/R 1	Commodity group
0	Agricultural products and live stock
1	Foodstuff
2	Solid mineral fuel
3	Crude oil
4	Ores, metal waste
5	Metal products
6	Minerals and building materials
7	Fertilisers
8	Other chemicals
9	Machinery, vehicles
10	Petroleum products

The 11 commodity group demand matrices, aggregated on NUTS2 level, had to be converted to the aforementioned NUTS 3 level zone system. For this task, available NUTS3 data from ETIS+ was used to create a weight matrix, which contained the share of each NUTS3 zone compared to the whole of the NUTS2 zone that contains it. Figure 4. shows the methods of OD matrix conversion.

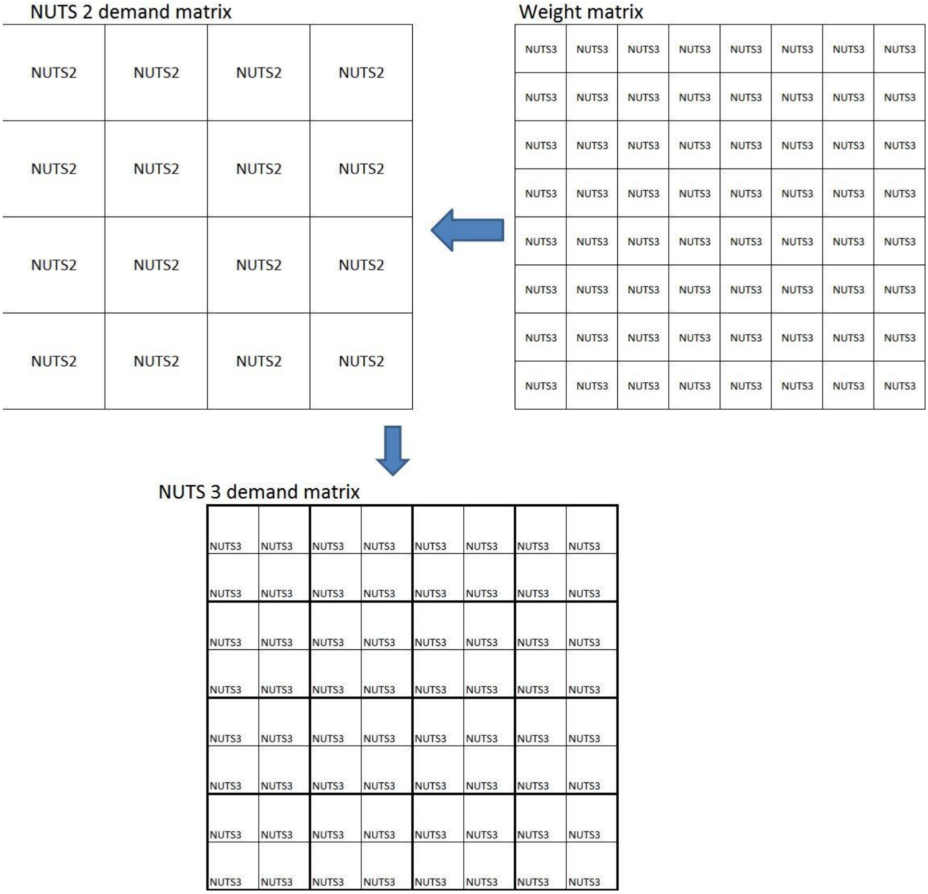

Figure 4. Methods of OD matrix conversion

The converted commodity group matrices were added together to form a single demand matrix for both rail and road freight demand. To assign the traffic, the commodity matrices had to be converted to vehicle matrices. For this, a 1200 t/ train conversion factor was used for rail traffic, which complies to the Iron Rhine study of TNO [4] and the MAV PASS2database. For road traffic, the original 14,3 t/vehicle factor was kept.

The economy of Hungary also has connections to overseas regions, with which the freight flows through the Adriatic and North sea ports, mainly in containers. Data on commodities lifted in containers is scarce, however there’s quite detailed data on vehicle movements between the European seaports and the Hungarian combi freight terminals. Using this data, an additional matrix was created on NUTS 3 level containing the container train movements. The entire demand therefore is comprised of the vehicle movement matrices created from commodity flows and a vehicle matrix of container flows created from data European port and railway companies.

3. Results of the macro model

By assigning the vehicle matrix to the network, the results were in line with the available statistical data.

On commodity flow level:

Table 2. Results of the macro model compared to the National Statistics Office's data

	Model [ton/year]	NSO [ton/year]	Model/NSO
Import	15859200	15470899	103%
Export	12289200	11859336	104%
Transit	7215260* (9495600)	9768501	97%

*the NSO data was incomplete in the Russian-Ukrainian relation, data for 2010 in brackets

On vehicle flow, the crossings of the river Danube were used as validation sections. Table 3 shows the results of the model compared to available statistical data.

Table 3. Rail freight data of the macro model on validation sections

	South Budapest bridge		Baja Danube bridge		Total	Total	Goodness of fit
	train/y	train/d	train/y	train/d	train/y	train/d	Model/MAV [%]
EU macro model	17 337	58	365	1	**17 702**	**59**	
EU macro model*	31 522	105	664	2	**32 185**	**107**	
MAV PASS2adat	30 234	101	228	1	**30 462**	**102**	**106%**

*with correction factor

Since the demand matrix doesn't contain empty runs, a correction factor is needed. According to interviews carried out in the projects with transportation companies, an average proportion of loaded/empty runs can be set at 55%/45%, which means, that an average of 1.8 multiplication factor is applied to obtain the actual traffic load on the network.

4. Summary

With the improvements in detail to the original TRANSTOOLS model, a tool has been developed for the national level strategic examinations on rail freight traffic. It is important, that this tool is not sufficient as a standalone model for feasibility studies, the results of the strategic modeling have to be further analyzed by more detailed models with focus on a much narrower section of the infrastructure, thus allowing more complex parametering.

Using these amendments and more complex approach at the analysis layers in the study, it justified the benefits of the V0, even in economic scenarios of moderate growth unlike the study carried out by Panteia-PWC [5], where it was stated that “the Budapest bypass should be postponed until 2020”.

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The Road Traffic Modelling and Design of the Traffic Database of Győr in Project Smarter Transport

S. Fazekas, T. Péter

Budapest University of Technology and Economics, Department of Control for Transportation and Vehicle System
H-1111, Budapest, Műegyetem rkp. 1-3.
Phone: +36 1 463 1013, fax: +36 1 463 3087
e-mail: alexanderfazekas@gmail.com, peter.tamas@mail.bme.hu

Abstract: In this paper we review our tasks in project Smarter Transport, and overview the network modelization process of city Győr. We also review the main concepts of the traffic road network databank, which will store the measured and assessed quantities and the road network model. We discuss the goals and the main requirements of the database system, which aims to support the modelling process. We briefly overview the architecture.

Keywords: traffic modelling, macroscopic model, traffic database, Smarter Transport

1. Introduction

The Smarter Transport project aims to aid public road transportation via the application of infocommunication technologies. The following steps will be executed within the confines of this project:

- the current state and traffic load of Győr’s road traffic network will be assessed, the collected data will be structured
- the macroscopic model of the road traffic network will be set with PannonTraffic, our proprietary modelling software
- the macroscopic mathematical model will be applied on the network model and the simulated traffic load will be calculated
- the simulated traffic levels will be compared with measured data.

Setting up the road network model with correct parameters could be very time consuming process because of the large amount of data. Therefore a customized databank system should be planned and implemented to subsidize the above described process and to improve the speed of the modelization. The further advantages of the databank system are the following:

- all input data - which is required by the simulation process - can be stored in one place, despite input data can derive from different sources (different measurements, various authorities)
- paper documentations and plans can be processed before the application of data
- input data can be preprocessed and filtered, noise can be reduced

If the modelling software and the databank system are connected, there is no need to adjust every single model parameter manually. The databank system could aid these tasks based on the location of the current element.

Considering these advantages, a databank system could improve the pace and the quality of the network modelization. To achieve this, the databank software should be able to

- store and display all data related to a district's or a city's road network
- aid PannonTraffic in the process of parameter assignment to model elements
- store and display the model of the road network.

2. Software development for traffic modelling

In scientific researches there is no possibility to use simulation software without knowing exactly the mathematical model working in the background. The PannonTraffic Engineer developed by our team [11, 14] is a complex software for creating the road network, simulating the traffic and analyzing the simulation results. This software works with the published macroscopic traffic model of T. Péter in [7, 9, 12, 17, 18, 19, 20, 21] and Péter and Bokor in [6, 15, 16]. The advantage of the PannonTraffic software to similar, commercial software products is that the computation algorithm is not a black-box, but a well-known process. This model is developed for high-speed modeling of large-scaled traffic networks, to be able to apply for control optimization and prediction. The elements of the transportation infrastructure (lanes, traffic lights, pedestrian crossings, bicycle roads, etc.) are mapped through an interactive surface input while they are parameterized by several feature. We succeeded to implement the simulation with a high-performance algorithm. With the PannonTraffic Engineer we are able to achieve complex analysis to examine the effect of changes in the traffic orders, the road network geometry or the predictable traffic.

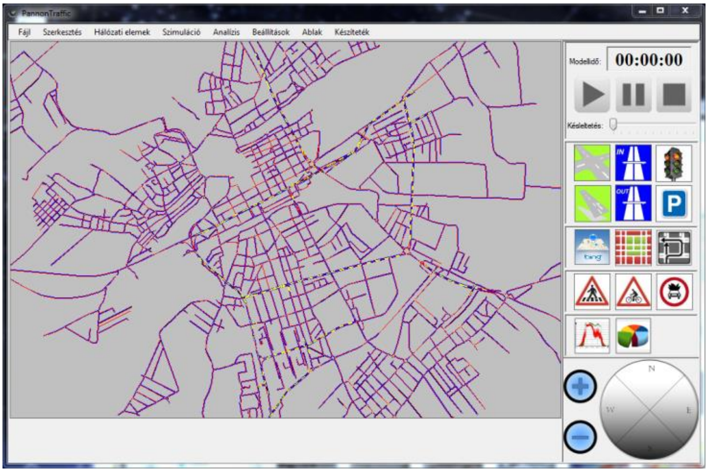

Figure 1. Main screen of PannonTraffic Engineer with the network of Győr

2.1. Creating the network

The road network graph's vertexes represent crosses in the traffic network, they are connected with directed edges representing the lanes. If there are parallel lanes in the real road network, then they are connected with more edges. The edges (lanes) are joined with connections. The transmitting of vehicles between lanes is described by α(t) and β(t). These functions are assigned to connections. α(t) describes the macroscopic vehichle distribution in the end of the lanes, β(t) represents the priority relationships of the connection. These functions are assigned to every connection between lanes.

The network graph can be set up based on the public social map data of OpenStreetMap service. The aim of the development was to reduce significantly the human-processing time of the network development.

In practice this means, that the region of a city about ~460 km^2 can be downloaded and reconstructed in 2 minutes by our software. In this road network we have crossings and road sections (with one lane each direction – except of one-way streets of course). Running simulation is not possible in this phase, few more add-ins, fixes and settings are needed. It's necessary to create lanes with the competent item number, and assign pedestrian crossings, parking places to them. Although the length of the lanes is correct thanks to the proportional mapping, but there is no information for example about the capacity of parking places, so we have to set it up manually, like the settings of the cooperation functions (for example α(t), α(t) and γ(t) functions) which we are able determine only after doing some measurements on the network.

2.2. Setting the model parameters

After creating the examined road network there are following the user made intervention operations. This large network was divided into 19 segments. These segments are basically bounded by major streets, and their size depends on the complexity of the actual territory. Three working phases were defined properly which are easy to divide into further parts.

I. Recover of the missing crossings

II. Split up the long streets to approx. equivalent distances

III. Adding parking places to the inside lanes

By parceling the network to 19 segments, the working process and the time requirements turned into well-planned, furthermore not a single street fails when doing the improvements.

The definition of the capacity of the parking places and the lanes can be automatized partially. Estimating the capacity of lanes or parking places could be managed by image processing, but there are two main difficulties. Firstly the quality of the satellite- and aerial images are not adequate. Secondly the time interval of our project does not allow such a long-term task.

In the case of lanes there is an easy solution. Using the GPS coordinates of the end point of the road sections the lane distances can be calculated unambiguously by reconverting the GPS coordinates to model coordinates.

The same process for the parking places is available only partially. In case of parallel or angled parking the capacity can be estimated knowing the length of the owner lane and the angle of the parking place arrangement. In the national standards it is fairly equally defined at which angle arrangement what sizes must be insured for each places. In this case the process is automatizable as we can see. On the other hand if there are parking lots (typically at residential area or warehouses) we cannot count the capacity like we did above. There is only the possibility to make personal counting on the spot or rely on the satellite images of the territory and count the parking places. There is the same case with the underground or multi-storey car parks, except of the fact that no satellite images can give information about them. Of course nowadays it is not hard to find information about this hidden park lots on the internet. Surveying the parking place capacities with the help of aerial images we can get some extra information about hidden parking places in a city. Namely there are lots of buildings having inner court, where the owners have sometimes more dozens of parking places, which would not be discovered in all cases.

During the verification process of the road network using the OpenStreetMaps integration it was noticed that the number of the parallel lanes is not defined at all in the internet database. This problem led on the same solution like described above related to the parking lots. For being able to do this process as fast as possible we improved the user interface of PannonTraffic Engineer. The panel dealing with parking places now contains some extra functions for determination of capacity (e.g. arrangements types, manual counting results). The parallel lanes have to be set manually.

3. Designing the traffic database

There are two main group of requirements defined about the databank system [4,5]. Firstly there should be an intuitive user interface where users can browse, search, compare and upload the measured and simulated traffic data easily. Secondly we have to design a proper interface for the PannonTraffic application. The PannonTraffic modelling software is based on a public, macroscopic model [8, 9, 10]. It is developed by our team; we can easily extend its functionality and integrate with the database system. PannonTraffic software should be able to connect to the databank system via this interface and query the quantitative (measured and estimated) parameters of the traffic network, adjust them to the proper model element, and upload the simulation results into the database after applying the mathematical model.

During the design process we aimed to create a general solution.

The databank system should be a way where measurement and simulation results can be published, namely it should be available remotely, thus we will implement it as a web application.

3.1. About storing data

The database system is designed to store every type of data which could be required as input or output for the simulation process, or describe the current state of the network. The stored data can be classified based on how are they produced and on what are they relating.

Some kind of data is linked to model objects. For example traffic density of time functions are linked to lane objects. Other quantitative parameters are assigned to GPS positions. In PannonTraffic simulation software, parameters can be assigned to the objects and not to the positions. For example a parameter can be assigned to a lane or a cross object, hence the database system should support to determine the owner objects which are initially assigned to locations, but not to objects.

The database should store density of time functions for each lane. These functions can be generated based on the measurement results, but simulated density of time functions should be also stored in the databank.

Users should be able to:

- Estimate and set the quality of the road surfaces for each lane and the width of each lane with the user interface of the application
- Set the maximum (and optionally minimum) allowed speed for each lanes
- Assign the traffic-distribution and priority describing ratios or functions for every crosses, for every connection. (These functions are defined in the macroscopic model as α and β functions. In the current phase, these ratios and functions will be estimated, because there will be no measurements of traffic-distribution in the interchanges.)
- Estimate the transparency of each cross and assign these estimations to the crosses. (To support and help this task, the sampling cars may record their run with camera, and the application should store and display these photographs taken from the sampling cars.)
- Assign the list of traffic signs to the given sampling point based on the photographs. (These datasets should be queryable and searchable. Place of pedestrian stops can be set manually also.)

There are exact, measured and estimated parameters in the traffic network. The nature of data determines the way how data should be handled and stored. Exact data can be set and stored once, they are valid in every circumstances in the given traffic network. Programming of traffic lamps belongs to this category. The time intervals of green and red signs can be set and check on the user interface of the application.

There will be measurement data collected via GPS samplings. Some sampling cars having GPS equipments will run in the traffic on predefined routes. These chronological data of car positions and speeds will be the base of calculated vehicle density of each lane of the traffic network [13]. These data may be distorted by noise, so filtering processes should be elaborated. The exact way of filtering will be determined later, in the development phase.

In some cases (especially in sudden, non-traffic depending impacts and events) manual exclusion may be required. For this purpose we design the system to store the photographs bound to sampling points. Using these photographs, users can roam the sampling routes again. During these steps, the user interface will support the necessary manual processing steps, for example the recognition and administration of the road quality or the traffic signs.

During the manual data processing special properties of the network can be recorded also. Custom tags (similar to labels) can be assigned to every single measurement location or recognized object, and this list of tags could be modified freely during the whole term of the modelling and data recording process. The meaning of tags can be administrative only (for example to mark those areas of the network, where the modeller would like to perform more detailed reviews, or to tag the areas where some uncertainty is or further review is required), but in a later stage of the modelling process these labels can get extra meaning in the model.

After exclusion of distorted samples, the system estimates the density of time functions of every lane in the network from the GPS data of the sampling cars. The estimation is based on the „relevant speed” of the advance on the lane. „Relevant speed” means the velocity determined by the traffic on the lane. Estimation is done by using these speeds with the fundamental correspondence between vehicle density and average speed.

This calculation of traffic density of time functions should be repeatable with different parameter sets, hence the database system should store unprocessed, raw datasets of GPS measurements and the calculated density of lane functions separate.

Not only density functions are based on estimation, but α and β coefficients, but till the vehicle densities are calculated automatically from GPS coordinates, α and β coefficients are judged manually.

3.2. Supported processes by the database

Measurements and collecting the required data should be done in the first phase. GPS sampling measurements and the traffic lamp programmes of interchanges are necessary.

In the second phase further position assigned parameters can be set manually on the interface of the application. By iterating through the photographs of the traffic network created during the GPS sampling runs [1, 2, 3] every traffic affecting factors can be registered and estimated including quality of road surface and traffic signs. These parameters will be linked to the positions. It is important that the classifications are not quantitative, but subjective. Users can group the objects and impacts into several classes. For example if the question is about the transparency of a cross, the user can assign adjectives like „good”, „moderate”, „dangerous” „very dangerous”; and „good”, „potholed” can be used in case of quality of the road. The quantitative meaning of these adjectives can be modified later by the modeller, so the parameters of the simulation can be refined after setting up the model. The classifications can be customized; the list of the available properties and the quantitative meaning of these items can be modified every time.

In the third phase a PannonTraffic Engineer model is created by users. This model can be based on the public database of OpenStreetMaps, but it can be a high-level model containing only the priority roads.

In the fourth phase the PannonTraffic model will be uploaded to the database application, which resolves the owner model object for each position-assigned parameter. Assume that there are more position assigned parameter for the same lane. The system should determine the root parameter, which should be assigned to the macroscopic model element. Before these steps the engineers should select the way of calculation of the root parameter for each parameter type. All required data are stored before this step; hence the calculation of the root parameter is repeatable, if a better way of root calculation is identified.

In the fifth step the macroscopic model is applied to the traffic network

In the sixth step the output of the macroscopic simulation – including the simulated density of time functions of the inner sections – are uploaded to the database system.

In the seventh step the differences between the measured and the simulated density functions can be compared. If it is required the process can be restarted to refine the parameters from the second or third phase.

3.3. Integration objectives

The PannonTraffic modelling software and the planned databank website has some common functions and use cases, as users should be able to display the simulation results, to navigate on the network graph, and to adjust the traffic network parameters with both software.

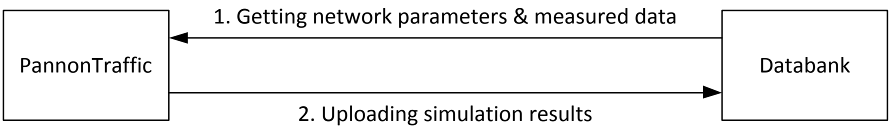

Figure 4. The modelling software gets the parameters from the databank and uploads the simulation results after the simulation process

The weaknesses of the software could be eliminated if PannonTraffic was a web application. In this case it would be reasonable to make this implementation in the databank, so the two systems could be integrated: the process of registering measurement results, storing model dependent an independent network parameters, traffic network modelling, simulation and analysis could be executed at one place. This solution suits to the Software as a Service (SaaS) paradigm, so customers, engineers, students should not deal with the installation and the operation of PannonTraffic software. It could be easy to give a trial to the would-be users. In case of this solution the users would get not an instance of the modelling software, but some user accounts to the databank and the modelling software with modelling and processor time. The business logic will contain the data processing and filtering implementation, furthermore the user authentication and administration. The data access layer will suit the database engine to the business logic. The simplified figure of the architecture is shown below.

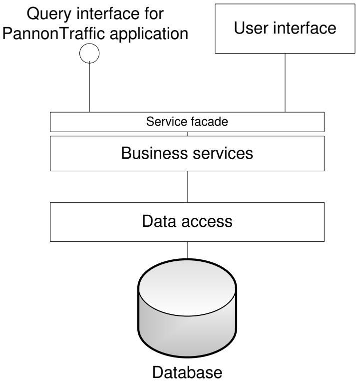

Figure 5. The simplified architecture of the database system

4. Summary

We introduced our first tasks in the Smarter Transport project [22, 23, 24, 25, 26, 27, 28, 29]. We defined these tasks accurately and made suggestions to schedule the processes according to the detailed segmentation of city Győr. By the 19 segments it is possible to distribute the tasks to more persons and execute the work processes parallel. We detailed some solutions for defining capacity of the road sections and car parking lots and presented a software development related to the problem. We have overviewed the main requirements related to the databank system. We have discussed the main types of stored data and the process which will be supported by the software. We have reviewed the main items of the planned architecture. Finally we have investigated the advantages of considering the further development of the databank system and the PannonTraffic application as one integrated web application despite of two different stand-alone software.

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Look-ahead Cruise Control Considering Traffic Information Based on Floating Car Data

A. Mihály[1], P. Gáspár[2]

[1]Budapest University of Technology and Economics, Department of Control for Transportation and Vehicle Systems, H-1111 Budapest, Stoczek J. u. 2.
e-mail: mihaly.andras@mail.bme.hu

[2]Systems and Control Laboratory, Computer and Automation Research Institute Hungarian Academy of Sciences, H-1111, Budapest, Kende u. 13-17.
e-mail: gaspar.peter@sztaki.mta.hu

Abstract: The paper focuses on the design of an adaptive cruise control system which optimizes the longitudinal energy and fuel consumption of the vehicle. In the velocity design process a look-ahead method is used considering road information of road sections ahead of the vehicle. By using road information about the characteristics of the oncoming road sections, e.g. oncoming speed limits or road slopes, it is possible to modify the speed during the journey in advance. The main novelty of the paper is the adaptation of forward traffic mean speed in the look-ahead control algorithm. It is demonstrated in real data simulation that with the proposed method significant amount of fuel can be saved compared to a conventional cruise control or a human driver.

Keywords: floating car data, look-ahead control, energy optimization, cruise control

1. Introduction

Vehicles equipped with conventional cruise control systems are able to maintain steady speed set by driver. In general this is the maximum prescribed velocity on the given road section, i.e the speed limit. Adaptive cruise control systems are becoming widespread in vehicles of today. This device augments the functionality of the standard cruise control by following the preceding vehicles automatically at a predefined safe distance. However, these cruise control systems do not have information about farther road sections (speed limits and terrain characteristics), thus the selected speed is not optimal in terms of economy and emission.

Several methods in which road inclinations are taken into consideration have already been proposed, see [13, 3]. In [12] the approach was evaluated in real experiments where the road slope was estimated. Thus a look-ahead system with road information consideration can select speed in coherence with the oncoming road, for example reduce the speed in advance of slopes or speed limits. A look-ahead control method for the design of the vehicle's speed has been proposed by [10, 9], where it has been shown that by considering oncoming road sections significant amount of energy can be saved.

However, as adaptive cruise control systems mentioned above consider the instantaneous traffic information by following the preceding vehicle velocity profile if necessary, the look-ahead systems proposed by the authors do not consider traffic information about the oncoming road sections.

The aim of this paper is to incorporate traffic information gained by floating car data (FCD) systems in the velocity planning process of the look-ahead cruise control system. By this means, the energy optimal velocity profile of the vehicle can be in coherence with the oncoming traffic augmenting the functionality of the look-ahead method.

This paper is organized as follows. In Section 2 the technical issues and future trends in the field of FCD systems are detailed. In Section 3 the proposed look-ahead control method augmented with the consideration of FCD data is discussed. In Section 4 the operation of the look-ahead controller is presented in a real data simulation example. Finally, Section 5 contains some concluding remarks.

2. Floating Car Data

As on-board electronic devices such as GPS systems are becoming increasingly popular in today's vehicles, the possibility of gaining useful information about vehicles on the road network to improve short and long term predictions of traffic data is getting increasingly desirable. The main idea of FCD systems is to collect data available by already existing on-board devices. The basic FCD collection system records time and vehicle location provided by a GPS receiver or cellular data of mobile phones, and uses a GSM/GPRS transmitter to send the information package to the central system for post-procession. If a sufficient number of vehicles (often referred to as probe vehicles) are involved in the data collecting process this can be used to detect congestion on given road sections and estimate the traffic flow speed.

In contrast with traditional and widespread fixed-point traffic data collection technologies (video cameras, inductive loops, radar sensors, etc) floating cars act as moving sensors traveling with the traffic stream. One of the biggest advantage of the FCD system is that it does not require any additional instrument to be set up and maintained on the road network, thus the cost of gathering real-time traffic information makes it valuable to realize. If additional information is gained from the vehicle electronic control unit (gear status, brake usage, revolutions per minute, windshield wipers application, temperature, traction control, etc.) weather conditions can be estimated and accident hazards can be detected as well. These data are referred to as Extended Floating Car Data (xFCD). Several FCD research projects have already been proposed by authors. The main contributions in the field of FCD and xFCD data systems have been summarized by [2].

A method based on GPS floating-car data (FCD) to acquire traffic congestion information is studied by [5]. Here data is generated by 500 taxis and after preprocessing, map matching, travel speed estimation, and several other key steps, a map which exhibits the traffic congestion distribution of the city is produced. A traffic estimation method based on a large scale real-time FCD system was developed and operated along the Italian motorway network with a penetration level of about 1.7 percent, as depicted by [8]. A historical floating car data based travel time estimation for the traffic network links was presented by [7]. An extension of the FCD principle was introduced by [11] with a novel approach based on a method of indirect detection of traffic objects (cars, cyclists, pedestrians) using radio-based Bluetooth/Wi-Fi technologies. The spatial structure and the interpolation of floating car speeds were analyzed by exact floating car speed data of the study area in Beijing, see [16]. The results showed that geostatistics as a new spatial analysis method can solve the spatial variability problems which traditional statistics methods cannot.

2.1. Communication and data acquisition

Communication is an essential element of the FCD systems. The communication is two ways: reporting data from the probe vehicles to the traffic information center and transmitting processed data back to the drivers of the vehicles (see Figure 1).

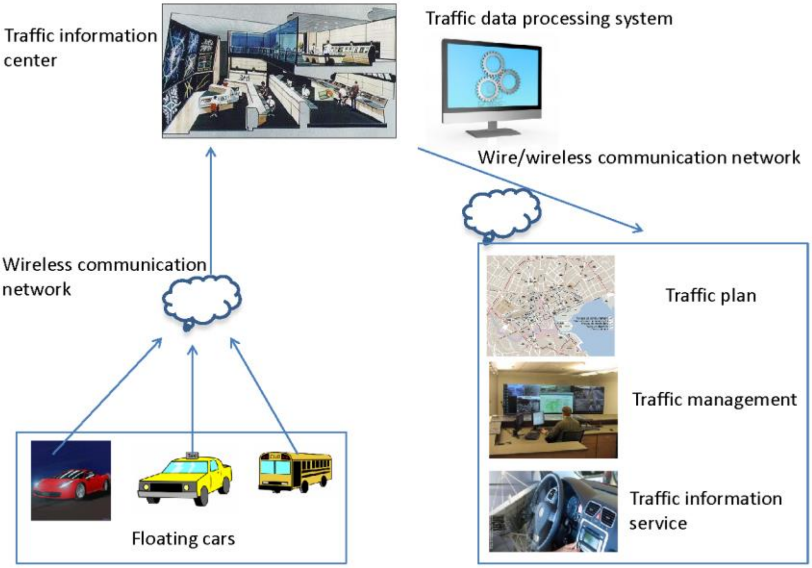

Figure 1. Composition of the floating-car system (based on [17])

During the data reporting of the FCD system time-relevant short messages are sent containing traffic relevant information such as location, speed and direction data. In the case of xFCD system other safety-related information collected by the vehicle sensors and ECU can also be sent for post procession. However, these data are outside the scope of this paper. Transmission delays of several minutes are acceptable in the case of standard FCD messages. The frequency of the messages are much more important. Implicitly, shorter sampling period results in higher data precision. [17] presented a theoretical method for floating-car sampling period optimization: considering velocity as a stochastic signal its frequency spectrum is analyzed using Fourier transformation and the optimal sampling frequency is decided by the Shannon sampling theory. The result shows that the optimal sampling frequency can achieve high data precision, which is suitable for practical applications.

The traffic stream must contain a certain number of probe vehicles as well in order to obtain reliable information for traffic analysis. The so called penetration level refers to the proportion of probe vehicles in traffic. Depending on the type and quality of the data required, this proportion can vary from 1 to 5 percent [4]. Speed is one of the most important floating car data used in this paper to develop a new look-ahead cruise control method. Accurate and reliable speed information is possible when the proportion of floating cars is over 3 percent in the traffic [6].

Data reporting can be accomplished with different types of communication channels, including cellular data, GPRS, DSRC, or wireless hotspot technology [2]:

- DSRC beacons are operated by the governments of Japan and Europe for their ITS information systems. This two-way short- to medium-range wireless communication channel is specifically designed for automotive use and its main function is electronic toll collection.
- Wireless hotspots are beginning to proliferate along the road network to serve professional truck drivers. The nature of the messages is not radically different from that used for electronic payment.
- Cellular network-based data is provided by the switched on mobile phones of the drivers and passengers of the probe vehicles. Triangulation and hand-over data stored by the network operator are used for localization, which is less accurate than GPS based systems. Thus, for reporting high data quality, several devices need to be tracked and more complex algorithms must be used. However, in metropolitan areas, where congestions are frequent and the distance between antennas is smaller, high data accuracy can be achieved. One of the main advantages of this data reporting is that no extra hardware is needed aboard in the probe vehicles.
- GPS-based FCD systems are the most common today. The GPS device receives the satellite signals to determine the location and speed of the probe vehicle.

2.2. FCD acquisition of mean speed for road sections

The principle of FCD data acquisition is shown in Figure 2. The speed data are recorded with a certain frequency using a GPS receiver or a cellular network database and sent to the traffic information center where these data are analyzed and statistically condensed with different algorithms. Every FCD message transmitted contains the probe vehicles' last-known positions for the evaluation of the map matching process. The mean journey speed and the variation on the predefined road sections can be calculated, which provides the basic information to augment the look-ahead cruise control system described later.

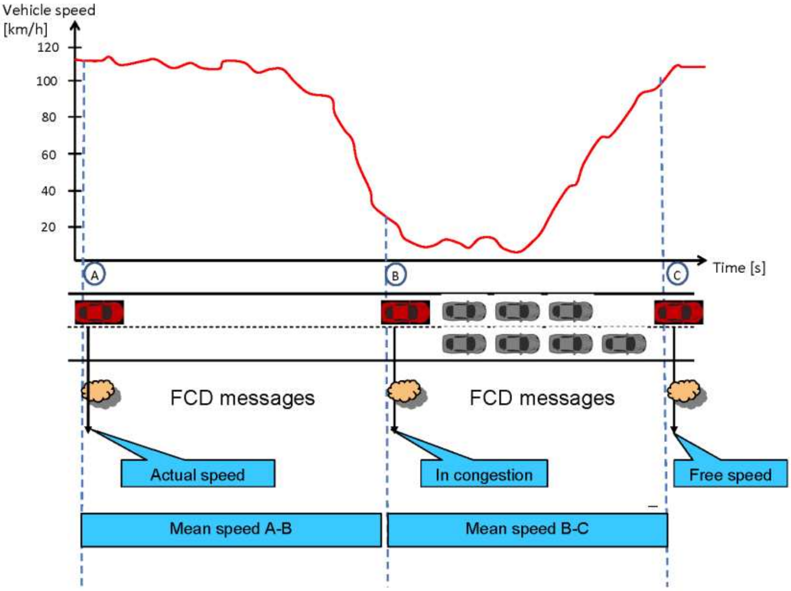

Figure 2. FCD vehicle speed acquisition (based on [4])

The FCD algorithm can be divided in three steps [8]:

- Map matching for each position using reported data. The most commonly used map-matching algorithms are the algorithm of point-to-curve and the algorithm of curve-to-curve [1]
- Routing (between subsequent positions) to determine the average speed along the tracks.
- The link travel speed is estimated based on the GPS position speed and the track average speed weighted exponentially with the GPS time distance for all cars passing the links.

3. Look-ahead control considering traffic information based on the FCD system

Given the real time mean velocities of the road network sections by the FCD system, there is an possibility to consider the oncoming traffic in the individual vehicle velocity design. If the forward traffic mean speed is considered, the look-ahead cruise control operation can be more effective and comfortable for the driver. For example, a cruise control system without the knowledge of oncoming traffic conditions must be deactivated and braking must be applied before a congested road section, which results in discomfort for the driver and an increase of the fuel consumption and emission. A look-ahead cruise control considering traffic information gained by the FCD system can adopt the real time (or even historical) data in the velocity design of the vehicle, thus the speed can be decreased in advance of a congestion (or slower traffic flow) on the road.

3.1. Energy efficient look-ahead control

The relationship between the energy optimal speed profile and the road inclinations was introduced in [10]. Thus, in this paper the detailed calculation of the optimal velocity is omitted, only the main results are summarized. The assumption is, that the path of the vehicle can be divided into *n* number of sections using *n*+1 number of points, see Figure 3.

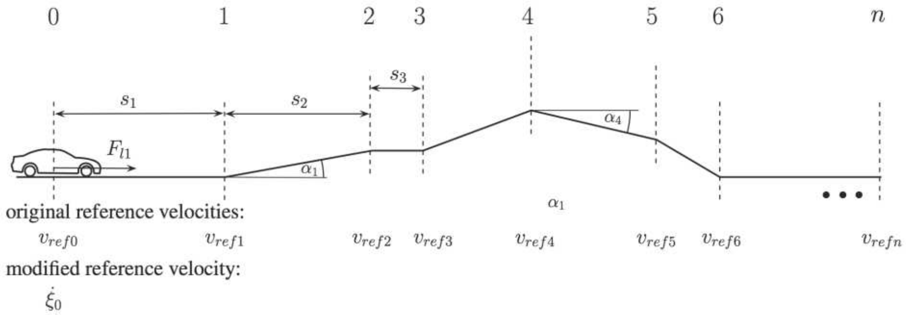

Figure 3. Division of predicted road

The rates of the inclinations of the road and those of the speed limits are assumed to be known at the endpoints of each section. The speed at section point *j* should reach a predefined reference speed $v_{ref,j}$, *j in [1,n]* which is the speed limit on the section, while the momentary value of the speed limit must also be taken into consideration in the following form: $\xi^2 \to v^2_{ref,0}$. The speed of the n^{th} section point is the following:

$$\dot{\xi}_n^2 = \dot{\xi}_0^2 + \frac{2}{m} s_1 F_{l1} - \frac{2}{m} \sum_{i=1}^{n} s_i F_{di} \tag{1}$$

where F_{di} is the disturbance force originating from the road slopes ($F_{di,r}$) and other disturbances such as rolling resistance, aerodynamic forces ($F_{di,o}$).

After adding weight *Q* to the momentary speed and weights γ_1, γ_2,..., γ_n to the reference speeds of the road sections in advance ($\gamma_1+\gamma_2+\ldots+\gamma_n+Q=1$) following formula is yielded for the optimal vehicle velocity:

$$\lambda = \sqrt{\vartheta - 2 s_1 (1-Q)\left(\ddot{\xi}_0 + g \sin\alpha\right)} \tag{2}$$

where

$$\vartheta = Q v_{ref,0}^2 + \sum_{i=1}^{n} \gamma_i v_{ref,i}^2 + \frac{2}{m}\left(\sum_{i=1}^{n}\left(s_i F_{di,r} \sum_{j=i}^{n} \gamma_j\right) + \sum_{i=2}^{n}\left(s_i F_{di,o} \sum_{j=i}^{n} \gamma_j\right)\right) \tag{3}$$

Equation (2) shows that the modified reference speed depends on weights *Q* and γ_i .Weights have an important role in control design. By making an appropriate selection of the weights the importance of the road condition is considered. The aim of the control design is to find an adequate balance between longitudinal force required by the travel (energy efficiency) and the tracking of the momentary value of the reference speed. This requirement can be fulfilled with the use of quadratic optimization procedure detailed in [10].

3.2. Energy efficient look-ahead control integrating traffic information in the design

The look-ahead control method discussed in Section 3.1 has defined the path ahead of the vehicle and divided it into n number of sections. It is assumed that the road inclination rates and the speed limits are known for all of these sections by using on-board devices such as GPS. Assuming that the vehicle can receive traffic information from the FCD system discussed in Section 2, there is a possibility to consider the mean speed of the traffic stream along the designed path of the vehicle. Denoting the mean traffic velocities at each section point ahead with $v_{traffic,j}$, j *in* $[1,n]$, it is possible to modify the look-ahead control algorithm as follows.

If the speed limit $v_{ref,j}$ at section point j exceeds the traffic stream velocity $v_{traffic,j}$, i.e $v_{ref,j} > v_{traffic,j}$, then the speed limit $v_{ref,j}$ is substituted for the mean traffic velocity $v_{traffic,j}$. Thus in the calculation of the optimal velocity λ in equation (2) theta is modified as follows:

$$\vartheta_{\mathrm{mod}} = \vartheta - \sum_{i=1}^{n} \gamma_i v_{ref,i}^2 + \sum_{i=1}^{n} \gamma_i \min(v_{ref,i}; v_{traffic,i})^2 \tag{4}$$

After adding design weights for the road sections as detailed in Section 3.1, the energy optimal momentary velocity can be calculated using equation (2) substituting with the modified theta.

3.3. Realization of the method

The proposed look-ahead cruise control system can be realized in three steps. Based on optimization tasks the weighting factors are calculated along with the reference speed is, see equation (2). In the second step the longitudinal control force of the vehicle (F_{l1}) is calculated. F_{l1} can be positive or negative forces as well, therefore the driving and braking systems are actuated. In the third step the real physical inputs of the system, such as the throttle, the gear position and the brake pressure are generated by the low-level controller. Figure 4 shows the architecture of the low-level controller.

In the proposed method the steps are separated from each other. Thus the reference signal unit can be designed and produced independently of automobile suppliers and only a few vehicle data are needed. The independent implementation possibility is an important advantage in practice.

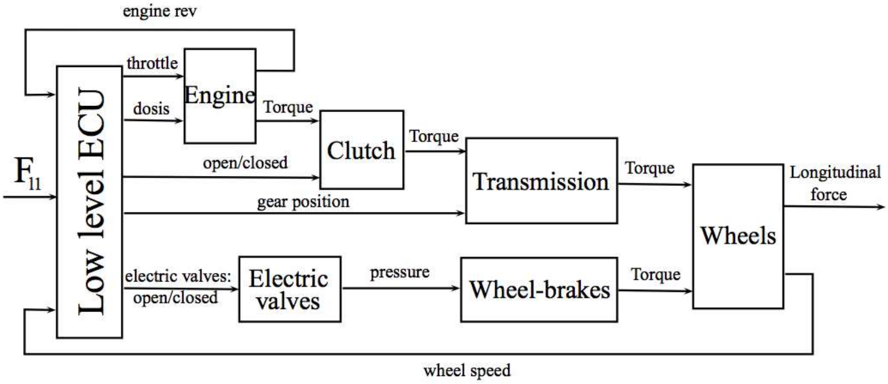

Figure 4. Architecture of the low-level controller

4. Simulation results

In this section the proposed look-ahead method considering road and traffic information is tested and compared in a real data simulation using Carsim simulation environment. The proposed look-ahead control method considering FCD for the velocity design is implemented in Matlab/Simulink. The road characteristics are those of the access road between M7 Hungarian motorway and the city of Gyor in a 5.3 km long section, as it is shown in Figure 5 denoted by the black line.

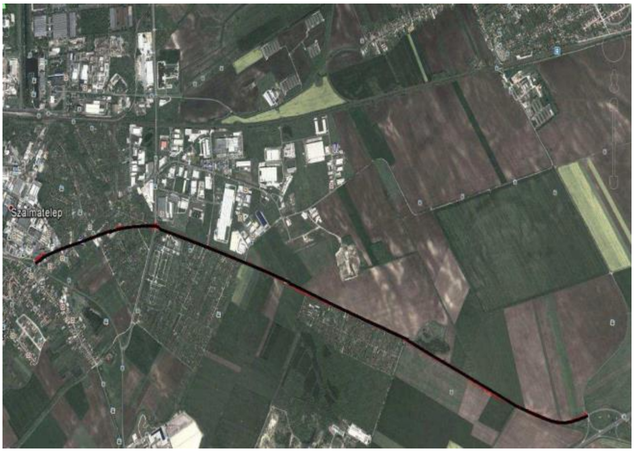

Figure 5. Selected road for simulation

The selected road section has a maximum slope angle of 5 percent. The terrain characteristics are shown in Figure 6. The vehicle used for the simulation is an F-Class sedan with a 300 kW engine, meeting the EURO 4 emission standards. The speed limit on the road is 90 *km*/*h* before it reaches the urban area, where it is decreased to 60 *km*/*h* and 50 *km*/*h*, as it is shown in Figure 7 denoted by the red line. It is assumed that before the first roundabout between 3.5 *km* and 4.5 *km* the velocity of the traffic stream decreases to 25 *km*/*h*.

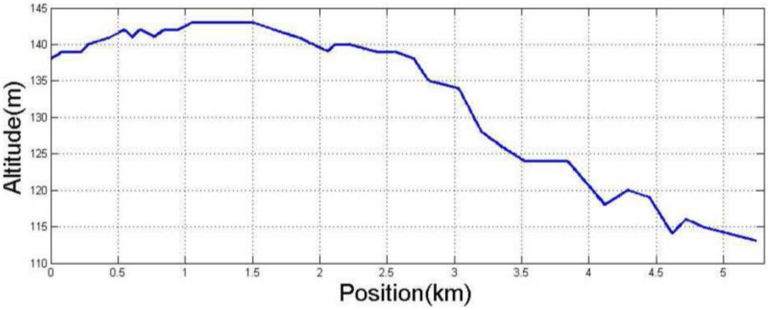

Figure 6. Terrain characteristics of the road

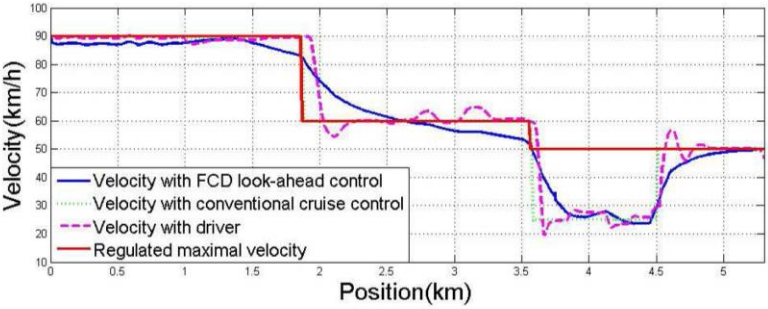

Figure 7: Velocity profile of the different methods

For the validation of the optimization method listed in Section 3 three different simulations were carried out and compared. In the first simulation the behavior of the driver is demonstrated using a longitudinal linear driver model described in [2]. In the second simulation the operation of a conventional cruise control is realized. The look-ahead control considering FCD system traffic information detailed in Section 3.2 is implemented in order to minimize the actuated energy of the vehicle, thus minimizing the fuel consumption of the vehicle.

In Figure 7 the velocity profile resulting from different control methods is shown, including the case where the speed is regulated by the driver. It is well demonstrated that the different methods result in very different velocity trajectories. The conventional cruise control follows the velocity set by the driver accurately, and does not consider the forward speed limits, terrain characteristics or traffic conditions in the velocity control. The velocity profile of the driver is more uneven and the vehicle velocity exceeds the speed limit when traveling on a steep slope, while the velocity of the vehicle falls back on uphill sections. This is due to the fact that the driver does not have information about the oncoming road disturbances or traffic, and responds with a time delay to changes in road conditions. The velocity profile resulting from the proposed look-ahead method is basically different because of the consideration of forward road and traffic information. It is well demonstrated that the controller calculating with FCD information begins to decrease the vehicle velocity in advance of the road section where the heavy traffic induces lower travel speed than that given by the speed limit.

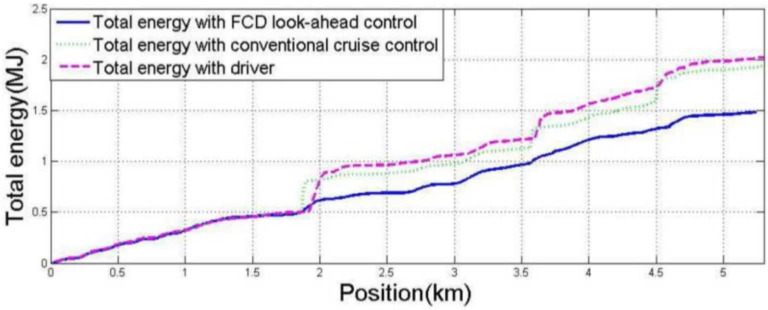

Figure 8: Total energy consumption of the different methods

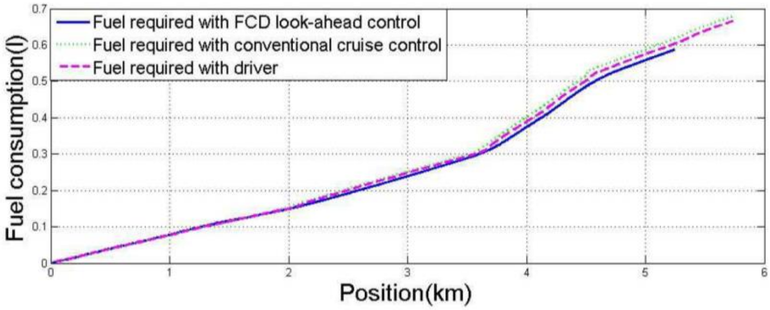

Figure 9: Fuel consumption of the different methods

In Figure 8 the total actuated energy of the different methods are compared. The lack of forward road information consideration resulting in abrupt speed changes by the driver and the conventional cruise control induce harder and more frequent use of the brake and acceleration compared to the proposed method. Thus, the total energy consumption (including the energy of the braking process) can be decreased by almost 25 % with the proposed method. The same conclusion can be drawn for the fuel consumption of the vehicle, which correlates with the total energy consumption. The difference in fuel consumption between the three methods is smaller because it does not reflect the energy loss of the braking process, see Figure 9. However, it is worth mentioning the reduced usage of the brake system implies longer lifetime for the brake pads and discs, thus the cost of vehicle maintenance can be decreased as well.

5. Conclusion

The paper has presented a design for vehicle speed control considering forward road information such as speed limits, terrain characteristics and traffic stream velocity gained with the use of a floating car data system. It has been demonstrated by simulation that the proposed method has great traffic benefits in terms of actuated energy and fuel consumption. The main novelty of the paper is the incorporation of the forward traffic mean speed information gained by the FCD system in the automatic look-ahead cruise control velocity design process.

Acknowledgment

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Development of Vehicle On-board Communication System for Harsh Environment

Sz. Aradi[1], T. Bécsi[1], P. Gáspár[2]

[1] Department of Control for Transportation and Vehicle Systems Faculty of Transportation Engineering and Vehicle Engineering, Budapest University of Technology and Economics
e-mail: aradi.szilard@mail.bme.hu; becsi.tamas@mail.bme.hu,
[2] Systems and Control Laboratory, Computer and Automation Research Institute, Hungarian Academy of Sciences
e-mail: gaspar.peter@sztaki.mta.hu

Abstract: Utilizing the already installed train interconnection cables as the physical layer of an extended intra-train communication could be a cost-effective solution. However these interconnection solutions are not optimal for the standardized digital data transfer solutions. The paper gives a brief summary of the theoretical aspects of data transmission, and experimental test results of the digital data transfer using non-standard physical layers.

Keywords: rail transport, on-board communication, network structures

1. Introduction

On-line communication, telemetry and fleet management has gained a significant role in today's modern rail transport. Such systems utilize high level integration of communication, data management and control systems. The intra-train communication network is a significant among them. To extend the information chain on the train level, a network is needed to reach all units of a train. Multiple train communication networks exist for general train control purposes, such as remote traction control to handle push-pull train operation, door and light control, or audio channels. However the need for extended services of intra-train communication has arisen.

They serve two purposes:

- First is to improve passenger satisfaction by providing real-time information about the state of the journey, i.e. current delay, estimated arrival, connections etc. This information could be displayed in passenger cars via different kinds of displays, which are supplied with reliable data from the on-board unit of the driver's stand.
- Second is to improve train information for the operator. The telemetry or the automatic enrollment of train units can be centralized on the train level with a closed communication solution, where the only connection to a central data centre of the operator is managed by the on-board unit.

There exists a standardized extension of the Train Communication Network [8] [9] in newly introduced passenger and traction units providing additional channels and protocols for these purposes. However the spread of these solutions is limited, and the operators need to handle the problem on existing units, which are intended to be in service for a long time.

This motivates the operators to implement such a communication system on their current fleet [12]. The task can be handled in two different ways of which the first is to install additional wiring and connectors on their units. This solution could result in a well-designed multi-purpose and, most importantly, closed and independent communication system. However, the installation costs are high. The other way is to use the already installed connection system of the trains. Naturally one must examine the pin allocation of the connectors of the current system and determine those wire pairs that do not carry safety-critical information in order to maintain the safety level of the train operation.

The paper deals with the problems of using the already-installed interconnection for extended communication purposes with alternative protocols. The non-standard physical layer, the non-fixed topology of the network, network length and speed are discussed.

In Section 2 the specialities of the vehicular environment are presented. The brief introduction of the transmission line theory and the differential signalling technologies are described in Sections 3 and 4 respectively. The experimental results are presented in Section 5.

2. Vehicular environment

The topology of the train units and the formation of the already installed interconnections indicate that such a communication system could only use two kinds of network topology: the chain and the bus topology, as shown on Figure 1. Since the chain topology breaks the continuity of the cable, the bus topology seems to be the suitable solution for the proposed network solution.

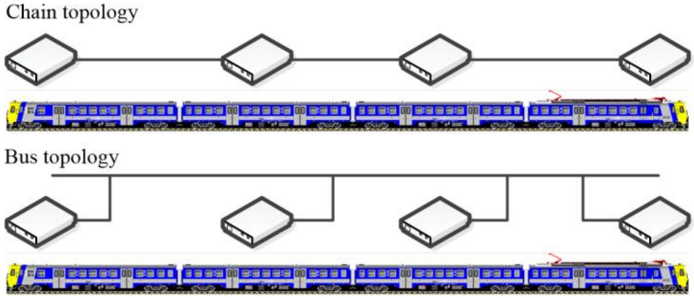

Figure 1: Train network structure

The problem becomes more complex, since the Hungarian State Railways uses four different systems for train interconnection: three old standards left from the Comecon era, and the UIC 558 [11] standard. Each system has different wiring, shielding, and termination carrying multiple kinds of analogue or digital signals on high or low voltage and current. These parameters influence the feasibility of the communication.

Moreover the network topology of the train is not fixed, since the individual units can build up different formations in length, or in the position of the traction and/or control units. This feature of the modular network poses several problems. The proper or even adaptive termination of wire pairs, the determination of achievable network speed, and the network build-up must be solved. Another problem is the separation of communication devices if the train uses the interconnection wire for its primary function. The discussion of these topics is not intended in this paper, though the examination of the physical layer and the determination of the feasible data transfer are discussed in the coming sections.

3. Transmission line principle

The term transmission-line in electromagnetics is commonly reserved for those structures which are capable of guiding Transverse Electromagnetic (TEM) waves. Transmission-lines are a special class of the more general electromagnetic waveguide. TEM waves can only exist in structures which contain two or more separate conductors. Coaxial lines, parallel plates, and two-wire lines are examples of practical transmission-lines [3]. Practically a transmission line is a two-port network (see Figure 2) connecting a generator circuit at the sending end to a load at the receiving end.

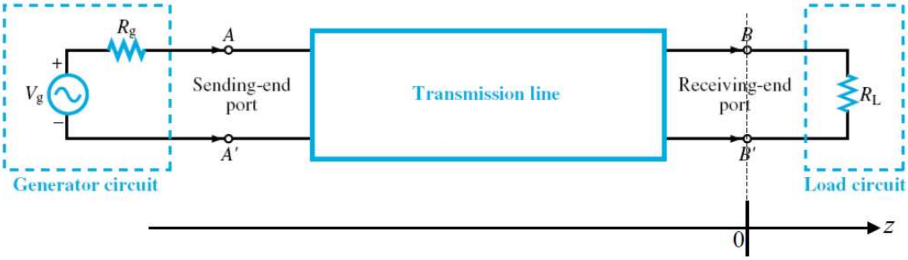

Figure 2: General transmission line [4]

One can analyse the transmission lines using circuit theory concepts breaking the line into small sections so that the circuit element dimensions will be much smaller than the wavelength. To do this, the transmission-line is described by a series resistance per unit length R, series inductance per unit length L, shunt conductance per unit length G, and shunt capacity per unit length C. A small section of the transmission-line with length dz thus has the following equivalent circuit as shown in Figure 3. This concept is also known as distributed parameter representation.

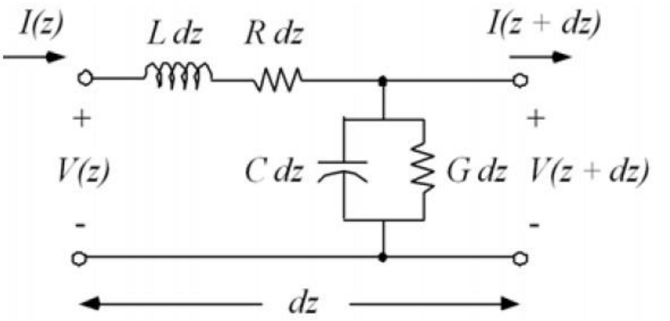

Figure 3: Transmission line section [3]

The following parameters are related to the physical properties of the material filling between the wires:

$$LC = \mu\varepsilon, \ \frac{G}{C} = \frac{\rho}{\varepsilon},$$

where μ, ε, ρ are the permittivity, permeability, conductivity of the insulator of the wires respectively. The characteristic impedance Z_0 is the most important parameter of the transmission line. It depends on the distributed parameters (which depend on the material of the conductor and the surrounding of the wires) and ω:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

For lossless transmission lines $R = G = 0$ and it can be proved that the frequency dependence of the characteristic impedance will cease thus we can approximate $Z_0 \approx \sqrt{L / C}$.

3.1. Reflections in transmission lines

In subsequent analyses, only lossless transmission lines will be considered. Take a finite length transmission (see Figure 4) terminated with load impedance Z_L at the end.

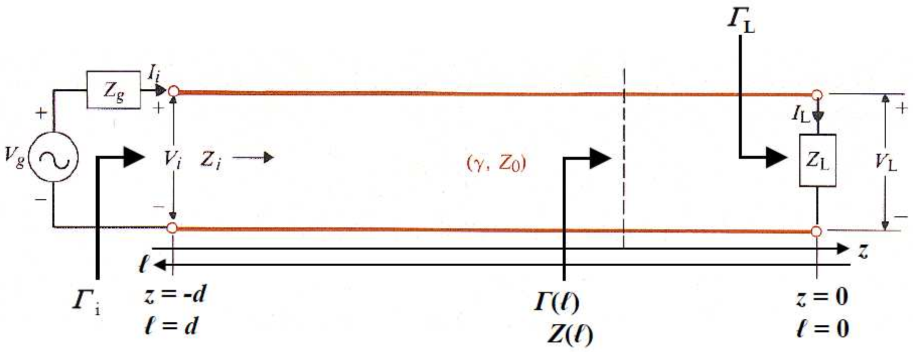

Figure 4: Terminated transmission line circuit [4]

At the position of the load (l=0) the voltage is V_L and the current is I_L thus:

$$V_0^+ + V_0^- = V_L$$

$$V_0^+ + V_0^- = V_L$$

$$\frac{V_0^+}{Z_0} + \frac{V_0^-}{Z_0} = I_L$$

$$\frac{V_L}{I_L} = Z_L$$

where V_0^+, V_0^-, I_0^+, I_0^- are the wave amplitudes in the forward and backward directions at z=0 and γ is the complex propagation constant given by $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$. By solving the above equations the following expression is obtained:

$$\Gamma_L = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Finally, the summary of the special cases yield the following results:

- Short circuit: Z_L=0→Γ_L=−1
- Open circuit: Z_L=inf→Γ_L=+1
- Matching termination: Z_L=Z_0→Γ_L=0

From a practical point of view it can be stated that when the data rate is low or the cables are short, termination may be unnecessary. As data rates increase, termination becomes important. Since any device on the bus can transmit, it is probable that a node within the middle of the bus will transmit requiring that termination be applied to both ends of the bus segment. The termination impedance must match the characteristic impedance of the wire. Using high frequency communication the imaginary part of the impedance is negligible thus a normal resistor (termination resistor) can be used.

4. Differential signaling technologies

During the review of the possible solutions the constraints of the vehicular environment must be considered, which fundamentally affect the technological possibilities.

- The train interconnections are considered as a transmission line, which consists of shielded and twisted wire fours.
- The maximum bus length is 500 m.
- Bus topology will be used.
- Harsh environment (extreme temperature, humidity and mechanical stress).
- Standard communication technology will be used.

Based on the above the solution could be one of the differential signalling technologies. Two of the collision domain segment network buses can satisfy all of these requirements: EIA-485 and Controller Area Network.

4.1. TIA/EIA RS-485-A

One of the more popular technologies for interconnecting devices on a network is TIA/EIA-485-A, known throughout industry as RS-485, see [1] [2]. According to the standard it specifies the characteristics of the generators and receivers used in a digital multipoint system. It does not specify other characteristics such as signal quality, timing, protocol, pin assignments, power supply voltages or operating temperature range.

An EIA-485 bus usually consists of two or more communication controllers each powered by a separate power source. At a minimum, a single shielded or unshielded twisted-pair cable interconnects the various controllers in a daisy-chain fashion. In some instances a short stub is allowed; however, higher speed networks usually do not allow stubs. Star topology is definitely not recommended. Termination is usually applied to the ends of the network.

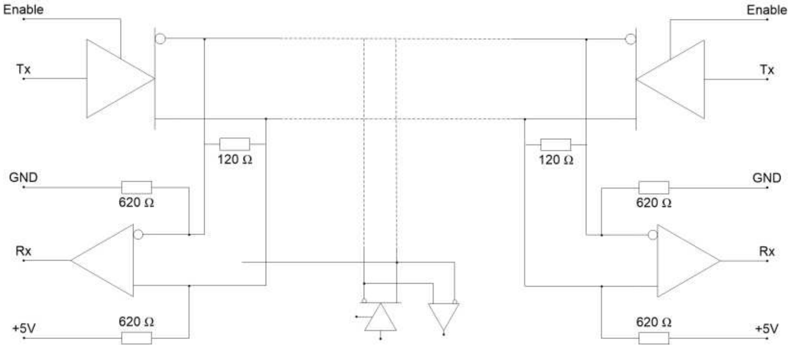

Figure 5: EIA-485 network structure

The standard basically specifies the parameters (unit load, output drive, common mode voltage etc.) of the drivers, receivers and transceivers attached to the network. Basically a driver must be able to source at least 1.5 volts differentially into 60 ohms (two 120 ohm terminators in parallel along with 32 unit loads) under a common mode voltage range of -7 to +12 Vdc. Data rates are not specified and there is a wide range of devices that conform to the standard but are intended either for high speed (up to 50 Mbps) or low speed (skew rate limited). In terms of the Open Systems Interconnection Reference Model (OSI), EIA-485 only defines the lowest layer â€” the physical layer. It is used by several higher layer protocols such as Profibus, ARCNET and other token-based protocols. There are several key topics that must be considered when deploying EIA-485 networks such as termination, fail-safe bias, connectors, grounding, cabling and repeaters. Form our point of view the most important parameters are the termination and the cabling. Terminating a data cable with a value equal to its characteristic impedance reduces reflections that could cause data errors. The most popular approach is DC termination although this approach results in higher power dissipation. Resistive terminators typically have values of 120 to 130 ohms although twisted-pair cable impedances can be as low as 100 ohms. An 100 ohm termination resistor is too low for the EIA-485 drivers. A value closely matching the cable impedance must be applied at some convenient location as close to the ends of the cable segment as possible.

One of the more critical decisions to make is the selection of cable. Cable selection depends on several factors including data rate, signal encoding and distance desired. Cables attenuate the transmitted signal and introduce distortion of the signal waveform itself. Additional distortion occurs by the way receivers are biased. Jitter can occur when the receiver attempts to recover the distorted data. Intersymbol interference results when a new signal arrives at the receiver before the last signal reached its final value. Therefore, the two successive symbols interfere with one another resulting in a time shift in data recovery which is called jitter. Some jitter is usually acceptable, however, if it is excessive, the only solution is to obtain better cable, reduce the modulation rate or reduce the distance.

4.2. Controller Area Network

The Controller Area Network (CAN) [6] is a serial communications protocol which efficiently supports distributed real-time control with a very high level of security. Its domain of application ranges from high-speed networks to low-cost multiplex wiring. In automotive electronics, engine control units, sensors, anti-skid-systems, etc. are connected using CAN with bitrates up to 1 Mbit/s.

CAN is a multi-master bus with an open, linear structure with one logic bus line and equal nodes. The number of nodes is not limited by the protocol. Physically the bus line (Figure 6) is a twisted pair cable terminated by termination network A and termination network B. The locating of the termination within a CAN node should be avoided because the bus lines lose termination if this CAN node is disconnected from the bus line. The bus is in the recessive state if the bus drivers of all CAN nodes are switched off. In this case the mean bus voltage is generated by the termination and by the high internal resistance of each CAN nodes receiving circuitry. A dominant bit is sent to the bus if the bus drivers of at least one unit are switched on. This induces a current flow through the termination resistors and, consequently, a differential voltage between the two wires of the bus. The dominant and recessive states are detected by transforming the differential voltages of the bus into the corresponding recessive and dominant voltage levels at the comparator input of the receiving circuitry

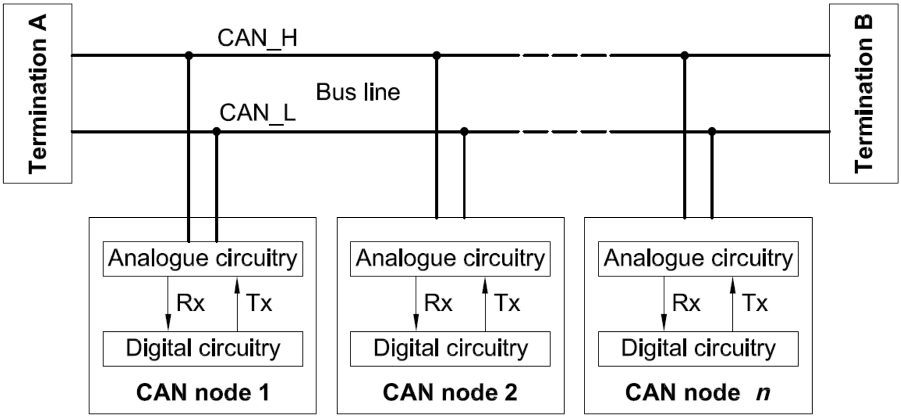

Figure 6: CAN bus structure [7]

The CAN standard [7] gives specification which will be fulfilled by the cables chosen for the CAN bus. The aim of these specifications is to standardize the electrical characteristics and not to specify mechanical and material parameters of the cable. Furthermore the termination resistor used in termination A and termination B will comply with the limits specified in the standard also.

Besides the physical layer the CAN standard also specifies the ISO/OSI data link layer as well. CAN uses a very efficient media access method based on the arbitration principle called "Carrier Sense Multiple Access with Arbitration on Message Priority", see [7]. Summarizing the properties of the CAN network the CAN specifications are as follows [6]: ű

- prioritization of messages
- guarantee of latency times
- configuration flexibility
- multicast reception with time synchronization
- system wide data consistency
- multi-master
- error detection and signalling
- automatic retransmission of corrupted messages as soon as the bus is idle again
- distinction between temporary errors and permanent failures of nodes and autonomous switching off of defect nodes

These properties result in significant advantages over the EIA-485 standard.

4.3. Experimental verification

In this section the result of our experimental verification is presented. It is assumed that the ends of the network cannot be terminated because in practice one should switch the termination resistors at both ends of the train during every train composition. Thus every node on the locomotives must have its own termination which cannot have a standard value because more than two nodes may be connected to the bus. In this case the equivalent resistance of the parallel resistors may be too small, which could cause the overload of the transceivers. In these laboratory tests the effects of the non-standard termination resistor with different cable lengths and data rates on a CAN bus are examined.

The effects of an order of magnitude higher termination resistors were tested with different cable lengths and baud rates. The test setup was composed of standard UTP cable (Z_0=120Ω) with switchable termination resistors at both ends and USB-CAN interfaces. During the measurements 10 different messages with extended ID and 8 data-bytes were sent with a suitable frequency causing approx. 100 % bus load. In every test case 10 000 messages were sent from the one end and logged on the other end of the network. In Table 1 the termination type and value are signed: -/-: open circuit, 120/-: termination at one end, 120/120 termination at both ends. Firstly entirely unshielded twisted pairs (U/UTP) cables were used with different bus lengths, then shielded twisted pairs (F/UTP) were used with fixed length. The measurements found that at lower baud rates the bus can work without termination, but using only one termination resistor can result in significant improvement in the communication. Of course the measurements verified that the highest baud rates can be achieved with standard termination at both ends.

The most important result is related to the non-standard termination resistors. In this case 1500 ohm resistors (weak termination) were used, which resulted in a sufficiently high equivalent resistance with more than two nodes. These tests found that the maximum baud rate decreased to a quarter of the standard values, but it is twice the open circuit values. These tests were performed with 1200 ohm resistances with the same results. It is also remarkable that in a borderline scenario the CAN protocol detected the errors (15 error frames) and resent the messages.

Table 1: Laboratory test results

Length	Termination (Ω)	Baud rate	Error rate	Cable type
10m	-/-	250K	0%	UTP Cat. 5
10m	-/-	500K	100%	UTP Cat. 5
10m	120/-	1M	0%	UTP Cat. 5
20m	-/-	125K	0%	UTP Cat. 5
20m	-/-	250K	100%	UTP Cat. 5
20m	120/-	1M	0%	UTP Cat. 5
40m	-/-	100K	0%	UTP Cat. 5
40m	-/-	125K	100%	UTP Cat. 5
40m	120/-	500K	0%	UTP Cat. 5
40m	120/-	1M	100%	UTP Cat. 5

40m	120/120	1M	15.17%	UTP Cat. 5
80m	-/-	50K	0%	FTP Cat. 6
80m	-/-	100K	100%	FTP Cat. 6
80m	120/-	250K	0%	FTP Cat. 6
80m	120/-	500K	0%+15% error frame	FTP Cat. 6
80m	120/120	500K	0%	FTP Cat. 6
80m	120/120	1M	100%	FTP Cat. 6
80m	1500/-	100K	0%	FTP Cat. 6
80m	1500/-	125K	100%	FTP Cat. 6
80m	1500/1500	125K	0%	FTP Cat. 6
80m	1500/1500	250K	100%	FTP Cat. 6

4.4. Conclusion

In this paper the first step of our research was presented focusing on on-board vehicle communication systems in a special environment. The motivation for using train interconnection cables was explained. The theoretical basis of the transmission line and the differential signaling technologies were briefly introduced. For its significant advantages the CAN standard was chosen for further examination. It was stated that the network would be terminated only with non-standard termination resistors because of the variable topology. The aim of the tests was the verification of the behavior of such a CAN bus. The laboratory experiments found that the network with non-standard termination could operate with twice the data rate of the open circuit. The next step will be the field test using the train interconnection cable with maximum required length. With this "weak termination" method the maximum reliable data rate will be located in the real environment. Based on the results possible further research will be conducted for increasing the data rate.

5. Acknowledgement

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Estimation of Passenger Demand in Urban Public Transport

B. Horváth, R. Horváth, B. Gaál

Széchenyi István University, 9026 Győr, Egyetem tér 1.
Phone: 503 400, fax: 613 561
e-mail:hbalazs@sze.hu,ricsi@sze.hu, gaalb@sze.hu

Abstract: This article shows a renewed, improved, practical variant of a former theoretical matrix estimation method. The authors will demonstrate the method's theoretical and practical sides on a test network.

Keywords: public transport, travel demand, OD matrix estimation, VISUM

1. Introduction

The principle of every transport planning task is the knowledge of travel demands. It is especially in public transport, where demand and supply heavily related. As the operation of public transport financed from common sources, it is utmost importance, that the creation and development of the public transport system must be based on objectivecriteria. Estimation of transport demand has long history, the authors also have dealt with the problem in the quoted publications [8][7] earlier.

Former procedures usually oversimplified the complex issue of route selection or contained an excessively high number of non-automatable, manual steps making impossible the modelling of extensive and complex networks [16].

In the first part we show the accomplishments of this field, in the second part we specify the theoretical background of our procedure, the third part contains the embedment of the procedure into a state-of-art transport planning software. Finally we prove the method's applicability in practice one test network.

2. Previous accomplishments

The bibliography of the matrix estimation methods is abundant. Even so, only a little portion of these deals with public or multimodal transportation, the great majority is about private transportation.

In the last few decades the 4-step (or 4-stage) model has become the most recognized transport planning procedure. In this method travel demand can be determined during a four step process. The first step is trip generation. Homogeneous areas, zones have to be defined on the basis of different aspects and the departing and arriving traffic of these zones have to be given. Consequently, the sums of the rows and columns ofan OD (origin-destination) matrix have to be defined. The next step is modal split. Practically, so many OD matrices have to be done as many transport modes are actually studied. In the third step (trip distribution) the OD matrix is filled, the from-to traffic is determined. Finally, the last step is the flow assignment, when demand is assigned onto the transport network.

One of the most problematic parts of the model is the filling of the OD matrix. Detailed data are needed for the knowledge of the accurate demand. Traditionally, these data were obtained by home interviews and roadside surveys. However, this kind of data collection is expensive in terms of money and manpower and at the same time it contains internal sources of error because of sampling processes and problems in elaboration [13].

Hence, professionals mostly apply some kind of matrix estimation method. Through these methods relatively precise estimations can be made by considering traffic counts and other information. Advantages of traffic count are less expenditure (money, manpower) and suitability to follow the changes of demand in time. Also, it is developable and automatizable by means of modern technology.

Among OD matrix estimation methods there are several approaches.

Van Zuylen and Willumsen suggested the application of an entropy maximization method for un-congested networks [15]. Partially, this was the base of the most likelihood estimation [11][2], the least squares estimation [3][1] and Bayesian framework methods [11]. These approaches were generalized and enhanced by other authors [17][10][6].

Beside static estimations, which assume time-independence, dynamic estimations have evolved. By the help of these time-varying OD flows and matrices can be determined using time-varying traffic counts [4]. On the field of the usage of dynamic estimators there are two main approaches. Simultaneous estimators give estimations jointly for all OD matrices for all time slices using every obtained data set. Sequential estimators ensure computational advantages since they disassemble the whole optimization problem into more manageable pieces and give the possibility of using the estimates for an interval as a priori estimate of subsequent intervals [12].

Matrix estimation methods are tightly connected to flow assignment methods. It is possible to verify the retrievability of the counted traffic with the estimated data by assigning the OD matrix onto the transport network. When there is a significant difference between the counted and computed values, the results can be refined by subsequent iteration steps.

The abovementioned methods can be used for estimating public transport demand also. Li and Cassidy created an algorithm to estimate the OD matrix of transits by boarding and alighting data on (bus) stops [9]. The number of boarding and alighting passengers at a stop can be counted simply and solely. These data give the sums of rows and columns of the OD matrix. These sums can correspond to many OD matrices, the most appropriate must be selected out of them. To get the most likely OD matrix another seed-matrix (or base matrix, model matrix) is needed, which contains the travel preferences of passengers. (Generally, this is an older OD matrix.) In the algorithm, the authors differentiate „minor” stops like the ones in residential areas and „major” stops, the ones that serve activity centres such as large business, multimodal transit point etc. On this basis, different likelihoods can be assigned to the trips between single stops.

Obviously, a trip between two residential stops has less likelihood than a trip between stops of residential and industrial or service areas (i.e. trip between home and workplace) on a common weekday.

The algorithm suitable to assign not only the OD matrix of the passengers on the examined route, but also the likelihood of alighting in each stop. Since this latter characterize the destination of trips, it is assumable that it remains approximately the same in case of transit trips under the same circumstances. Utilizing this assumption the OD matrices of future travels can be estimated more precisely.

OD matrices of public transport can be used for example to evaluate the service quality of public transport networks and to compare them. Good example is the survey of the bus network of Porto, Portugal by Guedes et al. They made an OD matrix from data of electronic ticket validation (utilizing the fact that most of the passengers also travel back). The parameters of service quality like travel time, number of transfers, waiting time etc. easily computable in view of the matrix and the network [5].

Transport planning in the field of public transport became accentuated subsequent upon the problems caused by the intense growth of urban traffic and increase in demand for liveable environment. The large-scale headway of private transport in cities and the increasing demand for mobility forced positive discrimination of public transport upon the decision-makers to handle the problems. To substantiate decisions and strategies connected to these challenges theoretical and methodological bases are needed, therefore researches will be more frequent in this field of science expectedly.

3. Theoretical background of the matrix estimation method

The basis of the matrix estimation procedure shown in this article was developed by Prileszky [14]. This is the revised, improved version of the original method sunk into oblivion.

3.1. Theory of the matrix estimation method

As mentioned before, the basis of the transport planning is the knowledge of transport demands. Considering the fact, that the budget and elaboration time of short-term and medium-term planning is restricted, there is no possibility of detailed data collection in every case. In case of most projects, however, there is a full-scale cross-section passenger counting and OD survey sample during the preparation of the planning.

The essence of this method is, that the data gathered in the course of the passenger counting let us be allowed to correct the elements of the sample matrix gained from the survey.

It is possible to make use of the data of the passenger counting in two ways. On the one hand these give information about the number of boarding and alighting passengers at each stop; on the other hand these give information about the travellers' number between stops.

These data can be produced with the use of a suitable flow assignment procedure.If we compare the obtained data from the two sources (counting, assignment) we have an opportunity to correct the model matrix. In order to do this correction, we have to use the boarding and alighting numbers and the numbers of passengers between stops.

3.2. Operation of the model

The sums of rows and columns of the OD matrix that is the number of departing and arriving passengers of each zone equals to the sum of the boarding and alighting passengers of the stops in the given zone. Because all of this, the sums of rows and columns of the OD matrix (to be determined) are known on full scale cross-section passenger counting.These are utilizable as target values through the following calculations.Boarding and alighting numbers compared to the sums of rows and columns of the model matrix expose the difference between the model (seed) and target matrices, which difference can be corrected by row and column factors. It is especially important to notice that the p_i and a_j values refer to departing and arriving passengers in the model matrix, however, the P_i and A_j values are the boarding and alighting numbersof the passenger counting, that is the latter contains transfers. Taking account this problem the planned sums of rows and columns have to be corrected before the above mentioned factor calculation. This means that the sums of rows and columns of those relations where the transfer occurs have to be corrected.

The basis of the transfer correction is the following connection:

$$\frac{p_i}{p_i + \acute{a}t_i} = \frac{P_{korr,i}}{P_i} \tag{1}$$

where $\acute{a}t_i$ numbers of transfers in i. stop

By this correspondence it is possible to calculate the corrected target row and column sums.

$$P_{korr,i} = P_i \cdot \frac{p_i}{p_i + \acute{a}t_i} \tag{2}$$

$$A_{korr,j} = A_j \cdot \frac{a_j}{a_j + \acute{a}t_j} \tag{3}$$

$$P_i = \sum_{n=1}^{k} F_{i,n}; \quad A_j = \sum_{m=1}^{k} L_{j,m} \tag{4}$$

where k number of stops in studied zone

$F_{i,n}$ boardings in n. stop of i. zone

$L_{j,m}$ alightings in m. stop of j. zone

Executing this correction step the row and column factors can be calculated as the following:

$$s_i = \frac{P_{korr,i}}{p_i} \tag{5}$$

$$o_j = \frac{A_{korr,j}}{a_j} \tag{6}$$

where s_i i. row’s factor

o_j j. column’sfactor

However, as we mentioned, this matrix estimation method doesn’t use only stop point data. We take into consideration the data of passenger numbers between stops to achieve adequate precision. These are called link data, factors deriving from them are link factors. Preparation of these link factors is more complex task than of the row and column factors taking into consideration that the model link data are unknown. To determine model link data we have to assign the model matrix onto the transport network. The generated link loads give the model link data, which can be compared to the counted number of passengers between stops.

$$él_{i,j} = \frac{real\ link\ load_{i,j}}{computed\ link\ load\ from\ assignment_{i,j}} \tag{7}$$

After calculating the factors of every row, column and link, they have to be linked to each travel relation. Or vice versa, we have to collect the row, column and link factors of given relations for every single element of the OD matrix. While the determination of the first two is quite simple as departing and arriving zones are known in every relation, association of link factors needs another single study.

To associate the link factors, we have to know the shortest path or k shortest paths in the given relation and we have to associate all the links covered by these paths to the given relation.

After execution of the abovementioned steps, factors needed for following calculations are known regarding all relations. But these factors can be used in different ways:

- only the shortest path
- k shortest paths
  - every factorweighted equally
  - link factors associated to paths
  - link factors associated to paths and weighted by assignment

We show the differences further on the model network.

4. Matrix estimation method in the practice

The key for the functional correctness of the matrix estimation method is the accuracy of the applied flow assignment method. To aid the future improvementof the method, we fitted the procedure to the VISUM transport planning software of the PTV AG.

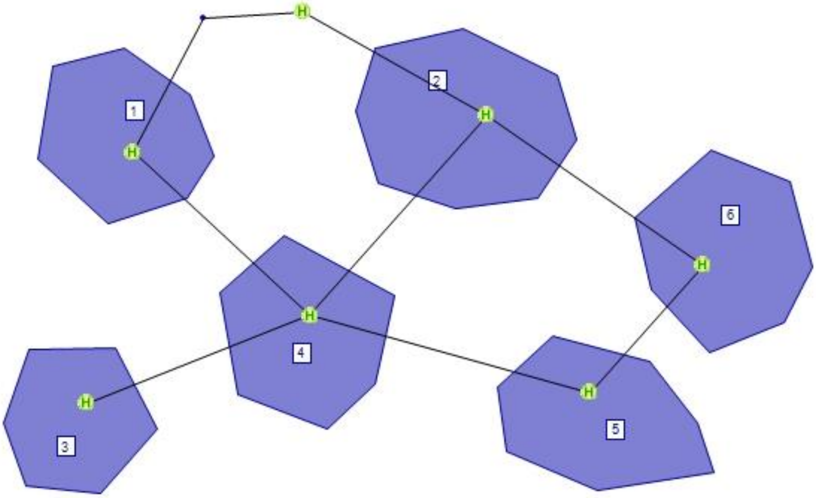

Figure 1.The test network

Applying this software was obvious, as the VISUM is one of the market leading productsin this field and we use it for ten years. Another asset of the program is the cooperation with numerous program languages through Windows COM protocol. This possibility helped the development of the method. In the first phase of the development we used the Python script based language. The third reason was that the VISUM can be used as [transport] data bank for containing different network data.

The matrix estimation procedure is the following:

The matrix estimation method reads out the model data built up previously in VISUM through the COM interface then process it. The readout contains the results of the base assignment, executed previously.

After the former computing method the Python script modifies the OD matrix and writes it back into the transport model. Then another monitoring assignment and assignment analysis are executed (which is part of the VISUM).

The analysis shows how accurate the results - we get from the OD matrix – transport network – flow assignment method trio - are. In case of necessity the whole process can be repeated. According to our tests so far, about 30-50 iterations are needed to calculate the right matrix in cases of minor networks.

5. Practical example, application verification

We made a model network to verify the functioning of the method. Out of the former four approaches we tried three pieces. We didn't deal with the shortest path approach only, assuming that it doesn't give adequately realistic results.

5.1. Application results: k shortest paths, every factorweighted equally

In this approach we took into consideration every factor belonging to certain relations equally. So the row and column factors and every link factor concerned with this relation were taken into consideration with simple averaging.

After implementing the iteration method 50 times according to the results of the assignment analysis (Fig. 2.) the measured and calculated values were bordered on each other, as the correlation factor was R^2=0,97, while the relative error was only 6 percent.

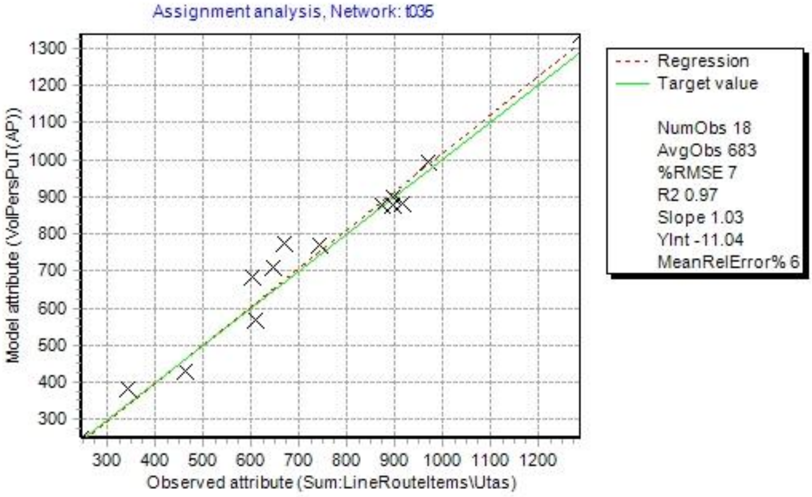

Figure 2. Assignment analysis in case of simple mean, after 50 iterations

At the present state of the research, this method gives the best results. However, according to our assumption this is the result of a calculation error. We will specify this error later.

5.2. Application results: k shortest paths, link factors assigned to path

In this approach we took into account every one of the links assigned to the examined path. Thus, we got a link factor mean for every single path. Averaging these with the row and column factors again, we got the characteristic factor of the relation.

We have executed this method with 50 iterations too. The results can be seen in Fig. 3. The analysis shows slightly worse results compared to the first case.

The cause of the deterioration in our opinion is the averaging of the link factors of every path (by path) thus the links concerned with many different paths fell into the calculations multiple times, disfiguring the correctness of the factor relevant to single relations.

At the same time, it is worth considering whether the whole approach is incorrect or only the multiple accounting of links in simple model networks caused the errors.

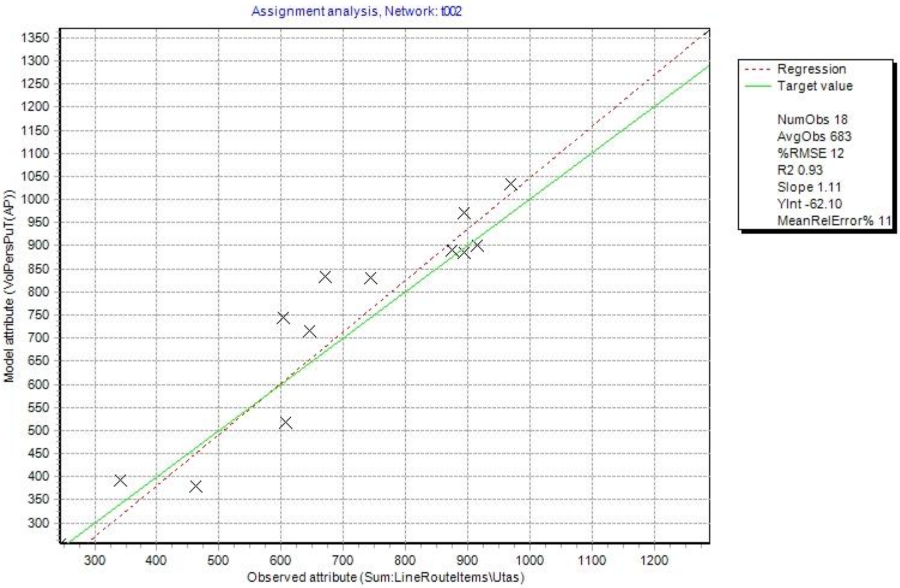

Figure 3.Result of assignment analysis in case of means of paths without weighting

5.3. Application results: k shortest paths, link factors assigned to path and weighted by result of assignment

This third approach practically the same as the latter. The only difference is that the means of the link factors assigned to single paths are weighted by the assignment proportion calculated in the course of the flow assignment. This means that the most preferential path gets the highest factor, while an inferior path in the given relation has lower factor.

We have also executed this method with 50 iterations. The results are in Fig. 4.

This approach conducted the worst results, what is the opposite of prior anticipations. Presumably this is connected to the formerly discussed problem of the links taken into consideration multiple times.

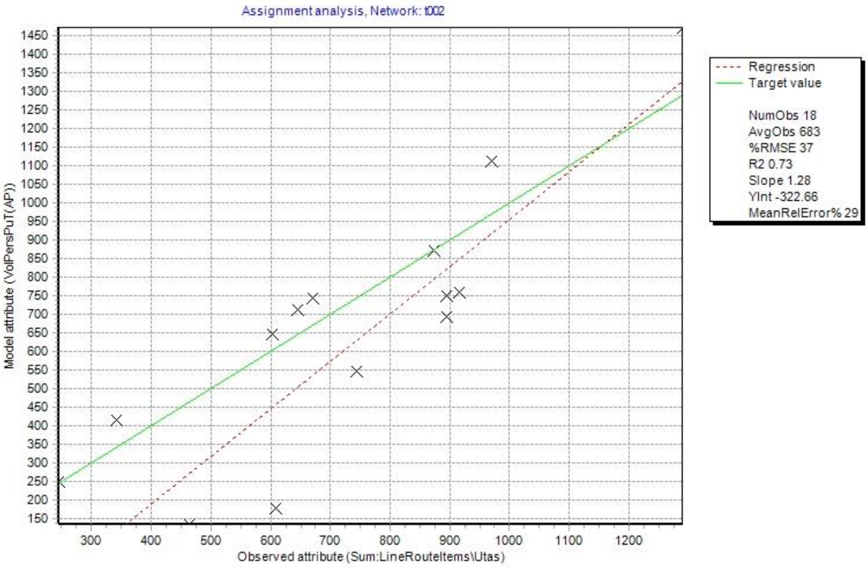

Figure 4. Result of assignment analysis in case of means of paths with weighting

6. Conclusion

The first tests with the evolved matrix correction procedure show that this method is capable to correct a model matrix by the help of cross-section methods. However, uncertainties emerged during the tests pointed out the necessity of improving the application of factors to improve the correctness of the result.

Another observation was that the VISUM program is suitable to the actuation of the method, however the Python as script language has inadequate speed, thus the authors couldn't test the method on real networks, as the computing demand is approximately 300000 times higher in the case of Győr than of the model network.

To eliminate this problem, the next step of the development is the transcription of the program code into C or Pascal environment.

7. Acknowledgement

„TÁMOP-4.2.2.C-11/1/KONV-2012-0012: "Smarter Transport" - IT for co-operative transport system - The Project is supported by the Hungarian Government and co-financed by the European Social Fund”

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The Dynamic Model of the Slider-crank Mechanism

Zs. Horváth, Gy. Molnárka

Department of Mechatronics and Machine Design
Széchenyi István University, Egyetem tér 1, H-9026, Győr, Hungary
zsolt2.horvath@audi.hu

Abstract: The paper presents a dynamic model of the slider-crank mechanism for combustion engines. The formulation is expressed by only one independent variable. The mass of the connection rod has been concentrated on two ends (two eyes). The model uses the Euler-Lagrange equation and it has been computed for numerical simulation by using MAPLE system.

Keywords: *Euler-Lagrange equations, slider-crank mechanism, connection rod, adiabatic process, turning moment*

1. Introduction

A slider-crank mechanism is used in combustion engines, it has been studied extensively in the past three decades.

Lot of methods can be found in the literature about this [1-3,5]. Geometrical approach, Newton-Euler Law, Wittenbauer method, Hamilton principle, and Lagrange multiplier are typically used.

This study is to demonstrate that the Lagrange equation by using only one independend variable (the rotation angle) can give a good and simple interpretation for the dynamic of the slider-crank mechanism. The model has been computed by using MAPLE system [7]. This basic model is the first step to develop a cylinder pressure model of the combustion engine for diagnostics (fault detection) Cold-Test in an engine plant.

By using only one independent variable the model should be running easily in real time. That is important for any application of control or diagnostics.

Table 1. Nomenclature

m_{hr}	(kg)	the concentrated mass in the big eye of the connecting rodmass
m_{ha}	(kg)	the concentrated mass in the small eye of the connecting rodmass
m_d	(kg)	the mass of the piston and piston pin
m_h	(kg)	the mass of the connection rod
l_h	(m)	the distance of the center of gravity with the center of the big eye of the connecting rod
m_k	(kg)	the mass of the crankshaft
m_r	(kg)	sum of rotationed mass for one cylinder
m_a	(kg)	sum of alterned mass for one cylinder
J_{f1}	(kgm^2)	inertia of the crank and crankshaft for 1. cyl.
J_r	(kgm^2)	inertia of the rotational masses for 1. cyl.
p_d	(N/m^2)	the gaspressure acting on the piston
D	(m)	diameter of the piston
F_d	(N)	the gas force acting on the piston
F_T	(N)	the tangential force
M_k	(Nm)	the driving moment
r	(m)	crank radius
l	(m)	the length of the rod
λ		ratio of crank to connection rod length
ε		compression ration
φ	(rad)	the angle position of the crankshaft
β	(rad)	the angle of connection rod with X-axis
A_d	(N/m^2)	the cross –sectional area of the piston
p_d	(Pa)	the gas pressure in the cylinder
p_0	(Pa)	atmospheric pressure
V_0	(m^3)	the volume of the cylinder
κ		expansion coefficient
x_d	(m)	displacement of the piston

2. The dynamic formulation of slider-crank mechanism

The simple model of the slider-crank mechanism (Fig. 1) consists of three parts: a crank-shaft, a connection rod, and a piston. In this study, the simple dynamic formulation is expressed by only one independent variable, of the rotation angle ϕ.

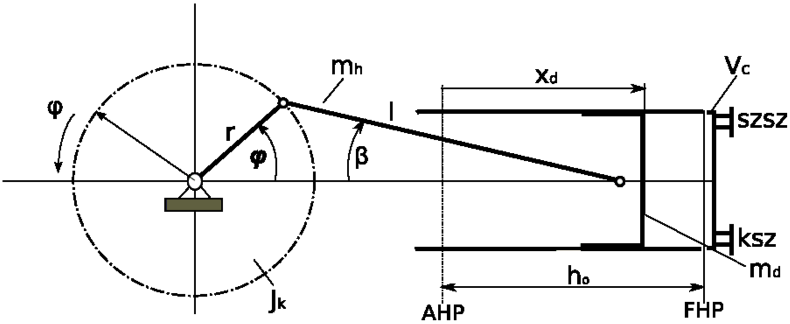


Figure 1. Slider-crank mechanism

2.1 Kinematic equations

The mechanism (Fig. 1) has a constrained condition as follows

$$r \sin \varphi = l \sin \beta \tag{1}$$

The piston has a linear motion in *x*-direction:

$$x_d = r(1 + \cos \varphi) + l(-1 + \cos \beta) \tag{2}$$

The ratio of crank to connection rod length:

$$\lambda = \frac{r}{l} \tag{3}$$

trought substitution *cos β* with function of *φ*:

$$\cos \beta = \sqrt{1 - \lambda^2 \sin^2 \varphi} \tag{4}$$

So we can get the displacement of the piston with the following formula:

$$x_d = r(1 + \cos \varphi) + l(-1 + \sqrt{1 - \lambda^2 \sin^2 \varphi}) \tag{5}$$

The speed of the piston by taking the first derivates of displacement (Eq. 5) can be written:

$$\dot{x}_d = -r \sin \varphi \, \dot{\varphi} - \frac{l\lambda^2 \sin \varphi \cos \varphi \dot{\varphi}}{\sqrt{1-\lambda^2 \sin^2 \varphi}} \tag{6}$$

It is influenced by only one independent variable, the rotation angle ϕ.

2.2 The mass distribution in the crank mechanism

To avoid complicated calculations, the mass is divided to two parts in the crank mechanism:

1) the reciprocating masses,
2) the rotational masses.

The dynamics of any rigid body can be characterized by considering an equivalent system of finite number of particles. So the connection rod can be approximated by a system of two particles. This simple consideration can be taken from low to middle engine speed.

As the connecting rod has both transferring and rotating movements, we consider its masses concentrated on two ends (two eyes). So the mass in the small eye performs transferring movements and the one in the big eye (crank end) does rotational movement.

So the connection rod can be approximated by a system of two particles.

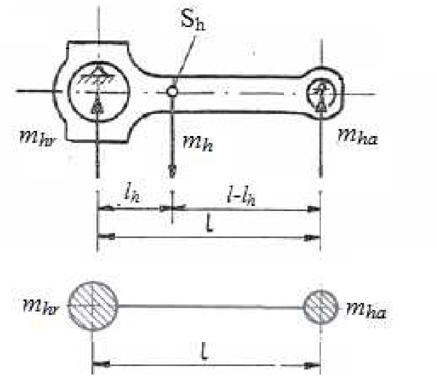


Figure 2. Approximation mass of the connection rod

If it is in the center of the mass of the connection rod Sh, as shown in the Fig. 2, the equivalent system of two particles of mass mhr and mha is given by:

$$m_{ha} = m_h \frac{l_h}{l} \tag{7}$$

$$m_{hr} = m_h \frac{l - l_h}{l} \tag{8}$$

where m_h is the original mass of the connection rod.

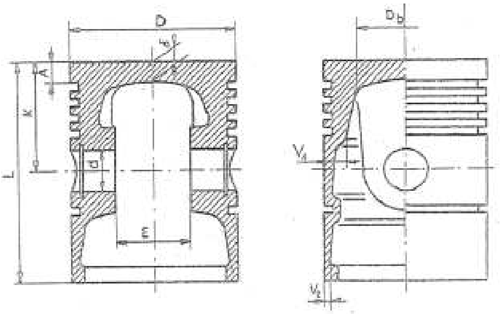


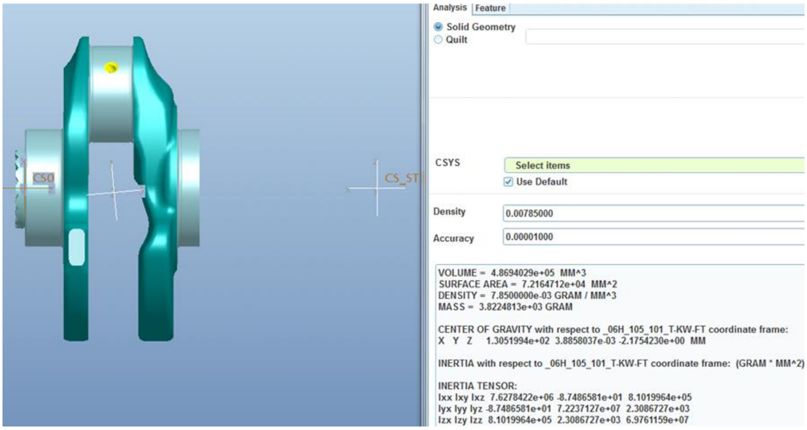
Figure 3. The piston

The reciprocating mass as sum of mass of the piston (Fig. 3.) and the concentrated mass in the small eye of the connecting rodmass is expressed with:

$$m_a = m_d + m_{ha} \tag{9}$$

The inertia of the rotational masses (Fig. 4.) can be obtained by:

$$J_r = J_{f1} + m_{hr}r^2 \tag{10}$$



● Solid Geometry
○ Quilt
☑ Use Default
Density 0.00785000
Accuracy 0.00001000

```
VOLUME = 4.8694029e+05 MM^3
SURFACE AREA = 7.2164712e+04 MM^2
DENSITY = 7.8500000e-03 GRAM / MM^3
MASS = 3.8224813e+03 GRAM

CENTER OF GRAVITY with respect to _06H_105_101_T-KW-FT coordinate frame:
X  Y  Z    1.3051994e+02  3.8858037e-03 -2.1754230e+00  MM

INERTIA with respect to _06H_105_101_T-KW-FT coordinate frame:  (GRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz  7.6278422e+06 -8.7486581e+01  8.1019964e+05
Iyx Iyy Iyz -8.7486581e+01  7.2237127e+07  2.3086727e+03
Izx Izy Izz  8.1019964e+05  2.3086727e+03  6.9761159e+07
```

Figure 4. The inertia of the crank and crankshaft for 1. cyl. has been computed in ProEE. (from Audi 2.0L TFSI 4cyl. Engine)

2.3 The Euler–Lagrange equation

The Euler–Lagrange equation will be applied in the following form:

$$\frac{d}{dt}\frac{\partial E}{\partial \dot{q_i}} - \frac{\partial E}{\partial q_i} + \frac{\partial U}{\partial q_i} = Q_{ni} \tag{11}$$

where:

E: the total kinetic energy of the system
U: the total potential energy of the system
Q_{ni}: the generalised constrained reaction force
W: the virtual works

The generalised constrained reaction force can be written:

$$\mathrm{Q}_{ni} = \sum \frac{\partial W}{\partial Q_i} \tag{12}$$

Specification of the kinetic energy

The total kinetic energy of the mechanism is given by:

$$E = \frac{1}{2} J_r \dot{\varphi}^2 + \frac{1}{2} m_a \dot{x}_d^2 \tag{13}$$

The generalised coordinate is:

$$\dot{q} = \dot{\varphi} \tag{14}$$

From (Eq. 6) trough substituting $\dot{x}$ to (Eq. 13) we can get:

$$E = \frac{1}{2} J_r \dot{\varphi}^2 + \frac{1}{2} m_a (-r \sin\varphi\, \dot{\varphi} - \frac{l\lambda^2 \sin\varphi \cos\varphi \dot{\varphi}}{\sqrt{1-\lambda^2 \sin^2\varphi}})^2 \tag{15}$$

Substituting (Eq. 15) into the Euler-Lagrange equation (Eq. 11) we have the following formula:

$$-J_r \ddot{\varphi} - m_a \left(-r \cos\varphi\, \dot{\varphi}^2 - r \sin\varphi\, \ddot{\varphi} - \frac{l\lambda^4 m^2 \varphi \cos^2\varphi \dot{\varphi}^2}{\sqrt{(1-\lambda^2 \sin^2\varphi)^3}} - \frac{l\lambda^2 \cos^2\varphi \dot{\varphi}^2}{\sqrt{1-\lambda^2 \sin^2\varphi}} + \frac{l\lambda^2 \sin^2\varphi \dot{\varphi}^2}{\sqrt{1-\lambda^2 \sin^2\varphi}} - \frac{l\lambda^2 \sin\varphi \cos\varphi \ddot{\varphi}}{\sqrt{1-\lambda^2 \sin^2\varphi}} \right) \left(-r \sin\varphi - \frac{l\lambda^2 \sin\varphi \cos\varphi}{\sqrt{1-\lambda^2 \sin^2\varphi}} \right) \tag{16}$$

External forces, moments:

Denote the pressure in the in-cylinder by pd. The piston moves from BDC to TDC (Fig. 5), compressing the gas in the cylinder. No heat exchange occurs between the gas and its surroundings. So the process is considered as adiabatical.

The pressure in the in-cylinder is manifested by:

$$p_d = p_0 \left(\frac{V_0}{V_x}\right)^{\kappa} = p_0 \left(\frac{h_0}{h_0 - xd}\right)^{\kappa} \tag{17}$$

The formula of the gasforce is:

$$F_d = (p_x - p_0) A_d = p_0 A_d \left[\left(\frac{h_0}{h_0 - xd}\right)^{\kappa} - 1\right] \tag{18}$$

The tangential force can be expressed by :

$$F_T = F_d \sin\varphi \frac{1 + \lambda \cos\varphi}{\sqrt{1-\lambda^2 \sin^2\varphi}} \tag{19}$$

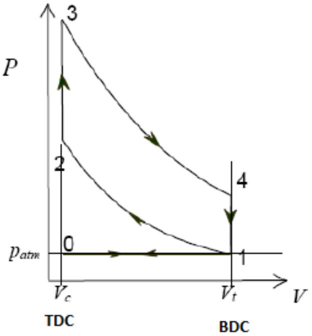


Figure 5. P-V diagram for the ideal air cycle the four stroke internal combustion engine

The gas moment acting on the crankshaft:

$$M_d = r\,F_t \tag{20}$$

Denoting the driving moment acting on the crankshaft:

$$M_k \tag{21}$$

So the generalized force is written with:

$$Q = M_d + M_K \tag{22}$$

Finally the Euler–Lagrange equation can be obtained in the following form:

$$-J_r\ddot{\varphi} - m_a\left(-r\cos\varphi\,\dot{\varphi}^2 - r\sin\varphi\,\ddot{\varphi} - \frac{l\,\lambda^4 m^2\varphi\cos^2\varphi\dot{\varphi}^2}{\sqrt{(1-\lambda^2\sin^2\varphi)^3}} - \frac{l\,m^2\cos^2\varphi\,\dot{\varphi}^2}{\sqrt{1-\lambda^2\sin^2\varphi}}\right.$$

$$\left. + \frac{l\lambda^2\sin^2\varphi\dot{\varphi}^2}{\sqrt{1-\lambda^2\sin^2\varphi}} - \frac{l\sin\varphi\cos\varphi\,\ddot{\varphi}}{\sqrt{1-\lambda^2\sin^2\varphi}}\right)$$

$$\left(-r\sin\varphi - \frac{l\,\lambda^2\sin\varphi\cos\varphi}{\sqrt{1-\lambda^2\sin^2\varphi}}\right) = p_0 A_d\left[\left(\frac{h_0}{h_0 - xd}\right)^{\kappa} - 1\right]\sin\varphi\,\frac{1+\lambda\cos\varphi}{\sqrt{1-\lambda^2\sin^2\varphi}} \tag{23}$$

3. The numerical simulation in MAPLE

For the numerical simulation the data has been taken from the Audi 2.0L TFSI 4cyl. engine.

The Euler-Lagrange equation given by (Eq. 23), which specifies the applied forces, turning moments, and initial conditions we solve using rkf45 method built in MAPLE16.

The input data of the engine for the simulation is the following:

$$h_0 = 0{,}13\,m\,;\;\; r = 0{,}054\,m\,;\;\; l = 0{,}144\,m\,;\;\; \lambda = \frac{r}{l} = \frac{0{,}054}{0{,}144} = 0{,}0375;$$

$\varepsilon = 9{,}6$; $D = 0{,}082\ m$; $l_h = 0{,}144\ m$; $m_d = 0{,}456\ kg$;

$m_h = 0{,}568\ kg$; $J_{f1} = 0{,}007627\ kgm^2$; κ=1,4 ; $p_0 = 10^5 Pa$.

The result of the simulation is showed on the following measured curves (6a., 6b., 7a, 7b., 8a., 8b., 9.):

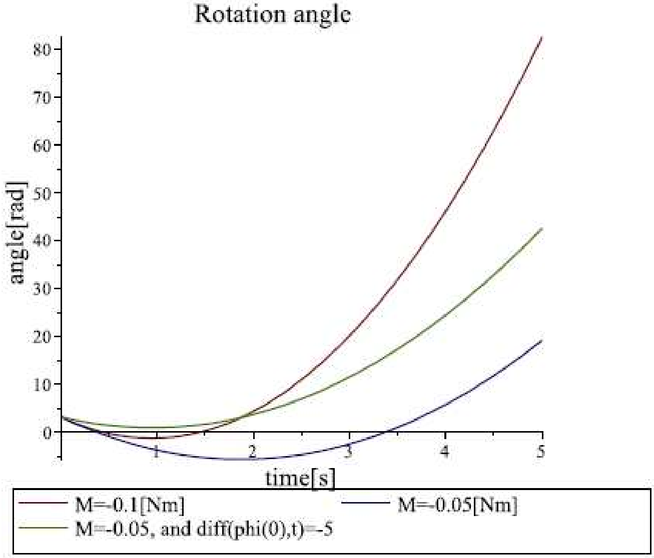


Figure 6a. Rotation angle „without gas pressure”

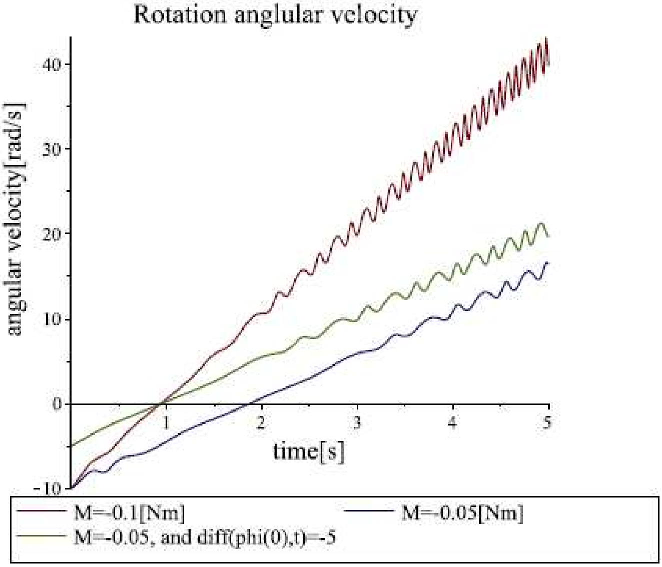


Figure 6b. Rotation angular velocity „without gas pressure”

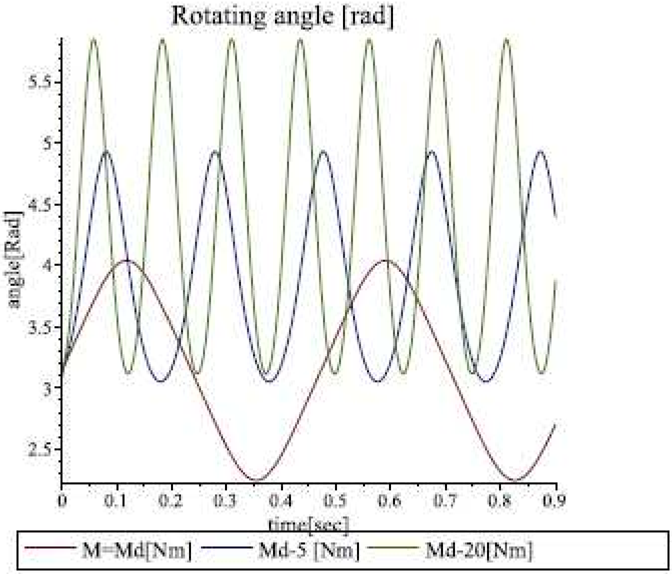


Figure 7a. Rotation angle „with gas pressure”

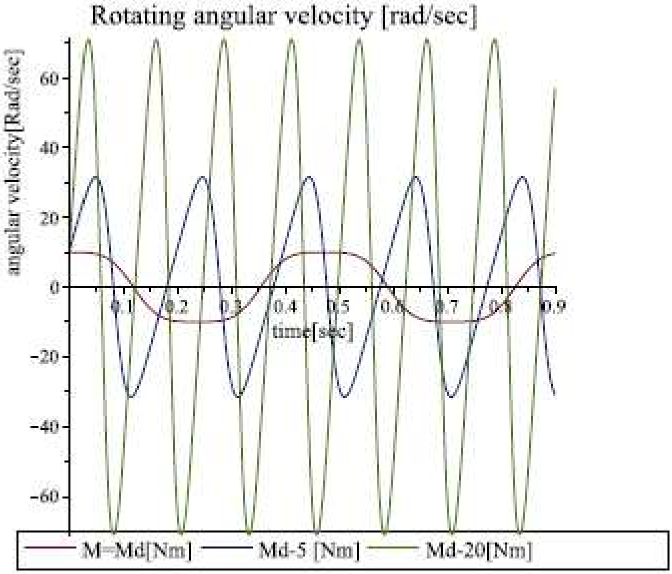


Figure 7b. Rotation angular velocity „with gas pressure”

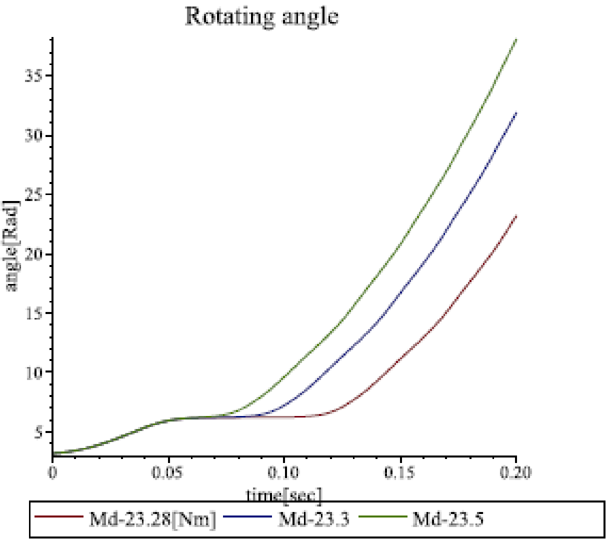


Figure 8a. Rotation angle by gas pressure by arising the driving moment

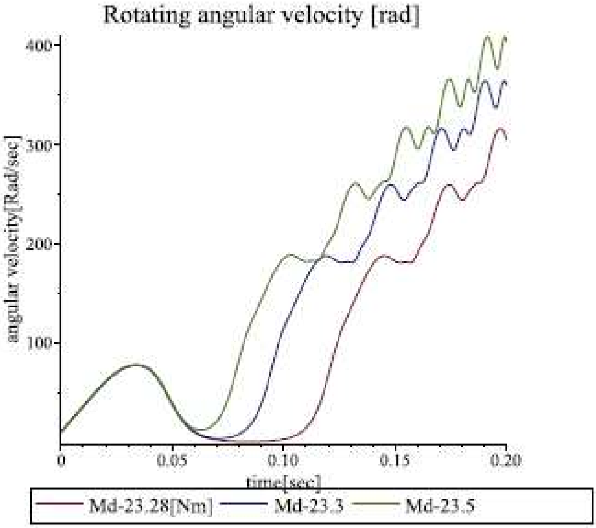


Figure 8b. Rotation angular velocity by gas pressure by arising the driving moment

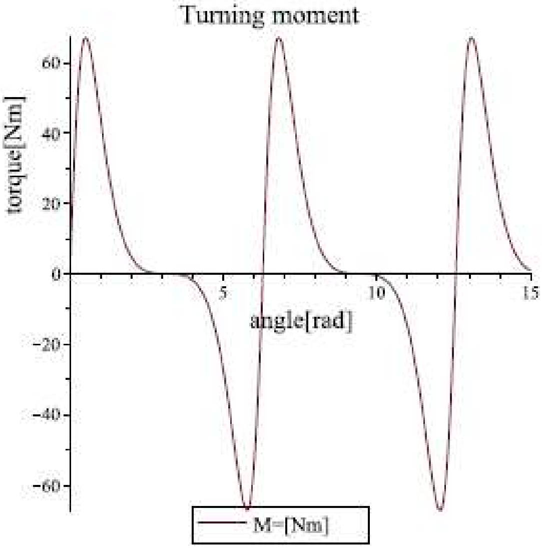


Figure 9. Turning moment

4. Results and discussion

On the Figure 6a. we can see the rotation angle depending on time φ(t), the gas pressure forces doesn't appear when the cylinder is empty. There is a little driving torque on the crankshaft, it causes the rotation of the mechanical system and accelarates it. The curves showed on the figure belong to different initial conditions.

The initial conditions φ(0)=π for each curve, then the initial conditions $\frac{d\varphi(0)}{dt}$ are different, they are

$$\frac{d\varphi(0)}{dt} = -10\,; \quad \frac{d\varphi(0)}{dt} = -10\,; \quad \frac{d\varphi(0)}{dt} = -5\,; \qquad (24)$$

The result of the acceleration is mirrored by the Figure 6b, where the angular velocity of the rotation can be seen for the turning torque. The oscillation of the angular velocity is the result of the mechanismus of our model.

In the case of non-empty cylinder- that is filled with gas-, the rotating torque consist of two components, the rotating torque arrising from gas compression forces and rotating torque applied on the system forces outside.

On the Figre 9. the first component of the turning moment is showed for the adiabatic gas processes. In this case the rotating angle φ(t) is showed on the Figure 7a. by the condition where the applied torque from outside is such small, that it can not cause the rotation of the system. It is clear from the calculation and the figure, that by these conditions, the system will oscillate. The frequency and its amplitude depend on the magnitude of applied torque. In our case they are M={0 ; -5 ; -20 Nm} .

A very interesting situation is, when the applied torque is greater than the maximum value of the torque arrising from gas pressure. At this situation the system begins to rotate and this rotation movement will accelerate. The acceleration is very high because of the of the large value of applied torque. On the Figures 8a. and 8b. we present this situation. For our mechanical system specificed by the data given at the beginning of this section the critical torque outside is near -23,28 [Nm]. A little larger torque applied on the system causes rotation. This is a slow process but the rotation accelerates very fast.

From these figures it can be furtherly seen, that the angular velocity oscillation becomes assymetric and can cause vibration forces.

5. Conclusion

In this work we have constructed a mechanical mathematical and a computer model of one cylinder, a slider-crank mechanism. The model has been solved with real mechanical data by using the numerical package rkf45 built in MAPLE16 software.

The results obtained are in well accordance with the results of real mechanical system. The analysis of the results shows some interesting effects such as the angular velocity oscillation and its assymetry in the presence of gas compression forces. The model and its numerical solution methodology presented here can be the starting point for construction of more complicated and more realistic models.

This model is mathematically compact enough to run in real time, and can be used as an embedded model within a control algorithm or an observer.

Acknowledgements

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Handling Missing Data in Transportation

T. Kulpa

Politechnika Krakowska, 31-155 Kraków, Ul. Warszawska 24.
Phone: +48 12 628 25 33, fax: +48 12 628 25 35
e-mail: tkulpa@pk.edu.pl

Abstract: In this paper missing data methods application was presented. Three types of missingness were listed and two groups of imputation methods were characterised. Particular methods of missing data imputation were described using fictional examples. Next, chosen procedures were used to deal with missing data in number of trucks registered in districts. Each method was evaluated and conclusions were formulated.

Keywords: missing data, data bases, travel studies

1. Introduction

Reliable and complete data bases are the basis to develop travel models. In transportation studies the main sources of data are questionnaires (e.g. in households within comprehensive travel studies, roadside survey) and traffic measurements (e.g. traffic volume, through traffic). Other group are data bases collected by national census offices (e.g. GUS in Poland).

Sources of missing data might be various. Most often missing values are caused by refusal to answer the question in inquiry made in household or company using trucks. Other reasons of missing data are carelessness of person conducting the measurement e.g. omitting a question in inquiry, incorrect writing of answer, imprecise measurement. In some cases data are not collected or collected only for certain groups.

Despite of missingness in some cases uncertainty of data may occur. Although values are available there are doubts about its correctness. Often values might be gained as a range instead of one number or as a descriptive variable and assigning to one object two values of the same parameter may occur.

Three types of missing data can be characterised ([6], [7]):

- MCAR, Missing Completely at Random, missing values are distributed randomly in sample,
- MAR, Missing at Random, missing values are dependent on other variable,
- NMAR, Not Missing at Random, missing values are not distributed randomly in sample.

In case of MCAR data missing values are distributed randomly in whole sample. It means that occurrence of missing values is not dependent either on variable with missing data nor on other variable [6]. For instance, if in questionnaire survey results missing data about salary is not dependent on gender, place of living, age or other characteristics of person the data are MCAR. For MAR data occurrence of missing values might be dependent on other variable, but not on variable for which missing values occurred [7]. For instance, if in questionnaire survey persons living in large cities or in older age will avoid answering the question about salary the data will be MAR. In last type of data, NMAR, occurrence of missing values is dependent on variable for which values are missing. To continue example, if the refusal to answer the question about salary is dependent on level of salaries the data are NMAR.

Two groups of missing data imputation methods can be characterised:

- single imputation,
- multiple imputation.

Single imputation methods consist of:

- deletion of incomplete records (record is a one row in data base),
- mean or median imputation,
- imputation of value from record with similar characteristics,
- imputation on the basis of linear regression.

Currently missing data imputation methods are widely used in medicine and in social studies [1]. There are also few applications in transportation ([2], [5]), which show usage of missing data imputation techniques to deal with incomplete input data bases to ITS.

2. Characteristics of imputation methods

2.1. Single imputation methods

2.1.1. Listwise deletion

Listwise deletion is the simplest method of missing data handling. It has two main advantages: it can be used in every type of statistical analysis and does not need advanced computation methods. In listwise deletion method records with missing data are simply deleted from data base. In case of MCAR missingness values of statistics for reduced sample will be equivalent to values of statistics for full sample and will not be biased [1].

2.1.2. Mean imputation

In this method missing values are imputed using mean value calculated on the basis of known values, what is represented by equation:

$$Y_B = \frac{\sum_{i=1}^{n_Z} Y_{Z_i}}{n_Z}, \tag{1}$$

where: Y_B – missing value,

Y_{Zi} – known values,

n_Z – number of known values in whole sample,

i – number of subsequent record.

In Table 1 fictitious example of questionnaire surveys results is presented. The missing value is number of trips made during a day by fifth person. Each row in table represents one record in data base.

Table 1. Example results of questionnaire surveys prepared for purposes of missing data imputation

No	Gender	Number of trips per day	Car availability	Age
1	Female	1.9	Yes	30
2	Female	1.7	Yes	52
3	Male	2.4	No	30
4	Male	2.0	Yes	44
5	Male	?	Yes	30

Using mean imputation method missing value might be replaced using average trip per day in whole sample, which equals 2.0. On the other hand it is also possible to use average among males (2.2), persons in age of 30 (2.15) or among persons which have a car (1.87).

2.1.3. Hot-Decking (Pattern Matching)

The idea of this method is to search in whole sample record which is most similar to record with missing values, considering one or more characteristics. Missing value is imputed from found similar record. If more than one similar record is found usually value from first founded record is taken or value to be imputed is drawn from set of similar records.

In analysed example (Table 1) considering age and gender most similar record is number 3 and imputed number of trips per day is 2.4. On the other hand, considering age and car ownership most similar record is number 1 and imputed number of trips per day is 1.9. Considering all characteristics (gender, car ownership, age) none similar records can be found. Very often in this case in pattern matching method missing value is drawn from whole sample.

As may be saw in above examples imputed value is highly dependent on characteristics used to search similar records. At the same time including of too many characteristics may cause difficulties in searching similar records.

2.1.4. Last Value/Observation Carried Forward (LVFC/LOFC)

This method may be used when analysed characteristic is variable in time. The assumption of LVFC method is that even values are variable in time they become constant from last observed value. In analysed example (Table 2) imputed value in row 1 would be 2.6. In third row all missing values would be imputed with 1.8, while in fifth row with 1.7.

Table 2. Example number of trips per day for 5 persons in particular weekdays prepared for purposes of missing data imputation

No	Number of trips per day (Monday)	Number of trips per day (Tuesday)	Number of trips per day (Wednesday)	Number of trips per day (Thursday)	Number of trips per day (Friday)
1	2.3	2.0	2.5	2.6	?
2	1.9	2.2	2.5	1.9	1.7
3	1.6	1.8	?	?	?
4	1.7	1.9	2.5	2.4	1.7
5	1.8	2.5	1.7	?	?

2.1.5. Regression Imputation

If variable Y for which values are missing is dependent on the other variable (or variables) X for which all values are available, it is possible to impute missing values on the basis of regression analysis. In first step listwise deletion method has to be applied to the sample. Next, for reduced sample, relationship between variable Y and variable (variables) X has to be found. Next missing values are calculated using estimated regression equations.

For analysed example in Table 1 linear relationship between age and number of trips per day may be created. The regression equation is as follows: $TRIPS=2.7–0.02 \cdot AGE$ ($R^2=0.47$). Calculated number of trips per day for fifth person is 2.1.

Example given above presents procedure of missing data imputation using regression imputation. Considering regression analysis sample size as well as obtained coefficient of determination are too small to accept the model.

2.2. Multiple imputation methods

Multiple imputation (MI) methods were proposed in 1970 by Rubin [6]. The idea of multiple imputation method is to generate *m* data sets ($m=3\div10$) to be imputed using for example k-closest neighbours or propensity score method. Preparation of few random data sets represents uncertainty of value which will be imputed. Next, each set of imputed data is analysed separately what gives in result *m* partial statistical parameters. In the last step final values of parameters (e.g. regression coefficients, means, and errors) are calculated.

Considering complexity of multiple imputation methods in this paper simple example using data from Table 1 and k-nearest neighbour's algorithm in terms of age was presented. Different MI methods are described in details in [8]. Let us assume that in multiple imputation k-nearest neighbours method will be used, where $k=3$. The closest observations to record with missing number of trips considering age are 1, 3 and 4. Then from set of number of trips values (in observations 1, 3 and 4) one is drawn with equal probability. In this way first set of imputed values is obtained. Procedure has to be repeated *m* times, where *m* in number of generated data sets. For instance, assuming m=2 imputations and k=3 closest neighbours for data set in Table 1 number of trips per day for fifth person are: 1.9 and 2.0. Thus final number of trips for fifth person will equal 1.95.

Usually number of imputations varies from 3 to 5. If the number of imputation is more than 5, the effectiveness is not increasing significantly while there might be more calculations needed, what represents formula:

$$e = 100\% \cdot (1 + \frac{\gamma}{m})^{-1}, \tag{2}$$

where: e – percentage effectiveness [%],

γ – share of missing values [-],

m – number of imputations.

Example values of percentage effectiveness e for different share of missing values and number of imputations are shown in Table 3.

Table 3. Percentage effectiveness e of multiple imputation methods depending on share of missing values and number of imputations

		Share of missing values γ				
		0,1	0,3	0,5	0,7	0,9
Number of imputations m	3	97	91	86	81	77
	5	98	94	91	88	85
	10	99	97	95	93	92
	20	100	99	98	97	96

Analyzing Table 3 it may be questioned if in case of 70 % or 90 % of missing values missing data imputation methods are suitable. In general multiple imputation procedure is as follows:

- generate data to be imputed using algorithms that include variability of imputed values,
- impute missing data *m* time to obtain *m* sets of complete data sets,
- calculate estimates for each complete data set,
- calculate final values of estimates using *m* estimates calculated for each complete data set.

To calculate final values of estimates for *m* imputed data sets Formula 3 should be used:

$$\overline{\mathrm{Q}} = \frac{1}{\mathrm{m}} \sum_{\mathrm{i}=1}^{\mathrm{m}} \widehat{\mathrm{Q}}_{\mathrm{i}}, \tag{3}$$

where: m – number of imputations,

$\widehat{\mathrm{Q}}_{\mathrm{i}}$ – estimate for i-th complete data set,

$\overline{\mathrm{Q}}$ – final values of estimate for *m* imputations.

3. Assessment of imputation methods on example of number of registered trucks

Within other studies [3] author adapted Vomberg method to Polish conditions to estimate freight truck flows between communes. In model development results of roadside origin-destination survey conducted in Poland in 2006 were used [10]. Author of original Vomberg method shown that car traffic flow between two cities depends on number of vehicles registered in both cities and distance between them [9]. Similarly in adaptation it was assumed that truck flow between two communes is dependent on number of trucks registered in both communes and distance between them. For purposes of Vomberg method adaptation it was needed to obtain number of trucks registered in particular communes. While this data is available only for districts it was assumed that average number of trucks registered in district per 1000 inhabitants will be valid for all communes in particular district. However from 2009 for all districts number of registered truck is available, in 2006 it was possible to gain this data only for around 40 % of districts. This limitation caused reduction of sample size to estimate inter-commune truck flow model. Thus author decided to use missing data imputation methods not to lose sample size. Additionally most recent data for the year 2011 was gained to assess different methods of missing data imputation.

For all district number of registered trucks in 2011 was gained. In 2006 in group of 379 districts in Poland for 142 numbers of registered trucks was available. Number of trucks registered per 1000 of inhabitants varied from 16,0 to 142,0 in 2006 and from 38,7 to 217,6 in 2011. First in data set for 2011 records for which number of registered trucks was unavailable in 2006 were deleted. Then using different imputation methods missing values were imputed. Next calculated numbers of registered trucks based on imputation methods were compared with factual numbers. For each observation as well as for whole sample mean absolute percentage error (MAPE) was calculated. Results are presented in Table 4. To apply imputation methods SOLAS software was used [8].

Table 4. Assessment of missing data imputation methods on example of registered trucks in districts in 2011

Method		MAPE [%]
Mean Imputation		48.0
Hot-Decking (Pattern Matching)		20.1
Regression Imputation	Independent variable: Number of inhabitants	16,8
	Independent variable: Number of transportation companies	16,9
Predictive Model Based Method		17.5
Propensity Score Method		40.0
Mahalanobis Distance Method		18.4

In mean imputation method mean was calculated for all districts with available number of registered trucks. In hot-decking method similar records were searched using two district characteristics: number of inhabitants and number of transportation companies. In regression imputation missing values were imputed using regression equations as follows:

for cities with district rights

- $NTR=0{,}086 \cdot INH$, $R^2=0{,}96$, (n=18),
- $NTR=9{,}60 \cdot TRA$, $R^2=0{,}99$, (n=18),

for other districts

- $NTR=0{,}072 \cdot INH$, $R^2=0{,}96$, (n=124),
- $NTR=11{,}4 \cdot TRA$, $R^2=0{,}90$, (n=124).

where NTR – number of trucks registered in district, INH – number of inhabitants in district, TRA – number of transportation companies in district.

In predictive model based methods also linear regression was used. The only difference to simple imputation regression is variability in estimation of regression coefficients. In propensity score method in set of complete records, records with tendency, understand as probability of missing values occurrence, similar to record with missing values. In Mahalanobis distance method complete records closest to record with missing values in terms of Mahalanobis distance were searched. In each method m=5 sets of imputed values were generated for which final values were calculated. Obtained numbers of trucks registered in districts in imputation procedure were compared with factual numbers from Central Statistical Office in Poland.

Analysing achieved results it may be seen that the highest MAPE was gained for mean imputation. Also propensity score method resulted in high mean absolute percentage error. Comparable errors were obtained for single and multiple imputation methods: regression imputation, predictive model based and Mahalanobis distance. Thus may suggest to use on equal terms single and multiple imputation methods.

4. Summary

There are missing data in almost every discipline of science at the level of data base creation. Most often incomplete records are deleted what causes reduction of a sample size. In case of large samples this method seems to be reasonable and may be used with no data quality lost. On the other hand in some cases listwise deletion may lead to lost of records which might be important, especially in small samples.

Replacing missing values with mean can be often found. As a main reason simplicity of this method is given. It is also considered as a “safe” solution. As it was shown in assessment this method is the worst from all analysed. Thus it is not recommended to use mean imputation to replace missing values. While the sample size is big it is better to use listwise deletion instead of mean imputation.

An alternative to single imputation methods are multiple imputations methods. However the calculation effort is bigger obtained results show that effectives are comparable to single imputation methods. It was shown on example of regression imputation. Thus it should be considered to use regression imputation instead of other multiple imputation methods.

In this paper different methods of missing data imputation were characterised. There were used to estimate number of trucks registered in districts. Missing data imputation methods can be useful in different transportation studies e.g. questionnaire studies or traffic measurements.

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Research on Automation of Operative Scheduling in Urban Public Transportation

E. Nagy, Cs. Csiszár

Budapest University of Technology and Economics, Department of Transport Technology and Economics
1111 Budapest, Stoczek utca 2. St. bld 4th floor
Phone: +36-30-3236501
e-mail: eniko.nagy@mail.bme.hu, csiszar@kku.bme.hu

Abstract: Due to the large number of incidents in urban public transportation, work of traffic control dispatchers is indispensable. At certain times they are overstressed as they have to consider too many aspects according to the regulations and current information system does not provide enough help. Implementation of a decision support system would allow more efficient traffic and incident management. The aim of this paper is to study the possibilities of automation of operative scheduling. The goal is to analyze the tasks of dispatchers, determine the processes that could be substituted with decision support system and prepare the architecture of an IT system showing the database connection of decision support subsystem. The paper contains the operation and decision process on a flowchart that is the algorithm of the operative scheduling.

Keywords: urban transportation, traffic control, operative scheduling

1. Introduction

Urban public transportation incidents can be caused by different factors (technical, human, environmental, etc.) As a result of this, planned schedule of vehicles cannot be punctual. Emerging traffic situations are handled by traffic control dispatchers using operative scheduling, vehicle replacement, etc. The aim is to maintain level of service and reduce disruption in passenger service. Operative scheduling is an incident management process when the vehicles - affected directly or indirectly by an incident - circulate based on the instructions of dispatchers in order to ensure a smoother follow-up interval of vehicles.

Operative scheduling could have several goals. Chinese research analyzed real-time planning of schedule based on unexpected growth of passenger traffic. The IT system is supporting the work of dispatchers as it monitors the changes in passenger's demand and recalculates the schedule considering the availability of vehicles and staff [6]. In Budapest, operative scheduling is used as a method of incident management.

Significant part of the work of dispatchers is real-time intervention, which is mainly done manually reclining on their personal experiences and predefined rules of traffic control. During operative scheduling, determination of new departure time of vehicles is calculated with minimal IT support. This method does not meet the standards of current available technology.

The aim of research is to determine the input data, calculation process and output data required for the process of automated operative scheduling in urban public transportation.

In order to illustrate the complexity of the task, effects of different events and decisions of dispatchers were examined through use cases. Based on the log-book of events and schedule modified by dispatchers, the aim is to make regularity rules. It could be the basic of the algorithm of automated operative scheduling.

Automation of operative scheduling could be part of a complex decision support system. A decision support system is an interactive, computer-based system that enables to help in solving the problems using databases, decision models and judgement of users. The decision is the result of the joint work of computers and humans that improves efficiency of professional activities [8]. In order to create a decision model, programming of manually implemented process of users is needed. Artificial intelligence can be used in this case, which implements the decisions of human users into computerized environment [1].

Based on static (planned schedule, regulation of incident management) and real-time data (type and site of event), algorithm calculates the new departure time of vehicles. As a result of automation, work of traffic control dispatchers become more efficient, in case of fail-safe operation, operative traffic control can be ensured with less human resource in a higher level of service. Labour rules of drivers and technological parameters of vehicles will be handled by the proposed algorithm. In case of any incident, it ensures smooth follow-up interval of vehicles taking into consideration the regulation and current traffic conditions.

2. Research method

During the research, work of traffic control dispatchers was examined in system and process approach. Firstly, information and communication system was analyzed. It is important to determine as current available data for dispatchers are served as input data of the planned algorithm.

Schedules that are used to monitor planned traffic of vehicles and Traffic Management Technologies for Different Lines (incident management strategies) are available as static data on the drive of their computers. Position data, information from drivers and data from on board unit of vehicles (after implementing FUTÁR - Traffic control and passenger information system in Budapest) are received via different communication channels. After processing of received data, information is forwarded to the persons shown on Figure 2. Used communication channels can be seen on the arrows; additionally transmitted data and information are indicated in italics. Results of future solutions are shown as dashed lines:

- direct communication between traffic control dispatchers and incident management dispatchers,

- communication between traffic control centre and vehicles is possible through vehicle's on board unit (OBU).

We analysed the Traffic Management Codex of BKK - Budapest Traffic Centre - which contains the rules and prescribed processes of dispatchers [10]. Based on it we classified the types of events and grouped by spatial and temporal extension of them. Depending on the type of incident we described the handling procedures of it. The mentioned information was used in the implementation of the decision model of automation operative scheduling. The type of event is the input data of algorithm. It determines the handling procedure including the possibility whether operative scheduling could be applied or not. We determined 4 factors which can cause incidents shown on Figure 1.: traffic problems, abnormal road status, vehicle problems and staff.

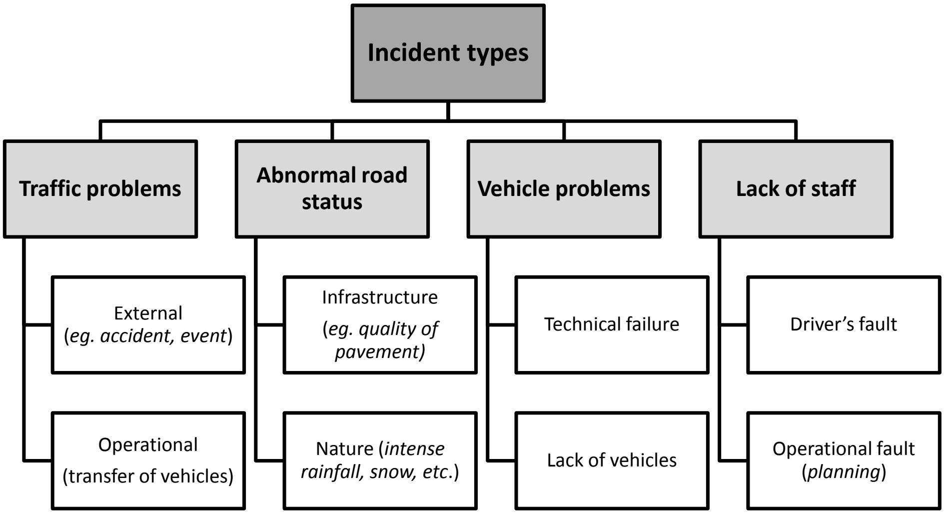
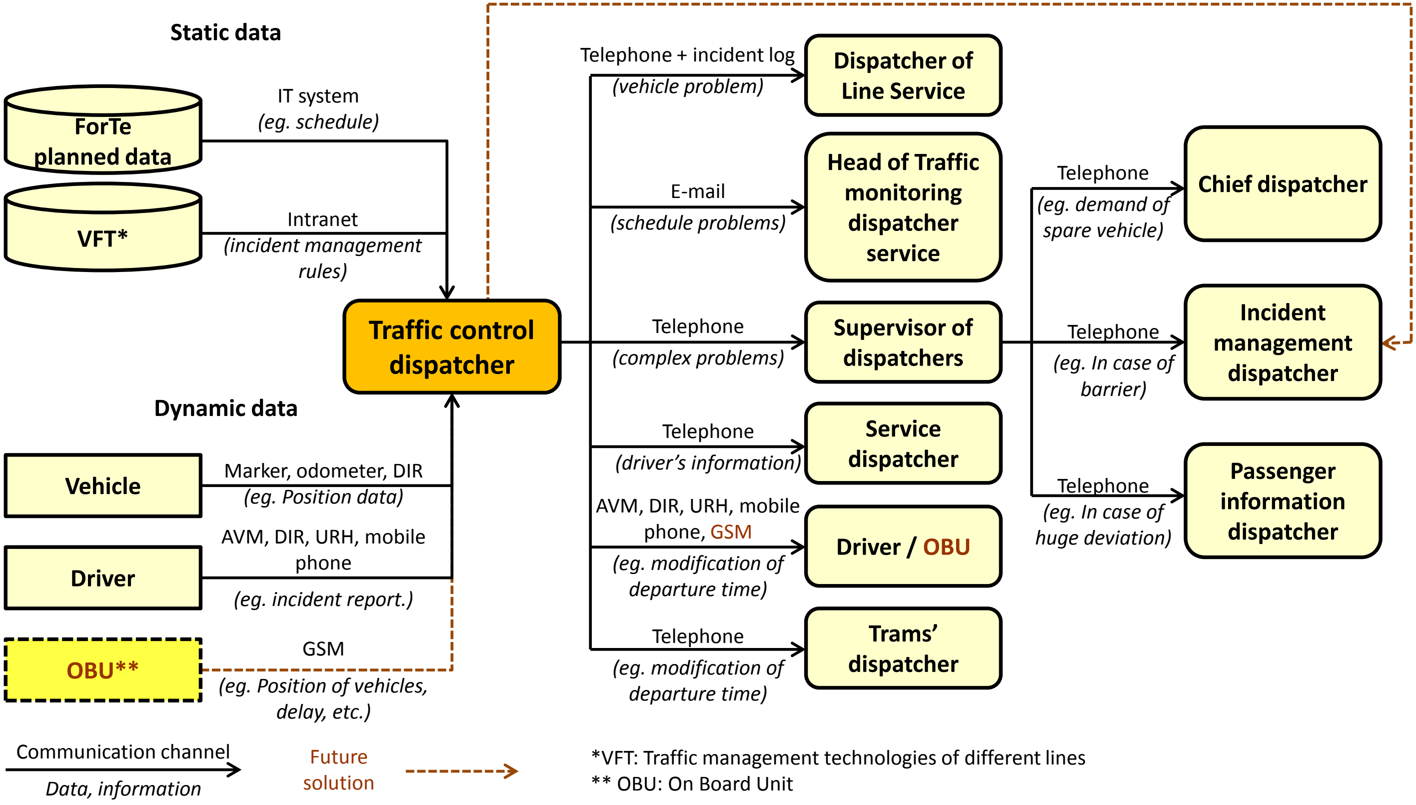


Figure 1: Incident types in public transportation

An incident could affect the circulation of vehicles. It could cause

- schedule deviation (delay), or
- loss of vehicles.

The aim is to ensure the planned departure time and minimize the delays and the impact of loss of vehicles. Traffic Management Codex [10] contains those handling procedures that dispatchers can apply depending on the current situation.



*VFT: Traffic management technologies of different lines
** OBU: On Board Unit

Figure 2: Information and communication channels of dispatchers

The rules are quite complex, in different cases, different handling procedures are needed depending on the type of event, effect of incident and the attribute of the schedule. We classified the cause and effects of incidents, the guidelines of incident management and the possible solutions, handling procedures to the problem. On the basis of the mentioned information it could be decided whether operative scheduling could be applied or not.

If an event occurs, not only the effect (loss of vehicles, delay, etc.) of the incident should be considered but the spatial, temporal extension of it moreover, the number of affected vehicles. From this information we can predict the end of the incident. Table 1 shows the summary of spatial and temporal of events, number of affected vehicles and the dispatcher actions according to the situation.

Table 1: Type and effect of incidents

Spatiality (interference point of origin)	**Timeliness** (time of interference suppression)		**Influenced vehicles**	**Examples**	**Provision**
local (at the terminus, on the network)	predictable	within the succession	one vehicle (affected by the event)	temporally technical failure of the vehicle (e.g. door closure problem in the stop)	monitor schedule
		over the succession	more vehicles (e.g. congested vehicles)	temporally road closure (e.g. transport of delegation)	slow down the following vehicles, modification of terminus departure times, etc.
	non predictable		more vehicles (e.g. vehicles travelling in the same direction)	incident with traffic relation (e.g. road blocks due to illegal parking)	replacement, transfer of vehicles, modification of terminus departure times, etc.
line	non predictable (over the succession)		all vehicles of the line	congestion	modification of terminus departure times, slow down the following vehicles, etc.

The elements of Table 1 can help to determine the code of the incident. According to the conception the code of incident would be the input data of the decision support system. The code stores the information about the possible handling procedures. The aim is to create a list that helps to analyze the circumstances of the incidents in order to determine the code of it. This code will be given to the decision support system by the dispatcher. As for the conception, all of the incident codes have a procedure package that contains the handling methods by priority. The appropriate procedure will be chosen from this package by the algorithm considering the studied circumstances.

3. Result of the research

In order to determine the data connection of decision support subsystem, different kind of data used by the algorithm were collected. Figure 3 shows the input and output of the mentioned algorithm.

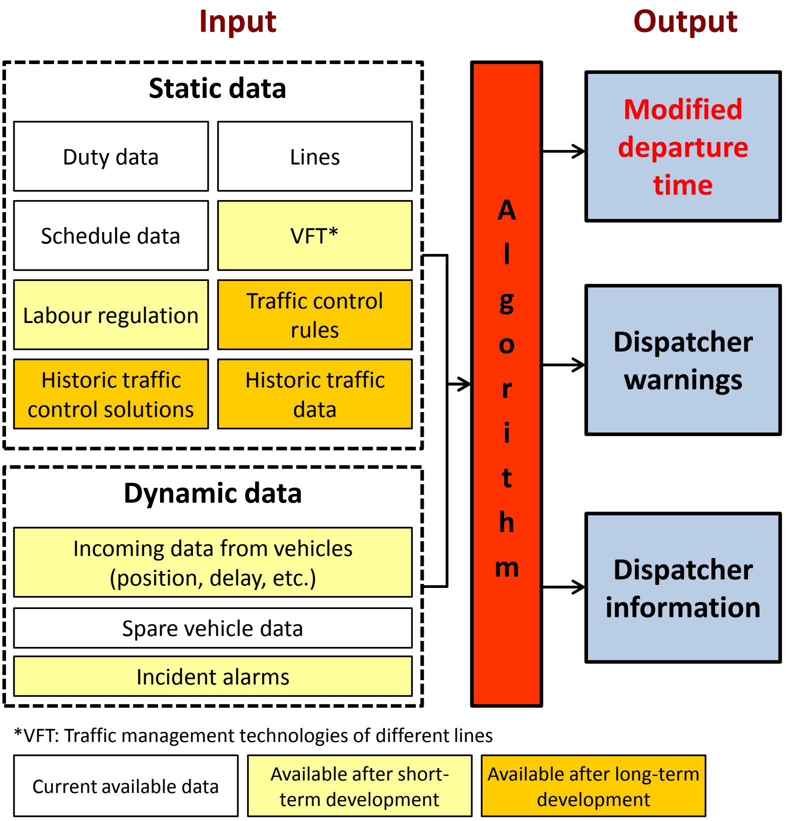


Figure 3: Input and output data of the algorithm of operative scheduling

Input:

Static and dynamic data could be separated while determining input data.

Static data:

Some of the data whose setting into the current database is under development are marked with yellow on Figure 3. We found out that some static data are necessary to the operation of the algorithm of operative scheduling. These are marked with orange as it is a future plan to set them into the database. These are the followings:

- Traffic management regulation: the aim is to program the rules used by dispatchers.
- Historic traffic management solutions: artificial intelligence has an area called inductive learning. Due to this function the program can store the tasks and

processes solved by dispatchers. From these use cases the program is able to set general rules in order to solve the future tasks according to the regulation.
- Historic traffic data: in case of congestion travel and arrival time of vehicles is unpredictable. Using prior data, the system is able to calculate expected arrival time.

Dynamic data:

- Data received from vehicle: traffic data under current circumstances. Based on the exact position of vehicles detected by GPS and the known planned data, the scheduling deviation could be determined.
- Incident alarm: in case of deviation, dispatchers receive incident alarms that could be connected to the incident log. The incident code could be determined after analyzing the incident alarm. That is the first step by the operation of the algorithm.
- Spare vehicle data: it is handled as dynamic data as the list of spare vehicles is constantly being updated depending the availability of spare vehicles.

Output:

- Modified departure time: define new departure time to all the affected lines using mathematical methods. During the determination of new departure time various optimization process could be examined (eg.: new departure time considering the number of passengers, minimizing the number of vehicles, etc). In this case the aim is to ensure smooth follow-up interval of vehicles.
- Warnings: If the algorithm proposes a solution where it is required to overwork the driver, the system sends a warning to the dispatcher, who will approve or reject the resulting solution. In case of rejection, after changing the input parameters, new solution could be expected from the decision support system.
- Information to the dispatcher to using another module: in some cases, modification of departure time is forbidden (eg. fixed schedule). In this case operative scheduling must not be applied. The system sends a message to the dispatcher and delivers the task to another module of the DSS.

During the development of the operative scheduling part of DSS is to have a system that is able to determine new departure time from input data. This is the operational or decision model.

The flow chart of the invented model could be seen on Figure 4 and 5. It illustrates the operation of the algorithm: what is the structure of the management process and what kind of factors are taken into consideration.

The operation process is divided into 3 parts by the human and IT components:

1.) processing the incident alarm and determining the incident code is done by the dispatcher,
2.) determining the management process based on the incident code, calculating new departure time and checking rules are the task of the algorithm and the IT system,
3.) the solution of the computer could be approved and sent to the OBU by the dispatcher.

Decision-making process is divided into 5 parts. These are the followings:

- *I.* Identification of the incident *(determination of incident code with the help of incident alarms)*
- II. Choice of incident management process *(examination of applicability of operative scheduling)*
- III. Determination of new departure time *(calculation of departure time with mathematical methods)*
- IV. Review of calculated departure time *(monitoring changing traffic conditions, control of labour regulations)*
- V. Realization *(approval of dispatcher, inform the driver)*

Operation of the model

I. Identification of the incident:

(1) Incoming incident alarms contain the location of the incident, the affected line, vehicle and driver. Dispatcher can process these information.

(2) Dispatcher selects the incident code based on the incoming information (type of the event, number of affected vehicles). This code will be entered into the system.

II. Choice of incident management process:

(3) Possible handling procedure could be determined by a pre-defined list that belongs to the incident code. The list contains the applicable handling procedures ordered by priority.

(4) According to the list, the system analyzes whether operative scheduling is the primary process or not.

If the answer is NO:

(5) The problem will be solved by other modules of the decision support system.

(6) Depending on the result of the analyzes it decides whether the problem could be solved without operative scheduling or not.

If the answer is YES:

(7) It gives the task to another module of the DSS.

If the answer is NO:

(8) It decides to do operative scheduling.

(9) It analyzes which lines' and trips' departure time has to be modified. Since now, all the lines and trips are handled separately. The followings will be examined to all of them:

(10) Is the schedule fixed? Study of the schedule of the affected trip:

If the answer is YES:

(11) In case of fixed schedule the operative scheduling is forbidden. In this case, dispatcher has to make the incident management manually or the task is forwarded to another module of DSS. Currently, this paper does not deal with this module.

If the answer is NO:

In case of flexible scheduling, determining the departure time is possible.

III. Determination of operative departure time:

(12) In order to calculate the new departure time it has to be examined whether the arrival time to the end station of affected vehicles could be known or not.

If the answer is NO:

(13) Prediction of expected arrival time according to historic data, then

(14) Determination of new departure time. The same process has to be done, if the answer is YES to the question mentioned in point (12).

IV. Review of calculated departure time:

(15) With monitoring real-time data the system continuously checks the calculated and estimated time of arrivals with the data coming from vehicles. (16). If the deviation occurs within an interval, the modification of departure time is needed.

(17) If there is no change within the interval, the system checks the labour regulations and the availability of resources (vehicles, drivers) considering the new departure time.

(18) Is the solution appropriate?

If the answer is NO, the process start from the beginning.

(14)If the answer is YES, realization could be started.

V. Realization:

(19) The calculated solution is displayed on dispatcher side at a pre-set time called (t0).
(eg.: 5 minutes before departure)

(20) The calculated departure time is approved by the dispatcher

(21) After approval, the departure time is sent to the OBU.

We studied which parts of the dispatcher tasks could be replaced by the operation of the decision support system. In order to get results, we illustrated on a flowchart the tasks of the dispatcher, the driver and the telecommunication system, from the received incident alarms until the approved departure time. Figure 6 shows the tasks indicating on which surface the activities will be done. The activities marked with purple could be replaced by computerized system instead of manual handling. Ideally, the decision support system can replace the manual work of dispatchers in 3 phases.

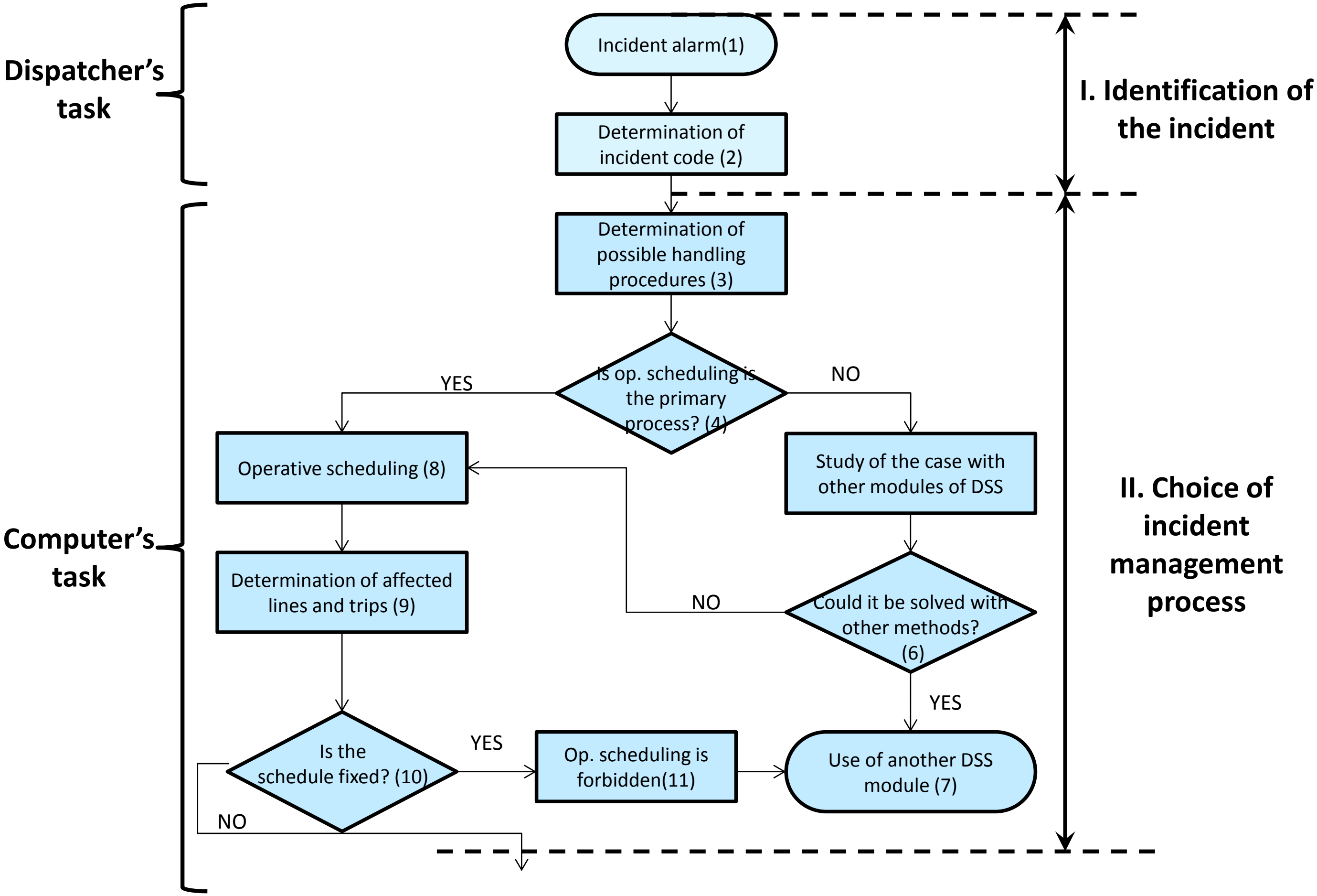


Figure 4: Flowchart of the operation of the decision support system (1st part)

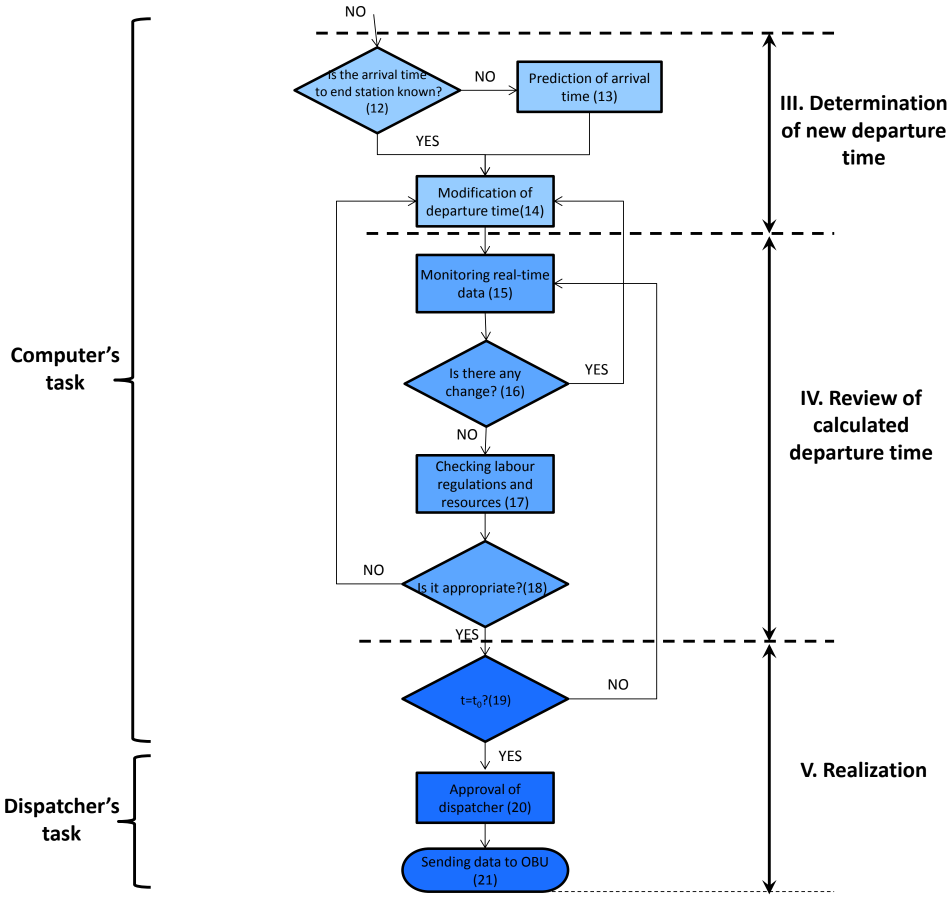


Figure 5: Flowchart of the operation of the decision support system (2^{nd} part)

The decision support system can make changes in the calculation of new departure time until t_0 time. This is the moment of the display on dispatcher side. The computer knows 2 time data: the new departure time calculated by itself and a pre-set time which can be parameterized by user ($t_{pre\text{-}set}$). Based on these $t_0=t_{new\ departure} - t_{pre\text{-}set}$

Pre-set time contains the interval of dispatcher's approval, the sending time and the interval of driver's approval. If the dispatcher misses the approval within the pre-set interval, the system sends an alarm.

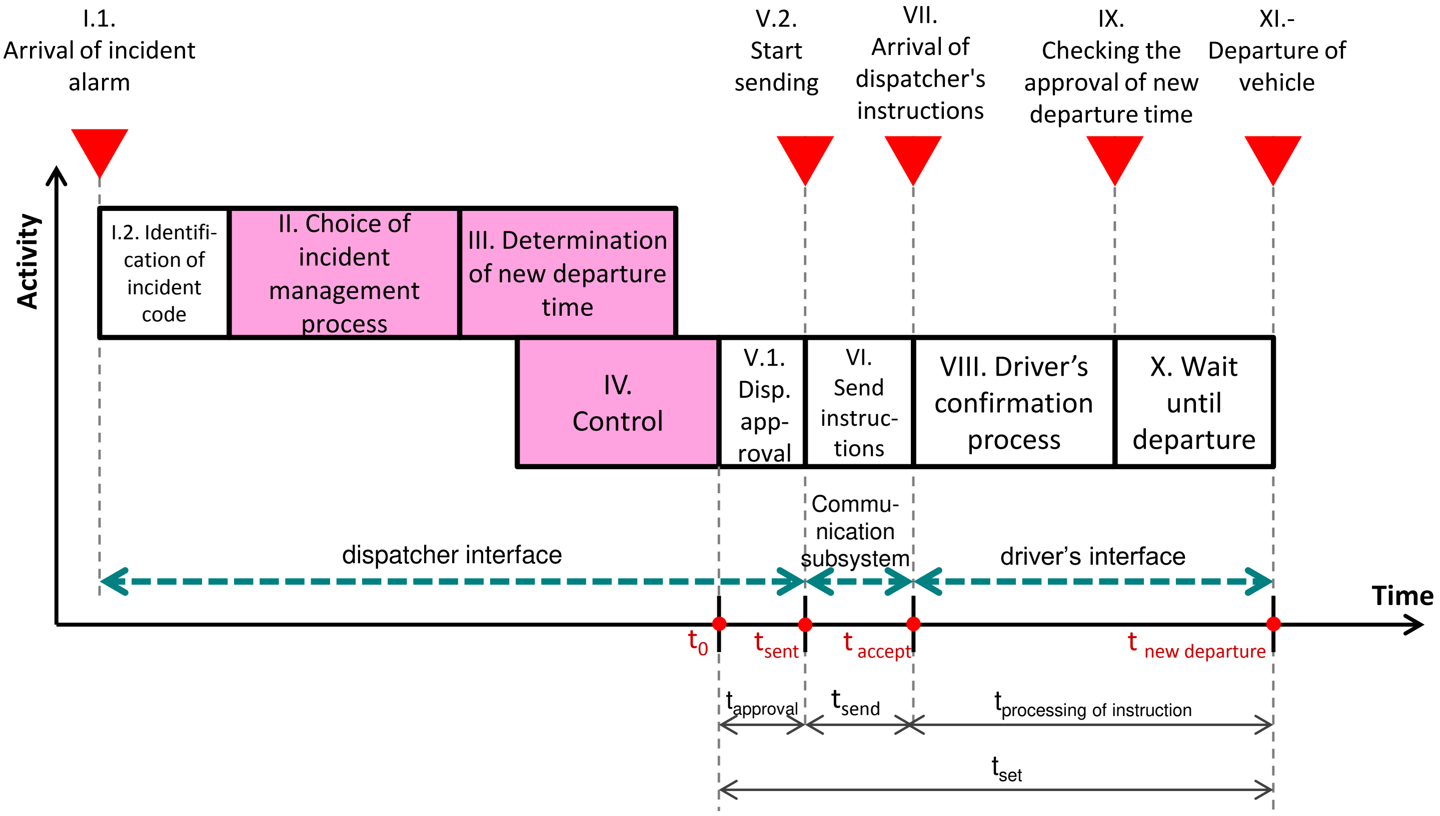


Figure 6: Time-activity diagram of the process of operative scheduling

4. The impact of the decision support system

Computer support of operative scheduling could replace some phases of dispatcher's work. The benefit occurs directly at dispatcher's work, however indirectly both on operation and on passenger side could have positive effects.

Positive changes on passenger side:

- Smoother follow-up interval of vehicles.
- Higher level of service.

Positive changes on operation side:

- Reduce the stress of dispatchers.
- If simultaneous incidents occur, the supporting of dispatcher's work is better. Computers can make more processes during the same time.
- Compliance of labour regulation. Currently, the instructions issued by dispatchers are not checked by computer system.
- Sending the departure time to OBU could be controlled.
- Labour power saving is possible. Employment costs can be reduced.
- Higher level of service, less passenger complaint.

With the installation of a decision support system the aim is to minimize the effects of incidents in urban transport of Budapest [2]. In order to reduce the amount of incidents, vehicle fleet expansion and significant investment in infrastructure development would be required. Reducing congestion would also be solved by infrastructure development or traffic management tools. As for the financial or time investment it does not result changes in short-term. But the effects of incidents could be minimized with appropriate incident management.

Economical impacts

The aim of the implementation of a computerized system is to support employer's work and beside it to improve economic and social benefits and minimize the losses.

Economic impacts will occur directly at the transportation company with cost savings and generating new incomes. Additionally, external effects can occur on passenger side as the benefit of travel time reduction that comes from delay reduction.

Economical impacts on passenger side

Cost reduction of journey time

Due to the incidents in urban public transport the follow-up interval of vehicles and the journey time is changing.

$$\begin{aligned} \mathit{Journey\ time} &= \mathit{Walking\ time} + \mathit{Waiting\ time\ at\ stops} \\ &\quad + \mathit{Time\ of\ getting\ on\ and\ off} + \mathit{Travel\ time} + \mathit{Walking\ time} \end{aligned}$$

Using operative scheduling, the waiting time at the bus stops can be reduced. This time value will be used while calculating journey cost reduction on passenger side.

The journey time cost reduction is based on the value of GDP/hour or average income (HUF/hour). If passengers get out of production due to the delay, it causes the reduction of GDP in national economy. During calculation we separated the average values of business and non-business journeys [9].

In order to calculate the cost of waiting time at bus stop we used the following formula:

$$C_w = C_j^b * P^b * \Delta t_{sw} + C_j^{nb} * P^{nb} * t_{sw}$$

$where:$

$C_w: cost\ of\ waiting\ time\ at\ stops\ [HUF]$

$C_j^b: cost\ of\ journey\ time, business\ journey\ [HUF/passenger\ hours\ ]$

$C_j^{nb}: cost\ of\ journey\ time, non-business\ journey\ [HUF/passenger\ hours\ ]]$

$P^b: number\ of\ passengers, business\ journey\ [person]$

$P^{nb}: number\ of\ passengers, non-business\ journey\ [person]$

$t_{sw}: saved\ waiting\ time\ at\ stops\ [hours]$

Value of journey time on 31 December 2008 [5]

- bus travel, business journey: 3585 HUF/passenger hour
- bus travel, non-business journey: 1255 HUF/passenger hour

To the calculation of actual value of journey time, the following inflation data has been used

Table 2: Inflation data between 2009-2012. [11]

Year	Inflation
2009.	+ 4,2 %
2010.	+ 4,9 %
2011.	+ 3,9 %
2012.	+ 3,5 %

According to Table 2, the value of journey in 2012:

- in case of bus travel, business journey: 4214 HUF/passenger hour
  (C_j^b= 3585*1,042*1,049*1,039*1,035=4214 HUF/passenger hour)
- bus travel, non-business journey: 1475 HUF/passenger hour
  (C_j^{nb}= 1255*1,042*1,049*1,039*1,035=1475 HUF/passenger hour)

Ratio of business and non-business journeys is 30%. This value can change [5].

The total number of passengers is the sum of business and non-business travellers:

$$P = P^b + P^{nb} = 0{,}3 * P^{nb} + P^{nb} = 1{,}3\, P^{nb}$$

As: $U^{nh} = 0{,}77U$; $U^h = 0{,}23U$

Using the previous calculation to the following formula:

$$C_w = C_j^b * P^b * \Delta t_{sw} + C_j^{nb} * P^{nb} * t_{sw}$$

The result is:

$$C_w = 2105\ HUF/passenger\ hours * P * t_{sw}$$

According to the results, the cost of waiting time at stops depends on the followings:

- cost of journey time that is changing year by year,
- number of affected passengers including business and non-business travellers,
- ratio of business and non-business travellers,
- waiting time at stops.

The calculated costs have been applied to the total waiting time. One part of this occurs even if there is no operative scheduling. Cost saving can be achieved with operative scheduling if the waiting time could be more than usual (eg. due to loss of vehicle).

Saved waiting time: Δt_{sw}.

Saved cost:

$$\Delta C_w = 2105\ HUF/passenger\ hour * P * \Delta t_{sw}$$

If we save 8 minutes with operative scheduling:

$$\Delta C_w = 2105\ HUF/passenger\ hour * P * \frac{8}{60}$$

Based on the foregoing we could say that due to incident the waiting time at stops is increasing, but the effect of it could be reduced with operative scheduling. It occurs in journey time cost as well. Better follow-up interval of vehicles ensure cost savings to the passengers of lines affected by incident. Economic impact of automated operative scheduling occurs not directly on operation side but on social side as well with the reduction of journey time costs of passengers.

5. Summary

In this paper feasibility of automated operative scheduling was examined. It is found that which parts of the operative scheduling process could be substituted with computer support and how it fits into the current IT system.

The issue of the paper is important as the handling of the incidents of Budapest public transport has a huge effect on dispatchers. During their work, they have to consider too many aspects and compliance the rules with minimal computer support. The development of a decision support system has already started and automated operative scheduling could be integrated into it. With the implementation of FUTÁR, more data will be available for dispatchers about the position of vehicles and sites of incidents.

The paper deals with tasks of dispatchers, the analysis of different type of incidents, the rules of traffic management and the steps of operative scheduling. The current and under development IT system was examined as well.

As a result of research, the types of incidents were categorized according to their effects on vehicles. We found that the key of the operative scheduling could be an incident code that contains the properties of the incidents and could be the basic of decision model. The input data of algorithm of decision support system were defined. Based on it we concluded that development of new database is needed. The operation of algorithm were prepared on a flowchart. That is the decision model. The steps and decision points were explained.

We found that the operative scheduling process would be partly automated but dispatcher support is needed as well. We analyzed the economic impact of the new information system both on operational and on social side. According to this, the efficiency of the system could be improved if based on vehicle diagnostic methods the occurs of incidents could be predict in advance.

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The Questions of Acquisition and Use of Operational Information in Urban Public Transport

I. Prileszky

Széchenyi István University, 9026 Győr, Egyetem tér 1.
Phone: 503 400, fax: 503 400
e-mail: prile@sze.hu

Abstract: In this article, we examine that beyond current standard methods which opportunities there are to obtain information about the traffic and in connection with this the use of this additional informations in planning and management.

Keywords: public transport operation, intelligent control

1. Introduction

The development of information technologies has brought great changes also in public transport. The first attempts to monitor the vehicle during the traffic was made in the '60s in Munich, still based on control points. Faced with this technology about 20 years later the satellite positioning became available as alternative option. Today, the GPS-based management and information systems spread to the extent that they are regarded as routine solution. The other main element is the electronization of the ticket system. In this area, more problems still seem to be solved, but in many parts of the world, the electronic ticket has long been a part of everyday reality. The future is definitely promising, in addition to the movement of vehicles about passenger traffic will also be possible to obtain complete information. Based on the huge amount of information further progress can be achieved in the field of planning and management methods, which allows the creation of more efficient intelligent transportation systems. In this article, we examine that beyond current standard methods which opportunities there are to obtain information about the traffic and in connection with this the use of this additional information in planning and management.

The public transport system can be divided into three major parts: design, operational and accounting components. Each of these components have streams of information which may play from the point of view of the individual components input or output role. The planning is based on the data of carried passengers which is an output of the operation, the output of accounting is the evaluation of the effectiveness of the system. The transport system must operate in continuously changing environment, that is, to adapt to environmental changes. The adjustment is done by means of feedback. Based on the feedback cycle time, we can distinguish between strategic, tactical and operational levels. Their schematic diagram is shown in Fig.1.

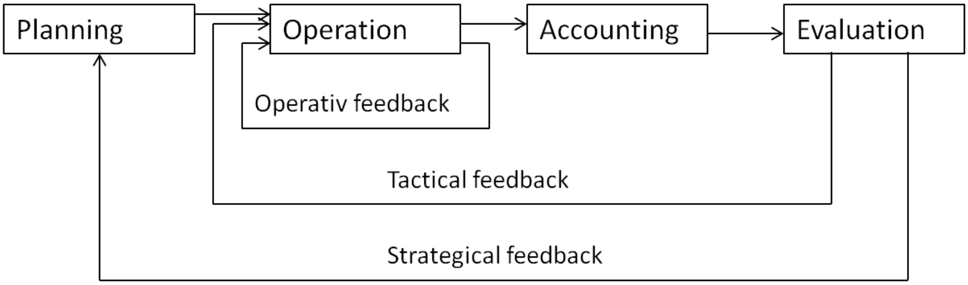

Figure 1. The strategic, tactical and operational level illustration

The quality of feedback is the decisive factor in how the system reacts to the outward changes, that is in which extent can be regarded as intelligent. The quality of feedback basically depends on information supply and due to character of transport the most important are the traffic information.

2. Resources of and ability to obtain traffic information

In the public transport the movement of people traveling and the movement of vehicles can be distinguished. In the course of operation these two processes temporarily are united, then the actual delivery is made. The planning and operating management are based on data of these two processes. Understanding the vehicle process is basically important for the running time planning and operational traffic management, understanding the "passenger process" is of relevance for the network and schedule planning and operational management.

2.1. Passenger traffic data

One and perhaps the most important source of information to recognize travel needs are the data of trips done. Full information you can talk about when about each trip is known

- the stop and time of boarding
- the service (vehicle run) travelled
- the stop and time of alighting
- the kind of the ticket
- all in such a way that
    - the change travels can be mapped and
    - trips by the same person within a period can be gathered from.

The automated data collection tools of passenger traffic include: passenger counting device, video camera and image processing system, electronic ticket detection, tickets on mobile phone detection, use of mobile cell phone information.

2.1.1. Automatic Passenger Counter

The counters are able to measure the number of boarding and alighting passengers or the number of occupants in the vehicle, so are only suitable for cross-sectional data service. However, the measured data can be used in monitoring and, if necessary, to correct OD data.

2.1.2. Video recording and image processing

The video and image processing is already suited to identify the passengers boarding and recognize again by alighting, so that can provide information of OD character. It is also possible that passenger making changes are recognized in the second vehicle again, and so the transfer travel information is ascertained. This requires that the face recognition software generates the same identification code to the same person by each camera and this data will be kept in a central database and be matched daily or periodically. The technical development of face recognition and identification software will certainly progress further, and this method will become more reliable and cheaper, but by this method the ticket-related information remain unknown. It is unrealistic to expect that the recognition software will be able always to identify people changing the appearance day by day, (or even within a day as well). So all trips taken by the same person over a longer period shall not be settled together, for example can not be known how many travels are performed with a monthly pass etc. The more in-depth analysis of travel habits can be ensured by this system in a number of respects only partially.

2.1.3. E-ticket

The electronic ticket is the only known means by which each - listed above - data can be acquired. Due to the fact that without condition, and fully free travel under the present state of knowledge is not considered a realistic alternative, we can say that a fare is definitely needed. In such cases, it is obvious that it is the e-ticketing system which should be the passenger data collection tool as well, i.e. the ticketing system has to be developed in such a way that on this basis all the above listed data could be produced.

In today's generally accepted view the radio frequency identification (RFID) technology is the best because it does not require to insert ticket to the ticket machine. Radio signals emitted by the reader unit activates the unit on the ticket, which is about in response, transmits the information stored there. The technology is bound to work only a short distance, so passengers have to pass in close proximity to the sensor. In transport, this seems to be less a problem because the vehicle doors can serve as natural "entrance gate".

Attributes of the passenger traffic can be obtained by recording and processing tickets scanned data (including the ticket identification code). Incorrect data may occur, in congestion the sensation may be incomplete, or passengers alighting in order to give place to others when boarding again will be identified as new passengers. These errors may be reduced or eliminated by means of software.

In application of electronic tickets there are some critical issues not yet fully resolved.

2.1.4. Way of ticket handling by alighting

There are systems where ticket identification is required also by alighting. The recorded data together with the data of boarding allow to determine the relation of trip. It works if boarding and alighting may happen only on designated doors, and it is respected by passengers It is possible that boarding and alighting are allowed on all doors and the reader device determines whether boarding or alighting happened. In this case several lines of sensors should be placed on, and the succession of detection is the key, based on which boarding or alighting can be isolated. These solutions have the disadvantage that they wish some cooperation from passengers, and sometimes (especially in the case of congestion) may provide incorrect information.

2.1.5. Determination of entitlement to use

Valid tickets will only be eligible for travel by a person authorized to use it. Methods for the automatic ticket checking are not yet offered a good solution to this problem. Since this problem is not linked to the cause of traffic data acquisition, it is not detailed in this issue.

2.1.6. The issue of one-way tickets

The problem is that, compared to the price of a single-use ticket a ticket with a chip unrealistically expensive, although it may be for the future this will not be a problem. Based on the current situation as a solution for the problem can be considered when buying one-way ticket is possible only on stop or vehicle from ticket vending machines and the ticket data are stored by the machine. In this case the boarding ticket control is done not by electronic ticket reader, but in other ways, such as reading printed on the ticket barcode or QR code. By purchasing ticket on stop the starting point of trip is a priori given and it is conceivable that while buying ticket the ticketing device may request the destination stop. The data of the tickets issued are stored by the ticket machine. The situation is similar for tickets purchased from vehicle driver. Under the system logic elsewhere (in advance) one-way ticket would not be available for purchase.

Enter the destination stop seems natural, in cases where the fare depends on the distance of travel as well. The pretty standard today's "flat rate" against the use of distance-related charges, originates rather in control and computer difficulties than than economic or other justification for this operation. If the electronics progress these difficulties may disappear, it is likely - especially in the larger cities, that tariffs reflecting the travel distance will be more extensively used.

2.1.7. Buying ticket on the vehicle

There is demand - mostly in small towns - for ticket purchase in vehicle from the driver. In this case, we must resolve that by issuing the ticket the data of the trip will be recorded, possibly with destination stop.

2.1.8. The processing of electronic ticketing information

Further information can be obtained by further processing of the recorded data. Trips with change can be identified. If several trips were made with the same ticket, the travel chains and travel habits can be studied. In many cases, it is possible to estimate the alighting stop even if no note has been recorded by alighting. The software tool will complement the primary data recorded during the trip.

2.1.9. Ticketing by mobile phone

Amongst the visions on the future of IT technologies it is often emerges that we will conduct a large part of our payment transactions with mobile phone (or with some sort of smart mobile devices which will be the successor of mobile phone). The traffic data collection can only be done if the ticket is purchased so that data can not only be red visually on a mobile device's screen, but also in electronic format. It is possible that the mobile device transmits the data by boarding, but it does not seem practical solution as the passenger should launch a specific application. Determination of the alighting stop is a further problem. Seems more realistic, if your mobile phone can only be used as payment for any ticket purchase, including ticket vending machine, and ticket is actually issued by any purchase. Of course the use of a mobile device for this purpose is conceivable, but specific application needs to be developed further into the future.

2.1.10. Use of mobile phone cell information

Theoretically the movement of cell phone holder is cognizable based on the cell information. By means of software the public transport users can be filtered. However, you can not assign a passenger to a certain vehicle run if more than one vehicle are at any given time in parallel motion, on the other hand, the dimensions of the cells do not make it possible to obtain data with sufficient accuracy. Mobile phone can give good information so that if cooperative passengers let a special application run on their phone during the journey. Distant future, of course, it is possible that mobile device will be able to present the required information, but it needs to be developed specifically for this purpose.

2.2. Number of passengers waiting at the stops

This is important information for traffic control, which is less pronounced in existing systems. Routine solution to install cameras at main stops and images are transmitted to the dispatch centre. The information obtained can be important in the daily control work, but since it does not provide a complete and exact data may not be a perfect solution. By today's development of image processing technology it is not a problem to determine the number of occupants in a designated area. Applications covering all stops will be probably commonly spread in the future.

2.3. Data recovered from travel planning services

The journey planning systems basically provide information to travellers, but a by-product may contribute to the understanding of travel needs as well. Search on a planner is not regarded implemented journey, as it is not certain that the person seeking the recommended route is actually going to travel, and secondly, if so, then we will fix the ride of the vehicle takeoff. Searches are nevertheless provide useful information because analyzing the relationships sought by frequency changes over time, and other aspects can complete the knowledge we have from the data of completed trips.

3. Information relating to the vehicle

The most important information about what is happening with the vehicle in the traffic, also at present is given by the systems already operating. In the following, only the critical elements and possible expansions are expected to be discussed here.

3.1. Identification of the vehicle and driver

The vehicle will get into operation if activation of the in-vehicle equipment happens. Since a driver belongs to each vehicle in operation, identification of the driver is also necessary at the same time. To prevent false registration, the driver must have some identifiable means For putting the vehicle into operation the joint activisation of vehicle and driver device is required. In addition to the identification function, ideally the drivers' device is suitable

- to accept the disposition of control centre or receive the signal that disposition arrived onto the vehicle on-board instrument , if the driver is not in the vehicle,
- for voice connection to the dispatch centre,
- to register the driver's job performance, the time spent at work and the data of the work performance are stored and are retrievable, viewable, so the driver can monitor the advancement of his working performance,
- to receive and display the provisions relating to the driver's work schedule, the monthly duty rosters and its occasional changes.

The functions of this driver's device are particularly important if a vehicle is operated by more than one driver within a working day and there are no paper-based documents on the drivers' work.

3.2. Location information and status characteristics of the vehicle

Obtaining the location data of vehicles by GPS (or entering into operation soon Galileo satellites) can be regarded as solved. Within the vehicle status characteristics traffic (operational) and technical data can be distinguished.

Traffic characteristics include all the factors that are related to quality of service. Among them is the number of passengers in the vehicle, as it shows the level of service and is the best factor to show the level of crowdedness, in addition is an important input information to the traffic management Obtaining this data are basically ensured applying the methods outlined above in point 2.1., but because of the there indicated inaccuracies an actual passenger load counter is also recommended. Thus, there will be two sets available of passenger numbers (measured by the instrument and revealed from the ticketing), these two sets of data together contain more information than either of those two alone. More traffic type parameter is considered as the temperature, the door position (open, closed), the lighting and air condition (off, on), and possibly other, similar factors. The acquisition of these data is a measurement routine.

By technical characteristics we mean the operating parameters of the structural components of the vehicle, we deal with these no longer.

The location and condition specific data must be sent to the dispatch centre. The frequency required to submit data depends on the nature of the data, for example, number of passengers in the vehicle is only one stop intervals (e.g. after leaving the stop) actually new information, by location and other data a greater frequency may be justified.

3.3. Alarms

The automated traffic management systems usually have alarm function that can be activated by the driver (often hidden switch). This function can be completed by an automatic alert system. The typical emergency sound effects can be filtered out by software tool and an automated alarm signal can be given on this basis. When the alarm is activated microphones placed in the vehicle are activated as well and what happens in the vehicle becomes audible and can be recorded in the dispatcher centre.

4. The dispatch centre

Information ensured by the outlined IT solutions is available in the dispatching centre (DC). The information flows are shown in Fig. 2. Hereinafter we made the assumption that all the information is available, which can be obtained from the operating process.

The processing of incoming information serves a dual purpose:

- display the traffic situation for the traffic management operational activities,
- storing the data for additional processing for a variety of purposes.

By the application type the further processing can be divided into three groups:

- processing for the passenger information system
- preparation and updating of historical data for traffic management,
- accounting and statistics.

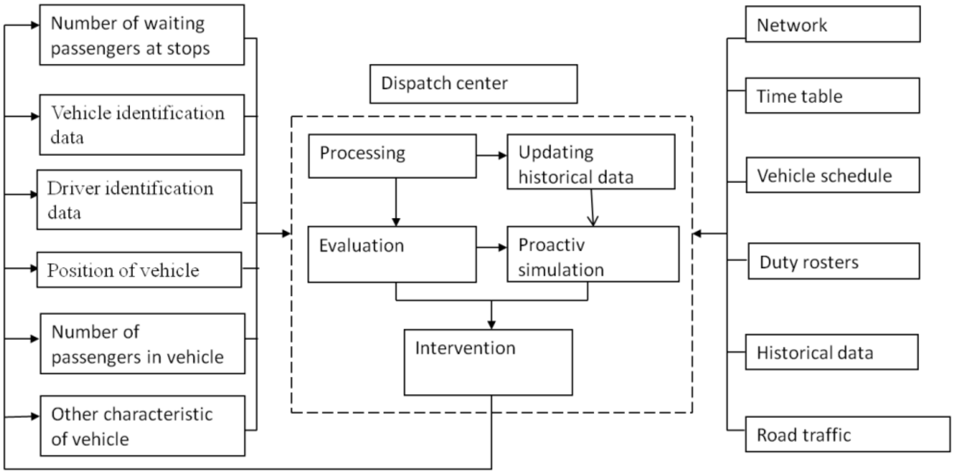

Figure 2. Operational information flows

4.1. Display the traffic situation

Formal elements of displaying the traffic situation as regards the vehicles are well established, for details of that are not discussed. Significant development in this area is desirable only to the extent that the saturation level of the vehicle (the amount of crowd) also reflect the show. The information system described contains the basic information you need to do so.

The number of waiting passengers on stops is other important information for the traffic control, the graphical representation of this is considered appropriate. This raises the question of whether the numerical data, the magnitude of the category, the trend of change, the deviation from the regular headcount, etc. should be included with the display. Of course, behind the graphical representation of data retrieval should be possible.

4.2. Processing of passenger information

The passenger information systems require both static and dynamic information. The dynamic information is taken from the operating process. On the stops beyond the usual information the saturation of the vehicles expected to arrive can also be displayed.

4.3. The historical data

Through continuous collection and processing of the passenger traffic data and data about movement of vehicles a historical data basis can be created. By analyzing the time profile of passenger volume and vehicle running time fluctuations homogeneous periods can be determined, within which almost the same parameters are prevalent. In this way typical time periods can be distinguished which depend on the month and day type, and may be further broken down by some other criterion (e.g., weather). The specific boundaries of each period for specific lines, where appropriate, may differ. A historical database will include for all of such periods of time

- the average values and distribution of vehicle running time between the stops for each lines
- the number and distribution of passengers loading and alighting on each stop for each services operated.

5. A proactive traffic control

In possession of advanced information technology and large databases a traffic control can be achieved that uses not only information about the current situation but also historical data in addition to these. In essence, on the basis of historical data the information system forecasts the further development of the existing situation and also evaluates the expected status. In doing so, the problems can be detected before their development, and actions for the prevention can be done occasionally The term "proactive" refers to this preventive character.

A proactive control system has to solve the following tasks:

- Based on the current traffic situation, calculating the number of passengers and vehicle travel time for the specified period of forecast,
- based on this calculated values determining the expected vehicle schedules,
- assessment of the resulting simulated traffic, definition of problems,
- simulating the effect of an intervention method selected by the traffic controller i.e. re-running of the forecast with the specified modification, in this way making possible to evaluate how effective this traffic management measure would be.

Normally what happens is that the system is being continuously simulating the further progress of vehicle runs in advance, and displays the characteristic features of the expected traffic situation, for example delayed arrival or departure, the evolution of the crowdedness.

The proactive management of public transport resolve stiffness and gives some flexibility to this service, which can approach to the flexible transport systems (DRT). Of course, there are limits to the flexibility of the service in consequence of what was previously announced, but especially in large cities where the headway is small, it is possible to change within the acceptable range. If this happens, the pro-active management will not only enhance the quality of service, but also can reduce the cost as well.

6. Accounts and statistics

The operating data can be processed into a variety of other purposes. By way of example: drivers' payroll can based on the data of performed services, the case is the same if transport operator reports on the performed service to local council in charge of public transport. The mileage of vehicles forms the basis of accounting, fuel, vehicle maintenance, engineering design, and so on. Information technologies also can ensure that these are based on real, factual data.

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Effects of Rainfall on the Motorway Traffic Parameters

Zs. Sándor

Budapest University of Technology and Economics, Department of Transport Technology and Economics
1111 Budapest, Stoczek utca 2. St. bld 4th floor
Phone: +36-70-3139977
e-mail: sandorzs@kku.bme.hu

Abstract: The relationship between traffic events and weather has been studied for over 60 years. During the last decades, several experts have analyzed the effects of weather on traffic and accidents in the world however in Hungary, such research has not been conducted yet. In this paper, the author examines the effects of rain on travel speed. The speed changes in traffic lanes (fast lane and slow lane) have been studied in different motorway cross sections with various traffic characteristics under heterogeneous traffic intensities and weather conditions.

Keywords: transport meteorology, precipitation, motorway, traffic flow

1. Introduction

Different environmental impacts significantly influence the contact between road surface, vehicle and driver. Adverse weather events and conditions have an impact on the pavement-vehicle relationship. Drivers try to accommodate to the new situation by changing their driving style. Traffic and road safety parameters can change considerably depending on the dimension and the intensity of the event. Several studies have dealt with the effects of rain on traffic, accident risk and traffic demand changes: [2,3,7,8,10,13,18,29].

Out of the weather events, the rainfall has the most significant impact on the traffic flow because of the (1) poor visibility conditions, (2) decreased adhesion coefficient between the road surface and vehicle and (3) increased risk of aquaplaning. In such cases drivers reduce their speed and increase headways, which results in a slowing traffic flow and increasing travel time. Due to the speed reduction speed-density functions, which describe the continuous traffic flow process are changing and stabile-instable domain are shifting.

In Hungary, in 2011, 21.1% of all personal injury road accidents happened on wet, snowy, or icy road. Adverse weather (like fog, rain, storm, snow, freezing rain, etc.) existed at 9.4% of the total accidents [16].

At 13.3% of the total person injury accidents that occurred in the motorway network prevailed adverse weather and at 21% of the event, the pavement was wet or slippery. In case of inclement weather the most accidents befell under foggy or during rainfall.

In this paper, the author presents his own, national study results about traffic changes due to rainfall. Currently only the effects of rainfall out of adverse weather conditions were investigated. Different cross-sections with different traffic loads were chosen on the M3 and M7 motorway for the study.

Several factors have been motivated the realization of the research:

1. In Hungary until now it has not been conducted yet any research that investigates the effects of weather parameters on traffic flow;
2. In the recent years, extreme weather events have been getting more and more frequent and intense (extreme precipitation, wind, etc.);
3. The recognition of driver behaviour in adverse weather conditions can be utilizable in further researches as input data. (e.g. emergency traffic control);
4. Drivers run with higher speed on the motorway networks and the configuration of the roads are different than the urban and main roads;
5. Drivers can be informed via the roadside collective information equipment and it can influence driving behaviour as well.

2. Literature review

The beginning of scientific research of the effects of weather events on traffic went back to the early 1950's. Tanner in [32] had investigated the connections first, and later, from the mid 1970' the traffic meteorology researches have become more intensive. In the references [2,6-8,10,15,18] the connections between weather, traffic and road accidents data have been analysed. It is not easy to compare the results, because (1) the applied traffic and weather data collecting methods; (2) the investigation spots and times; (3) the investigated sections and their configuration, (4) the traffic composition, (5) the technical quality of the applied equipment and several other factors were different. However, it can be declared that adverse weather conditions mitigate the travel demand, especially on weekends and holidays. Transportation mode choice is also affected by the weather. Those countries and regions where the proportion of cyclists and motorcyclists is high, in case of rainy weather the users switch from two-wheeled transportation method to closed-cabin vehicles. It can be individual motorized transport (especially cars) or public transport, depending on the degree of mobility.

Codling in [10] investigates the evolution of accidents in dry and wet weather. In the research it was highlighted that in Great Britain 31% of the accidents occurred in rainy weather – on wet pavement – and approximately half of them during rainfall. Keay and Simmonds in [18] found that rainfall increase the number of accidents by 1.9% during day-time and by 5.2% during night.

Tanner conducted researches in England [32]. Negative correlation was shown between traffic flow and the intensity of precipitation. It was calculated that the intensity how much decreases the traffic volume of personal cars (1.3-3.1 % /mm/h). Hogema [15] analysed the traffic parameters of the Dutch motorways and interestingly there was no significant difference in the traffic volume during the wet and dry weather, furthermore the modal split was not changed. Mainly it can be originated from the traffic culture. Changnon [6] examined the effects of rainfall in Chicago during the summer period, in urban traffic. On weekdays the effect of rain is negligible but on weekends it decreases the traffic by 9%. Chung determined that on the Tokyo urban motorways on weekdays in rainy weather the traffic flow decreases by about 3% and on the weekends by approximately 6-7% [7,9]. Keay and Simmonds studied the effects of rain in Melbourne, in Australia [18]. During spring and summer the traffic volume can decrease either by 2% in rainy weather. Traffic reduction is greater the more intense rainfall.

Chung in [8] established that the capacity of motorways could decrease by 4-7% but in case of extreme rainfall by 14%, depending on the intensity of rain. Rainfall has an effect on the free-flow speed (v_{free}) at the influenced section – because drivers have to adapt to the changed road conditions. Value of “v_{free}” can reduce from 4.5% to 8.2 % compared to the speed, experienced in dry weather conditions. Day and night visibility conditions also have an effect on the capacity of a given road section. Chung determined that capacity decreased by 12.8% in winter during the dark hours, compared to the values of summer period [8].

Alhassan and Johnnie [2] examined the effects of weather in Malaysia. Results were divided into three groups depending on the intensity of precipitation:

1. In case of light intensity (<2,5 mm/h) the capacity reduction is 8%, but in case of low vehicle density (5-25 veh/km) the impact cannot be measured.
2. In case of medium intensity (2,5-10 mm/h) the capacity can be reduced significantly even by 50%.
3. In case of heavy intensity (10-50 mm/h) 31% capacity reduction was observed.

Moreover it was found that in those sections where the capacity reduction is over 30% in case of rainy weather, significant congestions can occur there during dry conditions.

Hogema in [15] investigated the changes in headway time. It was established that in rainy weather the proportion of short time headways (less than *1 s*) were smaller (5%) than in dry weather (10.8%). Headway times under *3 s* and over *5 s* were also examined but in these cases the effects were smaller. The difference under *3 s* is less then 2% and over *5 s* there is no percentable difference. Alhassan and Johnnie [2] conducted their research in Malaysia and similar results were found. Headway times under *0.5 s* were investigated. In case of low traffic there is no significant difference, but the traffic volume increases, the headway times are longer, and changes in traffic flow is getting more conspicuous, compared to dry conditions.

Accident risk is closely related to weather. In Finland the accident risk is 9 times greater on snowy road and 20 times greater on icy road than on dry roads [29]. In Norway this value is 2.5 times more on snowy or icy road than on dry roads [13]. Canadian researchers Andrey and Yagar in [4] showed that accident risk is higher by 70% during a rainfall than on dry roads. Satterthwaite conducted that in State of California twice as much accidents occurred in rainy days than in dry days [30]. Brodsky and Hakkert established – based on American and Israeli data – that the accident risk in rainy weather is two-three times more than in dry weather [5]. Moreover this risk is higher when rainfall occurs after long dry periods. It has psychological explanation: drivers get unused to changed road conditions during the long and favourable circumstances.

Several researchers [12,19] have studied the effects of snow on traffic flow. It was found that in snowy weather the traffic volume is significantly lower – either by 30% – than in dry weather. However, during the snow, the accident risk is greater than in dry conditions, nevertheless less personal injury accidents occur [19]. The number of serious and fatal accidents is less than in dry weather. Researchers have shown that at the beginning of the winter period during the first snow days more accidents occur. Maze and Hans [23] showed that at the beginning of the winter period the accident risk is greater by 3.5 times than at the end. It has also a traffic psychological explanation: after the beginning of the winter period, the drivers are well prepared and they act according to the road conditions.

Based on the different research results it can be seen that adverse weather conditions pose a significant accident risk. Its rate depends on the traffic volume, drivers' behaviour and current status of the infrastructure (presence of drainage channel, purity, pavement condition etc.) in addition to the intensity of weather event. Drivers react to the changed road conditions (reduce their speed, increase headway), but not always properly (do not take into account the higher response time and longer breaking distances). In many cases, the drivers do not realize that the road friction coefficient is modifying with the weather changes [20]. Table 1 summarizes the effects of rainfall on traffic flow divided into countries.

Table 1. Most common effects of rainfall

Country	Analysed parameter during rainfall	Effect
United Kingdom	accidents	increasing frequency, especially at night
	traffic volume	decrease in rainy condition
USA	traffic volume	decrease at weekends
	accident risk	increase
Australia	traffic volume	depending on the intensity it is decreasing
Japan	traffic volume	has less effects on weekdays and has more significant effects on weekends
	capacity	depending on the intensity it is decreasing
Malaysia	capacity	depending on the intensity it is decreasing
Netherlands	traffic volume	has no effect
	headway time	depending on the intensity it is decreasing

Based on the table it can be seen that effects can differ from country to country, and even from region to region. Thus results can be evaluated only in their own environment, they cannot be generalized to other areas. The traffic culture, the degree of mobility, the motorization, the car ownership rate and the share of public transport are factors that limit the results for a particular country or area.

Surprisingly the foreign studies has not dealt with the speed changes of different motorway lanes caused by rainfall. Thus, in this paper the author studies the speed changes of different lanes too.

3. Methodology

During the research five relevant cross-sections on two motorways were selected based on traffic considerations. At the selection of test sites it was important that the given cross-section is characterized by different traffic parameters (traffic volume, traffic composition, etc.) that the effects of weather events can be examined at different spots with various traffic parameters.

Days – when significant rain has fallen, which has made difficult to transport on the spots – have been collected from a meteorology database [17]. The State Motorway Company (ÁAK) has given free run of their own raw traffic data measured by company owned traffic counting stations [31]. The analysis was performed with these data. During the study traffic parameters of advantageous (dry, rainless) and adverse (rainy) periods have been compared per lanes. Thus, it was possible to examine the effects of weather on traffic flow (especially effects on speed).

The weather database contained the rainy periods – with 10 minutes accuracy – and the amount of rainfall (Table 2). According to the weather data it was possible to search specific periods in the traffic database. Data provided by ÁAK contained the number and average speed of recorded trucks and cars divided into six-minute intervals for each counting station per lanes.

Table 2. Structure of weather database Időkép (2012)

Date:	Time:	Precipitation (mm):	Daily sum precipitation (mm):
…	…	…	**30.00**
2012-05-22	06:50:00	0.50	
2012-05-22	07:00:00	0.00	
2012-05-22	07:10:00	1.10	
2012-05-22	07:20:00	2.00	
2012-05-22	07:30:00	0.60	
2012-05-22	07:40:00	0.50	
2012-05-22	07:50:00	1.50	
2012-05-22	08:00:00	2.10	
…	…	…	

Weather data was not originated from the network of ÁAK, in consequence weather and traffic counting stations have different locations. This fact made a little bit more difficult the research. However the distances between the stations are just a few kilometre and it did not cause any problem, because at the traffic counting stations the effects of weather events could be measured a few minutes earlier or later.

During the study only the speed changes were analysed. Analyses of further data and parameters (like traffic density, headway time) were not possible from the available data, because these data are nowhere measured on the national road network. At the selected cross-sections “RAKTEL” measurement devices are operating which record the speeds and categories of the passing vehicles. Data that was collected by the traffic counting stations were handled in a simplified spreadsheet form from the Traffic Management System of ÁAK Table 3 shows the structure of the data and the values of a 6 minutes interval.

Table 3. Data structure of the traffic counting stations ÁAK Zrt. (2013)

Motorway	**Km section**	**Measurement interval**	**Direction**	**Lane**	**No of all veh.**	**Pass. vehicles**	**Trucks**	**Average speed of all veh.**	**Average speed of cars**	**Average speed of trucks**
...	...	...	...	...	...	...	...	...	...	...
M3	051 + 888 km	2012.05.07. 22:54 - 23:00	left	slow lane	15 pcs	10 pcs	5 pcs	103.67 Km/h	113.0 Km/h	85.0 Km/h
M3	051 + 888 km	2012.05.07. 22:54 - 23:00	left	fast lane	2 pcs	2 pcs	0 pcs	115.0 Km/h	115.0 Km/h	0.0 Km/h
M3	051 + 888 km	2012.05.07. 22:54 - 23:00	right	fast lane	0 pcs	0 pcs	0 pcs	0.0 Km/h	0.0 Km/h	0.0 Km/h
M3	051 + 888 km	2012.05.07. 22:54 - 23:00	right	slow lane	21 pcs	14 pcs	7 pcs	78.81 Km/h	85.0 Km/h	66.43 Km/h
...	...	...	...	...	...	...	...	...	...	...

Weather data were provided by the largest Hungarian private provider, who has the most measurement stations and the biggest percipient network on national level (few hundred stations in Hungary). Weather stations located closest to the traffic counting stations provided the weather data during the research. Table 4 contains the locations of traffic counting and weather stations and the distances between them. Figure 1 shows their location on a map.

Table 4. Locations of the applied traffic counting and weather stations and the distances between them

Motorway M3			**Motorway M7**		
Traffic counting station	Weather station	Distance	Traffic counting station	Weather station	Distance
38+040 km section	Bag	~1,5 km	32+430 km section	Martonvásár	~0 km
51+888 km section	Hatvan	~6 km	71+350 km section	Szabadbattyán	~1 km
			96+400 km section	Balatonvilágos	~0 km

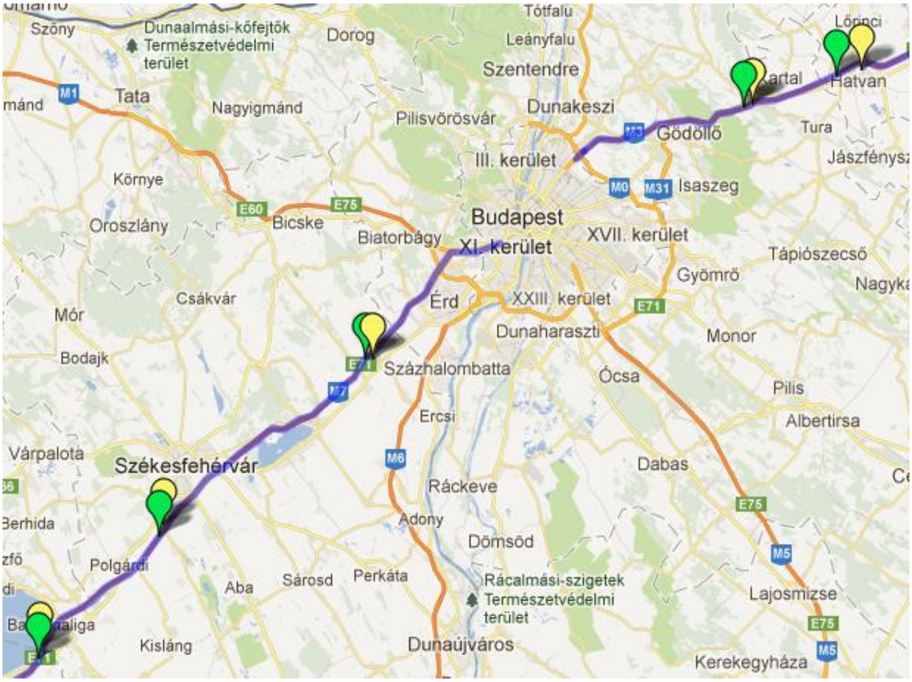

Figure 1. Location of traffic counting (green bubble) and weather (yellow bubble) stations

During the study from 2010 it was selected 180 days when significant rainfall fell from traffic aspect. The 180 days do means more than 180 weather events, because there were days when the total daily precipitation amount fell in more parts. Day and night, natural and artificial light conditions, low and high traffic periods occurred in terms of the time of the test events. This study does not examine the effects of string wind, because the traffic counting and weather stations are not located on the same spots and on-site data were not available. In contrast to the precipitation, there can be significant differences in the wind speeds in a few hundred meters distance too. It is non-negligible that that wind sensor is installed on a mountaintop, in a valley or on a spot with special microclimate characteristic.

4. Results

Based on the traffic data analyse it can be submitted that under 4-5 mm/h rainfall intensity the rain does not have any significant impact on the traffic, it does not influence the speed of vehicles. Over 5 mm/h intensity the rain can cause significant traffic speed reduction for cars. The degree of reduction depends on the intensity of rain, visibility conditions (day and night), actual traffic volume, tracing of the road and the lane (slow or fast lane). According to the intensity of rainfall four groups can be distinguished:

1. 0-4 mm/h: no significant impact, alteration of speed is negligible (within the measurement margin of error);
2. 5-10 mm/h: moderate impact, the speed decrease is up to 10-20 km/h;

3. 10-20 mm/h: intense impact, the speed decrease is up to 15-40 km/h;
4. Over 20 mm/h: extreme impact, the speed decrease may be greater than 40 km/h.

Based on the examination it is found that the speed decrease is not the same. Each intensity has a specific range. Figure 2. and 3. illustrate these ranges with the average upper and lower limits according to the lanes. It can be seen that the intensity increases the range is widen. The vertical bars illustrate the speed decrease for the given intensity (alteration that occurred at the given intensity).

The theoretical maximum of the speed decrease can be equal with the average speed measured on the motorway. It means that in this situation the traffic will stop. It may occur when the environment circumstances completely stifle the transportation conditions. This level can vary significantly based on the individual assessment of drivers.

The speed reduction on a given section can be caused by the drivers who temporally interrupt their journey (drive in the nearest parking facility or stop on the emergency lane) because of the inclement weather. Those who stop, they reckon the traffic conditions as not sufficient for the driving based on their own assessment. However in those situations, there can be drivers who undertake to continue their journeys. Really extreme weather is necessary for the full stop. Empirically in such case, an accident is the main cause that triggers the full stop.

During night conditions (lack of natural light, low traffic volume < 500 veh/h): speed decrease is equal with the upper value of rainfall intensity range.

During day conditions (natural light and traffic volume > 1000 veh/h): speed decrease is less, upper limits of the range is lower by 3-5 km/h. This is mainly due to the better visibility and, secondly a more combined traffic stream can form because of the higher traffic volume.

Interestingly, during the morning rush hours (1000-1500 vehicles / hour), beside daytime visibility conditions, the 5 mm/h precipitation has no significant effect. Traffic slows down due to heavy traffic. If the traffic is reduced, but the intensity of precipitation remains constant, the speed increases either up to the average value, which is the same as in dry weather.

Speed decrease is more significant on the fast lane in all circumstances. Trucks mainly use the slow lane (between 06-22 it is mandatory and at night because of the “keep right”), thus they reduce the average speed measured on the slow lane. (In dry conditions, the average speed difference is 15-30 km/h between the slow and fast lane. It depends on the time of day, light, trace of the road and the applied speed limits too.) Speed changes of trucks were also examined in the analysis, but no effects was detectable due to rainfall activity. According to the Highway Code trucks must not go faster than 80 km/h on the motorways and in case of rainy weather the speed of cars usually fall down maximum to 80-85 km/h. Empirically it can be stated that the rainfall has less effect on the drivers of heavier vehicles. Its reason might be found in the driving dynamics features of vehicles: higher and more secure adhesion, advanced driving dynamics and emergency support systems. This phenomenon may be also observed in case of heavier (larger, better equipped and more expensive) passenger vehicles. These cars give a higher “sense of security” for the drivers, but often they are effectless, because the supporting systems are not able to rewrite the laws of physics.

Although based on the available data it is not, but empirically it can be declared that the trace of the road and road condition also has a significant impact on the speed change. Those spots where the precipitation can be lead off only through the rood grooving, there the rainfall can accumulate on the road during a long-lasting and/or an intensive rain, thus there the speed decreases are more significant. It is caused by the coexistence of several factors:

(1) at those spots, the motorway operator places static warning or speed limit signs;
(2) drivers see the accumulated water on the pavement in case of adverse weather event;
(3) when the section is curved the intention to avoid aquaplaning is contribute to the speed decrease [1,14,22].

Further important factor is the degree of decrease of visibility caused by rainfall. When the visibility decrease is not significant during daylight conditions (horizontal sight is over 200 meters), the speed decrease is also not significant, because the passing vehicles in single file can see each other. This phenomenon cannot be observed in the night due to the limited visibility.

Besides the analysis of traffic parameters, the development of accident data was analyzed during the research. The Hungarian statistical data collection does not enable to examine the effects of weather events on traffic and accidents based on the accident report forms. Only the number and proportion of personal injury accidents occurred on wet pavement are available. It is not possible to draw accurate conclusions whether the accident occurred due to weather conditions or not. It can be determined only in the exact view of the circumstances of the accident, in the possession of police reports.

It is important to emphasize that values in Figure 2. and 3. are average values that are significantly influenced by the traffic volume, trace of the road, sudden change of road conditions (friction, visibility, etc.). Thus, these values provide guidance on the scale and rate of changes in the function of the rainfall intensity. Furthermore on those sections where the traffic volume reaches the maximum of capacity (e.g. during the morning rush hours on sections around Budapest), even more intense effects are expected. Heavy traffic cause slower progress and adverse effects of precipitation (decrease of visibility and road friction coefficient) contributes to these situations.

Fitting a polynomial to the measured value figure 4 and 5 illustrate the relative speed decrease on the slow and fast lanes. Figure 6 and 7 illustrate the absolute changes with 20% confidence intervals. Determination of the initial speeds – that are necessary for absolute values – were determined by averaging (v_0), with the examination of the average speeds in dry (rainless) weather at the examined cross-sections.

- **average speed of fast lane:** 125 km/h, standard deviation 2,5 km/h
- **average speed of slow lane**: 106 km/h, standard deviation 3,4 km/h

By the help of the fitted fourth-degree polynomial, it is able to forecast the speed decrease (with uncertainty) over 25 mm/h rainfall intensity. The results are in line with international trends, which indicate a total stop at ~ 30-50 mm/h rainfall intensity.

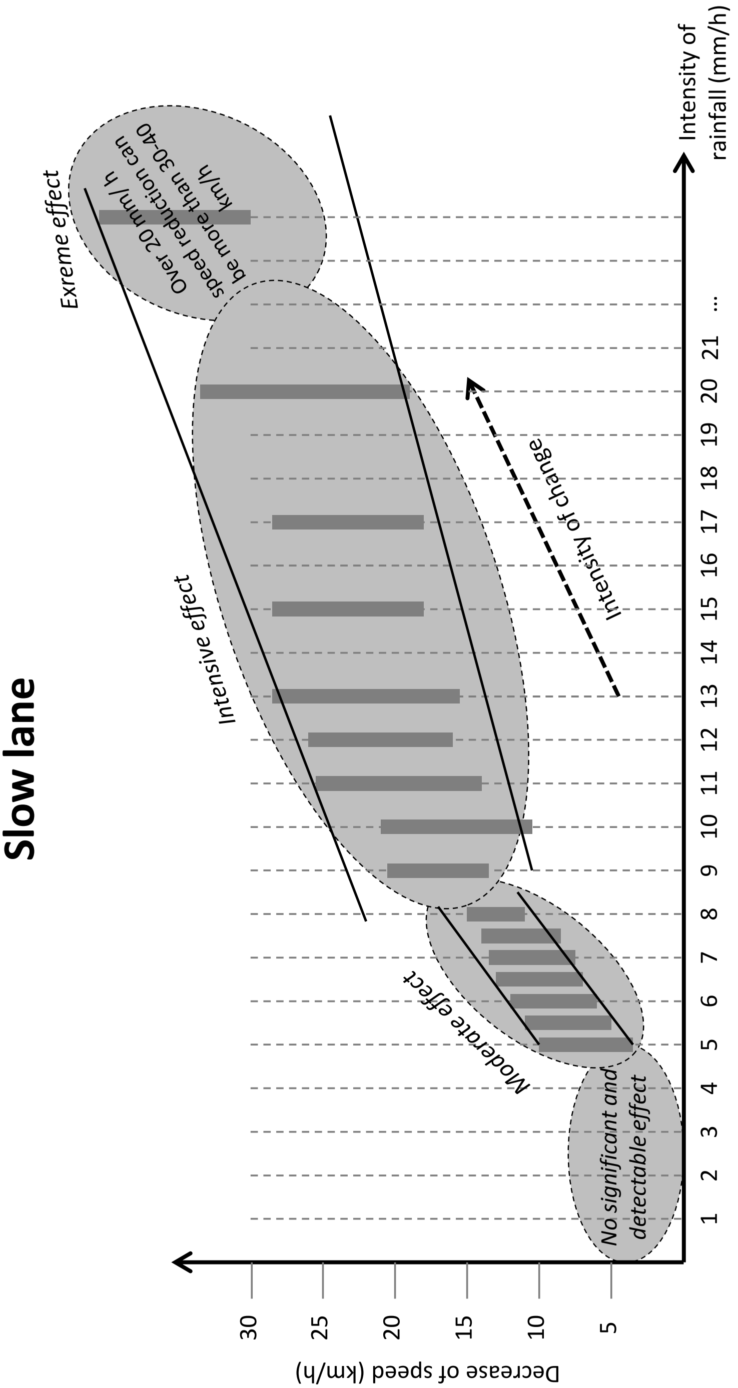

Figure 2. Effect of rainfall intensity on the speed of slow lane

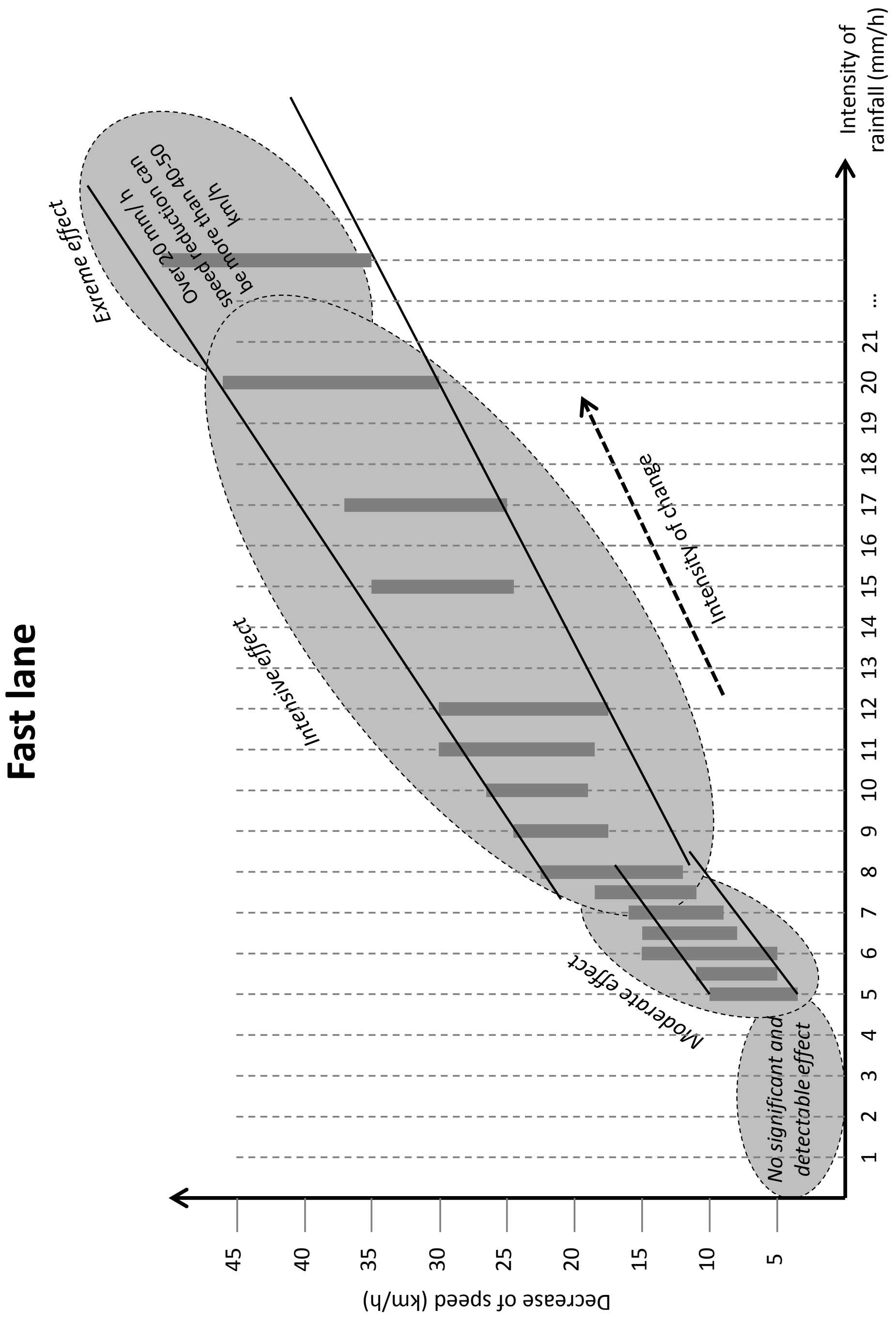

Figure 3. Effect of rainfall intensity on the speed of fast lane

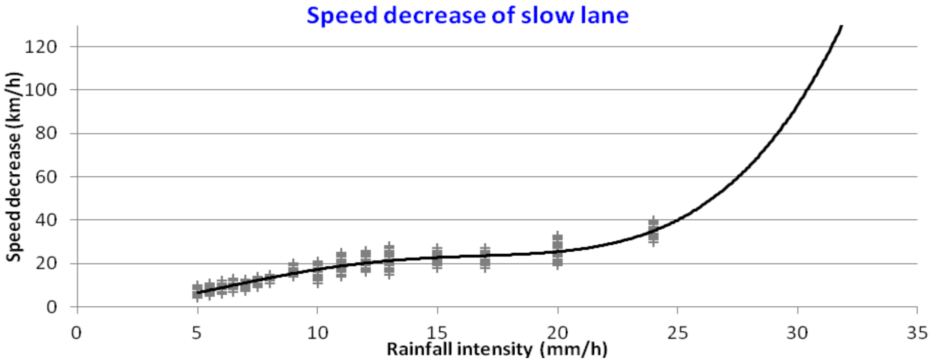

Figure 4. Relative speed decrease on slow lane

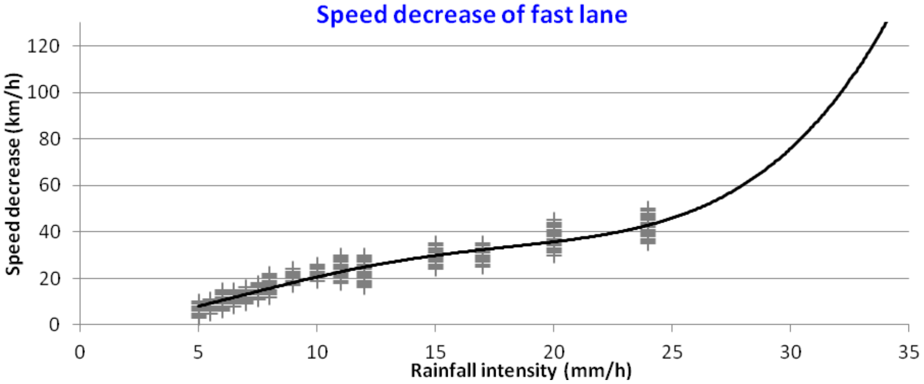

Figure 5. Relative speed decrease on fast lane

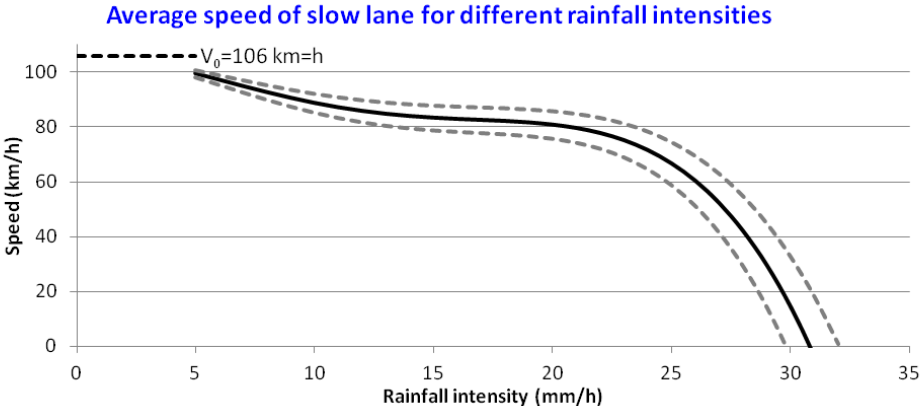

Figure 6. Absolute speed change for different rainfall intensities on the slow lane

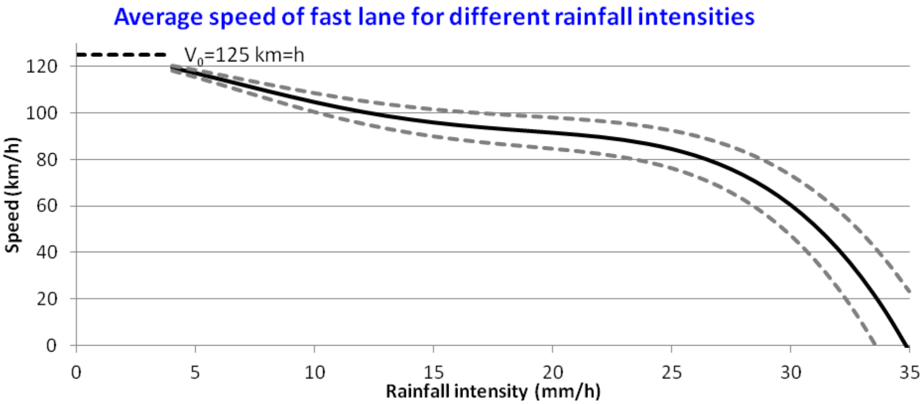

Figure 7. Absolute speed change for different rainfall intensities on the fast lane

5. Summary

The relationship between traffic events and weather has been studied for more than half a century. Researchers have highlighted for several connections, that are valid only in their particular test environment, in the view of the given mobility culture. In this research a context was set up between the motorway speed and rainfall intensity for the Hungarian motorway network, based on Hungarian data. The study has proved that rainfall has a significant impact on the speed and it depends on the intensity of rainfall. Based on the traffic data analyse it can be declare that under 5 mm/h rainfall intensity the rain does not have any significant impact on the traffic. Over 5 mm/h, the higher intensity causes the more significant speed reduction, which can be 30-40 km/h. On the slow lane the speed reduction is always smaller. The results of the research are average values. Trace of the road, traffic volume, natural and artificial light, time of day, seasons influence the measurable values of a specific site.

6. Outlook

Sudden speed reduction has a significant traffic safety risk. It can be reduced if drivers get information about the actual traffic conditions and weather events. Variable message signs on the Hungarian motorway network can be used for such information provision. Its aim to encourage drivers to reduce their speed, 1-2 km before the area concerned by rainfall. The interconnection of road weather information and traffic management systems allows realizing soft (e.g. information provision, inform about dangerous situations) and hard (e.g. traffic management, speed control) interventions.

Network efficiency can be increased by the application of line speed control (speed cone), thus the number and length of congestion and travel time can be reduced. Acceptance of the applied speed limit is improved by the increase of driver’s comfort and by the help of information provision, thus indirectly the road safety can be also enhanced. Preconditions of the operation of this information and management systems are:

(1) the availability of adequate quantity and quality of traffic and meteorological data from the controlled road section;
(2) presence of information infrastructure with adequate installation density for the successful implementation of the traffic control.

Data can contribute to the early detection of traffic and weather events with increased road safety risk.

Research results provide important information for the analyse of the traffic processions on large-scale dynamic networks. Input of data from the article into mathematical and simulation models can produce further useful results for the more accurate description of the operation of networks, because the effect of rainfall can spread for those areas where this impact of the weather cannot be observed directly [25-28]. Measured data can be also used in multimodal journey planner systems and they can handle these kind of data, thus the operation accuracy and reliability is getting better [11].

Further research area is the examination of the effect of wind on traffic flow. The author would like to study it as well. Traffic and weather data from the State Motorway Management Company would like to be used in the research.

Acknowledgement

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Examination of Complex Traffic Dynamic Systems

F. Szauter[1], T. Péter[2], J. Bokor[3]

Széchenyi István University, Hungary
Budapest University of Technology and Economics, Hungary
e-mail: [1]szauter@sze.hu, [2]tamas.peter@mail.bme.hu, [3]bokor@sztaki.hu

Abstract: A validated, quick and cost-effective alternative method can be applied to analyze driver load, which is based on the track record of the city, traffic simulation model and parameters of the vehicle and driver characteristics.

Keywords: positive systems, complex traffic dynamic systems, macroscopic model, traffic simulation, alternative method, examination of the network processes and the vehicles in the network,

Introduction

The road traffic is an extremely complex dynamic system. The up to date examination of this system requires complex methods. Nowadays the examination of the network processes and the vehicles in the network in the form of a system is inseparable.

For this purpose a test methodology is proposed based on the theory of positive systems, where, in essence, the model is a macroscopic model.

The terms of controllability and observability of positive systems are not derivable from the known methods applied in general systems [1]. The problem is particularly true when a non-negative co-domain is required not only for the states, but for the control input sign too. Therefore, describing the road system processes as pure positive systems is not a trivial task from the control engineering point of view. The control task in this case means that the system must be controlled from a state to another so, that the states remain non-negative values during the transitions too [2].

This environment - despite the fact that it is macroscopic model - will be suited to describe a real traffic process from any point A to a selected point B of the network at any departure time taking real transport processes (lights, congestion, etc.) into account, [3]. In addition to the route recommendations this is an important result in the area of intelligent vehicle studies (e.g., analysis of vehicle dynamics, engineering, environmental loads, emissions analysis, etc.) as it is possible to perform the calculations for a large number of vehicles very quickly at different times and places.

The trajectories measured in real traffic are suitable for validation of the network model as well.

The model

In the referred contributions a constructed network is discussed, which is bounded by a closed curve [4-8]. It contains n sectors of internal network and m sectors from external network. We assume, the external sectors have direct connection to internal sectors and their state is known by measurements. The differential equation system is the following:

$$\dot{x} = \langle L \rangle^{-1} [K_{11}(x,s)x + K_{12}(x,s)s] \qquad (1)$$

where $x \in \Re^n$, $\forall$ $x_i \in [0,1]$, (i=1,2,…,n), $\dot{x} \in \Re^n$, $s \in \Re^m$, $\forall$ $s_i \in [0,1]$, (i=1,2,…,m), $L = \mathrm{diag}\{l_1, \ldots, l_n\}$, l_i length of road sections in the main diagonal ($\forall l_i > 0$, i=1,2,…,n), $K_{11} \in \Re^{nxn}$, $K_{12} \in \Re^{nxm}$.

The operation of the network is determined by K_{11} and K_{12} relational matrixes. These matrixes assign the existence of the relationship between every sector of the system, and at the same time it represents the differential equation system describing the dynamic operation of the sections, so the constructed network.

Analysis of the velocity processes

It is assumed that to $\forall x_i$, ($x_i \in [0,1]$, n=1,2,…n) state parameter $v_i \geq 0$ velocity value can also be assigned by the application of an f_i function continuously differentiated by x_i:

$$v_i = f_i(x_i(t) \qquad (2)$$

By the retrieval of the unique velocity processes and application of a driver-vehicle model from the macroscopic network model the engine power demand and the exhaust gas emission can be examined.

The model can be validated by velocity processes. The model was validated in Budapest on the boulevard between Petőfi Bridge and Nyugati Square [9-11].

In different simulation times the examined route was reviewed by vehicles with GPS and during the measurements the real velocity profiles were also recorded. The comparison of velocity-time diagram acquisition by simulation and vehicle measurements obviously showed that time diagrams should be considered as realizations of a stochastic process and investigated by statistical analysis.

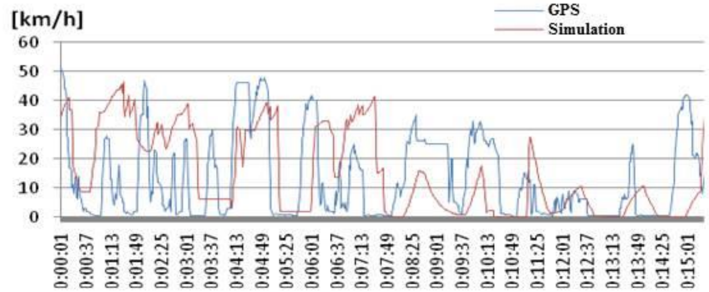

Figure 1: Simulation based velocity profiles measured by GPS

By large nonparametric statistical analysis, so called, homogeneity analysis was proven that the two samples got by simulation and measurement are considered homogeneous at 95%. From the velocity data the same result has come concerning vehicle engine power demand.

During the model validation it could be stated that the model makes vehicle process acquisition possible, which reflects reality [12].

Based on the above the vehicle profiles can be directly acquired by the arbitrary trajectories of the network as well. In the following vehicle dynamics is analyzed along an assigned trajectory from an optional A to B in t_0. Along the trajectory the X(t) path-time function and T (end time) can be calculated. The two-variant velocity function V(t, X) belonging to a rectified X trajectory and t time point can be calculated by the state equation (see Figure 2.)

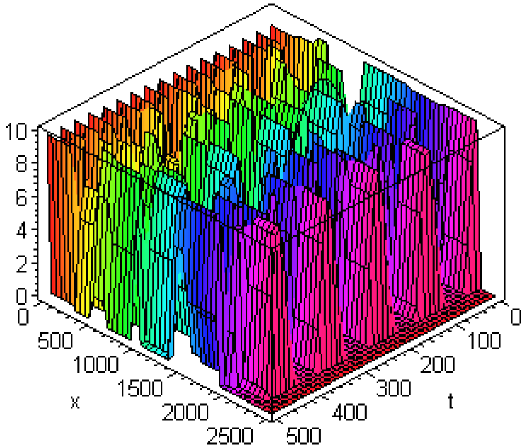

Figure 2: Two-variant velocity function V(t, X) belonging to a rectified X trajectory and t time point

By the solution of the following integral equation and the two-variant velocity function V(t, X) the X(t) path-time function can be determined:

$$\mathrm{x}(t) = \int_{t_0}^{t} \mathrm{V}(\tau, \mathrm{x}(\tau))\, d\tau \tag{3}$$

The problem needs the solution of the following first order nonlinear differential equation at the $X(t_0)=x_0$ initial condition:

$$\frac{dX(t)}{dt} = V(t, X(t)) - V(t_0, X(t_0)) \tag{4}$$

$$\mathrm{x}(t_0) = x_0$$

The solution is given by the application of numerical method, e.g. Figure 3.

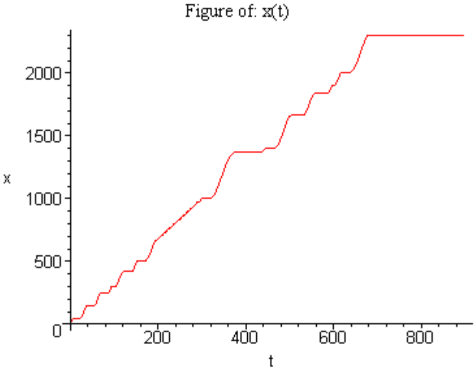

Figure 3: Path-time diagram

After t_1 end time there's no increase in X(t), e.g. end time $T=t_1-t_0$;

Note: If in case of more trajectories the optimal end point reach is investigated, the problem needs a solution of a variation calculation task. Along every trajectory the path X run until the t time point results in an X(t) path function, to which in point B belongs a T time and this mapping provides the real functional:

$$J:\ X(t) \rightarrow T \tag{5}$$

Therefore large traffic network model can be applied to real time route planning taking also the traffic changes into consideration.

Analysis of acceleration processes

On the basis of known velocity processes the longitudinal accelerations can also be calculated in the optional i. section of the traffic model:

$$\dot{v}_i(t) = a(t) = \frac{df_i(x_i(t)}{dx_i} \cdot \dot{x}_i(t) = f_i' \cdot \dot{x}_i \tag{6}$$

(i=1,2, … ,n). The velocity vector in the whole internal domain:

$$v(t) = f(x(t) = \begin{bmatrix} f_1(x_1) \\ f_2(x_{2)} \\ .... \\ f_n(x_n) \end{bmatrix} \tag{7}$$

After derivation the acceleration vector can be formed as well:

$$a(t)=\dot{v}(t)=\begin{bmatrix} f_1'(\dot{x}_1) \\ f_2'(\dot{x}_2) \\ \dots\dots \\ f_n'(\dot{x}_n) \end{bmatrix} = \begin{bmatrix} f_1' & & & \\ & f_2' & & \\ & & \dots & \\ & & & f_n' \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dots \\ \dot{x}_n \end{bmatrix} \tag{8}$$

Based on the system state equation the continuous acceleration vector can be directly calculated:

$$a(t)=\left\langle f_i' \right\rangle \cdot \dot{x} = \left\langle \frac{f_i'}{l_i} \right\rangle \cdot [K_{11}(x,s)x + K_{12}(x,s)s] \tag{9}$$

Where: $a \in \Re^n$, $\left\langle f_i' \right\rangle = diag\{f_1', f_2', \dots, f_n'\}$.

Conclusions

Along the assigned trajectory the X(t) path-time function can be calculated, which gives the location of the vehicle in t time point. Also the velocity and acceleration are known in t time point in the actual section of the trajectory.

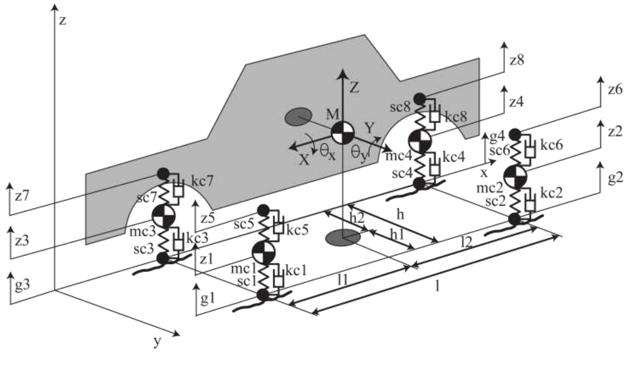

Figure 4: Vehicle model

According to the above the traffic network model already gives crucial data to vehicle dynamics analyses. Because of its fast use and applicability at one time to large number of vehicles, this analysis has a big effect on further automotive researches [13-17].

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