CONCEPT OF EXPERT SYSTEM FOR MODAL SPLIT IN TRANSPORTATION PLANNING

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Abstract: The objective of this paper is to develop a concept of expert system based on the survey of experts' opinions and their experience concerning relations in modal split, on the basis of parameters of transport system demand and transport supply, defined through PT travel time and city size, i.e. mean trip length. This expert system could be of use both to experts and less experienced planners who could apply the knowledge contained in this expert system for further improvement, on operational as well as on strategic level.

Keywords: Modal split, transport supply, transport demand, expert system.

INTRODUCTION

The expert system, created in this paper, has been envisaged as a tool to be used on operational and strategic level in some segments of transport planning. The basic idea for creating such an expert system was to define relations in modal split on the basis of parameters of transport system demand and supply in one city.

To enable the use of this expert system on both strategic (planning) and operational level, it is necessary to determine parameters which could be forecasted on short-term and long-term basis. For planning purposes, such an expert system should determine margins of share of specific transport modes. These limits should serve as benchmarks in forecast of the relations in modal split during planning period, on the basis of which, specific elements of future transport system are to be defined. In a similar manner this expert system can be used for operational purposes, providing that survey of parameter values is performed in the existing state or that a short-term forecast for these parameters is made.

As it is known [1] the basic parts of an expert system are the knowledge base and a program which will make application of the knowledge base possible. In this case the **knowledge base** has been created on the basis of an experts' opinions survey and on the basis of past transport studies in the subject field. The process of a knowledge base creation can be performed in the manner presented in Figure 1.
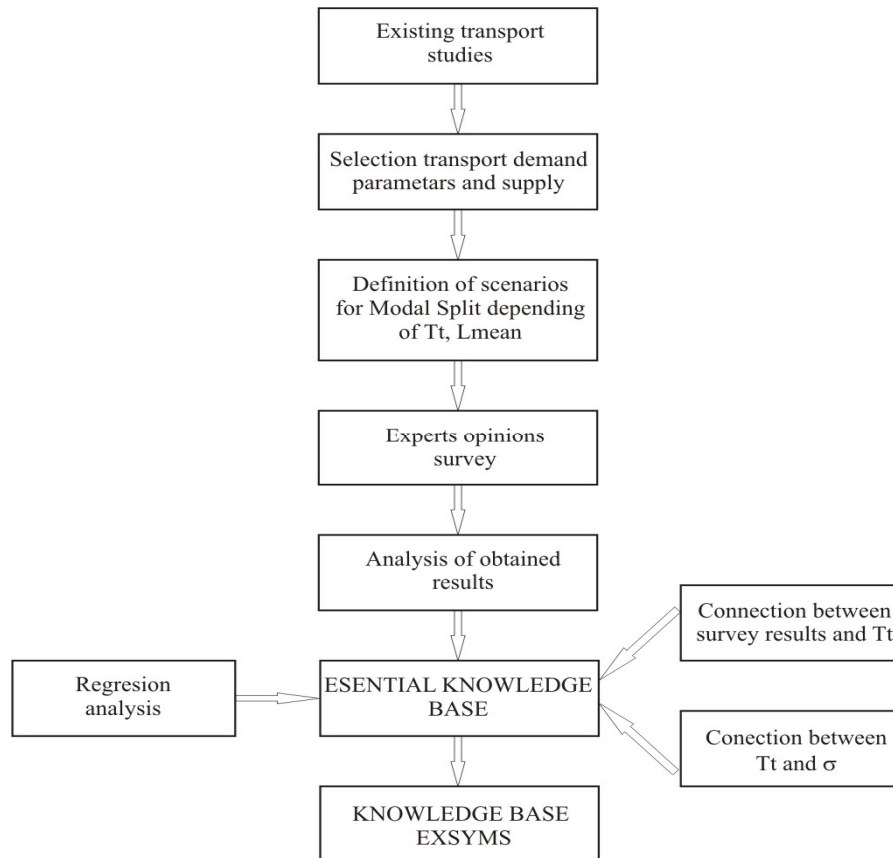
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Figure 1: Block diagram of the process of knowledge base creation - EXSYMS

The first phase of knowledge base creation is represented by an analysis of the existing transport studies. Characteristics of trip and modal split analyzed for Former Yugoslavia cities can be presented in the scope of this phase.

The second phase comprises selection of relevant parameters of transport system demand and supply. As a supply parameter, i.e. parameter of transport system quality, in the first phase, it is recommended to select public transport travel time (t_t), and the mean trip length (L_{mean}), as a parameter for transport system users' demand.

The third phase represents definition of scenarios for modal split modelling. These scenarios are being formulated by a combination of four values of mean trip length

(L_{mean} and three values of the time spent outside vehicle (t_1). The time spent outside vehicle (t_1) is a sum of the transfer time (t_{tr}), approach time (t_{acc}), waiting time (t_w) and terminating time (t_{ter}). In this phase travel time (t_t) is replaced by the time spent outside vehicle (t_1). In this way twelve scenarios were formulated. Based on these 12 scenarios the relations in the modal split were studied for three modes: *PC*-passenger car, *PT*-public transport and *OM*-other modes (walking, bicycle, motorcycle, etc.)

In the fourth phase a survey of experts' opinions on modal split relations was carried out. In the scope of this phase a study methodology was prepared and survey of experts was performed.

The fifth phase includes the first part of the analysis of the obtained results, i.e., elaboration of the survey of experts' opinions applying prepared mathematical tests. This results in interval evaluation of shares of defined modes, sample dispersion and mean value of shares of defined modes. In addition, a processing of the obtained data was performed.

Correction of the results obtained during survey of experts' opinions was carried out in the sixth phase. These corrections were made in accordance with perceived discrepancies and inconsistencies from the fifth phase.

After correcting these results, in the seventh phase, the EXSYMS Essential Base (Expert System for Modal Split) was created. The Essential Base was provided when, applying corrected survey results, regressive equations of dependence of specific transport mode share upon the time spent outside vehicle (t_1), as well as upon the mean trip length (L_{mean}) were formulated.

In the next phase, the Essential Base was enlarged by correlating PT travel time (t_t) with the time spent outside vehicle (t_1). In this way, by applying regression analysis, dependence equations of specific transport mode share upon PT travel time (t_t) were provided.

In the last phase of creating the EXSYMS Base formed were range dependence diagrams between share of *PC*, *PT* and *OM*, on the one hand and *PT* travel time, on the other for various mean trip lengths (L_{mean}). After that, *PT* travel time (t_t) was correlated to parameters of *PT* operation (line network density in *PT* (σ) and, thus, the EXSYMS Base was created.

The second part of the expert system, the **programme for knowledge application** (inference engine), should be selected from a group of those programs which are modelling a safe reasoning (in the function of the type of the subject problem, in each phase, it selects a single rule from the set of valid rules), because the nature of the subject problem is such that the queries raised in the expert system require a range solution. Deduction and regression are to be applied as modes of reasoning. In some specific cases this programme should enable providing responses to the following queries:

Assuming that transport supply parameter A has value "a" and transport demand parameter B has value "b", what is proportional share of certain transport modes (*PC*,:*PT*, *OM*); and

Assuming that percentages of transport mode share are *PC* = n%, *PT*=m% and *OM*=r%, what are the values of transport supply *A* parameter and transport demand *B* parameter?

This represents a description of the general concept of expert system for modal split. For purposes of this paper, the phase representing creation of knowledge base of the expert system was further elaborated.

2. CREATION OF THE KNOWLEDGE BASE FOR THE *EXSYMS* - EXPERT SYSTEM FOR MODAL SPLIT

The knowledge base for the concept of this expert system was created on the basis of a study of previous transport surveys in Former Yugoslavia cities, as well as on the basis of survey of experts' opinions with respect to relations in movement modal split in cities.

2.1. Selection of entry parameters for the expert system and definition of scenarios

Implementation of this expert system implies formulation of certain scenarios on the basis of the selected (studied) parameters of transport system demand and supply, which would enable definition of relations in movement modal split.

This means that for this expert system a modal split method has to be selected in the first place. After that, it is necessary, among a large set of influential parameters, to select parameters most adequately represent the current situation and prepare scenarios, which should represent a combination of parameters of transport system supply and demand by transport system users.

For modal split modelling a *normative method* was selected due to the fact that past experience in Former Yugoslavia cities indicates that this mode was the most frequent mode of modal split modelling in Former Yugoslavia region. Another reason for such a choice was that this mode, by its nature, is dependent upon planners' (experts') assessment. On the other hand, expert system creation implies formalization of the models to be implemented into expert system. Consequently, by selection of normative modelling this process is considerably simplified.

Selected parameters for creation of the knowledge base of expert system and for defining scenarios of survey of experts' opinions on relations in modal split are: PT travel time (t_t) and city size expressed through mean trip length (L_{mean}).

The idea behind formulation of such scenarios was, from a number of selected values during ride in PT and from the mean trip length, to make combinations (value couples) for which relations in modal split are to be studied. Such scenarios are defined for four values of mean trip length L_{mean} (km) and three values of travel time t_t (*min*).

Based on the review of the transport surveys carried out in Former Yugoslavia cities so far, as well as on the basis of recommendations of the experts in the field of Transportation planning and traffic control, *PT*, etc., city size parameter, i.e., **mean trip length** was defined as follows (Table 1):

Table 1: Dependence between mean trip length and city size

City size (number of citizens)	Mean trip length L_{mean} (km)	Remarks
50,000 to 100,000	2	A city with undeveloped *PT* (or without *PT*) with commuter transit having function of *PT* (Šabac, Užice, Valjevo, Čačak, etc.)
100,000 to 200,000	3	A city with mainly one *PT* subsystem and commuter transit (Subotica, Podgorica, Kragujevac, etc.)
200,000 to 500,000	4	A city with developed *PT* (one or two subsystems of *PT*) and commuter transit (Novi Sad, Niš)
over 500,000	8	A big city having more PT subsystems (bus, tramway, trolleybus, etc.), as well as developed commuter transit (Belgrade)

Travel time is a transport system quality parameter. In the process of travelling a series of difficulties are piling up for a user. The travelling benefits are realized only upon satisfying trip purpose at the end of a trip. Measurement of unattractiveness or attractiveness toward a specific form of transport in the scope of one transport system is made possible by comparing all inconveniences and benefits from the realized purpose. The time spent in transportation for the users of transport system is time lost, i.e. "cost", not only in terms of transport fare, but also in reference to "generalized costs" arising from a series of, for a user, undesirable circumstances in the course of operation of transport.

PT travel time (t_t), as one of the characteristics of a journey, is a complex indicator. It includes the following:

- Time of access to a system (t_{acc}) (time needed from the "door" to station/stop),
- Waiting time of (t_w),
- Riding time (time spent in a vehicle) (t_r),
- Transfer time (t_{tr}), and
- Terminating time (t_{ter}) (time needed from the last station/stop to the "door").

PT travel time comprises some of the essential transport supply parameters, such as:

- PT network density (as a supply indicator) – denser network $\Rightarrow$ bigger accessibility $\Rightarrow$ shorter access time $\Rightarrow$ shorter riding time,
- Number of vehicles on one line is included into time intervals, upon which waiting time is depending. Therefore, both number of vehicles and time interval are presented through waiting time – more vehicles $\Rightarrow$ shorter time intervals $\Rightarrow$ shorter waiting time.

For this reason, in this expert system concept, transport supply was defined in terms of the *PT* travel time t_t. PT travel time t_t was specified as dependence upon the riding time t_r and upon the time spent outside vehicle t_1, i.e., the sum of other components of time travel (access time (t_{acc}) + waiting time (t_w) + transfer time (t_{tr})+ terminating time (t_{ter}). The time spent outside vehicle t_1 is provided in three options:

- t_1= 10 minutes - "pink option"
- t_1= 20 minutes - "grey option"
- t_1= 30 minutes - "black option"

Time spent in a vehicle (t_r) is given for each city size (mean trip length). Value of the time spent in a vehicle is calculated for *PT* operating speed v=15 km/h. This speed value is assumed on the basis of average *PT* operating speed [2].

- Time spent in a vehicle for a city with mean trip *length* L_{mean}= 7 km is t_t= 28 min
- Time spent in a vehicle for a city with mean trip *length* L_{mean} = 4 km is t_t=16 min
- Time spent in a vehicle for a city with mean trip *length* L_{mean} = 3 km is t_t=12 min
- Time spent in a vehicle for a city with mean trip *length* L_{mean} = 2 km is t_t=8 min

By combining these values, twelve scenarios for determining relations in modal split for three modes of transport – *PC*, *PT* and *OM* - were defined. Since the concept of

this expert system is based on the survey of experts' opinions, the author of this paper believed that scenarios should be defined in a way which would allow provision of the most precise responses possible from the experts and which would make experts' work as easier as possible. Consequently, *PT* travel time t_t in the survey of experts was modified by the time spent outside vehicle t_1 (access time + waiting time + transfer time + terminating time). After processing the results of this survey, travel time t_t parameter was added to the expert system concept. These twelve scenarios, three for each four categories of city size, i.e. mean trip length, (for t_1=10, 20, and 30 minutes) are presented in Table 2.

Table 2: Scenarios for modal split modelling

Scenarios	Mean trip length (km) / Time outside vehicle (min) L_{mean} / t_1
S_1	8 / 10
S_2	8 / 20
S_3	8 / 30
S_4	4 / 10
S_5	4 / 20
S_6	4 / 30
S_7	3 / 10
S_8	3 / 20
S_9	3 / 30
S_{10}	2 / 10
S_{11}	2 / 20
S_{12}	2 / 30

Above mentioned scenarios served as a basis for the survey of experts' opinions on the subject of relations in modal split.

2.2. Survey of experts' opinions on relations in modal split

The objective of this survey is to provide an expert assessment of the impact of share of transport mode (modal split) to the function of transport supply quality expressed as per time spent outside vehicle (t_1), as a "negative" component of the travel time.

This survey was carried out for four different values of the mean trip length, i.e. city size, (as a transport demand parameter) and for three values of time spent outside vehicle t_1 (as a parameter of quality of PT supply), i.e. for 12 scenarios presented in Table 2.

In defining methodology of this study it was necessary to observe the following principles:

- objective selection of the expert group
- provision of independent judgment of experts, and
- unique formulation of questions and answers provided for each and all expert in the course of the survey

This methodology specifies:

- size of sample,
- interview form,

- survey method, and
- mode of data processing.

Selection of experts was carried out according to the following criteria:

- theoretical knowledge in the field of modal split in transportation planning
- practical knowledge in the subject field
- experience in planning and organization of transport system.

The number of experts who participated in the survey was partially reduced due to such criteria, but objectively, conditions for forming a bigger expert group were not available.

For this interview selected were 15 experts from three cities Belgrade, Niš and Subotica who, in the course of their work, had made significant contribution in the field of modal split.

Having in mind the delicacy of the issue under consideration in this paper, as well as the fact that it was needed on more occasions to consult the experts and to provide independence of experts' judgement, a modified **method of mutual expert evaluation** was selected.

The experts were requested, by employing their expertise and experience in the field of modal split modelling, to define proportional ratio in movement modal split, for three movement modes – *PC, PT* and *OM* – for the defined scenarios.

The results of this survey of experts were systemized by scenarios and they were elaborated by statistical tests for "variable mean value". For the needs of an easier data processing an EXCEL program was designed. *A* "variable mean value" test was applied to each scenario, i.e. to each defined transport mode in the scope of the twelve scenarios, with the following parameters:

- sample of volume n =15,
- risk α = 0.15 (selected risk assessment is in accord with tolerable variations in planning procedures, i.e. reliability interval of 85%).

Output results are: variable mean value, reliability interval of mean value and sample dispersion.

2.3. Survey results

The results obtained after data processing are presented in Table 3. Data from this Table 3 represent relations in modal split for three movement modes: *PC*, *PT* and *OM*. They are expressed as per mean value and reliability intervals. It should be mentioned that, in the course of this survey, no weight coefficients were determined, i.e. their scoring was not performed in the first phase of the analysis of results. At a later stage, correction of responses in relation to inconsistency with sample's mean value in responses of some expert groups was made.

After processing and analysing these results it was concluded that, by defining interval of confidence 15% around mean values obtained in the first phase of survey processing, reliability interval of 85% was obtained (what is acceptable for purposes of transportation planning), and, to some extent, previously mentioned inconsistencies were corrected. However, due to large sample dispersion, this interval forms functionality intervals which would be mutually overlapped, what could make application of the survey results difficult. Therefore, interval of 15% was reduced to interval of 5%. Correction of the results provided by this interval of ±5% will be made after regression analysis of the results.

Table 3: Corrected values: proportional share of *PC, PT* and *OM* depending on time spent outside vehicle (t_1) and mean trip length (L_{mean}), expressed by mean value

Time Out-Side vehicle(t_1)		Mean trip length L_z			
		7 km	4 km	3 km	2 km
	10 min	PC- 24.3.% PT -60.4% OM -15.3%	PC-24.2 PT -49.9 OM -25.9	PC- 24.1 PT -43.2 OM -31.7	PC- 24.0 PT -29.7 OM -46.3
	20 min	PC- 27.9 PT -54.4 OM -17.9	PC- 27.7 PT -44.4 OM -27.9	PC- 27.5 PT -37.7 OM -34.8	PC- 24.3 PT -28.8 OM -48.9
	30 min	PC- 31.1 PT -50.0 OM -18.8	PC- 30.2 PT -39.5 OM -30.3	PC-28.7 PT -31.1 OM -40.2	PC- 27.4 PT -21.1 OM -51.5

On the basis of data from Table 3, for each city size, regression dependence equations between share of specific transport modes and the time spent outside vehicle (t_1) were calculated. These regression lines are presented in the following diagrams.
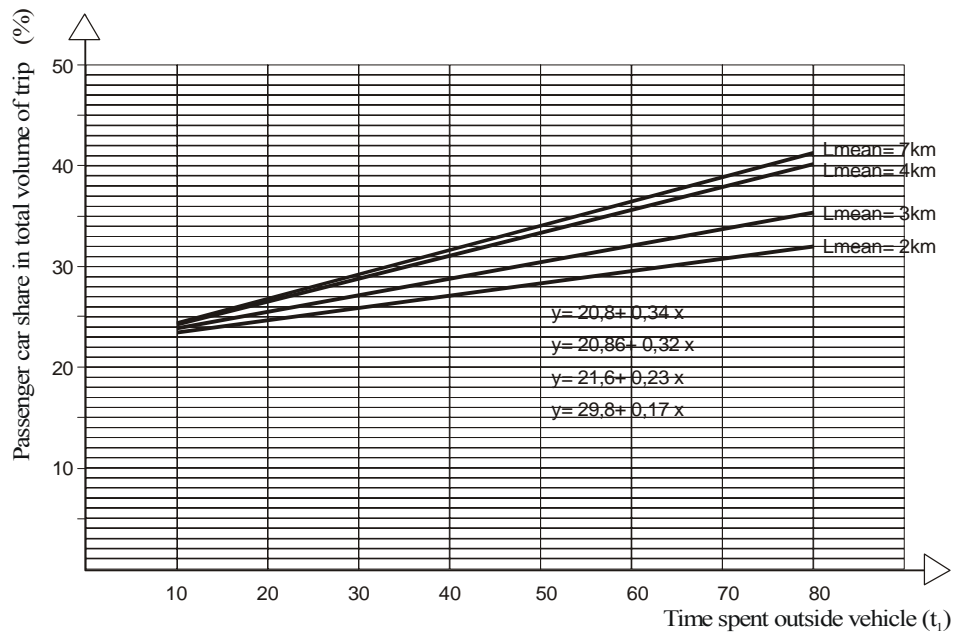
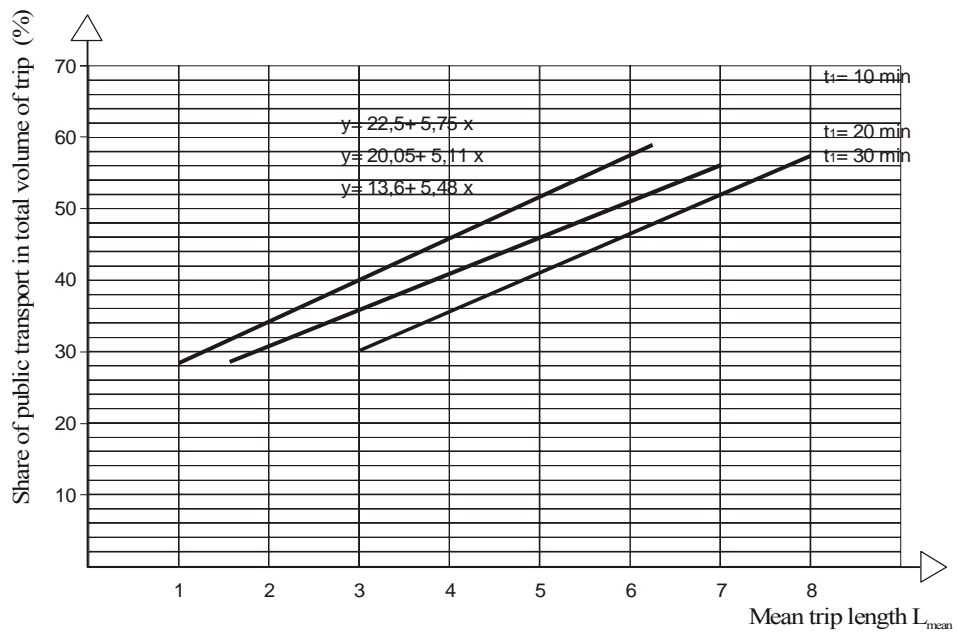**Figure 2:** PC share in total volume of trip depending on time spent outside vehicle (t_1)
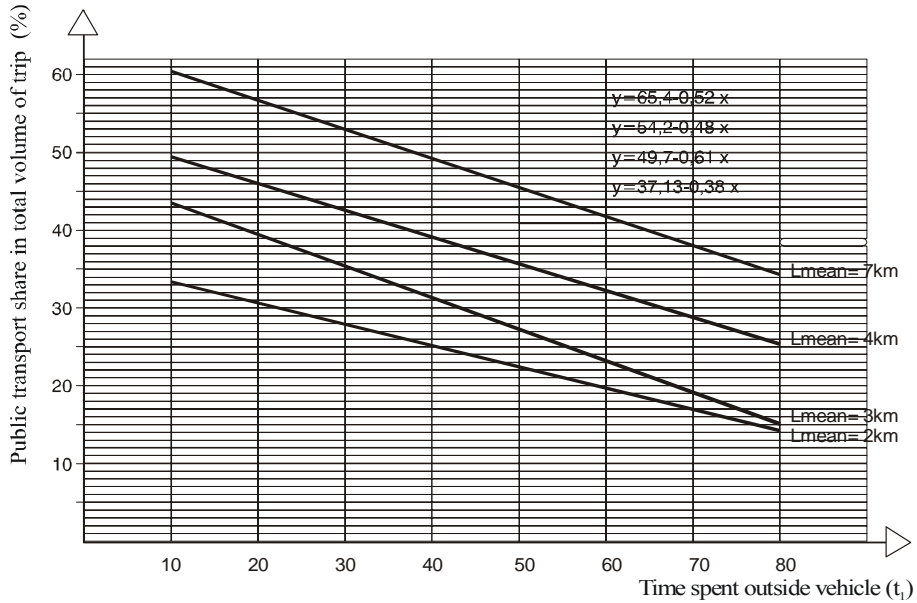
Figure 3: PT share in total volume of trip depending on time spent outside vehicle (t_1)

The equations shown in Figure 3:
$$y = 65.4 - 0.52 x$$
$$y = 54.2 - 0.48 x$$
$$y = 49.7 - 0.61 x$$
$$y = 37.13 - 0.38 x$$
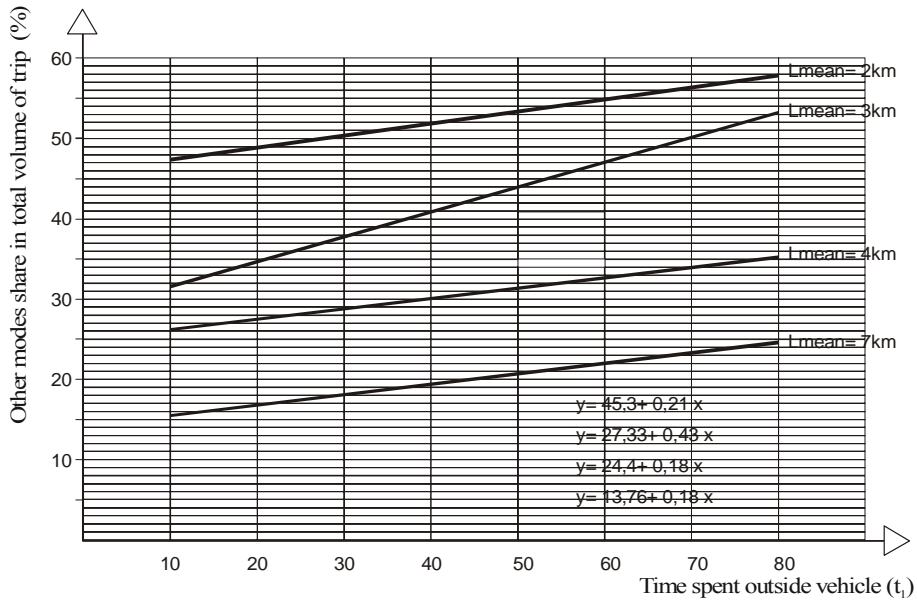
Figure 4: OM share in total volume of trip depending on time spent outside vehicle (t_1)

The equations shown in Figure 4:
$$y = 45.3 + 0.21 x$$
$$y = 27.33 + 0.43 x$$
$$y = 24.4 + 0.18 x$$
$$y = 13.76 + 0.18 x$$

On the basis of data from Table 4, regression dependence equations of share between specific movement modes and city size, i.e. mean trip length, were calculated. These regression lines are presented in the following diagrams.
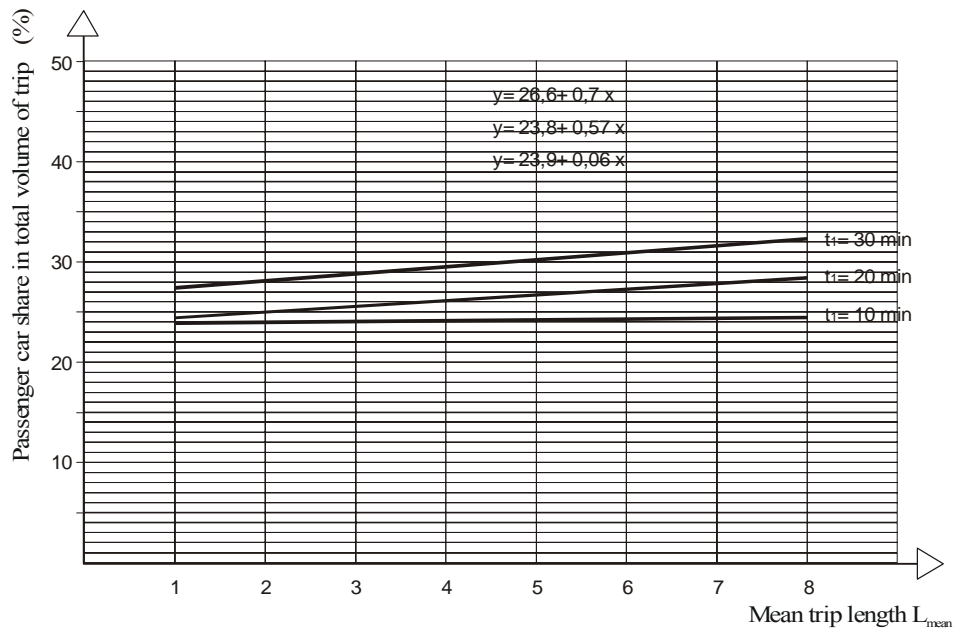
Figure 5: Share of PC in total volume of trip depending on mean trip length L_{mean}

Figure 6: Share of PT in total volume of trip depending on mean trip length L_{mean}
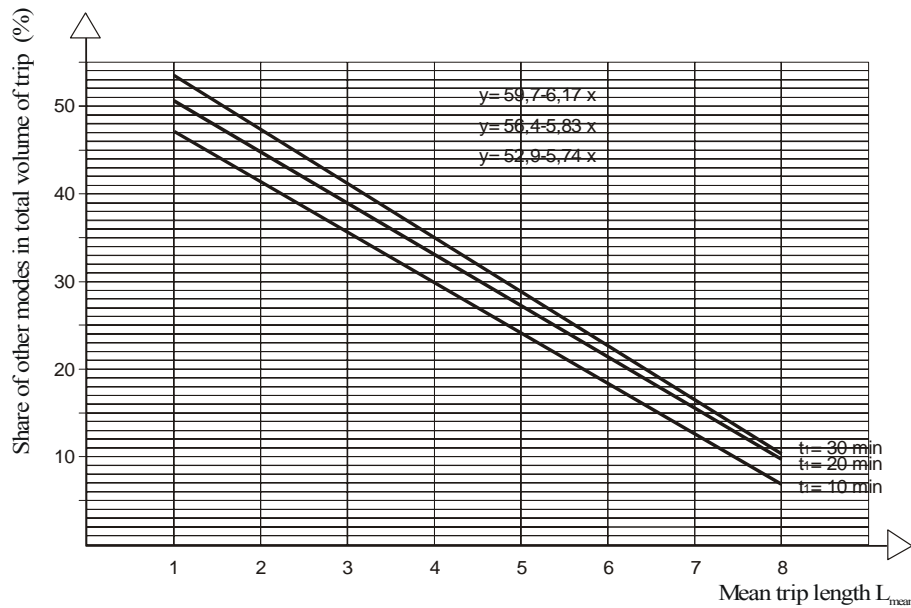
Figure 7: Share of OM in total volume of trip depending on mean trip length L_{mean}

By applying these diagrams it is possible to determine relations in modal split in the following manner. For the selected value of the time spent outside vehicle in *PT* t_1, and city size presented by mean trip length (L_{mean}), *PC* share in total movement volume is read from the diagram in Figure 5. After that, from diagrams presented in Figure 6 and Figure 7, percentage of share of *PT* and *OM* for identical values of the time spent outside vehicle in PT t_1, and mean trip length (L_{mean}) is read. The amount of proportional values should be close to 100%.

A procedure defined in such a way represents only a sub-phase in the process of creating knowledge base for an expert system.

2.4. Correlation between survey results and *PT* travel time

The next step in creating this expert system base is represented by correlating obtained results based on the time spent outside vehicle and results based on travel time. This was performed as follows: for each city size, i.e. mean trip length (2, 3, 4 and 7 km) calculation of PT travel time for all three values of time spent outside vehicle was made, as well as for the value of PT riding time with operating speed of 15 km/h.

- $t_t^{2,10} = 18$ min. – travel time (min) for a city with L_{mean}= 2km, t_{ter}= 10 min and t_r = 15 km/h
- $t_t^{2,20} = 28$ min. – travel time (min) for a city with L_{mean} = 2km, t_{ter} = 20 min and t_r =15 km/h
- $t_t^{2,30} = 38$ min. - travel time (min) for a city with L_{mean} = 2km, t_{ter} = 30 min and t_r =15 km/h

- $t_t^{3,10}$= 22 min. - travel time (min) for a city with L_{mean} = 3km, t_{ter} = 10 min and t_r=15 km/h
- $t_t^{3,20}$= 32 min. - travel time (min) for a city with L_{mean} = 3km, t_{ter} = 20 min and t_r=15 km/h
- $t_t^{3,30}$= 42 min. - travel time (min) for a city with L_{mean} = 3km, t_{ter} = 30 min and t_r=15 km/h
- $t_t^{4,10}$= 26 min. - travel time (min) for a city with L_{mean} = 4km, t_{ter} = 10 min and t_r=15 km/h
- $t_t^{4,20}$= 36 min. - travel time (min) for a city with L_{mean} = 4km, t_{ter} = 20 min and t_r=15 km/h
- $t_t^{4,30}$= 46 min. - travel time (min) for a city with L_{mean} = 4km, t_{ter} = 30 min and t_r=15 km/h
- $t_t^{7,10}$= 38 min. - travel time (min) for a city with L_{mean} = 7km, t_{ter} = 10 min and t_r=15 km/h
- $t_t^{7,20}$= 48 min. - travel time (min) for a city with L_{mean} = 7km, t_{ter} = 20 min and t_r=15 km/h
- $t_t^{7,30}$= 58 min. - travel time (min) for a city with L_{mean} = 7km, t_{ter} = 30 min and t_r=15 km/h

For these *PT* travel times, identical relations in modal split apply as in the case of the time spent outside vehicle in *PT* (t_1) 10, 20 and 30 min, for each city size. For example, for a city with mean trip length of 4km, travel time of 26 minutes provides identical relations in modal split as time spent outside vehicle of 10 minutes, i.e. travel time of 36 and 46 minutes provides identical relations in modal split as the time spent outside vehicle of 20 and 30 minutes, respectively.
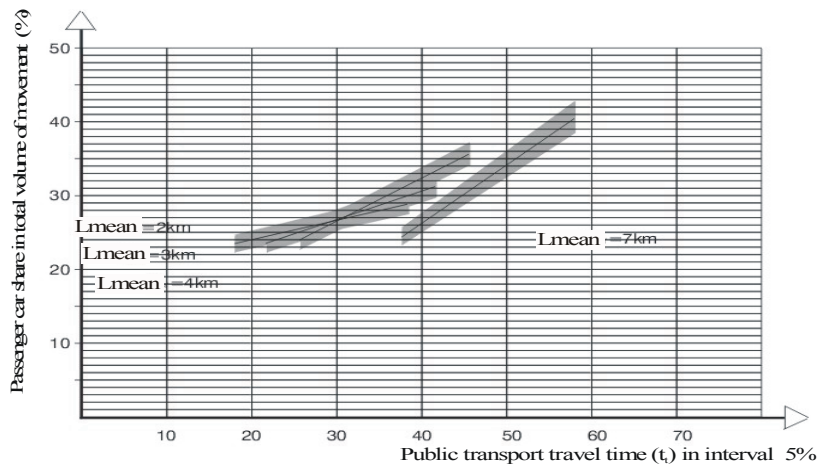

Figure 8: PC share in total volume of movement depending on PT travel time (t_t) in interval ± 5%

Required corrections are to be done in terms of forming intervals around the values read from diagrams or calculated from regression equations. It has been already stated that these corrections can be done by applying values in the interval (-5%, +5%)

around mean value, because, in such way corrections of variations occurring during analysis of expert group results (performed expert group by expert group) as well as during processing of the results itself. In the following diagrams presented are interval solutions for determination of certain transport mode shares, depending on travel time.
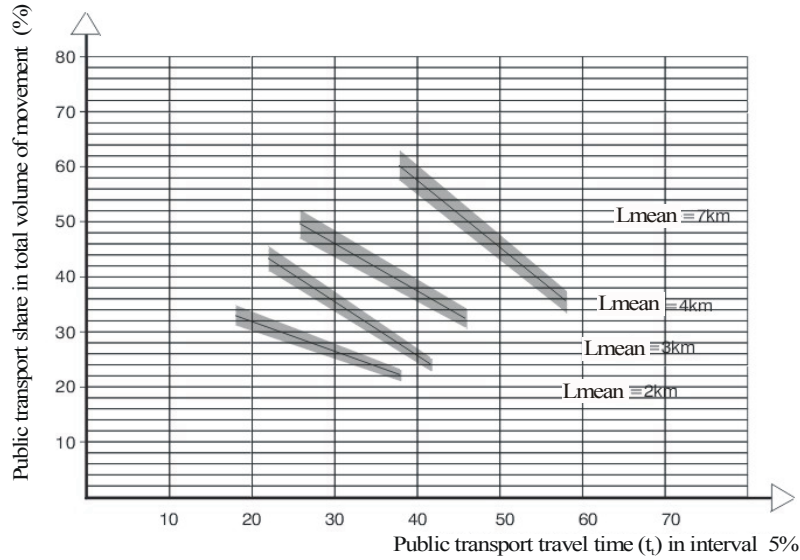
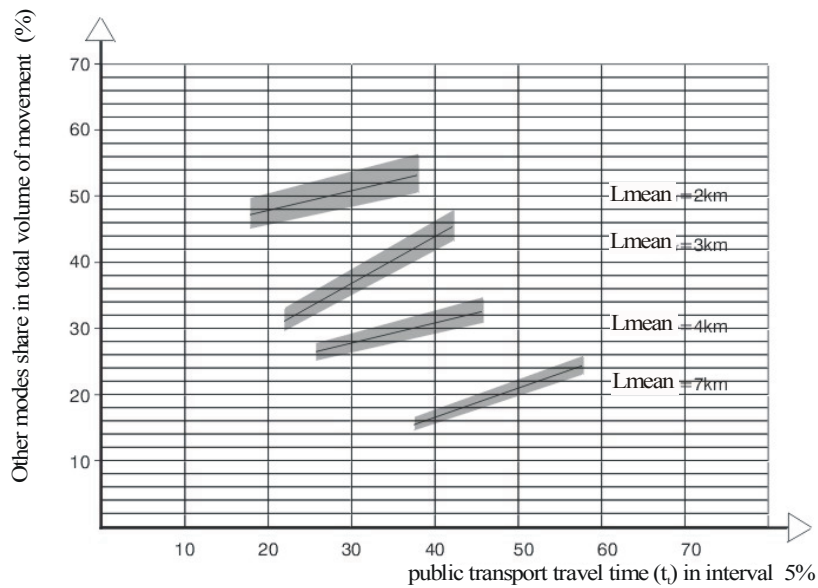**Figure 9:** PT share in total volume of movement depending on PT travel time (t_t) in interval $\pm 5\%$

Figure 10: *OM* share in total volume of movement depending on *PT* travel time (t_t) in interval $\pm 5\%$

The step forward in outlining the EXSYMS was correlation between travel time and specific transport system parameters. Each travel time components depends on a series of variables, such as: travel speed, time interval, network density, number of vehicles on a line, etc.

Because it is difficult to work simultaneously with greater number of parameters, particularly in transport demand forecast, we chose one parameter – network density σ (km/km^2), which represents length of line network per square kilometre of area surface. Research conducted by Zilbertal [2] shows how travel time can be expressed in terms of network density. According to Zilbertal [2], travel time (t_t) is:

$$t_t = \frac{120}{v_t}\left(\frac{1}{3\sigma}+\frac{l_n}{4}\right) + 60\left(\frac{\sigma}{\frac{N}{P}v_e}+\frac{L_{mean}}{t_r}\right)$$

The expression N/P represents density of transport units per kilometre of a city area. Values of this parameter for certain city categories are given in Table 4.

Table 4: Density of transport units per city area kilometre

City size (in thous.of citizens)	Mean trip length L_{mean} (km)	N/P (in trip /km^2)
50-100	2.0-2.2	1.5-1.8
100-250	2.2-2.5	2.0-2.2
250-500	2.5-3.0	2.4-3.2
500-1000	3.0-4.0	3.8-4.5

Source [2]

By analysing values from Table 4, as well as by analysing values of city size and mean trip length (L_{mean}), which are subject of this paper, values of indicators N/P from Table 4, were approximated and modified for mean trip lengths (L_{mean}) of 2, 3, 4 and 7 km.

Table 5: Density of transport units per city area kilometre (N/P)

City size (in thous.of citizens)	Mean trip length L_{mean} (km)	N/P (in trip/km^2)
50-100	2	1.85
100-200	3	2.6
200-500	4	3.8
>500	7	5.0

Assuming that the following applies to all city categories:
- interstation distance 400m,
- walking speed 4 km/h,
- operating speed 15 km/h,

travel time depending on network density can be calculated applying the following formula [2]:

$$t_t = 5\frac{\sigma}{\dfrac{N}{P}} + \frac{10}{\sigma} + 3.9\,L_{mean} + 3\,(\text{min.}) \tag{2}$$

For defined values from Table 5, travel time in correlation with network density, is presented in Figure 11.
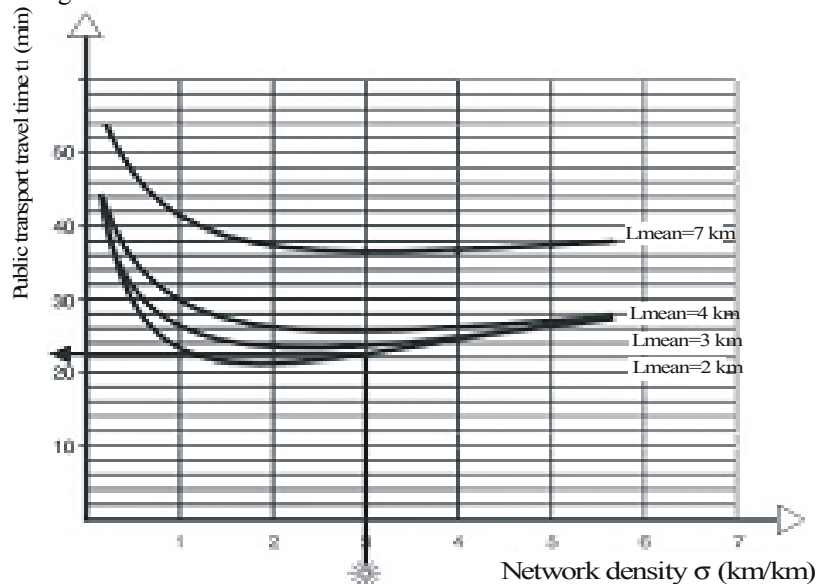

Figure 11: Dependence of PT travel time upon network density

In this manner PT travel time, which is an input value for application of this expert system, is correlated to network density, what increases potential application of the proposed concept.

3. APPLICATION OF EXSYMS

Two potential groups of users of hereby created "tool" could be recognized. In the scope of strategic operation of transport planners, such an expert system provides response to various scenarios of urban system development and its transport subsystem. Operational application implies an insight into effects of certain, actual, management and organizational activities in the scope of the transport system.

The EXSYMS represents a "tool" to be used in determining a framework in which modal split modelling[1] is feasible. Defined relations in modal split can be used as benchmarks in determining share of specific transport modes (their definition being done on the basis of two parameters). They should serve as margins within which planners

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[1] Utilisation implies existence of alternative "PT" in the transport system of the region under consideration, either developed PT or a commuter transit which has the role of PT in smaller towns.

should perform the final defining of these relations. Definition of final relations in movement modal split should be based on a comprehensive and detailed transport study which should illustrate particularities of a given region, in the sense of topographic characteristics, socio-economic parameters, movement characteristics, transport system, etc., as well as on setting up the trends of future modifications of such parameters.

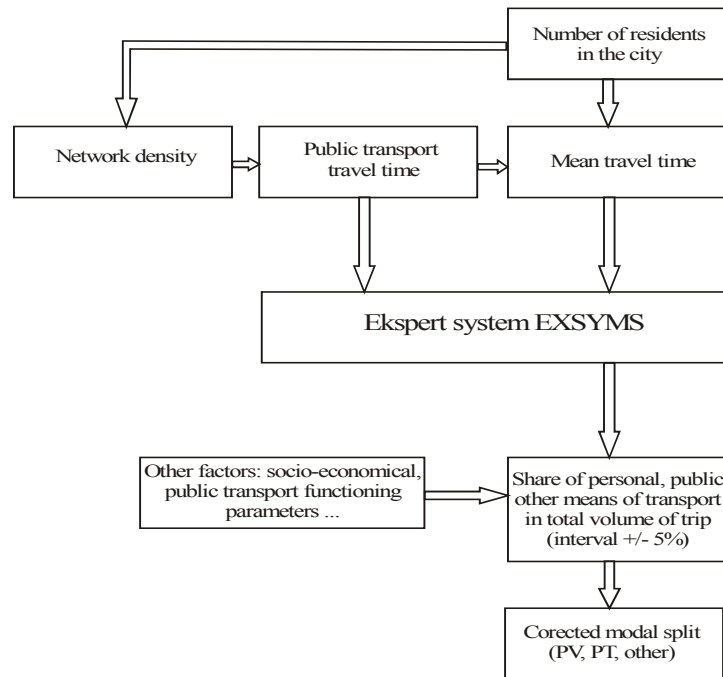The following algorithm presents a method of applying this expert system on planning level.

Figure 12: Method of applying EXSYMS on planning (strategic) level

In order to apply the EXSYMS on an operational level it is necessary to be acquainted with the current situation in transport system, what implies existence of a solid information base formed on research results. Having this view in mind, it is possible to apply such an expert system in "gaming" domain, i.e. testing a number of possible actions to be undertaken, and not for defining one specific action. This means that this expert system, for actual relations in modal split, can offer values only for those parameters which it contains, and which are defined on the basis of a number of assumptions, that may, more or less, vary for an actual case.
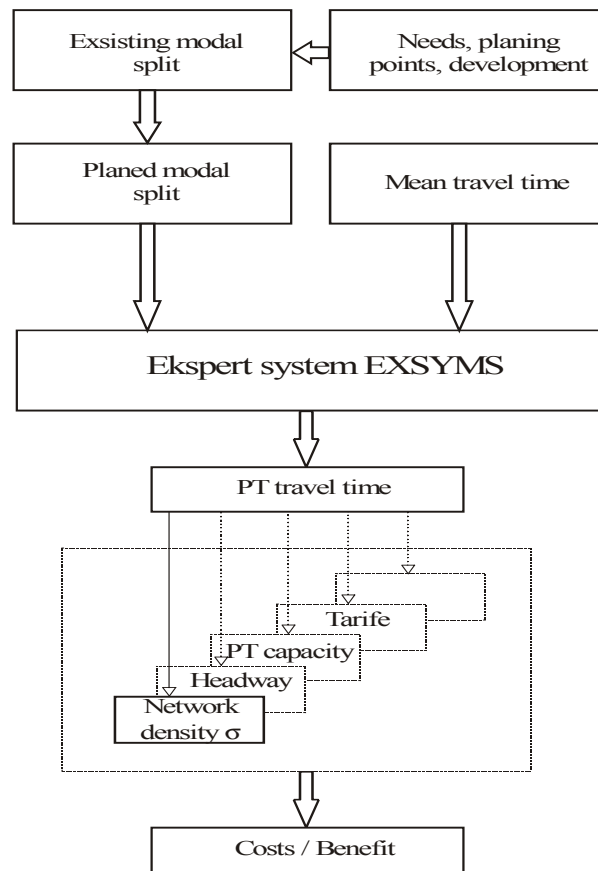
Figure 13: Method of applying EXSYMS on operational level

4. CONCLUSION

Considering the fact that expert systems involve use of computers, i.e. application of specific programs and "shells" to build-in an expert system, the procedure presented in this paper should be formalized and modified for building-in into the expert system. This means that it is necessary to, first of all, in more detail and on more samples, estimate parameter values affecting movement modal split as well as their dependencies. After that, it is possible to define such dependencies in terms of mathematical models which should be calibrated in accordance with specific characteristics of each domain, and built in into the expert system's knowledge base.

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