Micro-Level Road Network Evaluation using Fuzzy Signature Rule Bases

Gergely Cs. Mikulai[1], László T. Kóczy[2, 3]

[1] Széchenyi István University, Doctoral School of Regional and Business Administration Sciences, Egyetem tér 1, 9026 Győr, Hungary, gergely.mikulai@ga.sze.hu

[2] Széchenyi István University, Department of Information Technology, Egyetem tér 1, 9026 Győr, Hungary, koczy@sze.hu

[3] Budapest University of Technology and Economics, Department of Telecommunication and Media Informatics, Műegyetem rkp. 3, 1111 Budapest, Hungary, koczy@tmit.bme.hu

Abstract: Nowadays, due to fast-increasing economic development, the current available road infrastructure is more and more crowded, which creates frustration for the people using them. In the current research, a model is proposed for authorities, companies and individuals, to choose the best available route(s) and road sections(s) for improvement measures, optimal delivery or commuting. In the proposed model, a fuzzy signature rule base, is introduced for commuters, which distinguishes all the relevant factors during commuting. The actual decision process is based on various input data, such as peoples' habits, assumptions and preferences and various other factors.

Keywords: fuzzy signature rule bases; personal preferences; route selection

1 Introduction

Traveling is an inevitable factor in modern societies. In order to decrease its negative effects, traveling itself and its side effects should be modelled properly. In this paper, such a model is proposed, which is built on the three levels, which were formulated first by Bjønskov and Svendsen [1]. These three levels are the following:

- Macro-level – governmental level
- Meso-level – group level
- Micro-level – personal level

This classification into three levels describes the entire problem area in a systematic way. A macro-level evaluation model was already introduced in [2]. That model proposed a systematic overlook for governments, about which road sections should be renovated, expanded, or which one requires any special attention.

The meso-level may properly describe the decision-making process of a group of people, for example truck-drivers, or of individuals, such as commuters.

The currently evaluated micro-level describes the decision of individuals, how the choose their actual route in a concrete traffic situation. Nowadays, there are more and more tools available for the support of this decision, such as, mobile applications, or GPS aided devices. But these often do not offer the best solution, and there are always other factors to be taken in consideration, which may help the traveler choose the best option for a given route.

Behind these route selection algorithms, in many cases, there are learned habits, physical limitations, or simply assumptions, suggesting that one way is faster than the other.

The proposed model analyses these factors and helps categorize them and build up a fuzzy signature rule base in order to get a coherent result. In order to give a usable tool for commuters which route and which travel means should they choose. After creating the signature rule base, a decision with fuzzy elements is made, based on the individuals' specific inputs, in order to get them a personalized choice [3].

The currently proposed fuzzy signature rule base consists of multiple factors. One major group is formed by the objective factors, for example:

- The weather
- The congestion of the roads
- The available transportation options, etc.

The other major group contains the subjective factors, among others:

- Cognitive biases towards routes, or vehicles
- Personal preferences
- Travelling habits and beliefs, etc.

To sum up the model, it combines many currently difficultly measurable factors, makes them appreciable and by the fuzzy signature rule base it proposes an objective resolution for every route and selection, by evaluating objective and subjective factors as well.

2 Fuzzy Signature Rule Base Background

2.1 Problem Formation

Selecting the best potential route for a given trip is not an easy task. This selection is based on multiple inputs, which are difficult to evaluate manually within a short time.

The currently evaluated problem area is not describable by a linear, deterministic formula. In many cases, even complex correlation could be described by simple formulas, which help one to understand how the world works, for example the function of the gravity, which describes the uprising force by one single function.

However, the question area could be described with a non-deterministic, non-linear formula properly, since there are many flexible describing factors, such as the traffic, or the weather component. These factors could change extremely frequently.

First, it is important to identify the complex problem to be solved. To this end, several theoretical and empirical models have been created and validated up to now. Some of the models are based on technical approaches, while others are sociology-based. However, the realistic and multifaceted treatment of the issue needs a combined multidisciplinary approach, using the resources of both knowledge areas The substantial understanding of the phenomenon requires a wide scope and balanced work, taking all possible technical and societal aspects into account.

A clear and reliable model is needed, which can handle the uncertainties of several nonlinear and stochastic variables. Furthermore, it should reflect the foreseen individual preferences of the people involved.

2.2 Methodology

The phenomenon under our analysis is not deterministic: it is rather stochastic, rather complex, contains continuous subjective decisions. Therefore, there is no exact formula or model to find an explicit solution.

A fuzzy signature rule-based framework is proposed that can help to describe and analyze the relationship between the several factors. The proposed model, which has already been introduced in the article of our earlier article about Macro level road network evaluation [2], which proved to be suitable to produce clear results for highly complex and chaotic systems.

The method contains the following steps. First step, the problems and questions are listed and ordered in relevant sub-groups. Second step, the groups are weighted within the groups, that way the relative importance of the components within the subgroups is determined ($\Sigma = 1$). Third step, inside the groups, output scenarios are created, using the available data bases, evaluated by fuzzy methods. These scenarios simplify the possible outcomes and make the multiple inputs manageable. Fourth step, the answers are aggregated with help of fuzzy aggregations and the thus cumulated information is “forwarded” one level higher, until the root, where a single fuzzy membership degree will express the overall evaluation. [4] The aggregations are continued level by level until the final recommendation forming the base of a decision is obtained. It is not necessary that the aggregations within the local roots of the subgroups are identical, not even in the type of operation, so, e.g. while a weighted average type aggregation may be rather common in some nodes, other mean type operations, max and min, and more complex ones, like t-norms or t-conorms may be applicable. The selection of these aggregations should be carefully done on the base of expert domain knowledge, or model fitting, using a significant number of known results for real cases [5].

Mathematically the fuzzy signatures are built up with logical relations. This means, there is a clearly described connection between attributes. It is mostly a below and above ordinance. From the below level originates the above level. This helps the model to systematically describe the issue and prepare for evaluation [6].

In order, to evaluate the fuzzy signature, an aggregation is needed. For this aggregation, each root receives an aggregation type. There are multiple types of these aggregation, for example, the arithmetic mean, the geometric mean, the harmonic mean, weighted average, or the minimum and maximum. In the current article mostly the weighted average is used, while in some cases the maximum type of aggregation. It is important to highlight, that the weighted average is a non-commutative aggregation operator [7].

Optimizing a route crossing several points (stops, shops, cities, etc.) is a very classical problem, who’s most well-known prototype is the NP-complete travelling salesmen problem (TSP), which has a very wide literature where the following key publications may be mentioned [8] and [9]. Some recent alternative metaheuristic approaches may be found in [10] and [11]. A multitude of extended or modified TSP problems also has a very rich literature, however, here, we focused in the individual choice including subjective elements, such as preferences of the traveler and thus we omit a deeper analysis of the related route optimization literature.

3 Proposed Model

As mentioned above, based on the literature review, a three-level structure (macro, meso and micro levels) has been introduced. The highest level is the macro level, where the model focuses on the governmental level of road network evaluation, for example, about which routes or sections of a given region should be renovated, or extended. On the medium level, which is the “meso-level”, the model focuses on the route selection preferences of a specific group, for example, the route selection preferences of international truck drivers, or families going on holiday. The lowest level, which is evaluated in the current article is the micro level, where the model aims to evaluate the personal triggers of a specific route selection, why does a person select a given path between point A and B. Thus, the problem to be solved is to find a proper model and matching algorithm for describing the decision process by an individual traveler, including preferences and subjective components, where alternative routes and alternative means of traveling are considered. We are looking for a novel approach, where subjectivity and non-deterministic factors are modelled by non-probabilistic uncertainty, namely, a fuzzy approach. The multitude and partial interdependence of the components influencing the final decision are taken into consideration by a hierarchical, structured descriptor as explained in the next.

The model is using fuzzy aggregation by weighted factors, which makes it able, to combine 'hard' data from databases with 'soft' data, which are collected and estimated – or simply meant – by the participating people, reflecting their personal priorities and subjective experience.

The model proposes the structure described in Figure 1.

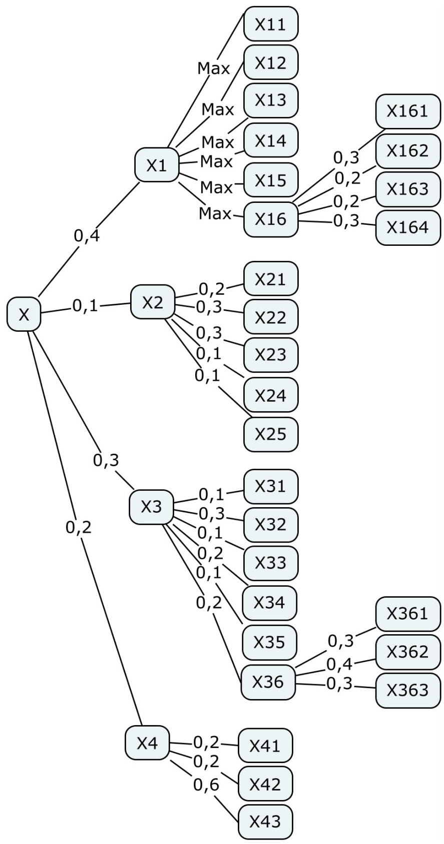

Figure 1

Micro level route selection graph for daily commute

The model consists of 26 + **4 variables**, where 24 variables are independent, forming 7 subgroups of membership degrees (recommendations), which together form a coherent model. These are the following:

X – Route selection (Which route should be used for daily commuting?) – In the current paper, the answer for an everyday commuter's route selection is evaluated, namely, which route should be taken, when a commuter has multiple options.

X1 – Infrastructure – The first big aggregation group is the evaluation of the infrastructural aspect of the route selection process. It describes the mostly objective aspects of the route, namely, what are the advantages, or disadvantages of the options [12].

X11 – Available transport options – It is important to see, what are the choices for the target person (the commuter), in order to evaluate, whether they have a choice, or the routing cannot be modified. The potential transport options could be walking, bicycle, car, local public transport (e.g.: bus, tram, etc.), distance public transport (e.g.: train, distance bus, etc.), taxi, self-driven car, or some other alternatives [13].

X12 – Available route alternatives – In most cases, there are alternatives for most of the commuters, despite the fact, that many people have habits, and tend to always use the same route alternative, and only modify it in case of some extreme circumstances, such as road closedowns, accidents, or other unavoidable barriers [14].

X13 – Accessibility – This variable describes how easily the given route can be accessed. In many cases, certain route options fall out because they are too far away from the person in question, or they are not accessible due to some unusual situation [15].

X14 – Economicality – It describes, how affordable is the given route option, both time- and cost-wise. Frequently it is one of the most important factors, since for many users, time and money are the most limited resources [16].

X15 – Environmental friendliness – Some users consider environmental friendliness as an important factor as well. In this case the user calculates with the ecological impact of their route and they try to minimize it [17].

X16 – Weather dependence – This describes to what extent the given route, especially the transport vehicle is weather dependent. For example, the option of riding a bike to the workplace is more weather dependent, than driving a car to there. This variable is an aggregated variable, which means, that the result of this is built up from the aggregation of X6, X7, X8 and X9 [18].

X161 – Temperature dependence – This variable describes whether the given route section is sensitive for the outside temperature, for example, whether there is any counter-indication of the route when the weather is too hot, or when it is too cold [18].

X162 – Rain dependence – It grades whether traveling the given section is affected by the rain. It could be that choosing a given section would be more dangerous in the sense of higher probability of traffic accidents in the case of e.g. a heavy rain shower [18].

X163 – Sunshine dependence – This attribute describes whether the section has a correlation with the grade of the sunniness of the weather. In some cases, it could be, for example, that the section is unusable by walk, or by bicycle, as the surface of the road is too hot due to the sun, or the tar is molten to some extent. [18].

X164 – Visibility dependence – It often happens, if the weather is foggy, some routes become uncomfortable, or even dangerous. There is a clear correlation between accidents and bad visibility. This could result in a strong tendency of choosing another way [19].

X2 – Social factors – The socio-demographic background of the commuter is clearly an important factor behind their route selection. Family/marital status often describes how many people intend to travel together, or whether there are any prestige aspects, etc. [20].

X21 – Age – The actual age of the commuter could be a significant factor, since often when people as get older, they tend to choose the more comfortable solution. the age could influence the person's flexibility of decisions and adaptability to changing circumstances [21].

X22 – Educational background – In general, the better the person is educated, the better they can evaluate their options and actually find the best route for the actual route. There is a clear negative correlation between education and prejudices, which concludes that better educated people can make better decisions [22].

X23 – Wealth – If a person has more available funds, than they can take more alternatives into account. For example, a user in a better financial situation could choose to buy a car, a motorbike, a bicycle and a public transport pass in the same time [23].

X24 – Preferences (determined by the life stage) – Every person has different transport selection preferences during their different life stages. During the beginning of their life, people (children, school pupils) are carried around. Later, young people tend to choose the best option optimizing the cost, during the time visiting school or college. Having the first job, people often change preferences and choose based on time. Once people have children, safety has a high influence, etc. [16] [24].

X25 – Gender – Men and women often have different views and preferences. Women usually tend to be more understanding and caring (e.g., taking environmental friendliness into consideration during route selection), while men tend to be more practical and more open for extreme solutions (e.g. riding a bike in heavy rain) [25].

X3 – Personal factors – In the end of the day, behind each and every decision, there is an actual person, who makes decisions not only based on raw data. People tend to take very personal, subjective parameters into account as well. In this variable, the most important parameters are collected, in order to have a holistic picture about one's personal motivations [26]. This is definitely the most subjective group of factors which necessitate the use of fuzzy variables in the model.

X31 – Mood – In case of a common daily route, the actual mood of the traveler may influence considerably the taken path. If a route is commonly known for frequent accidents, in some cases, it could influence the mood of the person in a way, that in the end, the commuter would consider other options, despite the fact, e.g., that the questionable route would be very likely the fastest, and/or cheapest [27].

X32 – Habits – As the English proverb states, "People do more from custom than from reason.". Most people are prisoners of their habits, which are difficult to get rid of from one day to another. In this respect, it is important to see, what people tend to do out of habit, as this could give answer for a couple of correlations which could be difficult to understand at first [28]. It is one of the most difficult tasks to transform the consequences of habits into fuzzy membership degrees.

X33 – Friends/family impact – People live in communities, in bigger, and smaller communities. This means that members of the same community have much stronger influence on each other than people outside of these communities do. It is important to have an overview, about the external influencing effects of the surrounding closer communities.

X34 – Time pressure – During the day of an average commuter, there could be bottlenecks in time, e.g., if the person in question has too many programs, close in time but located physically far from each other. If this is the situation, this could result in a rush, which pushes the user towards a faster traveling method [29].

X35 – Comfort – The quality of the commute could get more and more important for the users, as this journey could be a vital determining element of their choice. If the route has a more comfortable alternative, or vehicle, while they are completely, or at least almost equivalent to each other, the user tends to choose the more comfortable option. By psychologists it was observed that even, in case the shape of one of the alternative routes being more symmetric, or geometrically more "harmonic", users would often take that, in order to maximizing the aesthetics of the trip [30].

X36 – Daily program – Depending on the daily program of the commuter, e.g., if it contains evening sport, or leisure activities, it would require different equipment, time-frame, or transportation method. E.g. if there is a meeting with friends, it is quite a compromise, that the commuter person cannot drink alcohol because driving a car, or a bike.

X361 – Locations to visit – Whether the commuter has to go only to their workplace, it is a different scenario, then, if they have to make four or five different appointments at different locations, the user would plan the route and the vehicle of travel in a completely different way than in the case of one single destination, and without any load to take with.

X362 – (Overall) Distance – This trigger is one of the most trivial factors. In some cases, distance clearly determines the route, or the vehicle. It is important to see in advance, how far the commuter should travel on the given day [31].

X363 – Equipment needed – On the daily commute, there could be an important factor what are the equipment or tools which should be taken for the given day's activity, especially, when a large amount of equipment is needed for these appointments. For example, if there is a training in the afternoon, the training equipment should often be carried around the entire day if the traveler has no more convenient solution.

X4 – Available information – In order to plan a proper route, there is certain information, which could help to decide in advance, whether it is worth to travel in a given direction, or it is better to choose another way of transportation. Many of these data inputs could arrive as live feed (e.g., radio traffic information, or GPS routing advice) in the model.

X41 – Accidents – This variable describes whether there is any information about unusual happening during the planned route. If there is any, that could result in extra journey time, which is better to avoid.

X42 – Close downs – If there are close downs, either of roads, or of metro or train stations, it could significantly increase the time of the given route. Live information about the actual obstacles is crucially important in order to optimize the route for the best outcome [32].

X43 – Traffic – This variable describes how many people, bikes, cars, or any other travelers are observed on the given route, in the given time. This observation is extremely important, since, for example, if there is a huge traffic jam along the route originally selected, the journey could become two or three times longer in total time, or if there are overcrowded trams, trains, or metros, the trip would be a lot less pleasant for the traveler, and could be considerably slower as well. If this is the observed situation, the best is to avoid the critical bottlenecks, as in the result, they would slow down the progress of the traveler.

The overall question for the current model is: Which route should be used for daily commuting? This question should be answered by evaluating the fuzzy signatures, by comparing the resulting degrees represented by the calculated root degrees of the fuzzy signature trees constructed from the above listed variables appearing on the leaves of the tree, with the various fuzzy membership degrees assigned to the more or less objective, or just on the contrary, rather subjective aspects listed, with help of the fuzzy aggregation operators forming also part of the model, which are assigned to the intermediate nodes of the fuzzy signature trees.

It should be remarked that similar problems, where similar structures and interrelationships of uncertain, vague and subjective components emerge, may be modelled in a similar way, thus, when constructing the new model proposed in this paper, the potential solution technique of a family of similar problems is also given. Setting up this model, we claim that it would be a useful framework for a large variety of further research topics with similar structure as well.

If the values for a concrete situation (task to choose a route) are filled in, the frame of the signature describing the current option is given. If all the leaves have been assigned membership degrees or functions (the latter, if building a fuzzy signature set) the values are given for further evaluation by calculation of the lower level values (intermediate nodes) as these are the input data for the next levels. After evaluating the actual values given to every variable, fuzzy aggregations are used, in order to sum up the problem area (e.g., a group of connected variables forming a sub-tree) into one single degree for each group. Selecting the proper aggregation in the model for every sub-tree root is essentially important for the adequate decision making. This way subjective and unexcitable decisions with ambivalent answers containing "on one hand, on the other hand" elements can be avoided. In the simplest way, the aggregations mentioned are often weighted means where the key question is to find the weights which are the most adequate for the elements of the given sub-groups. The integration of the partial results by proper aggregations, using realistic weights helps to transform the essentially uncertain system with multifold obscureness into relatively unambiguous and sound results, which are easy to understand and to communicate [7].

In the current research, we propose the use of the most widely applied fuzzy inference mechanism model described by Mamdani and Assilian. Their approach could be seen in Figure 2 [33].

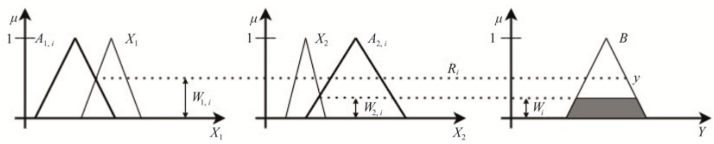

Figure 2
Schematic illustration of the Mamdani fuzzy inference [34]

This method could be used to build up generalized rules and based on these rules, to make consequent responses for the stated question, starting from more or less objective inputs. These generalized rules have the following general form:

$$If\ x_1 = A_{1,i},\ x_2 = A_{2,i},\ ...,\ and\ x_n = A_{n,i}\ then\ y = B_i \qquad /1/$$

where xi stand for the earlier mentioned variables, which represent the input to the fuzzy system. In the formula, y represents the output of the fuzzy system. $A_{n,i}$ and B_i are fuzzy sets (antecedents and consequents of the rules) defined by functions $\mu_{An,i}\ (x)$: $X \rightarrow [0,1]$ and $\mu_{Bi}\ (y)$: $Y \rightarrow [0,1]$, respectively [34].

In order to illustrate the way of the evaluation of the concrete problem, that may lead to a decision, a fuzzy signature set rule base will be introduced. In the next paragraphs, fuzzy linguistic values for the variables are proposed with some examples for the shapes of these membership functions representing the linguistic terms. We also present a very simple example, where we show that such a decision making is realistic and can be done with help of the proposed model.

The overall question is the ***X – Route selection***, which is:

Which route should be used for daily commuting (or, for today's trip)?

It is important, that the model is capable of comparing different routes, which means, that the user always needs to put in at least 2, or more route alternatives. Based on this, the one should be chosen, which requires less optimization. The following potential answers are expected after the evaluation:

- The given commuting route needs major optimization
- The given commuting route needs minor optimization
- The given commuting route is (more or less) optimal

In order to get an answer, the question was split into four major sub-questions, which help to organize a structured overlook of the problem. In case of each question, a membership function was proposed to describe and map all of the possible outcome possibilities. For example, in case of the ***X35 – Comfort***, the following membership function was proposed:

$$\boldsymbol{X35} \in \{Comfortable,\ Compromise,\ Uncomfortable\} \qquad /2/$$

In Figure 3 three actual membership function can be seen, which describe the uncertain boundaries between the personal preferences behind the route selection.

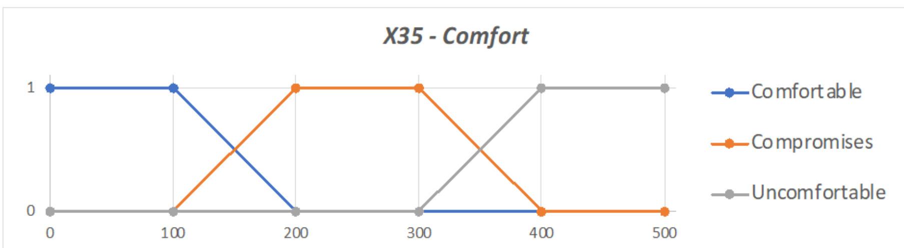

Figure 3
X3 (Personal factors) membership function

In Table 1, the potential values of *X*3 and three examples are reported.

Table 1
Linguistic value sets for X3, based on X31-X36

Attribute	**1. example**	**2. example**	**3. example**
*X*31 – Mood	Good	Good	Bad
*X*32 – Habits	Conventional	Ordinary	Innovative
*X*33 – Friends/family impact	Moderate	High	Minimal
*X*34 – Time pressure	High	High	High
*X*35 - Comfort	Compromise	Compromise	Uncomfortable
X36 – Daily program	One	Multiple	Multiple
*X*3 – Personal factor	Preferred	Compromise	Avoidable

A generalized if-then rule base is constructed using the actual values, in order to concretize the resulting values, and thus the final decision.

If X31 is A31, X32 is A32, X33 is A33, X34 is A34, X35 is A35 and X36 is A36 then X3 is D3 /3/

$$X31 \in \{Good, Average, Bad\} \quad /4/$$

$$X32 \in \{Conventional, Ordinary, Innovative\} \quad /5/$$

$$X33 \in \{Minimal, Moderate, High\} \quad /6/$$

$$X34 \in \{Minimal, Moderate, High\} \quad /7/$$

$$X35 \in \{Comfortable, Compromise, Uncomfortable\} \quad /8/$$

$$X36 \in \{One, Some, Multiple\} \quad /9/$$

$$D3 = \{Preferred, Compromise, Avoidable\} \quad /10/$$

Using this proposed structure, an adequate answer can be obtained for the major decision points, for *X*1, *X*2, *X*3 and *X*4, where the potential values are the following:

– for *X1* (Infrastructure)

$$D1 \in \{Good, Fair, Poor\} \quad /11/$$

– for *X2* (Social factors)

$$D2 \in \{Uninfluential, Neutral, Influential\} \quad /12/$$

– for X3 (Personal factors)

$$D3 \in \{Preferred, Compromise, Avoidable\} \quad /13/$$

– for *X4* (Available information)

$$D4 \in \{None, Some, Many\} \quad /14/$$

Based on the above stated decision parameters, an overall answer can be given for the original question (Which route should be used for daily commuting (or, for today's trip?), which could be the following:

D = {Major change for optimization, Minor change for optimization, already optimal} /15/

After mergers and reductions of the various decision points in all dimensions and categories (technical vs. societal), the structure leads to a transparent and clear deduction.

It is important to mention, that the current model does not necessarily propose the exact point of potential optimization, but with multiple iterations, in any case, a far better route may be achieved, based on a comparison.

In fact, the proposed model contains several personal, subjective steps: for example, the selection of the problems, the chosen data sources, the methods to find and interpret the answers and also the weights of the factors. Interestingly, despite the pronounced presence of several subjective elements, the results show strong correlation with the intuitively better route selection. Users could objectively evaluate between two possible routes, including their subjective preferences. In this phase, the result can be compared to the expectations of the stakeholders: project participants, involved experts and decision makers.

In order to have a holistic overview about the membership functions, in Table 2 the exact functions could be found, which describes the potential end values.

Table 2
Membership function descriptions

Attribute	Value set	fX(y) value levels
X161	X161 ∈ {Low, Medium, High}	[1-30]={Low=1} [40-70]={Medium=1} [80-110]={High=1}
X162	X162 ∈ {Low, Medium, High}	[1-30]={Low=1} [40-70]={Medium=1} [80-110]={High=1}
X163	X163 ∈ {Low, Medium, High}	[1-30]={Low=1} [40-70]={Medium=1} [80-110]={High=1}
X164	X164 ∈ {Low, Medium, High}	[1-30]={Low=1} [40-70]={Medium=1} [80-110]={High=1}
X16	X16 ∈ {Low, Medium, High}	[1-33]={Low=1} [34-66]={Medium=1} [67-99]={High=1}
X11	X11 ∈ {Walk, Car, Bicycle, Public transport, Distance transport, other}	[0-1]={Walk=1} [1,01-2]={Car=1} [2,01-3]={Bicycle=1} [3,01-4]={Public transport=1} [4,01-5]={Distance transport=1} [5,01-6]={Other=1}

Attribute	Value set	fX(y) value levels
X12	X12 ∈ {None, Some, Many}	[1-30]={None=1} [40-70]={Some=1} [80-110]={Many=1}
X13	X13 ∈ {Low, Medium, High}	[1-30]={Low=1} [40-70]={Medium=1} [80-110]={High=1}
X14	X14 ∈ {Low, Medium, High}	[1-30]={Low=1} [40-70]={Medium=1} [80-110]={High=1}
X15	X15 ∈ {Not, Fair, Outstanding}	[1-33]={Not=1} [34-66]={Fair=1} [67-99]={Outstanding=1}
X1	X1 ∈ {Poor, Fair, Good}	[1-30]={Poor=1} [40-70]={Fair=1} [80-110]={Good=1}
X21	X21 ∈ {20-, 21-30, 31-40, 41-60, 61+}	[0-20]={20-=1} [21-30]={21-30=1} [31-40]={31-40=1} [41-60]={41-60=1} [61-120]={60+=1}
X22	X22 ∈ {Primary, Secondary, Higher education}	[0-1]={Primary=1} [1,01-2]={Secondary=1} [2,01-3]={Higher education=1}
X23	X23 ∈ {Poor, Average, Rich}	[1-30]={Poor=1} [40-70]={Average=1} [80-110]={Rich=1}
X24	X24 ∈ {Children, Student, Working, With children, Pensioner}	[0-1]={Children=1} [1,01-2]={Student=1} [2,01-3]={Working=1} [3,01-4]={With children=1} [4,01-5]={Pensioner=1}
X25	X22 ∈ {Male, Female}	[0-1]={Male=1} [1,01-2]={Female=1}
X2	X2 ∈ {Uninfluential, Neutral, Influential}	[0-1]={Uninfluential=1} [1,01-2]={Neutral =1} [2,01-3]={Influential =1}
X361	X361 ∈ {One, Some, Multiple}	[0-1]={One=1} [1,01-3]={Some =1} [3,01-20]={Multiple =1}
X362	X362 ∈ {10-, 11-20, 21-40, 41-100, 100+}	[0-10]={10-=1} [11-20]={11-20 =1} [21-40]={21-40 =1} [41-100]={41-100 =1} [100-∞]={100+ =1}

Attribute	Value set	fX(y) value levels
X363	X363 ∈ {None, Some, Many}	[0-0,99]={None=1} [1-3]={Some =1} [4-20]={Many =1}
X36	X36 ∈ {Easy, Moderate, Complicated}	[0-1]={Easy=1} [1,01-3]={Moderate =1} [3,01-20]={Complicated =1}
X31	X31 ∈ {Bad, Average, Good}	[1-30]={Bad=1} [35-65]={Average =1} [70-99]={Good =1}
X32	X32 ∈ {Conventional, Ordinary, Innovative}	[1-3]={Conventional=1} [4-7]={Ordinary =1} [8-10]={Innovative =1}
X33	X33 ∈ {Minimal, Moderate, High}	[1-30]={Minimal=1} [40-70]={Moderate =1} [80-110]={High =1}
X34	X34 ∈ {Minimal, Moderate, High}	[1-20]={Minimal=1} [30-50]={Moderate =1} [60-80]={High =1}
X35	X35 ∈ {Uncomfortable, Compromise, Comfortable},	[1-100]={Uncomfortable=1} [200-300]={Compromise=1} [400-500]={Comfortable=1}
X3	X3 ∈ {Avoidable, Compromise, Preferred }	[1-33]={Avoidable=1} [34-66]={Compromise=1} [67-99]={Preferred=1}
X41	X41 ∈ {None, One, Multiple}	[0-0,99]={None=1} [1-1,99]={One =1} [2-20]={Multiple =1}
X42	X42 ∈ {None, One, Multiple}	[0-0,99]={None=1} [1-1,99]={One =1} [2-20]={Multiple =1}
X43	X43 ∈ {Low, Medium, High}	[1-30]={Low=1} [40-70]={Medium=1} [80-110]={High=1}
X4	X4 ∈{None, Some, Many}	[0-0,99]={None=1} [1-9,99]={Some =1} [10-20]={Many =1}
X	X ∈{Major optimization, Minor optimization, Optimal}	[0-10]={Major optimization=1} [11-20]={Minor optimization =1} [21-30]={Optimal =1}

In the next, an illustrative example will be given. In Table 3 a theoretical route is evaluated based on the proposed model. In the model the same person would be evaluated for her daily commuting route. This way it can be determined, whether the given route with the given input parameters would require an optimization, or not and it can be decided, whether one, or the other requires less optimization.

In this example the commuter needs to travel 9.7 km from her home to her workplace. The location is in Budapest, Hungary. There is public transport, but a short walk needed in both ends. Other alternative would be taking the car.

Table 3
Route selection example for exact case

Attribute's name	**Alternative 1**	**Alternative 2**
X161 – Temperature dependence	fX161(25)={Low}, N(fX161(25))={Low}	fX161(50)={Medium}, N(fX161(50))={Medium}
X162 – Rain dependence	fX162(15)={Low}, N(fX162(15))={Low}	fX162(57)={Medium}, N(fX162(57))={Medium}
X163 – Sunshine dependence	fX163(26)={Low}, N(fX163(26))={Low}	fX163(34)={Low=0,6, Medium=0,4}, N(fX163(34))={Low}
X164 – Visibility dependence	fX164(38)={Low=0,2, Medium=0,8}, N(fX164(38))={Medium}	fX164(14)={Low}, N(fX164(14))={Low}
X16 – Weather dependence	fX16[0,3*fX161+0,2*fX162+0,2*fX163+0,3*fX164]={Low}, N(fX16(y))={Low}	fX16(0,3*fX161+0,2*fX162+0,2*fX163+0,3*fX164)={Medium}, N(fX16(y))={Medium}
X11 – Available transport options	fX11[2]={Car}, N(fX11(2))={Car}	fX11[4]={Public transp.}, N(fX11(4))={Public transp.}
X12 – Available route alternatives	fX12[97]={Many}, N(fX12(97))={Many}	fX12[14]={None}, N(fX12(14))={None}
X13 – Accessibility	fX13[83]={High}, N(fX13(83))={High}	fX13[37]={Low=0,3, Medium=0,7}, N(fX13(83))={Medium}
X14 – Economicality	fX14[27]={Low}, N(fX14(27))={Low}	fX14[74]={Medium=0,6, High=0,4}, N(fX14(74))={High}
X15 – Environmental friendliness	fX15[19]={Not}, N(fX15(19))={Not}	fX15[57]={Fair}, N(fX15(57))={Fair}
X1 – Infrastructure	fX1[max(X11)+max(X12)+max(X13)+max(X14)+max(X15)+max(X16)]={Good}, N(fX1(y))={Good}	fX1[max(X11)+max(X12)+max(X13)+max(X14)+max(X15)+max(X16)]={Fair}, N(fX1(y))={Fair}
X21 – Age	fX21[34]={31-40}, N(fX21(34))={31-40}	fX21[34]={31-40}, N(fX21(34))={31-40}
X22 – Educational background	fX22[3]={Higher education}, N(fX22(3))={Higher education}	fX22[3]={Higher education}, N(fX22(3))={Higher education}

Attribute's name	**Alternative 1**	**Alternative 2**
X23 – Wealth	fX23[59]={Average}, N(fX22(59))={Average}	fX23[59]={Average}, N(fX22(59))={Average}
X24 – Preferences (determined by the life stage)	fX24[4]={With children}, N(fX24(4))={With children}	fX24[4]={With children}, N(fX24(4))={With children}
X25 – Gender	fX25[2]={Female}, N(fX25(2))={Female}	fX25[2]={Female}, N(fX25(2))={Female}
X2 – Social factors	fX2[0,2*fX21+0,3*fX22+0,3 *fX23+0,1*fX24+0,1*fX25] ={Influential}, N(fX2(y))={Influential}	fX2[0,2*fX21+0,3*fX22+0,3 *fX23+ 0,1*fX24+0,1*fX25]={Influe ntial}, N(fX2(y))={Influential}
X361 – Locations to visit	fX361[3]={Some}, N(fX361(3))={Some}	fX361[3]={Some}, N(fX361(3))={Some}
X362 – (Overall) Distance	fX362[19,4]={10-20 km}, N(fX362(19,4))={10-20 km}	fX362[19,4]={10-20 km}, N(fX362(19,4))={10-20 km}
X363 – Equipment needed	fX363[3]={Some}, N(fX363(3))={Some}	fX363[3]={Some}, N(fX363(3))={Some}
X36 – Daily program	fX36[0,3*fX361+0,4*fX362+ 0,3* fX363]={Easy}, N(fX36(y))={Easy}	fX36[0,3*fX361+0,4*fX362+ 0,3* fX363]={Easy}, N(fX36(y))={Easy}
X31 – Mood	fX31[78]={Good}, N(fX31(78))={Good}	fX31[32]={Bad=0,6, Average=0,4}, N(fX31(32))={Bad}
X32 – Habits	fX32[3]={Conventional}, N(fX32(3))={Conventional}	fX32[3]={Conventional}, N(fX32(3))={Conventional}
X33 – Friends/family impact	fX33[88]={High}, N(fX33(88))={High}	fX33[88]={High}, N(fX33(88))={High}
X34 – Time pressure	fX34[47]={Moderate}, N(fX34(47))={Moderate}	fX34[53]={Moderate=0,7, High=0,3}, N(fX34(53))={Moderate}
X35 – Comfort	fX35[452]={Comfortable}, N(fX35(452))={Comfortable}	fX35[139]={Uncomfortable= 0,6, Compromise=0,4}, N(fX35(139))={Uncomfortab le}
X3 – Personal factors	fX3[0,1*fX31+0,3*fX32+0,1 *fX33+0,2*fX34+0,1*fX35+ 0,2*fX36]= {Preferred}, N(fX3(y))={Preferred}	fX3[0,1*fX31+0,3*fX32+0,1 *fX33+0,2*fX34+0,1*fX35+ 0,2*fX36]= {Avoidable}, N(fX3(y))={Avoidable}
X41 – Accidents	fX41[1]={One}, N(fX41(1))={One}	fX41[1]={One}, N(fX41(1))={One}
X42 – Close downs	fX42[1]={One}, N(fX42(1))={One}	fX42[0]={None}, N(fX42(0))={None}

Attribute's name	Alternative 1	Alternative 2
X43 – Traffic	fX43[73]={Medium=0,7, High=0,3}, N(fX43(73))={Medium}	fX43[46]={Medium}, N(fX43(46))={Medium}
X4 – Available information	fX3[0,2*fX41+0,2*fX42+0,6*fX43]= {Many}, N(fX3(y))={Many}	fX3[0,2*fX41+0,2*fX42+0,6*fX43]= {Some}, N(fX3(y))={Some}
X – Route selection	fX[0,4*fX1+0,1*fX2+0,3*fX3+0,2* fX4]= {Optimal}, N(fX3(y))={Optimal}	fX[0,4*fX1+0,1*fX2+0,3*fX3+0,2* fX4]= {Minor optimization}, N(fX3(y))={Minor optimization}

Based on the model, when choosing public transport, minor optimization would be required, but choosing the car and the bike is optimal. The result was surprising, that public transport was not the preferred form of transportation. It is due to the fact, that there is a lot of compromise in this route, due to the long walks and not good weather dependencies.

Conclusions and Future Work

The main goal of this study was to propose a model, at a micro-level, that is suitable to integrate large numbers of uncertain and/or subjective input information and to create clear answers. A new model was proposed where the actual users could evaluate the commuting path for themselves, which could help them in choosing the most suitable route. This new approach contributes to establishing an efficient and reality-based model and evaluation algorithm, which offer a more adequate solution of the problem investigated, compared to all other approaches in the literature.

It is very hard to measure the efficiency of a decision, based on uncertain components, especially subjective elements. Validation of the decisions based on the new approach may happen by similarly subjective evaluation by human "experts", e.g. active participants of route selections experiments according to the original problem set. The observations we made on real life examples confirm and validate the quality of the decisions based on the proposed new model. Further validation could be carried out by extensive questionnaires and comparison of the replies to relevant questions. Construction of such a questionnaire and conducting such experiments may be an interesting continuation of the present research.

As a side-note, we have also proposed a novel, combined model, containing the fusion of fuzzy signatures and fuzzy rule based reasoning.

Under the umbrella of the study, we tested the system, with variable input data, with substantial deviations, and, despite that, the aggregated results show remarkable coherence. This demonstrates the power of the model.

Based on the categories of Bjørnskov and Svendsen (2003), the project covered three levels of social capital: macro level, meso level and micro level. Another paper (Mikulai-Kóczy, 2021, [2]) described the results achieved at a macro level. This paper focuses on the results at the micro level, using the same model. The next step is to carry out a similar study at the meso level, using the same model, making the three-part series complete. Thus, the third study will focus on the route selection habits of specific groups.

Acknowledgement

The research was supported by the National Research, Development and Innovation Office (Hungary) grant nr. K124055.

References

[1] Bjørnskov C., Svendsen G., Measuring social capital – Is there a single underlying explanation?, *Working Papers*, 2003

[2] Mikulai G. C., Kóczy T. L., Macro-level road network evaluation by fuzzy signature rule bases, *Hungarian Statistical Review*, Vol. 4, No. 1, 2021

[3] Long X., Zhao H., Zhou M., Hou C., Switching threshold of commuting Travelers' route choice under different patterns of information, *Travel Behaviour and Society*, Vol. 23, pp. 216-225, 2021

[4] Grabisch M., Orlovski S. A., Yager R. R., Fuzzy Aggregation of Numerical Preferences, 1998

[5] Mayne A. J., Klir G. J., Folger T. A., Fuzzy Sets, Uncertainty, and Information, *The Journal of the Operational Research Society*, 1990

[6] Kóczy L. T., Vámos T., Bíró G., *Proceedings of EUROFUSE -- SIC '99: Eurofuse '99, the Fourth Meeting of the EURO Working Group on Fuzzy Sets and SIC '99, the Second International Conference on Soft and Intelligent Computing*. University of Veterinary Science, Department of Biomathematics and Informatics, 1999

[7] Kóczy L. T., Cornejo M. E., Medina J., Algebraic structure of fuzzy signatures, *Fuzzy Sets and Systems*, Vol. 418, pp. 25-50, 2021

[8] Helsgaun K., Effective implementation of the Lin-Kernighan traveling salesman heuristic, *European Journal of Operational Research*, Vol. 126, No. 1, 2000

[9] Kóczy L. T., Földesi P., Tüű-Szabó B., An effective Discrete Bacterial Memetic Evolutionary Algorithm for the Traveling Salesman Problem, *International Journal of Intelligent Systems*, Vol. 32, No. 8, 2017

[10] Kóczy L. T., Földesi P., Tüű-Szabó B., Enhanced discrete bacterial memetic evolutionary algorithm - An efficacious metaheuristic for the traveling salesman optimization, *Information Sciences*, Vol. 460-461, 2018

[11] Tüű-Szabó B., Földesi P., Kóczy L. T., Analyzing the Performance of TSP Solver Methods, in *Studies in Computational Intelligence*, 2022, Vol. 955

[12] Winters M., Teschke K., Grant M., Setton E. M., Brauer M., How far out of the way will we travel? Built environment influences on route selection for bicycle and car travel, *Transportation Research Record*, No. 2190, 2010

[13] Bovy P. H., Stern E., *Route Choice: Wayfinding in Transport Networks*, 1st ed. Dordrecht: Kluwer Academic Publisher, 1990

[14] Tischler S., Finding the right way - A new approach for route selection procedures?, in *Transportation Research Procedia*, 2017, Vol. 25

[15] Bascom G. W., Christensen K. M., The impacts of limited transportation access on persons with disabilities' social participation, *Journal of Transport and Health*, Vol. 7, 2017

[16] Seliverstov Y. A., Seliverstov S. A., Lukomskaya O. Y., Nikitin K. V., Grigoriev V. A., Vydrina E. O., The method of selecting a preferred route based on subjective criteria, in *Proceedings of 2017 IEEE 2nd International Conference on Control in Technical Systems, CTS 2017*, 2017

[17] Leng R. B., Emonds M. V. M., Hamilton C. T., Ringer J. W., Holistic route selection, *Organic Process Research and Development*, Vol. 16, No. 3, 2012

[18] Böcker L., Priya Uteng T., Liu C., Dijst M., Weather and daily mobility in international perspective: A cross-comparison of Dutch, Norwegian and Swedish city regions, *Transportation Research Part D: Transport and Environment*, Vol. 77, 2019

[19] Hammad H. M. *et al.*, Environmental factors affecting the frequency of road traffic accidents: a case study of sub-urban area of Pakistan, *Environmental Science and Pollution Research*. 2019

[20] Handy S., Cao X., Mokhtarian P., Correlation or causality between the built environment and travel behavior? Evidence from Northern California, *Transportation Research Part D: Transport and Environment*, Vol. 10, No. 6, 2005

[21] Stinson M. A., Bhat C. R., Commuter Bicyclist Route Choice: Analysis Using a Stated Preference Survey, in *Transportation Research Record*, 2003, No. 1828

[22] Carvacho H. *et al.*, On the relation between social class and prejudice: The roles of education, income, and ideological attitudes, *European Journal of Social Psychology*, Vol. 43, No. 4, 2013

[23] Bocarejo S. J. P., Oviedo H. D. R., Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments, *Journal of Transport Geography*, Vol. 24, 2012

[24] Christiansen L. B., Madsen T., Schipperijn J., Ersbøll A. K., Troelsen J.,

Variations in active transport behavior among different neighborhoods and across adult life stages, *Journal of Transport and Health*, Vol. 1, No. 4, 2014

[25] Kronsell A., Rosqvist L. S., Hiselius L. W., Sustainability transitions and gender in transport sector decisions, *5th International Conference on Women's Issues in Transportation*, No. April, 2014

[26] Golledge R. G., Path selection and route preference in human navigation: A progress report, in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 1995, Vol. 988

[27] Kariryaa A., Veale T., Schöning J., Activity and mood-based routing for autonomous vehicles, *arXiv*, 2020

[28] Prato C. G., Bekhor S., Pronello C., Latent variables and route choice behavior, *Transportation*, Vol. 39, No. 2, 2012

[29] Hoogendoorn S. P., Bovy P. H. L., Pedestrian route-choice and activity scheduling theory and models, *Transportation Research Part B: Methodological*, Vol. 38, No. 2, 2004

[30] Papinski D., Scott D. M., Doherty S. T., Exploring the route choice decision-making process: A comparison of planned and observed routes obtained using person-based GPS, *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 12, No. 4, 2009

[31] Wasiak M., Vehicle selection model with respect to Economic Order Quantity, *Archives of Transport*, Vol. 40, No. 4, 2016

[32] Walker N., Fain W. B., Fisk A. D., McGuire C. L., Aging and decision making: Driving-related problem solving, *Human Factors*, Vol. 39, No. 3, 1997

[33] Mamdani E. H., Assilian S., An experiment in linguistic synthesis with a fuzzy logic controller, *International Journal of Man-Machine Studies*, Vol. 7, No. 1, 1975

[34] Kóczy T. L., Tikk D., *Fuzzy Systems - Fuzzy rendszerek*. 2001