Decision Support for Route Search and Optimum Finding in Transport Networks under Uncertainty

G. Szűcs

Department of Telecommunications and Media Informatics
Budapest University of Technology and Economics
szucs@tmit.bme.hu

ABSTRACT
The aim of this paper is to find solution for route planning in road network for a user, and to find the equilibrium in the path optimization problem, where the roads have uncertain attributes. The concept is based on the Dempster-Shafer theory and Dijkstra's algorithm, which help to model the uncertainty and to find the best route, respectively. Based on uncertain influencing factors an interval of travel time (so called cost interval) of each road can be calculated. An algorithm has been outlined for determining the best route comparing the intervals and using decision rules depending on the user's attitude. Priorities can be defined among the rules, and the constructed rule based mechanism for users' demands is great contribution of this paper. The first task is discussed in more general in this paper, i.e. instead of travel time a general cost is investigated for any kind of network. At the solution of the second task, where the goal is to find equilibrium in transport network at case of uncertain situation, the result of the first task is used. Simulation tool has been used to find the equilibrium, which gives only approximate solution, but this is sufficient and appropriate solution for large networks. Furthermore this is built in a decision support system, which is another contribution of this work. At the end of the paper the implementation of the theoretical concept is presented with a test bed of a town presenting effects of different uncertain influencing factors for the roads.

Keywords: Dijkstra's algorithm, Dempster-Shafer theory, transportation planning, routing, uncertainty, Wardrop equilibrium, decision support system, rule base.

1. Introduction

In urban regions the transportation planning [1] is an existing problem, and an appropriate implementation process has great impacts. Lot of works deal with route choice (mostly for cars or vans, but for aircraft [3] as well), and navigation [4][5] in transportation area [2], and some of them take uncertainty into account as well, e.g. dealing with stochastic shortest path [6], using fuzzy [7] or two limit values [8] or neural networks [9]. Route planning problem and uncertainty can occur in many different networks, like electric power systems, telecommunication networks, water distribution, networks, and transportation systems, but this paper (especially from session 4.2) focuses on transportation. Every transportation company would like to find the routes that represent the minimum delivery cost [21]. Solution of this problem in stochastic network having variations in attributes is more complicated, but there are some papers with promising suggestions and applications [22].

There is a question in best path search: if every driver travelled on the base of his/her perceived best path, they may influence to each other; so will be this situation the best for all participants? Wardrop [12] has investigated this question and he has recognized alternative possible behaviours of users of transport networks, and stated two principles, which are commonly named after him:

• First principle: The journey times of all paths actually used are equal. These are equal or less than those which would be experienced by a single vehicle on any unused path.

• Second principle: The average journey time is minimal.

The first principle corresponds to the behavioural principle in which travellers seek to (unilaterally) determine their minimal costs of travel whereas the second principle corresponds to the behavioural principle in which the total cost in the network is minimal. Two kinds of optimized system can be distinguished according to Dafermos and Sparrow [23]: system-optimized (S-O) and user-optimized (U-O) transportation networks (the U-O network problem also commonly referred to in the transportation literature as the traffic assignment problem [13][14]). In the U-O network problem the users act unilaterally, in selecting their paths; and in the S-O network problem the users select paths according to what is optimal from a societal point of view, in that the total cost in the system is minimized. The user-optimized (U-O) network problem coincides with Wardrop's first principle, and the S-O network with Wardrop's second principle. Wardrop investigated the route planning in road network with many users without uncertainty. On the other side a route search algorithm for any individual driver was presented in a work [11] taking uncertainty into account, but a more complex model was needed.

The aim of the work presented in this paper was to investigate the route search with many users at case of uncertainty. Individual drivers are presented in more detailed with attitude and decision possibilities in this paper. Furthermore a decision support system is elaborated based on simulation helping tool that is able to solve the equilibrium problem. The novelty of the suggested solution procedure is that the equilibrium solving tool can handle intervals (so called cost intervals coming from uncertainty) instead of constant values, furthermore during the determination of the best route the users' decision rules and priorities are considered.

2. Related works to uncertainty

The routing on a network is a general problem, as the users would like to find the best route with the smallest cost. In this paper a general solution is presented at first, where the network is represented by a graph and the cost may be any kind of cost of the edges in the graph (like length, number of steps, time, etc.) depending on the application area: biological network, computer, electrical, telecommunications, transport network. Then at the second part the focus is on the transport network with specially edge cost, namely the travel time. In this application area the routing can be user- or system-optimized; this paper presents a solution for both of them using a decision support system.

A network (represented by graph) is given with an ordered pair G: = (V, E) comprising a set V of vertices or nodes together with a set E of edges, which connect two nodes. The task is to reach a node from another in the graph at the smallest cost, where the costs of edges are given. Classical Dijkstra's [15] would give the shortest path in the graph with non-negative edge path costs, however this can handle only the certainty data. Therefore, a theory is needed that deals with uncertainty; and the Dempster-Shafer (DS) [16] is excellent solution for this, because it is able to handle the lack of the information also by belief functions [10].

In DS theory the set $\Omega = \{H_1, \ldots, H_n\}$ of all the possible states of the system, $H_1, \ldots H_n$ still mutually exclusive. Let us denote by $P(\Omega)$ the powerset 2^Ω, and by *A* an element of $P(\Omega)$.

$$P(\Omega) = 2^\Omega = \{\{\}, \{H_1\}, \{H_2\}, \{H_3\}, \ldots, \{H_1, H_2\}, \ldots, \Omega\} \quad (1)$$

DS theory defines functions (*m*) called basic belief assignment (BBA) on the $P(\Omega)$.

$$m: \ 2^\Omega \to [0, \ 1] \quad (2)$$

Thus it enables to work with non-mutually exclusive pieces of evidence, represented by powerset $P(\Omega)$. The *m(A)* represents the proportion of evidence that the actual state belongs to *A* but there is no knowledge about evidence of subsets of *A*. Using DS theory a lower and an upper limit can be defined for the real probability of the evidence. The DS theory gives a solution for the combination of more basic belief assignment functions:

$$m_{1,2}(C) = m_1(C) \oplus m_2(C) = \frac{1}{1-K} \sum_{A \cap B = C} m_1(A) m_2(B) \quad (3)$$

where $m_{1,2}(\phi) = 0$

and $K = \sum_{A \cap B = \phi} m_1(A) m_2(B)$

In previous work [11] based on probability intervals of DS theory we have defined the "cost

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