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Heuristic approach in a multimodal travel planner to support local authorities in urban traffic management

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Abstract

Effective urban traffic management requires knowledge about current situation and tools to transfer information between local authorities and transport systems users. From this point of view, individual user route planning should correspond with general traffic flow management. During recent years significant increase of interest of web-based travel planners was observed. Authors suggest to connect the above issues. For this reason, Green Travelling Planner (GT Planner) was implemented. What the tool allows, among others, is optimum route planning (four optimisation criteria: quicker, shorter, cheaper and greener) using one of the eleven travel modes (including multimodal combinations). It may be used as an official urban multimodal travel planner and can be controlled by local authorities. The heuristic approach which was implemented in GT Planner makes it possible to support urban traffic management by adding specified factors as attributes of links in the graph of transport network. This solution can also be used to optimise the transport systems and public transport planning based on actual travel needs collected as Big Data as GT Planner is used.

Examples provided in the article are based on partial results of the international project entitled “A Platform to analyse and foster the use of Green Travelling options” implemented under the ERA-NET Transport III Future Travelling programme and financed by the National Centre for Research and Development.

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Keywords: management of transport systems; route planning; heuristic methods in optimization; travel behavior; traffic flow modeling, real-time urban travel planning, dynamic control of traffic by travel plannner, urban traffic management support

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1. Introduction

In times of increasing mobility, contemporary cities are faced with intensifying problems when attempting to maintain smooth traffic flow. Congestion increases the probability of collisions in road traffic, it is primarily responsible for growing noise levels, fuel consumption and emission of harmful substances into the environment. Moreover, the prevalence of passenger cars in the modal split of traffic translates into reduced efficiency of urban space utilisation. This issue has recently been experienced more and more severely, particularly in city centres and areas densely developed with public utility features (Marshall and Kanister (2000)). Various guidelines prepared by such institutions as the European Union (White Paper (2011) and Clean Power for Transport (2013)) imply that mobility should not be limited, but rather transformed in terms of how it is pursued (means of transport). The concept of modal shift represents a trend proposed as one of the solutions to the problem of more efficient use of public space and a measure to reduce the negative environmental impact of transport. Another difficulty tackled in cities is to attain appropriate distribution of traffic streams in the transport network. Some streets become congested, while others (offering only slightly longer times to reach the destination point) retain considerable unused traffic flow capacity. Users of passenger cars prefer more familiar routes, even though they force them to wait in long queues and face congestion, which only makes the situation worse. Another problem is the information transfer. Contemporary cities should pursue integration in every domain, also in the sphere of transport processes. What is needed in this respect is good communication between the travelling population and local authorities. On the one hand, information transfer should encompass acquisition of data concerning travelling persons, which contributes to identification of their actual needs. On the other hand, a person who intends to make a trip should receive comprehensive information from the municipality about the possibilities to complete it. The foregoing comprises means of transport (including public transport services) as well as comparisons of costs, time etc. Consequently, travel planners are becoming increasingly popular services supporting the travelling population (among others Esztergár-Kiss and Csiszár (2015) and Borkowski (2017)). Furthermore, existing travel planners still have some functionality deficiencies (a review of them can be found in Földes and Csiszár, (2015)). Both the multitude of solutions available in this respect and the fact that local authorities are not involved in consultations cause that the tools in question transfer information in one direction only, taking the travellers' interest into consideration. Meanwhile, what seems equally important in this case is data standardisation and identification of a single information service for the given area. It should be emphasised that only under the foregoing conditions may the information transfer be considered complete in both directions, and all decisions made by local authorities can be directly delivered to the travelling population.

The potential to support local authorities in more efficient management of urban traffic by affecting the choice of routes and travelling modes made by the travelling population has been described in the article. The multimodal travel planner known as Green Travelling Planner (GT Planner) is one of deliverables of the international project entitled "A platform to analyse and foster the use of Green Travelling options" implemented under the ERA-NET Transport III Future Travelling programme and co-financed by the National Centre for Research and Development (Project Proposal (2013)). The following sections of the article describe the heuristic approach applied in the planner, extending its features beyond those offered by other route planning systems. The heuristics added to the solution may find practical application in many different situations tackled by local authorities while managing urban traffic. The article ends with a collation of results of numerical studies which followed implementation of specific heuristics over an area of 19 cities forming the Upper Silesia Conurbation (Poland).

2. Methodology

2.1. Green Travelling Planner

The main deliverable of a project entitled "A Platform to analyse and foster the use of Green Travelling options" is an expanded system that supports local authorities in decisions making concerning the incentives and restrictions applied to different groups of users (travelling population). As an outcome of these activities, it is possible to shape the travelling population's behaviour patterns. The system components include a tool for simulation of changes in the distribution of traffic streams caused by local authorities undertaking specific actions (prepared by project partners from the Basque Country: Saitec, DeustoTech and Factor), a multimodal travel planner (GT Planner) developed by the Silesian University of Technology (Poland) and an interface dedicated to mobile devices which expands the system functionality (prepared by Mantis from Turkey). This article focuses on specific features of one of the system components, namely GT Planner. Route planning systems are often limited in terms of the means of transport implemented, supporting either individual transport exclusively or being dedicated to travelling by public transport. The latter limitation applies to criteria according to which the transport network is searched through in order to establish an optimum route (usually the time criterion). GT Planner features the A* algorithms implemented to search for an optimum travelling solution (the choice of methods and algorithms was preceded by studies of the existing travel planning solutions, as described in Sierpiński et al. (2014)) using eleven available travelling modes, including e.g. conventional modes such as passenger car, motorcycle, public transport (all public means of transport available in the area), bicycle, walking, as well as alternative ones, i.e. electric cars, transport chains using Park&Ride and Bike&Ride systems, urban bicycle or car rental services and all travel modes rendered by local authorities (Sierpiński (2017a)). Consequently, a GT Planner user receives information on travelling options not only including one's own vehicle, but also comprehensive information about all services rendered by the municipality to ensure that one can travel by public and multimodal transport. The full array of options also encompasses optimisation criteria, and in this respect, besides the traditional time and distance criteria, two additional ones have been implemented, namely cost (described in more detail in Staniek and Sierpiński (2017)) and environmental impact (in the form of two indicators, CC/DALY, identified and tested in Pijoan et al. (2017) and Sierpiński (2017b)). The planner also features a return channel: the queries submitted by travellers to GT Planner are archived and rendered available to local authorities to be used as a source of information on the actual needs of the travelling population. This functionality may be used to improve the operating efficiency of public transport and introduce adjustments to municipal services.

2.2. Heuristic approach

The main goal of the article is to present a heuristic approach that local authorities may find useful. The transport network implemented in GT Planner assumes the form of a directed network graph. Graph G consists of nodes V (referred to as vertices) and arcs E (called edges) (1):

$$G = \langle V, E \rangle \tag{1}$$

The numbering of vertices and edges applied in the graph is based on Open Street Map. Consequently, each edge features two pre-defined vertices $\langle i, j \rangle$ (start point and end point) (2). By that means, a direction for the motion in arc has been defined.

$$V = \{1,2,...,i,...j,...,m\};\ E \subset \{\langle i, j \rangle : i, j \in V\} \tag{2}$$

Each edge has additional a set of parameters forming vector $\boldsymbol{X_E}$ (3), the values of which are used to define optimum routes.

$$X_{E_{ij}}{}^{T} = [x_1, x_2, ...x_s], \text{ where s – number of edge parameters.} \tag{3}$$

The pre-defined edge parameters can be divided into two groups:

- parameters comprising primary data of the transport network (such as the arc length, inclination/grade, road category, speed limit, accessibility for individual means of transport and pedestrians etc.),
- parameters determined while building the graph and in the course of the route planning process, such as time (determined based on the section length and the speed for the given travelling mode), cost (determined for

passenger cars based on the distance and the speed) or the environmental impact (determined by taking several additional parameters into consideration, like unit CC/DALY for specific means of transport, elevation changes, speed, distance etc.).

Public transport has been implemented in the planner as the second graph having selected vertices (public transport stops) shared with the transport network graph (public transport vehicles move in pre-defined routes according to a pre-defined timetable).

A network graph thus described (compared to individual transport) makes it possible to seek optimum solutions for different variants of travelling modes. When the traditional approach is displayed in this respect, even if the current traffic status is taken into account (for which the "`congestion`" parameter is responsible in GT Planner, affecting the time of travel in the given arc in the graph), the route planning options are narrowed down to this point. An additional heuristic approach has been implemented in GT Planner, thus extending the spectrum of the planner's features. Being familiar with the everyday issues tackled when trying to maintain smooth traffic flow in the city, local authorities can additionally affect the results received by travellers seeking optimum routes. It can also indirectly improve reliability of the transport network from the travellers' point of view (Section 3). Two types of heuristics have been applied:

- two independent sets of edge heuristics for pedestrians H_{Ewalk} and individual transport H_{Eveh} (car, bicycle, motorcycle, electric car)
- set of grid heuristic (as a matrix) addressing vehicles.

In both cases, the heuristic approach allows for the parameters of the network graph edges to be altered at the traversing stage by application of the A* algorithm. The foregoing is possible irrespective of the user's choice of the optimisation criterion (time, distance, cost, environmental impact). Sets of section (edge) heuristics are directly associated with individual arcs in the network graph (4) and (5). The only difference in their application is that travelling on foot has been isolated.

$$H_{E_{Walk}} = \{h_{E_{ij}} : E_{ij} \subset G; i, j \in V\} \qquad H_{E_{Veh}} = \{h_{E_{ij}} : E_{ij} \subset G; i, j \in V\} \tag{4) and (5}$$

As for the matrix heuristics, the values of additional heuristic factors have been defined in the area's geographic grid. The foregoing makes it possible to collectively impose the status of parameters on a larger number of arcs in the graph. While building a graph, the area is divided into mini-areas. The spacing of the division grid results from the assumed value of the „`gridEdgeSizeDegrees`" parameter which defines the increment of successive grid lines in the geographic space (longitude and latitude). A decision made in this respect depends on the chosen purpose of using the spatial heuristics in practice. A single heuristic factor is defined for a single square in the division grid. All the street edges that belong to a certain square (middle of an edge within a square) are assigned the heuristic factor of this square. In grid heuristics $\boldsymbol{H_{Grid}}$, the matrix notation is used, where each successive row corresponds to the vertical index and each column represents the horizontal index of the grid (6):

$$H_{Grid} = [h_{ij}]_{m\times n} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n} \\ h_{21} & h_{22} & \dots & h_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & \cdots & h_{mn} \end{bmatrix} \tag{6}$$

where $i= 1, 2,.. m$ – row number; $j= 1, 2,.. n$ – column number.

The grid based heuristic is applied for bicycles and cars/motorcycles/electric vehicles. This means that the combined (grid and edge) heuristic will be the multiplication of both heuristic values.

While traversing the graph, parameters of arcs are multiplied by adequate heuristic factor values. Consequently, the planner user receives the "optimum" route for which true comparisons of time, distance, cost and environmental impact are displayed. At the same time, what this route entails is a change in the target of the optimum solution search (regarding the premises of local authorities resulting from the additional heuristics implemented).

The above heuristic approach may prove useful in solving both the problems frequently tackled (heavy congestion in city centres) and the incidental ones (a collision or a mass event). Moreover, route planning may thus be enriched with an additional dimension, e.g. safe pedestrian routes, routes with appropriate facilities for disabled people etc. Both the aforementioned approaches may be applied by adding the travel planner to the existing Intelligent Transport System (ITS) structure, or to one being currently built. Selected implementation examples have been discussed in the next section of the article.

3. Implementation – a case study for different practical applications

3.1. Route adjustment using edge heuristics

The edge-based approach (see Jaunzems and Lektauers (2013), among others) may be applied in a graph to both pedestrians and vehicles. Planning of pedestrian routes typically addresses the distance criterion. Ensuring high quality routes is, in this context, a priority for municipalities in relation to introducing *walk friendly areas,* as they are commonly referred to. What proves to be equally important in such cases is ensuring that one can safely reach the travel destination. Owing to the approach proposed in the article, one can take this aspect into consideration in route planning. Applying the graph edge numbering based on OSM, each edge is additionally defined in a set of heuristics by two vertices, i.e. the start node and the end node. By integrating the travel planner with a police database of offences against pedestrians (both collisions with pedestrians and different kinds of assault), one can dynamically update the heuristics database in the planner. Figure 1(a) provides a sample visualisation for several edges (different heuristic values for edges have been represented using different colours).

Another potential application of edge heuristics, this time concerning vehicles, may be utilisation of congestion information through dynamic support of traffic distribution in a situation when some roads in the city are congested or dynamic traffic management in cases of emergency, e.g. an accident or a collision. In such cases, by considerably increasing the chosen parameter for the given edge, one can consequently achieve declining interest in this edge of the transport network, the outcome being minimisation of effects of the congestion caused by the road incident and acceleration of the traffic flow improvement.

A problem of completely separate nature is ensuring sufficient quality of travelling. Depending on the quality of transport infrastructure, edge heuristics may be used to create a "transport network quality map", where inferior quality has been represented by a higher parameter value in the set of heuristics.

3.2. Support through area heuristics

The area-based approach (see Pacione (2009), among others) makes it possible to interfere in route planning in a macro scale. A specific parameter value in the grid heuristics matrix is collectively assigned to a set of network graph edges located within a specific area (delimited by geographic coordinates). This approach supports zone-based traffic management which should be characterised by a reduced load due to vehicle traffic. The idea of the grid heuristics application has been illustrated in Figure 1(b). The need for traffic restriction may stem from various premises, including:

- necessity to isolate transit traffic and move it outside the city centre ensuring improved management of the city area land use (Stanley (2014), Stanley and Lucas (2014))
- reduction of negative impact of transport in a zone which requires special measures of environmental protection (by decreasing traffic intensity, emission of harmful substances into the environment and noise), (Chakravarty and Sachdeva (1998), Lewczuk et al. (2013))
- dynamic traffic management in cases when it is necessary to take mass event organisation into consideration (e.g. limiting additional traffic near a stadium).

Owing to implementation of area heuristics, travels made by public transport in specific routes can be more actively promoted in the planner. The shift paradigm sets one of the most important orientations of change observed in the sphere of sustainable development of transport systems (Banister (2008)).

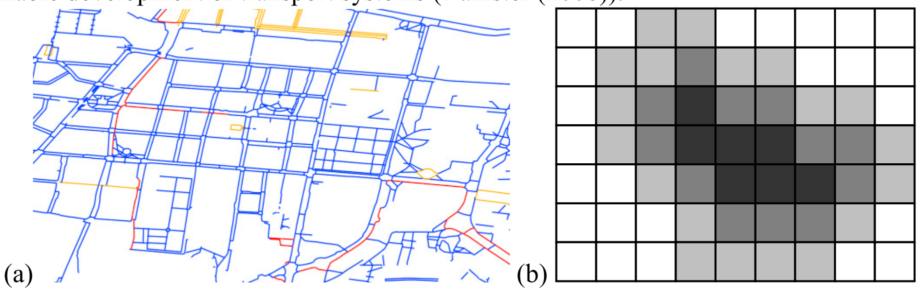


Fig. 1. Visualisation of the idea of (a) edge heuristics – an example of a parameter that describes pedestrian safety; (b) a set of area heuristics indicated parts where traffic limitation is needed (with grid density parameter `gridEdgeSizeDegrees`)

In this respect, the support offered by a planner providing comprehensive information and enabling the aforementioned limitations (by application of the heuristic approach) may be favourable to an additional change in the modal split of traffic to the benefit of public transport (as an incentive) (Meyer (1999)).

4. Experimental context

4.1. Assumptions

The case study addressed in the article covered 19 municipalities forming the Upper Silesian Conurbation (Katowice, Chorzów, Zabrze, Gliwice, Mysłowice, Sosnowiec, Dąbrowa Górnicza, Czeladź, Będzin, Bytom, Ruda Śląska, Świętochłowice, Siemianowice Śląskie, Tychy, Mikołów, Knurów, Tarnowskie Góry, Piekary Śląskie, Jaworzno). This region is characterised by a dense transport network and belongs to the most urbanised areas in Poland. It is additionally very densely populated, which contributes to more than 4.7 million travels being made every day. Currently, about 6 per cent of population declare regular use of travel planners in this area, but this share will grow because new generations are more open to tools of this kind and are also more demanding with regard to transport systems (based on the author's survey results in Sierpiński (2016)). The area in question was assigned an additional set of grid heuristic values. In each city, an area close to the centre was selected, characterised by the highest congestion level (based on information extracted from the Targeo and GoogleMaps portals and individual observations).

The heuristics implemented in the planner allowed for swapping the replies it had typically returned (for travelling through the city centre) with alternative routes. It was supposed to satisfy the following needs:

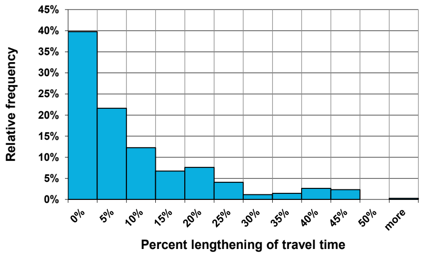
- alleviating the congestion problem at critical locations of the conurbation,
- improving distribution of traffic streams over the transport network,
- improving efficiency of bus transport services (in critical areas),
- ensuring that the travelling population is kept informed about alternative routes for individual transport, at the same time providing travelling time comparisons with public transport.

Next, for purposes of the numerical experiment, a point was chosen in each city where a public transport stop characterised by the largest number of departures a day was situated (Figure 2).

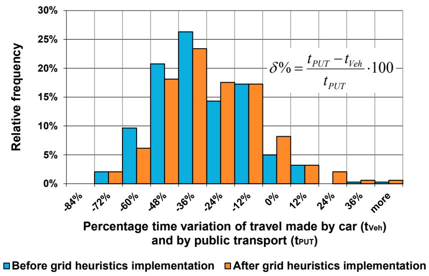
After the heuristics had been implemented, 342 queries about a travel using a passenger car were submitted to GT Planner (for 18 x 19 points, disregarding cases when the start point was the end point at the same time). Before that, with no additional heuristics implemented to mark the critical city areas, two series of queries were submitted for the same number of points and two travelling modes: car and public transport. For purposes of the analyses, morning rush hours were assumed.

4.2. Numerical results

Having compared the results obtained from queries submitted to GT Planner before and after the implementation of grid heuristics, one can examine how the impact on the travelling population may translate into travelling times and the image of public transport. Figure 2(a) illustrates travelling time changes for routes linking the points studied within the area of analysis, as determined for passenger cars. It is evident that the time change for alternative routes exceeding 5% of the original time (before the implementation of heuristics), i.e. compared with the actual fastest route identified in the transport network, only concerned 38.6% of situations. It should also be noted that in 32.4% of the cases, no travelling time change was observed. Further analyses and comparisons with public transport, considered as an alternative towards passenger cars, showed an increase in the number of routes attractive for a travelling person from 8.8% to 14.6%.



(a)



(b)

Fig. 2. Selected results of the numerical studies: (a) comparison of travelling time changes in the transport network after taking additional parameters into consideration (heuristic approach); (b) comparison of results of analyses conducted before and after taking area heuristics into consideration for the given transport network (comparison of travelling time for travels made by a passenger car against public transport).

The foregoing implies that even a slight interference with the parameterisation of the network graph representing the transport network of the given area in the travel planner may bring substantial results, for instance, by making it possible to unburden selected locations from excessive traffic (for travels with the points of origin and destination being outside the overloaded area). At the same time, being forced to make detours (increasing length of the routes for passenger cars) increases the attractiveness of public transport. Figure 2(b) provides a comparison of the percentage time variation of travel made by a passenger car against public transport. In the future, the change illustrated in Figure 2(b) may successfully translate into an increase in the share of travels made by public transport.

5. Conclusions

The studies discussed in the article concentrated on expanding the travel planner features (implementation in a tool known as GT Planner) aimed at providing support for local authorities in solving urban traffic management problems on a daily basis. Travel planners are becoming increasingly popular and the scope of their application is continuously growing. The approach proposed in the paper can be applied when building an urban travel planner (as an alternative to other route planning systems). At the same time, the impact exerted by such an approach on the distribution of traffic streams in a city can only be maximised by ensuring data standardisation and uniformity in pursuit of full implementation of ITS. Any potential doubts pertaining to the application of such a planner may only be legitimate against the vehicles already in use. Most new vehicles are equipped with on-board navigation systems, and where the latter is the case, imposing a standard with a potential to ensure that one can receive data transmitted directly by the municipality may considerably augment the effect of the solution proposed on the travelling population. Moreover, an identical optimum route will be found on all individual devices.

The numerical case discussed in the article, covering the area of 19 municipalities characterised by a dense transport network, has revealed that even a very limited intervention consisting in application of the heuristic approach may considerably affect the choice of travelling routes. It can reduce the congestion issue in a specific area and trigger a change to the modal split of traffic in favour public transport (two important benefits for cities and noticeable support for local authorities).

The large dynamism of changes in the distribution of traffic streams in the transport network throughout a day translates into the need for quick response, especially in critical situations (e.g. congestion caused by a road accident). The methodology addressed in the article makes it possible to dynamically modify parameters of heuristics, thus expanding the scope of its application.

Further research in this field is planned, and it has been devised an attempt to separate cyclists from cars and motorcycles as well as to isolate dedicated heuristics for electric cars. This approach (disaggregated level) will make it possible to further extend the capacity of local authorities to influence the identification of routes by the travel planner. Users of the current version of GT Planner can set a few additional personal attributes (like maximum walking or biking distance). Another extension planned to be implemented is adding specific conditions for disabled people by selecting specific public transport lines with appropriate facilities. It should also be noted that there already are solutions making it possible to apply edge and area heuristics at the same time, which significantly broadens their potential applications.

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Green Travelling

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