Smart Traveller of Future: Method for Personalisation of Routes

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1. Introduction

Nowadays online route planner applications play an increasingly important role due to

- changing expectations of quality and characteristics of mobility demands,
- rising traveller's information requirements and
- opportunity for mapping the passenger transport area in real-time.

A significant proportion of travel is realized by public transportation which is unable to satisfy each personal need and expectation entirely because of its nature. The existing passenger transportation route planner applications mostly operate with consideration only to settings of basic functions (origin/destination, travel date and time). Exemplary applications exist, where the range of settings are significantly wider (e.g. exclusion of transport mode, maximum walking distance, assistance for disabled users, bicycle carrying information).

The main aims of the route planner and route management applications (the latter one supports the navigation, and also gives other non-traffic information e.g. opening hours of the shops or the price of the services) are:

- reduction of both the preparation and travel time and
- minimizing travel expenditures.

These aims can be achieved by the enhancement of personalisation, or provision of value-added information. A significant proportion of existing route planner applications still use only static data[1], meanwhile elements of the passenger transportation system and the operation processes have dynamic properties (e.g. temporary closures, road reconstruction, broken down vehicle). Applications with dynamic and/or personalised multimodal information can be called as Personal Intelligent Travel Assistants (PITA)[2].

Travellers usually select their route or vehicle based on the shortest distance, time or a combination of the two aspects[3]. Personal optimum can be approximated more by improving personalization, and if the settings values are transformed to time base. This value is the minimum of the perceived time, namely the user's satisfaction, which depends on other aspects beside the travel time (e.g. number of transfer)[4].

Detailed network model and an algorithm, which takes physical properties of the routes and user's personal preferences into consideration are required to the evaluation of the routes. The range of managed information may include e.g. the vehicle, the barriers and objects on the route, the processes (walking, waiting and travelling) or the weather. A detailed inner mapping of transportation and other facilities (e.g. underground/railway stations) is mostly missing or less detailed in the current route planner applications, so the time of overcoming of the barriers cannot be determined accurately[5,6]. The personalised information impacts on the perceived expenditure are shown in Figure 1.

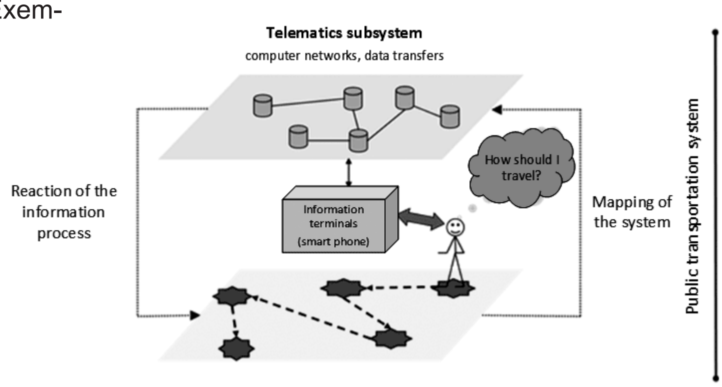

Fig. 1. Structure of the public transportation system – influence of the perceived expenditure[7]

Our research result is a route evaluation algorithm, which evaluates routes originating from exterior route planner applications by the personal settings. The algorithm operates by the network and operational models, the detailed properties of the elements (e.g. length of stairs, low-floor vehicle and number of transfers) and the user preferences. The best route is selected from the determined options. The operation and the accuracy of the algorithm has been proved and illustrated in several example areas (Budapest, Győr and Vienna).

The objective of our further research: development of an own route planner application, which includes both a route finder procedure and this route evaluation algorithm. In this way the two functions are integrated. The essence of this, that the 'search space' can be filtered by the personalised settings, so the effectiveness of the searching is improved, the required time is reduced[9] and better solutions are to be achieved. The passenger transportation space and the network have been mapped as a graph in the operational model. This graph, the theoretical principles of the integrated method, which performs both the route finding and the evaluation, will be presented.

2. Route evaluation algorithm (personalisation)

The developed algorithm takes physical properties of the routes and users' personal preferences into consideration. As a result, the route suggestions are closer to the reality and the user's expectations. Evaluation criteria have been devised for representation of user preferences. We strived for determination of such criteria, which take as much as possible physical characteristics of the traveller and their needs/expectations towards comfortable travel into consideration. The evaluation criteria of personalization have been determined by setting options of the existing route planner applications and our own experiences. The determined aspects concern to the process of walking and waiting, to the vehicle and their properties.

The personal settings can be adjusted in the following way:

- selecting from values (from set of finite element),
- determining the importance of the lack of the setting criteria ('indifferent'/'disturbing'/'disqualifying').

In our case numerical values have been assigned to each setting options taking into account the results of the scientific literature and our own experiences. These values are used as multiplicators during the evaluation. Values of variables regarding personalised settings are shown in Table 1.

The algorithm evaluates the routes in a simplified way. It does not content intelligent route planning method. It weights the properties of the route with the user's preferences, so creating different expenditure indicators according to each user.

3. Network model

Walking and travelling (on vehicle) phases have been distinguished in the developed evaluation algorithm. However the public transportation network is a complex system, it contains a lot of elements and more than one 'layer'. Multimodal travel is realized by several vehicles and transportation modes. The real network requires a model in more details.

Connection and proportion of infrastructure elements in the passenger transportation network are illustrated in Figure 2. The size of ovals is more or less proportionate to the spatial extension of elements, whereas the segment size is proportionate to the size of shared areas.

Settings		Options	Values
Symbol	Name		
x_1	Walking speed [m/s]	Very fast	1,67
		Fast	1,39
		Average	1,11
		Slow	0,83
		Very slow	0,55
x_2	Maximum walking distance [m]	200	200
		400	400
		600	600
		800	800
		1000	1000
x_3	Uphill slope/ downhill slope	Indifferent	1
		Disturbing	1,1
		Disqualifying	1000
x_4	Ramp	Indifferent	1
		Disturbing	1,05
x_5	Stairs	Indifferent	1
		Disturbing	1,15
		Disqualifying	1000
x_6	Escalator	Indifferent	1
		Disturbing	1,1
		Disqualifying	1000
x_7	Elevator	Indifferent	1
		Disturbing	1,14
		Disqualifying	1000
x_8	Pedestrian crossing with traffic light	Indifferent	1
		Disturbing	1,03
x_9	Pedestrian crossing without traffic light	Indifferent	1
		Disturbing	1,05
x_{10}	Intersection without pedestrian crossing	Indifferent	1
		Disturbing	1,06
x_{11}	Lack of sunken shoulder in the intersection	Indifferent	1
		Disturbing	1,02
		Disqualifying	1000

Settings		Options	Values
Symbol	Name		
x_{12}	Lack of step free access to the platform	Indifferent	1
		Disqualifying	1000
x_{13}	Lack of blind guide system (in passenger facilities)	Indifferent	1
		Disturbing	1,01
		Disqualifying	1000
x_{14}	Lack of staff assistance	Indifferent	1
		Disqualifying	1000
x_{15}	Lack of covered waiting place	Indifferent	1
		Disturbing	1,1
		Disqualifying	1000
x_{16}	Lack of information system in the stop	Indifferent	1
		Disturbing	1,08
x_{17}	Lack of comfort equipment in the stop	Indifferent	1
		Disturbing	1,11
x_{18}	Lack of ticket buying opportunity	Indifferent	1
		Disturbing	1,1
		Disqualifying	1000
x_{19}	Lack of step free access to the vehicle	Indifferent	1
		Disturbing	1,05
x_{20}	Lack of air-condition in the vehicle	Indifferent	1
		Disturbing	1,08
x_{21}	Lack of wheelchair accessible vehicles	Indifferent	1
		Disqualifying	1000
x_{22}	Maximum waiting time in the stop for an ideal vehicle [s]	0	0
		5	300
		10	600
		15	900
x_{23}	Exclusion of transportation mode	Bus	1000
		Tram	1000
		Underground	1000
		Trolley	1000
		...	...
x_{24}	Lack of direct journey	Indifferent	1
		Disturbing	1,4
		Disqualifying	1000

Table 1. Indicator of personal preferences and their values

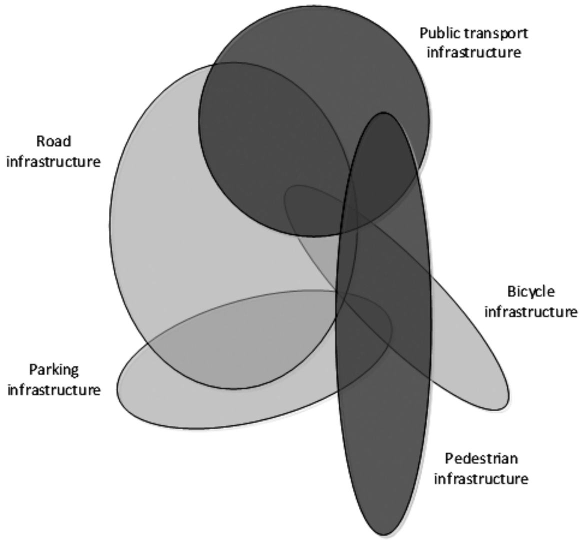

Fig. 2. Connection and proportion of infrastructure elements in passenger transportation network (source: own research)

Three main travel phases are distinguished in the urban public transportation:

1. access walking from the origin point to the first stop,

2. waiting and travelling (possibly with transfer),

3. egress walking from the last stop to the destination.

A complex G = (V;E), bimodal graph has been used to map the public transportation network, where [V] is set of vertices, [E] is set of edges[8]. Vertices correspond to stops or other points (e.g. top of escalator, entrance), edges correspond to walking or vehicle movements between nodes. Edges are undirected [i,j] in the walking network and directed (i,j),(j,i) in the public transportation network (Fig. 3.).

	Vertices	Edges
MACRO (A): surface walking network	▪ origin and destination points ▪ stops ▪ end points of pedestrian crossings ▪ breakpoints	walking paths between edges
MACRO (B): public transportation network	▪ stops	route between two neighbouring stops (edges), which is served by public transportation
MESO (C): walking network of interchanges and intermodal junctions	▪ stops ▪ end points of pedestrian crossings ▪ breakpoints ▪ other points ▪ entrances and exits	walking paths between edges
MICRO (D): walking network of passenger facilities	▪ entrances and exits ▪ breakpoints ▪ other points	walking paths between edges

Table 2. Vertices and edges. Breakpoints: end points of ramp, stairs, slope, escalator, elevator

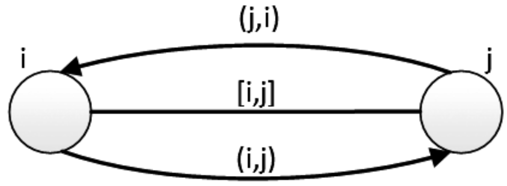

Fig. 3. Symbols of vertices and edges

Several graph levels with different structure have been defined due to the complexity of the real network (it will be extended by involving other transport modes):

- Macro graph (A): surface walking network,

- Macro graph (B): public transportation network,

- Meso graph (C): walking network of interchanges and intermodal centres,

- Micro graph (D): inner walking network of passenger facilities.

The door-to-door planning is essential for a competitive route planner application. In this case the size of the graph is significantly larger, as each source and target point has to be represented as a vertex (e.g. entrance of a house or a shop). Accordingly, the developed graph also contains a surface walking network makro graph, however walking phase can be found both in the meso and the micro graph. The meso and micro graphs are generated by increased resolution. Vertices and edges are shown in Table 2.

- MACRO (A): The surface walking network graph is situated on the same layer as the public transportation network graph. The origin and destination points are set by the user (concrete addresses, POI, etc.). This graph is connected with the public transportation network graph in the stop vertices and with the meso and micro graphs in the common vertices.

- MACRO (B): The vertices of the public transportation network graph are the stops. The model does not take the spatial extension of the stops into consideration. The stops are interpreted as one point (e.g. the stop table).

- MESO (C): Intermodal centre, where several transport modes are connected. Pedestrian underpasses and overpasses are also included here in this model. The meso graph is a more detailed version of the walking graph on a bordered area. Beside the transportation, the secondary functions are also taken into consideration. The passengers access to the services in the so called other points (e.g. ticket offices, ticket automats, information desks, POI)

- MICRO (D): Inner walking network of passenger facilities (railway stations, underground stations, etc). Access and egress points are the entrances and exits of these facilities.

The graphs are connected with the neighbouring graphs on the vertices with the same name. The surface walking network graph is a special one, it is also connected with the public transportation network graph, which is on the same level. The connections are shown in Table 3.

	Micro (D)	Meso (C)	Macro (B)	Macro (A)
Micro (D)		X		
Meso (C)	X		X	X
Macro (B)		X		X
Macro (A)		X	X	

Table 3. Connections between the graphs

The type of graphs and their connections are illustrated in Figure 4.

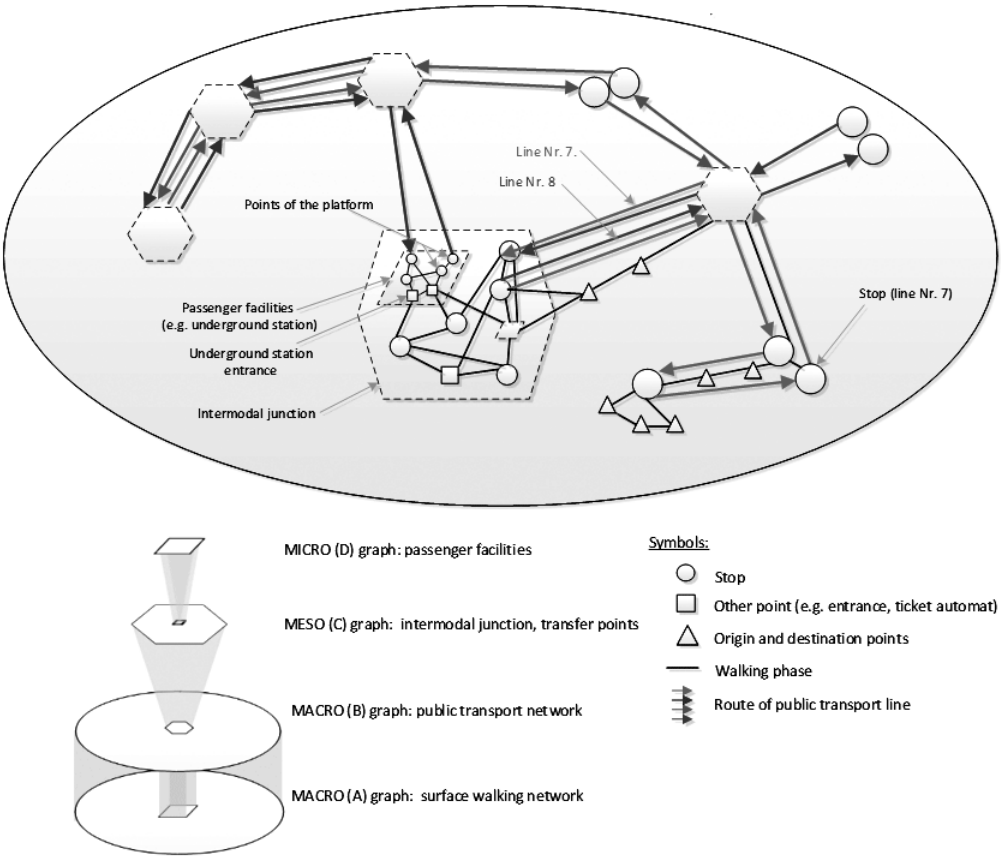

Fig. 4. Type of graphs and connections

4. Theoretical principles of operation of the integrated route planner method

The personalised settings and the network model have been included in the integrated route planner method.

Values are assigned to the edges and vertices of the graphs, which are based on the properties of the elements. These values are mostly static data, but some of them are dynamic ones. The properties are either

- logical variables [YES/NO], or
- concrete values
  - time [s],
  - distance [m],
  - speed [m/s].

An expenditure indicator is calculated for each edge and vertex. This is a complex value, which depends on time, user preferences and route properties. The goal is minimization of this indicator. The expenditure indicator of one route is calculated as the sum of the values of the elements:

c_n^p: expenditure indicator of the vertex, where n the number of the vertex,

c_m^p: expenditure indicator of the edge, where m is the number of the edge;

p indicates the type of the network element (see Table 4.).

Calculation of the expenditure indicator generally is the following (4.1):

$$c=h(t)\cdot x_i, \quad (4.1)$$

where h(t) indicator of temporal dependency of the properties of the elements; calculation is different for each type of the elements,

x_i indicator of personal preferences (i=1..24).

The elements of the network are considered to be ideal (it means e.g. there is air-conditioning in the vehicle, there is roofed waiting area in the stop). The expenditure indicators contain in an ideal case only the concrete times needed for performance of the routes. If the user assesses the lack of the properties (e.g. low-floor) as disturbing factor, the value of the expenditure is modified.

All the travel chains, the elements of the passenger transportation system and the operational processes have dynamic properties, so the managed data has also dynamic nature. The graph has also elements varying in time. Dynamism of the elements is of two kinds:

- it is missing from the network, because of the period of time (e.g. night) or the user's preferences,
- only the attributes are varying (e.g. public transportation edge according to the preferences or the vehicles).

In the following, the dynamism of the network elements for each layer is discussed. The h(t) value of the vertices, that have only one logical attribute, is not associated with complex formula. In other cases the calculation of the expenditure values of the elements of the network are shown in Table 4.

	Element type	Sym-bol	$h(t)$	x_i	Comment
Edges	Walking on flat surface	c^{w1}	$\frac{d_w}{x_1}$	x_1	d_w: walking distance on flat surface $[m]$; x_1: walking speed $[m/s]$
	Slope/Ramp	c^{w2}	$\frac{(e+1)\cdot d_r}{x_1\cdot 0{,}9}$	x_3/x_4	e: steepness [%]; d_r: length of slope/ramp $[m]$
	Stairs	c^{w3}	$\frac{d_s}{x_1\cdot 0{,}8}$	x_5	d_s: length of stairs $[m]$
	Pedestrian crossing with traffic light	c^{w3}	$\frac{d_{zcl}}{x_1}$	x_8, x_{11}	d_{zcl}: length of crossing $[m]$
	Pedestrian crossing without traffic light	c^{w4}	$\frac{d_{zc}}{x_1}$	x_9, x_{11}	d_{zc}: length of crossing $[m]$
	Intersection without pedestrian crossing	c^{w5}	$\frac{d_c}{x_1}$	x_{10}, x_{11}	d_c: length of crossing $[m]$
	Elevator	c^{w6}	$\frac{d_l}{v_l}+t_{vl}$	x_7	d_l: length of the elevator route $[m]$; v_l: elevator speed $[m/s]$; t_{vl}: average waiting time $[s]$
	Escalator	c^{w7}	$\frac{d_e}{v_e}$	x_8	d_e: length of escalator $[m]$; v_e: escalator speed $[m/s]$
	Vehicle route between two neighbouring stops	c^v	t_v	$x_{19}-x_{23}$	t_v: vehicle journey time $[s]$
Vertices	Ends of pedestrian crossing with traffic light	c^{c1}	$t_{c_{zcl}}\cdot a_{s_{zcl}}$	x_8, x_{11}	$t_{c_{zcl}}$: average waiting time $t_{c_{zcl}} = 8\,s;\ a_{s_{zcl}}$: correction factor of the perceived safety $a_{s_{zcl}} = 0{,}85$
	Ends of pedestrian crossing without traffic light	c^{c2}	$t_{c_{zc}}\cdot a_{s_{zc}}$	x_9, x_{11}	$t_{c_{zc}}$: average waiting time $t_{c_{zc}} = 3{,}5\,s;\ a_{s_{zc}}$: correction factor of the perceived safety $a_{s_{zc}} = 0{,}95$
	Ends of intersection without pedestrian crossing	c^{c3}	$t_{c_c}\cdot a_{s_c}$	x_{10}, x_{11}	t_{c_c}: average waiting time $t_{c_c} = 2\,s;\ a_{s_c}$: correction factor of the perceived safety $a_{s_c} = 1{,}05$
	Stop	c^s	t_{wait}	$x_{10}-x_{15}$	

Table 4. Type of the network elements; calculation method of the expenditure values

x_2 and x_24 user preferences are considered after the route finding procedure.

The expenditure indicator of the stop vertex depends on the waiting time, properties of the stop and user's preferences. The logical attributes of the stops are the following:

- roofed waiting place,
- information terminal,
- comfort equipment (furniture),
- blind guide system,
- staff assistance,
- ticket purchase opportunity.

The waiting time is the elapsed time from step to the platform until vehicle arrives. The algorithm runs in several procedures simultaneously, if the user is willing to wait longer time for an ideal vehicle. The algorithm 'foresees' within the tolerable waiting time limit and examines the properties of the arriving vehicles, calculating an expenditure indicator for each one.

Logical attributes belong also to the vehicle:

- air-conditioning,
- low-floor,
- wheelchair accessibility,
- type of vehicle (e.g. tram, bus).

The expenditure indicator of the public transportation edge is calculated by the journey time between two vertices, the vehicle properties and user's preferences. The relationship between a stop vertex and a public transportation edge is presented by an example in Figure 5.

Operation of the method (Fig. 6.):

a. Input origin, destination points and travel date and time.

b. Input the levels of the personal settings. Three setting levels have been determined:

- Without setting (2): routes are evaluated by default values.
- Group setting (3): one of the predefined typical passenger groups (motivations) can be selected; these groups are the following: student, worker, pensioner, tourist and disabled person. Default values were determined based on statistical data to each group.

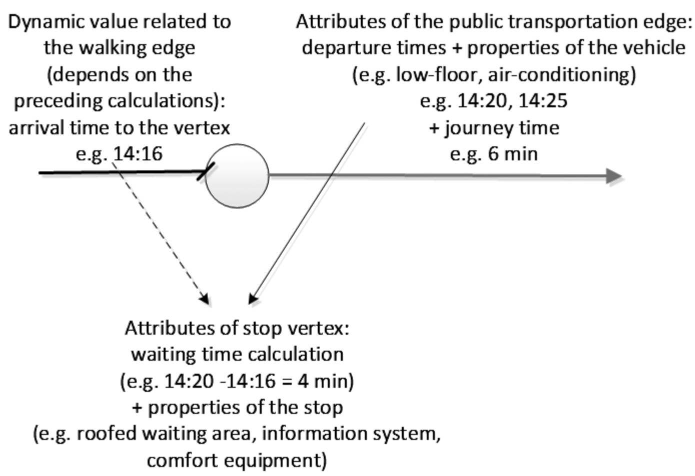

Fig. 5. Relationship between stop vertex and public transportation edge

- Every detail (4): each setting is adjusted by the user.

c. Pre-evaluation of the basic network based on user's preferences and the attributes of the edges and vertices.

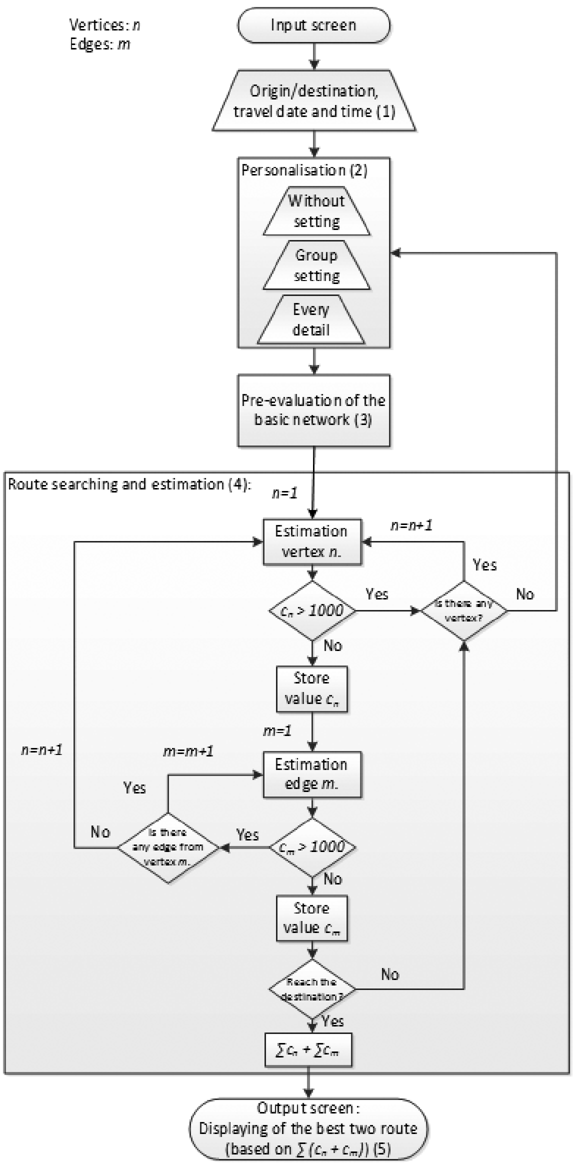

Fig. 6. Simplified operational flowchart of the integrated route planner method

d. After the evaluation of the basic network, the method searches routes between the origin and destination points.

- Each edge and vertex is evaluated one by one.

- If there are several edges from a vertex, each direction is examined.

- If an edge with high value (e.g.: value over 1000 of a walking or a public transportation edge, because of disqualification) is reached during the steps, returning to the former vertex, and searching further from that point.

- After each "edge step" examining if it is the destination point. If the destination point was reached, the former values of the expenditure indicator are stored, in order to determine the expenditure indicator of the entire route.

- The method is being repeated, as long as there are some more unexamined routes.

e. The details of the best two routes are displayed.

5. Demonstration of accuracy of the route evaluation algorithm

The accurate operation of our evaluation algorithm has been proven in three example areas (Budapest, Győr, Vienna). The routes are determined by foreign route planners and then the detailed attributes (e.g. length of stairs, length of slopes, steepness) have been added to these routes. The properties of the routes have been revealed by site visits. The results of our algorithm have been compared with the results of the existing route planner applications.

Such attributes have been examined which are available in most of the applications. The following options can generally be found in the existing applications:

- exclusion of transportation modes,

- preference of step free journey and

- selection by qualification of the entire route (the quickest route, routes with fewest changes, routes with less walking).

We have chosen an example area, where all kind of hindrances are available and the created routes are various both in lines and in vehicle types. We have used the default preferences from section 2.

As a result of the analysis the weaknesses of the existing applications have been revealed, such as

- lack of description (mapping) of internal areas (e.g. possible walking movements within the university),

- ignoring walking time in the indoor facilities (e.g. underground, railway station) and escalator time, and

- using different walking speeds for calculating walking time.

The accuracy of our algorithm was proved by the time results, which are more realistic and in the majority of cases were the lowest result, despite the inclusion of extra time elements (e.g. loss of time by the pedestrian crossing, deceleration because of an uphill slope). In some cases the longer travel time calculated by our algorithm can be considered as better one, because it is more realistic value thanks to the detailed mapping.

The most remarkable differences in results are to be noticed in Budapest. Accordingly this example area is discussed in details. Public travel options between Budapest University of Technology and Economics, Building "St" and Main Railway Station/Keleti pályaudvar have been analysed based on data from Autumn 2013. The results of our algorithm were compared to the results of three Hungarian applications (BKV, utvonalterv.hu, BKK-Google Maps). The routes created by the following personalised settings have been compared:

- the quickest route,
- routes with fewest changes,
- routes with less walking distance (the maximum walking distance was 400 meter),
- bus excluded routes,
- step free journey.

Table 5 summarizes the most relevant data (e.g. total travel time, used lines and their boarding stops) of the routes by applications (column header) and by settings (row header).

		A	B	C	D
		Algorithm	**bkv.utvonalterv.hu**	**maps.google.hu**	**utvonalterv.hu**
1.	**The quickest route**	**21 min** Tram 6 (Petőfi híd) + bus 7E (Blaha Lujza tér)	**28 min** Bus 7 (Szent Gellért tér)	**23 min** Bus 233E (Szent Gellért tér)	**23 min** Tram 6 (Petőfi híd) + underground M2 (Blaha Lujza tér)
2.	**Routes with fewest changes**	**27 min** Bus 133E (Szent Gellért tér)	**28 min** Bus 7 (Szent Gellért tér)	**23 min** Bus 233E (Szent Gellért tér)	**31 min** Bus 7 (Szent Gellért tér)
3.	**Routes with less walking**	**21 min** Tram 6 (Petőfi híd) + bus 7E (Blaha Lujza tér)	**28 min** Bus 133E (Szent Gellért tér)	**25 min** Tram 6 (Petőfi híd) + underground M2 (Blaha Lujza tér)	**25 min** Tram 6 (Petőfi híd) + underground M2 (Blaha Lujza tér)
4.	**Bus excluded routes**	**31 min** Tram 47 (Gárdonyi tér) + underground M2 (Astoria)	**31 min** Tram 6 (Petőfi híd) + underground M2 (Blaha Lujza tér)	**25 min** Tram 6 (Petőfi híd) + underground M2 (Blaha Lujza tér)	No such option
5.	**Step free journey**	**48 min** Bus 133E (Szent Gellért tér)	**44 min** Bus 7 (Szent Gellért tér)	No such option	No such option

Table 5. Results of queries per applications

The algorithm demonstrated that travel on the surface is more favourable and requires less time on a one or two stop long trip, than the parallel underground travel. This can be also observed in the example area, where several bus lines and an underground line run in parallel (Astoria – Blaha Lujza square – Main Railway Station/Keleti pályaudvar). The algorithm suggests travelling by underground only in the case that travelling by bus is set as "disqualifying". The comparison also indicated that results (routes, times) of our algorithm are much closer to the reality, than the results of the existing applications.

6. Conclusion

The developed algorithm evaluates travel chains, covering walking and public transportation routes by several aspects. It takes physical properties of the routes (detailed properties of walking paths, passenger facilities and vehicles) and users' personal preferences into consideration. In the development, focus has been placed particularly on the walking phase because walking plays an important linking role in the travel chains. As a result, the route suggestions of the algorithm are much more detailed and closer to the reality than the results of the existing applications.

The presented multilevel, graph-based network model and route evaluation method are the basis of the integrated route planner application. Both the walking and public transportation processes are covered by the four layers of the network. The network model will be extended by further graph levels (e.g. bicycle and individual car transportation macro graphs). The expenditure value of the vertices and edges will be improved by additional properties. Further development possibility is using POI data. Activity based route planning can be realised with it, considering not only the travel expenditures, but the activity costs as well.

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