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Optimization of multimodal travel chains

PhD thesis overview

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1 Relevance of the research topic

The growing mobility demands define new and innovative directions of transportation research, as they are both the preconditions and consequences of economic development. It is resulted in increased challenge towards passenger transport systems. The journey times of passengers should be decreased, while the quality of transportation services should be increased and the whole transportation related processes should be optimized.

In order to reach these aims, an integrated approach is to follow when carrying on transportation research. The fast development of Intelligent Transportation Systems (ITS) enables intervention in processes of transport, which contributes to the enhancement of service quality. To assist that strategic developments are realized in those areas, where they can provide most efficient functioning, a comprehensive evaluation of transportation information services has to be performed. Through the results of the evaluation the user preferences can be derived. In order to realize the requested features, optimization methods can provide information to passengers about how to plan and realize their journeys in the most personalized way. With the development of optimization methods the service quality can be significantly enhanced, especially in urban areas, where the increasing population and therefore the extensive use of transportation means tends to generate problems.

Having up-to-date ITS systems and a high amount of data does not implies automatically provide a better transportation information service. In order to use ITS systems and available data efficiently, results from more research fields have to be integrated (e.g. information technology, transportation infrastructure, passenger behavior, optimization methods. Considering this paradigm shift, smart systems are to be created, which provide comprehensive solutions through different aspects of transportation. A complex smart system includes personalization and adaptivity, which corresponds to the dynamically changing mobility demands of the users.

The elaborated research contributes to the field of mobility solutions with models, optimization strategies and systems of advanced information services based. As a result the travel information needs are revealed, which help to determine typical travel behavior and personalize activity chains. With the creation of personalized activity chains an optimum regarding predefined aspects can be obtained (e.g. in terms of travel time). High quality transport services (especially considering travel time and information provision features) can be provided through planning and realization of smart mobility solutions.

2 Research objectives

Technological development and changing mobility requirements, which are caused by societal changes, set new scientific challenges towards the researchers. Since the capacity of transport systems is limited, the increase of passenger transport performance is primarily obtainable by the enhancement of the modal share of public transportation and the introduction of new (telematics based) transportation services, which are more efficient in term of serving personalized needs. Travelers tend to choose public transport, if they experience high transport quality (e.g. clean and modern vehicles, punctuality, guaranteed transfers and personalized route-planning service). To reach this goal measures are to be taken, as soft measures (e.g. computer aided route planning, location-based information services during the journey) or hard measures. These measures are often called management or infrastructure type measures.

The aim of this research was to provide solutions in the field of soft measures, where the focus was set on the improvement of the most relevant transport service features, such as information and time. This can be obtained by the application of evaluation results of information provision services (e.g. online journey planners). The optimization is performed by developing optimization methods regarding activities and trips of travelers, where utility function is the total travel time. The order of the activities for each traveler is set with consideration to the constraints, the maximum number of activities, and the least travel time.

The aims correspond to management type strategic objectives, especially to the concept of NKS, which prefers the development of integrated planning of travel chains and the usage of cutting edge ITS solutions. Based on the discussed research objectives, the following research questions were defined:

- What kind of information services are needed by the users before and during traveling? How to provide this information to the travelers? How much multimodal journey planners correspond to the information needs and expectations of users?
- What differences can be revealed among user groups regarding journey planning aspects? How can be user groups created? What are the most common and different needs and expectations of specific user groups? How can new survey methods be applied for the evaluation of multimodal journey planners?
- How can users optimize their daily activity chains regarding travel time? How flexible are activities within an activity chain? How can the optimization algorithm provide services almost in real-time? How can the benefits of the optimization algorithm be measured?
- What parameters are to be applied during the optimization of activity chains? How can the utility function be defined? How can be the optimization algorithm realized in a real system? What are the main development directions of information systems and services?

In order to answer the research questions in integrated and systematic approach, the following structure was created (Fig 1). The numbers in the figure represent chapters of the dissertation.

- My aim was to elaborate a comprehensive method for the evaluation of multimodal journey planners, to compare and evaluate several relevant journey planners.
- In order to obtain a detailed insight into preferences of user groups, I aimed to analyze differences and similarities of user groups regarding the evaluation aspects of multimodal journey planners. As well as to create such new user groups, whose members evaluate aspects in the most similar way. I also aimed to investigate the applicability of new survey methods to calculate weights regarding the user groups and main aspects.
- My goal was to develop such an optimization method for daily activity chains, which can reorganize activities and thus total travel times are reduced. With the development of the optimization algorithm I aimed to provide a service, which considers several constraints and optimization parameters at the same time. I also intended to analyze the benefits of the optimization of activity chains.
- I aimed to define and classify parameters of activity chains. I wanted to identify the utility function of activity chain optimization and to model such a system architecture, which includes the operational model of an application to be realized. Finally, I outlined the future development directions of information services.

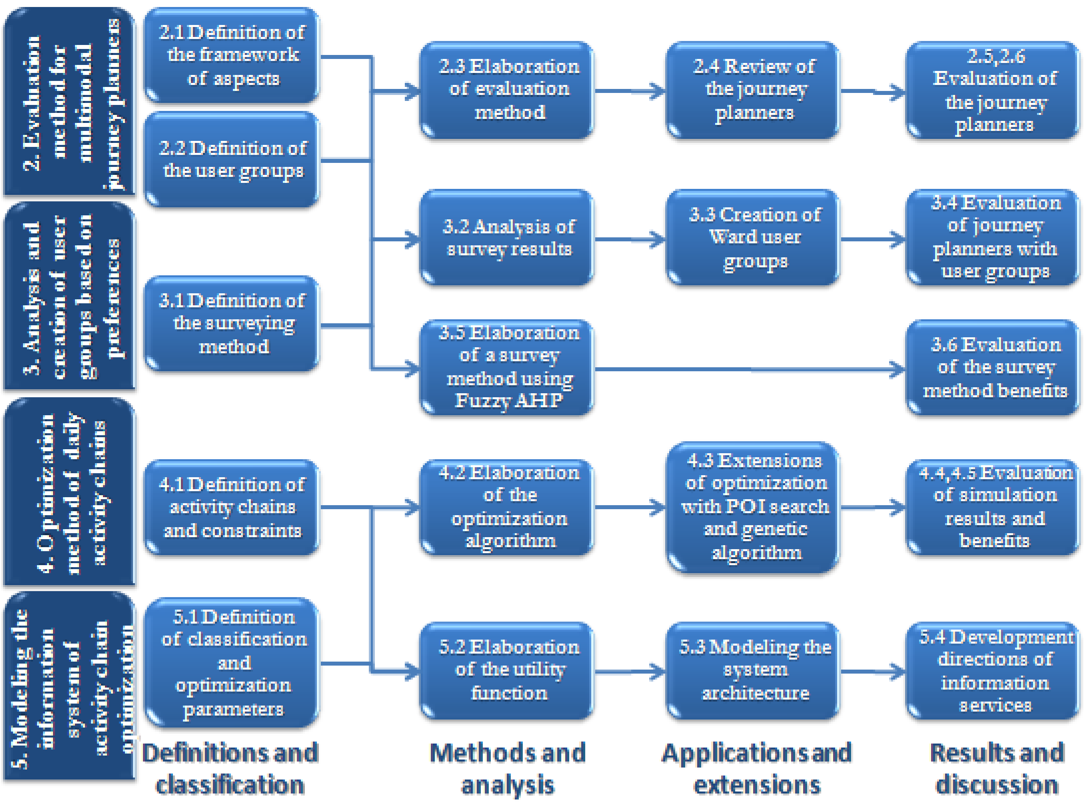

Fig 1 Structure of the dissertation

3 Applied methods

The travel information aspects were collected and assessed from the user perspective. The evaluation of multimodal journey planners was performed in two main steps. For the scoring step the Multi-Criteria Analysis (MCA) was adapted and implemented, because it produces clear and well-comparable results. The weighting, as a second step, was introduced in order to take into consideration different preferences of the user groups.

The key of collecting reliable data was the elaboration of a survey based on the aspects. This survey was necessary to calculate realistic weights for the user groups. Having the results of the survey a statistical analysis was performed. Standard statistical methods were applied, as the Bartlett test, which examines whether the user groups are similar to each other or not. In cases the Bartlett test was refused, a two-sample t-test was performed in order to reveal, which groups differ from each other concerning means and variances. Significant differences among user groups assign development directions to the operators.

The Ward method was used to create new user groups. The user groups have higher similarity considering the answers of their members regarding aspects of journey planners. Thus it is easier to develop new targeted features for user groups with similar answers. This analysis provides as an output a number of clusters or groups, in which the users are classified.

The Analytic Hierarchy Process (AHP) is an effective tool for setting priorities among different alternatives (e.g. journey planners). Using AHP I introduced a new survey method, which provides consistent results. With the Fuzzy AHP method I defined weights of aspects regarding journey planners in a consistent way.

In order to optimize the organization of daily activity chains a novel method has been elaborated, in which flexible demand points are introduced. The main idea was that some activities are not necessarily fixed temporally and spatially, therefore they can be realized in different times or locations. A basic scenario is generated for fix demand points using TSP-TW (Traveling Salesman Problem-Time Window) as a reference for further comparisons. The output of the basic scenario is an order of demand points and the total travel time. In the flexible scenario the optimization was implemented for the TSP-TW problem, where flexible demand points are spatially and temporally replaced.

The Genetic Algorithm (GA) was applied to compute all possible combinations of flexible demand points. The calculation was implemented in Matlab simulation tool. The alternative demand points were searched by Overpass API, if there are flexible demand points. The travel time matrix is calculated using Google API queries between demand points for all possible activity chains.

4 New scientific results

4.1 Thesis 1. Evaluation method development for multimodal journey planners

In order to evaluate multimodal journey planners framework of aspects was defined. Based on the aspects qualitative evaluation method was elaborated to compare and rank the journey planners. With the creation of user groups I have taken into account requirements of the users. The method was applied to international and Hungarian journey planners.

The evaluation and comparison of multimodal journey planners was previously performed only in a descriptive (not in a quantitative) way. The aim was to provide a quantitative evaluation method, to that a framework of aspects was defined. The most important aspects from the passenger point of view are route-planning services, booking and payment, handled data, comfort service information, supplementary information.

The method consists of two main steps (Fig 2). First the journey planners were evaluated based on the elaborated framework of aspects, which resulted in the general evaluation number (scoring). For the scoring step the Multi-Criteria Analysis (MCA) was adapted, because it produces clear and well-comparable results. Since the appreciation of the information service depends significantly on the personal characteristics of the passengers, user groups were created from the passengers by age, mobility features and motion abilities. As a second step taking preferences of the user groups into account the average evaluation number was calculated (weighting). Finally the multimodal journey planners were compared to each other.

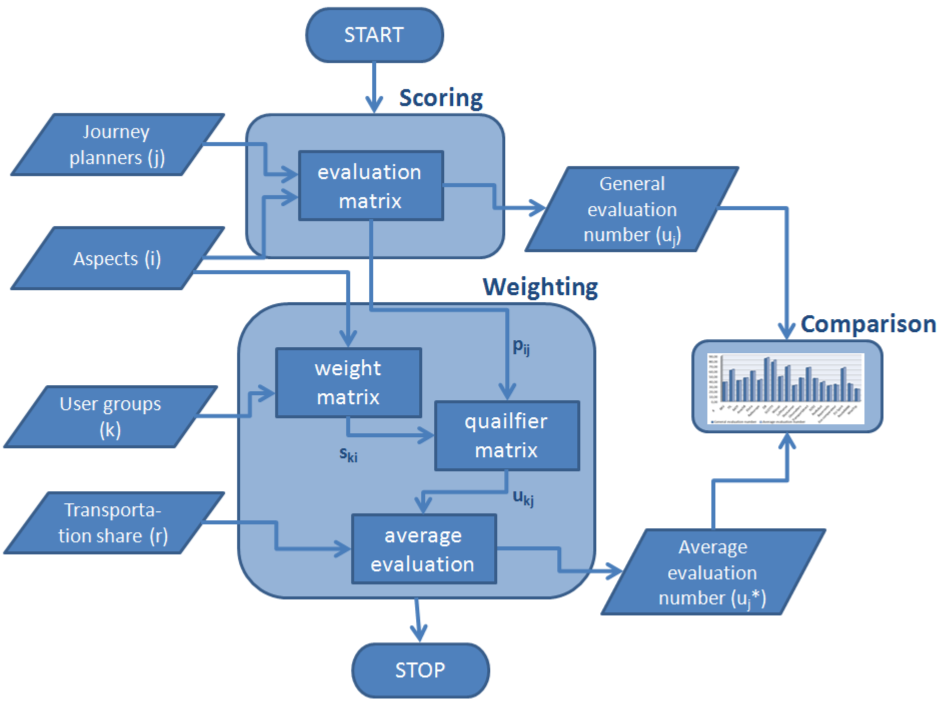

Fig 2 Process of the evaluation of multimodal journey planners

Popular journey planners were selected, whose innovative features were highlighted. The developments mainly focus on the actuality of handled data and supplementary information, while no real novel solutions were available concerning booking and payment. The elaborated method helps the operators to rate and compare information services from the viewpoint of the passengers. The introduction of user groups did slightly affect the evaluation numbers, but it highlighted some aspects (e.g. route planning, handled data), which are more important for certain user groups.

After the survey of international journey planners, the Hungarian online travel information services were analyzed, primarily bus transport operators (Volán). According to the evaluation it can be stated that Volánbusz offers the highest level of information services, Kisalföld Volán, Vértes Volán and Kunság Volán also have outstanding features, as route planning functions and handling of dynamic data. Finally the most important attributes of an ideal journey planner was defined based on top features of current systems and development trends.

Related publications: [1], [2], [3], [4], [12], [15]

4.2 Thesis 2. Analysis and creation of user groups based on preferences and evaluation aspects

In order to improve the accuracy of the evaluation, an analysis method regarding user group preferences was elaborated. A survey was performed to define the importance of the aspects. Based on similarities of the answers of users, new user groups were created with application of Ward method. With these enhancements, the evaluation method provides more specific results for decision makers about directions of development based on real needs of the users. To make the survey more consistent, a new survey method was applied by customization of the AHP and the Fuzzy AHP method.

In order to describe the passenger needs in quantitative way, user groups were defined (Fig 3). The importance of the aspects was defined by a survey. Having the results statistical analysis was performed. The most important main aspects are route planning (33%) and handled data (31%), while booking and payment (16%), comfort service information (10%), supplementary information (10%) have lower relevance. The ranking of multimodal journey planners was updated with the real user preference values. Although, big differences were expected among the user groups, no significant differences could be detected concerning the main aspects.

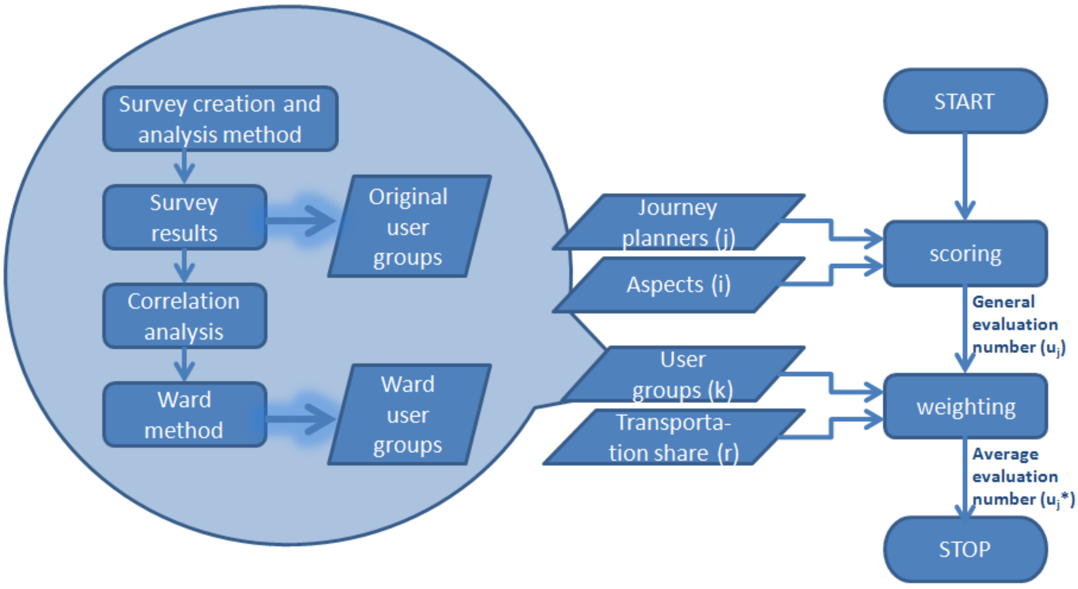

Fig 3 Analysis of requirements of user groups and definition of new user groups

The correspondences between single aspects were investigated using correlation analysis. In case of high correlations latent user needs can be discovered. Considering connections among more aspects I applied Ward clustering method and created such new user groups, whose answers are similar within the group, and different among the groups. The clustering algorithm was implemented in MatLab. As a result 5 new user groups were created with the following highlighted preferences: searching for alternative routes, need for visualization on the map, interested in dynamic information, rejecting mobile payment, not interested in WiFi. With the application of the further elaborated method the results of the evaluation are based on real user needs, thus they support the journey planner operators and decision makers in the definition of possible directions of development.

The Fuzzy AHP based survey method was elaborated for weight calculation regarding main aspects. The weights are different for the user groups. The results of AHP are the pairwise relative evaluations of the main aspects. With the AHP method the consistency of the pairwise comparison values can be checked, which reduces the possibility of contradictory results. I defined the original and Fuzzy AHP weights, which were compared. As a result it could be obtained that using the Fuzzy AHP method the survey can be simplified. The original survey method can be further developed by the pairwise relative questions.

Related publications: [7], [9], [10], [14], [16], [18]

4.3 Thesis 3. Optimization method development of daily activity chains

A method with flexible demand points was elaborated to optimize the set of activities of travelers regarding travel time and the number of postponed activities. To reduce optimization processing time, a genetic algorithm was applied. The algorithm was tested on a real transportation network in Budapest using GTFS timetable data.

The initial assumption was that some activities performed by the users during a day are not necessarily fixed temporally and spatially, therefore they can be carried out in different times or locations The order of flexible demand points can be also changed. Before and after an activity a travel phase is realized by different transportation modes. By introducing flexible demand points, it is possible to find all combinations and to choose the optimal activity chain by implementing a solution for the TSP-TW problem (Fig 4). When establishing activity chains, it is assumed that the user already is aware of the activities of a certain day. With the introduction of flexible demand points the number of possible sets of activity chains grows exponentially, and the calculation needs more computational resources. Therefore a genetic algorithm was applied to reduce computation time by 90% enabling the application of many flexible demand points. The extension with POI search algorithm was also introduced.

The developed algorithm takes into consideration many constraints, as opening times of the shops or maximum waiting times before the planned arrival. During the implementation 3 different modes of transportation were determined: car, public transport and public transport with car-sharing opportunity. The optimization criterion was the minimum travel time, as the most important parameter. Also other parameters can be taken into account (e.g. comfort features), but these are generally hard to be quantified.

As an output of the optimization Pareto optimal results are presented, where the parameters are the number of postponed activities and the total travel times. The simulation of activity chain optimizations was performed on arbitrarily chosen test networks in Budapest using Matlab. In case of car usage about 8%, with public transport about 10% and with car-sharing opportunity about 14% decrease of the total travel time was realized. The elaborated method can be build in an advanced information service.

Related publications: [6], [8], [11], [13]

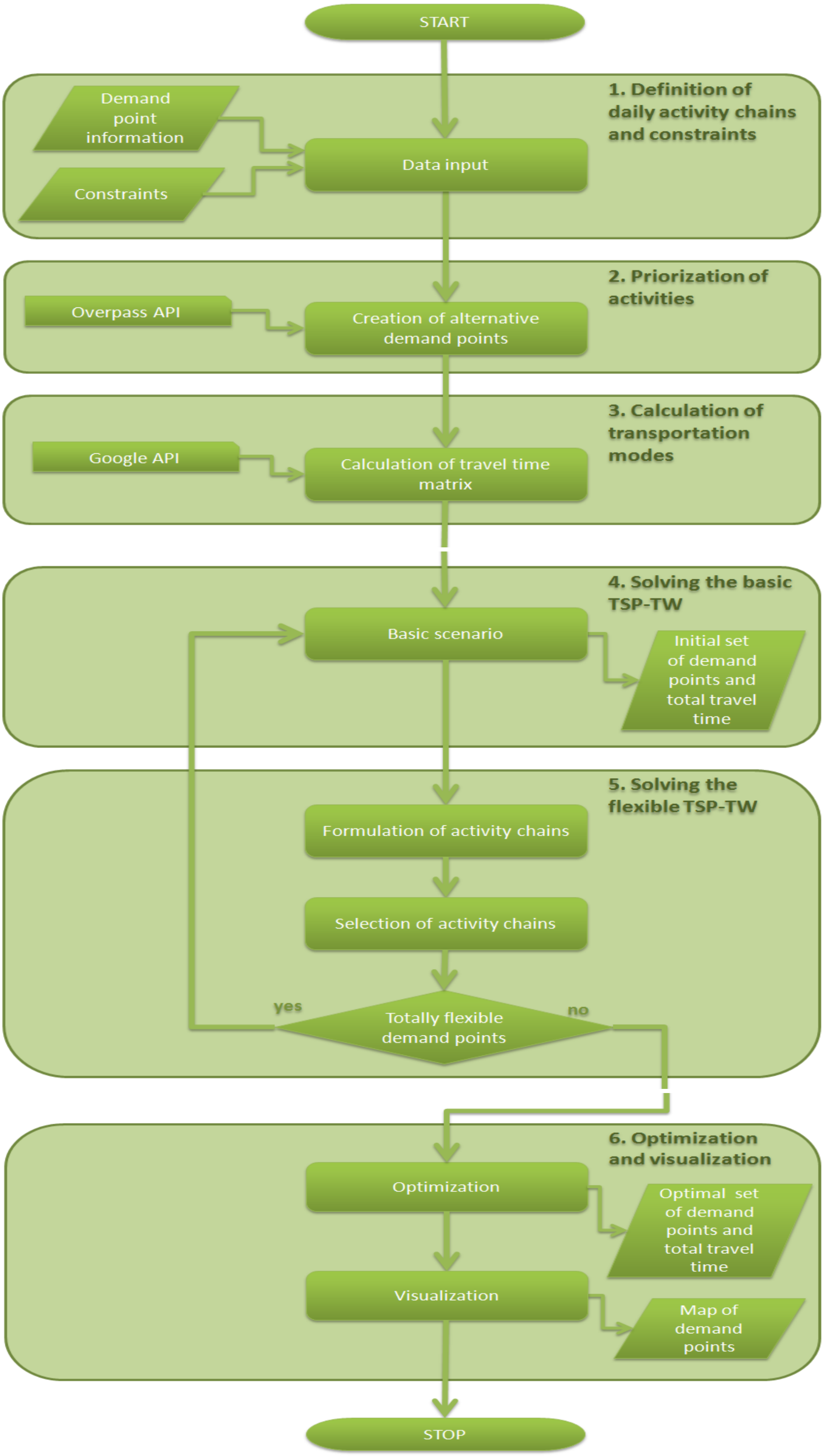

Fig 4 Daily activity optimization method

4.4 Thesis 4. Modeling the information system of activity chain optimization

I have modeled the information system containing the activity chain optimization method. The most important optimization parameters were identified, described and classified. The utility function was determined combining the optimization parameters and the aggregated weights, in this way the individual user preferences have been mapped. The information system architecture was modeled to map information about the environment and connections of the optimization algorithm. I have summarized future development directions of information services based on activity chain optimization.

In order to model the complex requirements of users regarding an urban activity chain, the possible parameters were identified. They were grouped into two main types: classification parameters (to create user groups) and optimization parameters (to calculate utilities regarding the optimization algorithm). In case of optimization parameters further grouping was performed, I have introduced general and comfort parameters. The possible values and data sources of the parameters were also identified. In case of comfort optimization parameters, the possible values were defined in such a way that low values represent ideal conditions and high values represent not preferred conditions.

Utility functions have been introduced in order to take into account the optimization parameters and to measure the goodness of activity chains. The utility functions were created from optimization parameters and weights. Weights related to comfort optimization parameters have been aggregated to decrease the number of required settings by the users.

I have modeled the information system architecture, which contains the optimization algorithm and its environment (Fig 5). The system architecture consists of the user interface, the server applications and external databases. The optimization parameters are provided through the external databases, where data sources and update frequencies of information services were identified. The model is the prerequisite and guideline for the implementation of the information system.

I have identified main development directions of information services based on comprehensive analysis, which are the following: data collection (reliable real-time data and crowd sourcing data), data storage (standardization and functional integration), value-added services (personal preferences, multimodality, location based services and premium information).

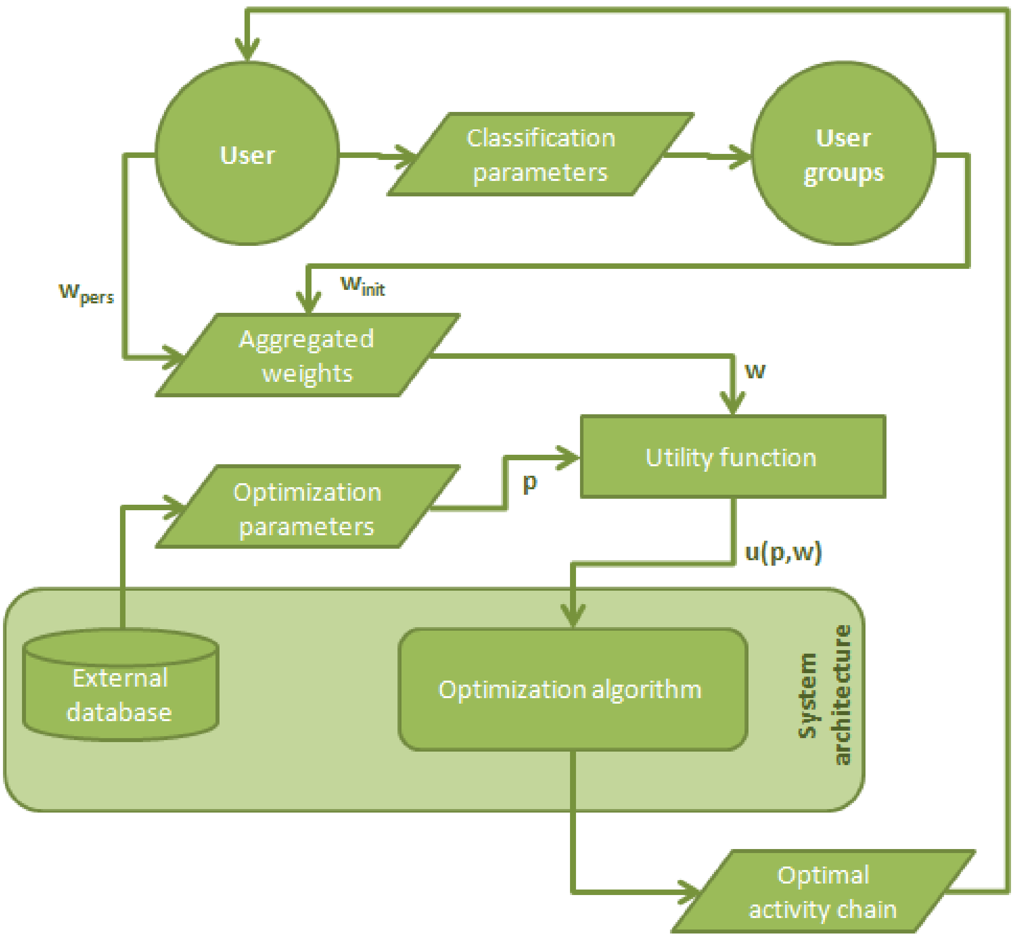

Fig 5 Operational model of the information system of the activity chain optimization

Related publications: [5], [17]

5 Application of the results

The results of the research are applicable both in the scientific and the practical field. The elaborated methods have been already included in some teaching materials at the university (e.g. Passenger transport).

The idea of the elaboration method for multimodal journey planners originates from an initiative of the European Commission in 2011, when the best multimodal journey planner was sought, but no quantitative calculation method was behind it. In case of a new call in the future, the journey planners can be evaluated and compared based on the provided method. However the continuous review of the elaborated method has to be realized, as the technological background and user requirements may change. A modified version of the method was used in a national project concerning the development of an online personalized passenger information system.

The decision makers and operators of journey planners benefit from the detailed analysis of user group requirements and its interdependences, as they can directly apply the method and its results to identify development strategies and concrete task, or to define the order of introducing new features of journey planners.

The optimization of daily activity chains results in a reduction of total travel time, which is a direct benefit for the users. This is not only beneficial for the traveler, but also considering the societal-economic aspects, as resource saving. Based on the method an application is to be developed, which can be used in everyday life with a mobile phone.

6 Future work

A research can never be finished, it can be only discontinued at a given stage, therefore I present a plan, how to proceed with the elaboration of new scientific methods.

In the case of evaluation method for multimodal journey planners an important research question is how to receive much information from and about the passengers with a few simple questions. This helps the effectiveness of the survey and raises the willingness of filling in the questions. Furthermore the survey will be conducted in many European countries, so that different user group preferences across Europe could be compared.

Considering the optimization of activity chains the theoretical model and first simulation results are promising, therefore they have to be followed by the fine-tuning using big amount of real passenger behaviour data. In the model it was assumed that the passenger's start and end point is the same. In the most cases it is valid, but the destination could be different, which requires the application of another type of TSP method. The travel times are fixed for all routes. Considering the actual traffic situation, the travel times will be changed and predicted.

Introducing predictive TSP the latent demands of the passengers will be served. These latent demands will be derived from the requested demands of passengers with similar characteristics.

To enhance the dynamics of the model, changes in the activity plan during the day will be taken into consideration, as the appearance of a new demand (respectively a new demand point) or the occurrence of a delay at a demand point. Thus the daily activity plan has to be re-planned and recalculated according to the new situation. The required information about daily activities are collected automatically from calendar services. Regarding daily activity planning some other optimization aspects may play an important role, and the cost function could be interpreted as a more general function, which takes into account travel times, travel costs, comfort, energy efficiency, environmental impact and personal preferences.

7 Publications

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