In-Vehicle Application for Multimodal Route Planning and Analysis

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Abstract—People are constantly inventing new ways of reducing traffic in big cities and encouraging the use of public transport. The idea of park-and-ride facilities is to increase the usage of public transport. However, it imposes additional problems for a driver to plan her trip and does not state clear benefits of using the approach. We developed a seamless solution to guide a user to public transport transfer spots by combining web services, vehicle data and integration with an in-car infotainment system. Our solution offers optimal park-and-ride transfer points, instantly shows the benefits of taking a transfer to means of public transport and guides the driver throughout the whole trip, in car and in the public transport. We tested the system in Helsinki Capital Area and developed a tool for analysing multi-modal transportation scenarios. By customising the system using various optimisation parameters such as CO₂ emissions or trip time, we show what savings can be achieved in different scenarios.

Keywords—Multimodal transportation, multimodal user interface, SmartDeviceLink, car platforms, route planning, In-Vehicle Infotainment, car apps, public transport, private transport

I. INTRODUCTION

Over the years, multiple major cities such as London, Berlin and Helsinki have developed sophisticated public transport systems. They involve not only buses, but also trams, metros, trains and ferries used by thousands of citizens to travel inside cities. Public transportation systems are claimed to be generally cheaper, faster and significantly greener means of commutation than utilisation of personal vehicles. However, growing numbers of cars in large cities remain concerning and therefore various measures are being taken to encourage people to switch to public transport. Some of the measures include taxing parking areas, completely banning cars from city centres or restricting parking during the working hours. Whereas authorities claim they are increasing utilisation rates of public transport and keep raising awareness of the society about the advantages of public transport, many people still use private cars for their daily activities.

One of the main reasons for the mentioned choice is that people living on the outskirts of cities are provided with inconvenient or no means of public transportation, even though the central parts of cities contain convenient and reliable public transport infrastructures. In such a case, using a car at a preferred moment is much more comfortable than, for example, walking long distances to a nearest suitable bus stop and/or waiting a certain period for a bus to reach desired destination points.

Another problem is a lack of real-time information about the public transport and its time tables. The problem was partially solved by using cloud-based route planners that can run on consumer smart-phone devices. However, car drivers are not regular public transport users and thus are simply not aware of public transportation options. Therefore, bringing relevant information into personal vehicles in a convenient way may promote utilisation of public transportation alternatives.

Multimodal transportation [1] is seen as one of the solutions to encourage people to use the public transport. The main idea is to complete a part of a trip by car, park in one of the designated park-and-ride [2] parking lots, and continue the trip by using a certain means of public transport. In this way, people living in areas not covered by convenient public transport systems may complete the mentioned "last mile" by utilising their personal vehicles to a point where public transportation system is more dense and then continue their trips by the public transport.

However, merely providing a parking lot infrastructure does not enable drivers to effectively switch to suitable means of public transport that would bring them to their destinations with minimal cost and shortest travel time. Therefore, the infrastructure has to be supplemented with the mentioned real-time information system. Unfortunately, current multimodal trip search mechanisms are based on static, pre-defined information about car’s characteristics and expected transport schedules. However, the overall transportation system depends on multiple factors, may experience traffic jams, accidents and other planned or unexpected events. Thus, static trip calculation is often insufficient and thus has to be recalculated during the actual trip.

We notice that currently, an increasing number of newly produced vehicles are equipped with infotainment systems that provide drivers with route navigation, text-to-speech delivery of information, e.g. e-mails and text messages obtained from drivers’ smartphone, as well as digital media playback features. Furthermore, advanced In-Vehicle Infotainment (IVI) systems enable even more sophisticated collaboration with drivers’ devices by allowing them to run custom third-party applications inside the vehicle’s system. Developers of such applications are allowed to make use of in-car displays and speakers, as well as consume real-time data from the vehicle itself in order to create vehicle performance-responsive functionality. If the driver’s device has Internet connection, it can act as a proxy and provide Internet access to the in-vehicle applications.

Considering the problems of current multimodal route
planning and the new technologies introduced in contemporary vehicles, we created an in-vehicle application for multimodal route planning. Our solution utilises a connection between a driver’s smart phone and vehicle’s IVI system to run a mobile application that obtains data from both the car itself and cloud data providers to guide a driver during the whole commute. Furthermore, this application utilises an in-car display as the main interface to show processed route-related information. As soon as an application user chooses a trip destination, our system analyses the route and suggests the driver to leave the car at a certain point during the trip and continue the journey by the public transport. The system suggests several transfer points where the user can change the means of transport. The suggestions are made regarding the savings in CO$_2$ emissions, fuel consumption, costs and time that would be achieved by choosing to transfer to public transport instead of driving all the way. The user can choose any of the suggested transfers and after choosing, she is guided to a parking place near the transfer point. The system keeps searching for better transfer points throughout the whole trip. Due to a dynamic behaviour of transportation system and possible delays the previously chosen transfer may not be optimal any more or even invalid. Thus, by constantly checking the possible transfers, our system ensures that a user is offered the best one. When a user arrives to a transfer point, the system shows how much money the user saved, how much less CO$_2$ will be emitted during the trip or how much faster will she arrive to the destination. Once outside the car, she is further guided by the mobile app. The app shows how to reach a public transport stop and which bus to take to reach her destination.

An example video of the prototype implementation can be found online.$^1$ 

Our research presented in this paper addresses the mentioned problems and provides the following contributions:

- We propose a multimodal route planning solution that seamlessly integrates with the car data and controls.
- We discuss our implementation of the solution in the Helsinki area that combines a local route planning cloud service, Google maps, open-source GenIVI vehicle interface, and Android mobile phone.
- We test the system to investigate how various optimisation parameters (travel time, cost, overall distance and CO$_2$ emissions) influence the optimal route selection.
- Finally, we investigate how a dynamic route optimisation compares to the static route selection.

## II. ARCHITECTURE

Our multimodal journey planner application comprises several components. A high level overview of the system is presented in Figure 1. The main system logic is contained inside a mobile application that runs in an Android device. The SmartDeviceLink$^2$ library acts as a bridge between the mobile application and the In-Vehicle Infotainment (IVI) system. The connection between a mobile device and the IVI system is established using Bluetooth or WiFi. For our system to work, the mobile device is assumed to have a working mobile Internet connection (either 3G or LTE), since it has to communicate with several cloud API providers.

The application communicates with the different cloud services using Representational State Transfer (REST) calls over HTTP. Google Directions API$^3$ is used to obtain the car route between the current position of the vehicle and a destination. From the service we can extract not only the estimated length of the trip but also the projected total trip duration. Public transport route planner API provides information about the public transport timetables. The API must be able to plan a public transport route between two points in the area. From the API we also need to extract the duration and length of the planned trip. The extracted information is later used to compare with the same type of data obtained from the Google Directions API and to compute an optimal transfer point.

## III. IMPLEMENTATION

The key part of our multimodal route planner system is the mobile Android application. The main components of the application are: routing algorithm, which calculates the optimal transfer points, SmartDeviceLink proxy library for communicating with IVI system and navigation modules to guide a user in-vehicle and when she is taking public transport.

Even though the mobile application contains lots of functionality, a user interaction with the device consists of merely specifying a destination. Clearly, a driver should not be distracted and forced to directly interact with a mobile device while driving. Therefore, the driver only has to input her travel destination by using a smartphone before the trip. The destination can be supplied from a map, a calendar event or any other application running in the phone. Any further interaction is performed by using in-vehicle system’s display and steering wheel mounted controls.

We use SmartDeviceLink component to communicate with the open-source GenIVI$^4$ infotainment system. The SmartDeviceLink generates a user interface on the IVI system and forwards user interaction events. Thus, our mobile application creates the user interface on Heads-Up Display (HUD) and responds to user actions performed on the HUD or steering wheel mounted buttons. An example of the generated interface on HUD is shown in Figure 2. Furthermore, SmartDeviceLink component provides various information about the vehicle, such as current fuel consumption, odometer data, engine speed, 

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1https://www.youtube.com/watch?v=1ezf-fEwhhA
2http://projects.genivi.org/smartdevicelink/
3https://developers.google.com/maps/documentation/directions/
4http://genivi.org/
vehicle speed, current heading and Global Positioning System (GPS) position. We use the data to locate the current position of the vehicle and to calculate trip statistics such as distance driven and fuel consumed. By constantly collecting the data we can estimate the real values of the vehicle fuel consumption and CO\textsubscript{2} emissions.

We implemented navigation modules, which show turn-by-turn navigation instructions on HUD and instructions for taking public transport on a smartphone screen. In-vehicle navigation instructions guide a driver to a selected transfer point. Once the car reaches the transfer point and the user exits the car, the in-phone navigation module starts guiding the user. It runs on the mobile device and shows how to reach the public transport stop, at what time and which means of public transport to use to reach the destination (see Figure 2).

A. Routing algorithm

The routing algorithm calculates and decides the best transfer points where a user can park her car and continue the trip by a public transport. Currently, the routing algorithm works in Helsinki Capital Area and we are using Reittiopas local transport planner API\textsuperscript{5}. There are 43 special park-and-ride parking lots\textsuperscript{6}, where drivers can leave their cars free of charge near the public transport stations and continue their trips using the public transport. Therefore, all the transfer points considered by the algorithm are the park-and-ride parking lots.

The algorithm makes routing choices according to various parameters. There are two groups of parameters:

- Parameters for selecting which transfer points to check. These include:
  - Maximum radius distance from current car position to a parking lot
  - The number of closest parking lots to choose

  The parameters help to decrease the number of transfer points to check.

- Optimisation parameters for describing which factors influence selection of the best route. Each factor considers both, driving and public transport. The factors are:
  - CO\textsubscript{2} emissions
  - trip cost
  - total trip time
  - trip distance

Transfer suggestions are made by comparing values of optimisation factors between an original trip when a driver travels solely by car and other routes that include a transfer point. The factors are weighted and one or more factors are used in searching for optimal transfers. If, for example, a user wants to reduce fuel consumption and thus minimise CO\textsubscript{2} emissions during a trip, then transfers are chosen considering only the emissions, disregarding time, price and distance. If one wants to travel in a fastest way, then CO\textsubscript{2} emissions, price and distance are disregarded. Of course, it is possible to have a trade-off between the factors. One might want to have equal weights of all four factors. Then it is possible to have e.g. 0.25 importance of each of the four factors, trying to optimise for all four at the same time.

We present an example of how the algorithm works when only the time factor is considered. Firstly, the algorithm calculates the time of a trip if a driver used only his personal vehicle to reach the destination. We use Google Directions API to obtain the directions from the current user position to the destination and to extract the required time from the response. Secondly, the algorithm estimates the time needed to go to a transfer point by car and to reach the destination by the public transport. In this case we utilise both Google Directions and Reittiopas APIs. We get trip information from Google Directions for the trip between the current location and a transfer point, and public transport trip information from the local public transport planner API for the trip between a transfer point and the journey destination. The algorithm calculates trip information regarding current time of a day and current traffic congestion information. Finally, the algorithm compares both times and if the time to reach the destination is shorter using a car and the public transport, the transfer point

\textsuperscript{6}https://www.hsl.fi/en/information/park-and-ride
is added to the suggestions list. The algorithm checks all the possible transfer points by repeating the second step. After all the points are checked, the best transfers that are not worse than the original trip by a certain threshold value are showed to the user.

IV. EXPERIMENTS

We tested our solution using an enhanced SmartDeviceLink vehicle HUD emulator. Since the emulator provided by SmartDeviceLink does not fully support the original device-to-car communication protocol, we had to enhance the emulator by adding the missing functionality. We also implemented our own test data generator that produces car data in real time. It allows choosing start and destination points on a map and generates car data events such as current engine speed, fuel consumption, GPS coordinates, heading and odometer data during a trip. The data generator feeds car data to the emulator and thus simulates a real vehicle.

Our reference vehicle had an average fuel consumption of 9.2 litres/100km in the city area. This accounts for around 200 g/km of CO\textsubscript{2} emissions\textsuperscript{7}. Buses in the Helsinki region are considered to be emitting 73 g/km CO\textsubscript{2} per person, metros, trams and trains are treated as zero-emission vehicles\textsuperscript{8}. The defined numbers are important when talking about fuel consumption and emissions. In this work, we assume that the car is used only by the driver, without passengers.

A. Impact of optimisation factors on optimal transfer selection

We performed extensive simulation tests to find an optimal combination of optimisation factors (time, emissions, cost and distance) for planning a trip that involves multiple means of transportation. We selected random locations in Helsinki Capital Area as start and destination points. Afterwards, we launched the vehicle simulator and observed the application on the emulator HUD. The suggested transfer points and related statistics were recorded. We analysed potential savings and losses related to travelling time, emissions, costs and distance in case a user chose a suggested transfer offer.

Here, we discuss the most interesting findings acquired when optimising trips by focusing individually on factors of overall CO\textsubscript{2} emission and trip duration, as displayed in Table I. In the table, each value expressed as percentage represents a certain ratio of a value associated to a trip when a driver accepts a transfer offer to a corresponding value when a trip is made solely by car. For example, 152.64\% on the “Emissions” row and “Distance” column means that a trip that includes a public transport transfer can be up to 3 times longer than a trip made solely by car. Similarly, a trip with a transfer when optimising trip duration also increases the time needed to complete the route compared to a route without transfers, but only twice. As the table rows representing different optimisation factors show, achieved journey time reduction by one third increases the total amount of emitted CO\textsubscript{2}, which is also approximately 30 per cent larger than the optimised emission value. Additionally, travel cost also increases proportionately to the rise of CO\textsubscript{2} emission amounts, since a driver has to travel further to reach a transfer point and thus consume more fuel. A substantial increase in time regardless of an optimisation factor can be explained by the time needed to park a car near the transfer point (5 minutes parking time is assumed by the algorithm) and wait for public transport. However, for the experiments we did not consider the time needed to park the car at the destination. Thus, if the destination is in a crowded city centre, parking time would add up to the car-only trip, decreasing the duration difference between the car-only travelling and a trip with a public transport transfer.

B. Static and dynamic route planning

Our proposed system involves a dynamically executed routing algorithm that addresses unexpected changes in the overall transport system. At the start of a journey, the route selection algorithm offers the best currently possible transfer. After the journey starts, the routing algorithm continues the search of better transfers and, if one is found, a driver is provided a list of newly discovered convenient transfers. In our work, the transfer search procedure involves two strategies, i.e. static and dynamic routing strategies, performed before the actual trip starts and during the trip, respectively.

The dynamic strategy greatly increases the number of remote Application Programming Interface (API) calls, thus we tested our solution to see if the dynamic strategy benefits the whole system. In our implementation, the dynamic strategy offers a driver only those new transfers that are better, in respect to certain optimisation factors, than already offered ones, e.g. the ones offered by the static strategy. Therefore, we analysed whether static and dynamic strategies offer the same optimal transfer points for different trips, i.e. combinations of random start and destination points.

Results of comparing static and dynamic route planning strategies are presented in Table II. Different rows and columns of the table represent specific features of analysed trips, e.g. distance and chosen optimisation parameters. Table cells show the rate of trips configured with the same parameters (overall

\begin{table}  
\centering  
\caption{Impact on the journey when optimising for different factors: low emissions and short time}  
\begin{tabulary}{\textwidth}{c|c|c|c|c}
\hline  
\textbf{Factor} & \textbf{Time \%} & \textbf{Cost \%} & \textbf{Emissions \%} & \textbf{Distance \%} \\
\hline  
Emissions & 301.70 & 31.70 & 46.74 & 152.64 \\
Time & 204.05 & 40.82 & 60.56 & 118.30 \\
\hline  
\end{tabulary}  
\end{table}

\begin{table}  
\centering  
\caption{The match ratio of transfer points suggested by static and dynamic strategies for different types of trips}  
\begin{tabulary}{\textwidth}{c|c|c|c}
\hline  
\textbf{Trip length (km)} & \textbf{Optimising for time} & \textbf{Optimising for emissions} \\
\hline  
< 10 & 0.9 & 0.9 \\
10 - 25 & 0.7 & 1 \\
25 - 35 & 0.3 & 0.8 \\
> 35 & 0.4 & 0.9 \\
\hline  
\end{tabulary}  
\end{table}

\textsuperscript{7}http://www.ecoscore.be/en/how-calculate-co2-emission-level-fuel-consumption  
\textsuperscript{8}http://www.reittiopas.fi/co2INFO/?routeStart=Espoo, Espoo&routeEnd=Helsinki,Helsinki&lengths=21.3:21.3:22.2&walks=1.2:1.2:0.5&emissions=0:0:1.58&absDistance=16.21
10 for each configuration) that give matching best transfer point suggestions by both static and dynamic strategies. The ratio of 1 means that for all the trips static and dynamic strategies chose the same optimal transfer points.

We found out that optimisation factors highly influence whether the static and dynamic strategies yield the same results. Considering optimisation for low CO₂ emissions, the strategies of both types mostly suggest the same optimal transfer point. However, if a trip is optimised for the time factor, the initial and succeeding suggestions rarely match. In such a case, static and dynamic strategies offer the same transfer points only in short trips. Therefore, when trying to find the fastest route, a continuous review of available transfer points is required.

Minimising the number of remote API calls greatly improves execution speed of the dynamic routing algorithm. Furthermore, less frequent execution of the dynamic algorithm preserves computing and network resources. We experimented with different transfer point filtering techniques to optimise the number of transfer points to check by the dynamic routing strategy. In our solution, static routing strategy initially checks all the transfer points, since such an algorithm is executed only once and there is enough time for processing before the driver starts a trip. Regarding the dynamic routing strategy, we obtained up-to-date suggestions by continuously executing the algorithm to find 5 closest transfer points, specifically every 1 kilometre driven by the car or after 60 seconds pass after the last execution of the algorithm, whichever happened first.

V. DISCUSSION

We implemented an in-vehicle multimodal route planner system that works by integrating a smartphone application with a car infotainment system.

We used SmartDeviceLink interface to establish a communication between a car and a smartphone. SmartDeviceLink is an open sourced version of the Ford SYNC AppLink solution.² AppLink is compatible with multiple Ford car models released after 2007. SmartDeviceLink is targeting even a wider range of vehicles, though it is still in an early stage of deployment.

Initially, the SmartDeviceLink was used only with a very limited number of applications such as radio streaming apps.However, our application requires more sophisticated integration since we utilise real time vehicle information. We also aimed at using in-vehicle displays more extensively and showed all the required information for the driver on the HUD. By using Google Static Maps API, we were able to construct a fully fledged user interface which displays navigation instructions and suggested transfer points on a in-vehicle display (see Figure 2).

In order for the system to be usable by regular drivers, it should offer clear benefits of using it. The experiments showed an increased trip time which is one of the factors that may halt the drivers from choosing a public transport transfer. While saving CO₂ emissions is globally preferred, an individual may not care whether one cuts the emissions by half or by one third, especially if this significantly increases the trip time. Therefore, we propose to choose optimisation parameters of the following weights: 0.9 for time and 0.1 for CO₂ emissions. In this case the routing algorithm would try to find a fastest way, while still minimising the emissions. In the future, it would be useful to develop optimisation profiles that would fit the needs of different driver classes as well as adapt to different time of the day. Users should also be allowed to create custom parameter profiles suiting their specific needs.

In our current implementation, the major part of data processing is performed on a driver’s smartphone. Another way to implement the solution is to move computations to the cloud. Thus, a smartphone would only be responsible for user interface creation on the IVI system and delivery of requests to a single API. However, before moving data processing to the cloud it is important to analyse whether cloud processing would benefit the system. The amount of data obtained from cloud APIs would decrease, since the cloud would provide only the results after computations. However, there is a need to upload the current and collected data obtained from the vehicle to enable dynamic route planning. It would increase the mobile up-link usage. Moreover, the collected data is sensitive in terms of privacy and one may not want to expose data such as current car location to a third party cloud service.

Our solution uses Reittiopas public transport API that can plan public transport routes in Helsinki Capital Area. In the future, we are planning to test the system in other cities. Many of the major cities already have similar public transport planning APIs, for example Transport of London API.³ As a future work, we plan to utilise data about the parking lots in city areas and improve our routing algorithm to consider personal vehicle parking time and price of parking.

VI. RELATED WORK

In this section we briefly overview the previous scientific effort related to multimodal transportation systems and usage of park-and-ride facilities. The researches mainly focus on promoting usage of public transport, reducing the number of privately owned vehicles in cities, as well as reducing the environmental impact caused by cars.

Duncan et al. [3] analysed the impact of park-and-ride parking areas in USA Charlotte, near the light rail train stations. They found out that even in a highly car oriented cities, the existence of park-and-ride parking lots decreased the average amount of kilometres travelled by car. A regular park-and-ride user decreases the distance travelled by car up to 15 kilometres per trip. However, the study was conducted only by surveying the current users of the park-and-ride facilities and does not include simulations or direct observations of different travelling scenarios.

Skoglund and Karlsson [4] claim that efficiency of a transport system may be increased only if travellers are aware and adopt the prospective features of travel planners. In their research, scientists performed and compared two similar surveys, with the second one performed nine months after the first one, and analysing the expected and perceived values of a modern co-modal transport information system introduced.

²http://support.ford.com/sync-technology/applink-overview-sync
³http://support.ford.com/sync-technology/pandora-for-sync-applink-sync
⁴https://developers.google.com/maps/documentation/staticmaps
in Stockholm, Sweden, in 2009. The travel planner system involves both private and public means of transport, including cars, bicycles and buses. The research reveals that both the expected and perceived value of the system’s functionality dropped in time. Additionally, continuous utilisation of the system was claimed only by less than 40 per cent of the respondents. The authors explain this decline with high initial expectations, an attractive idea of sustainable transportation and limited understanding of the system prior to using it, which was afterwards replaced by better understanding of the system due to usage experience. Furthermore, although the transport information and planning system increased utilisation of public transport means, it failed to reduce usage of personal vehicles, although the latter was the primary goal of the system. The authors discuss that in order to achieve the expected goals of shifting to more sustainable means of transportation, users themselves have to be looking for such a shift, and be aware of available transportation alternatives and their search systems.

The research work discussed above analyses a general impression of the system and users’ willingness to use it with a help of a questionnaire that includes questions with abstract answers such as “agree” and “strongly disagree”. Thus, the research is focused on acceptance of the service, rather than its technical features. Nevertheless, the discussed system has the same goal as our system, i.e. to minimise environmental impact of transportation by presenting the users with information about potential savings of time, money and CO₂ emissions. However, the system in this related work is designed for access using a web-browser, rather than to work in personal vehicles.

In order to increase awareness of potential transfer points, Fröhlich et al. [5] analysed driver-induced requirements and expectations for an in-car park-and-ride based navigation system intended to solve traffic congestion-based problems in the district of Vienna, Austria. A prototype application provided respondents with suggestions for parking their personal vehicles and continuing their trip by using public transport, thus saving a certain amount of time and/or money. Respondents that accepted suggested transfers, i.e. almost half of the participants, claimed that large time savings were the primary reason determined their choice to switch to public transport. However, a requirement to pay more than several Euros when switching to public transport, e.g. for parking and public transport ticket, regardless of the price of the remaining trip solely by car, was the main cause for rejection of suggestions to switch to public transport. Research participants indicated that in order to enable effective evaluation of suggested transfer points, the system needs to provide information about public transport connections, walking distances as well as costs related to parking and public transport. The participants also appreciated that most of the transfer point information is delivered as spoken language, whereas vehicle display provides summarised data.

Although the discussed work involves a survey of users, the prototype is limited to predefined transfer points and only intends to solve congestion situations rather than encourages green travelling. Furthermore, it does not inform a driver about future journey actions after she leaves her vehicle.

VII. CONCLUSION

During the research presented in this paper, we implemented and tested a multimodal route planner running in a driver’s car and her smartphone to promote utilisation of public transportation in the city area, reduce the number of cars on the road and thus lower the total emissions of CO₂. Our system combines functionality of open car platforms and a mobile application, as well as utilises information obtained from public cloud API services.

Our system was also used to analyse multimodal transportation scenarios and tested in the Helsinki Capital Area by using real time simulations of a vehicle. We analysed the influence of time, CO₂ emissions, cost and distance factors for choosing an optimal transfer point to the means of public transport. We show that by using our system, a driver can reduce the CO₂ emissions by more than 50%. We suggest a combination of optimisation factor weights of 0.9 for time and 0.1 for emissions to ensure fast trip while still minimising overall CO₂ emissions. Furthermore, we implemented a dynamic transfer point searching algorithm that offers better transfers than using only an initial checking before the trip. We showed that dynamic routing strategy is useful for longer trips and especially when trips are optimised for trip time factor.

However, the analysis of our system shows that routes which require leaving personal vehicles in a park-and-ride parking lot and afterwards using public transport typically require more time than routes completed solely by car. As related work indicates, time factor is of prime importance to travellers, thus in order to make our system more attractive to users, transfer suggestions have to offer larger or additional benefits, e.g. cheaper parking, faster trips by public transport or discounts for certain activities. Currently, our system offers trip cost savings and reduction of CO₂ emissions. Thus, further development of our technology may require collaboration with other parties responsible for management of parking lots and public transportation system, as well as local businesses that may offer additional benefits. Nevertheless, our proposal shows a mechanism capable of providing drivers with public transport-based information and identifies viability of the system in real environments. With a few improvements, our system can contribute to park-and-ride multimodal transportation initiative already taking place in Helsinki.

REFERENCES