Multimodal journey planners

Annual international markets overview

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Monika Graczyk-Raczyńska
Mateusz Olszewski
Kacper Gówczewski
Damian Derebecki

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Introduction

Smart, sustainable transportation, together with energy and resource efficiency and physical infrastructure, is one of the key problems smart cities are facing nowadays in urban planning and management. Since the transport system's efficiency determines the efficiency of the city itself, municipalities find it crucial to always improve and optimise private and public transportation services. All smart solutions, implemented in *e.g.* Barcelona or Singapore [1] are based on a data hub, that supports the collection and management of huge quantities of relevant data. Such dedicated systems can collect data about traffic, vehicles, usage of different modes of transport, as well as some additional factors, such as noise and air pollution or collision reports. One of the main reasons for cities to implement smart transportation system is to incentivize city residents and visitors to switch from private to public transport. While there are many elements of the transportation system that cities have to consider when improving their sustainability, this review will focus solely on Mobility as a Service (MaaS) solutions, namely multi-modal trip planners.

MaaS solutions offer travellers various mobility options, based on their needs, requirements and current resources. They integrate such functions like trip planning, booking and payments. They usually also offer commuters one interface for multiple modes of transport, such as train, bus, taxi, ride-sharing, bicycle-sharing, *etc.*, without the need of switching between different app providers [2].

Multi-modal trip planners

A multi-modal journey planner (also known as trip or route planner) is a specialised search engine used to find an optimal means of travelling between two or more given locations using more than one transport mode [3]. Although first route planning systems appeared in the 1970s [4], it was the growth and common accessibility of the Internet, together with the proliferation of geospatial data, and the development of information technologies that led to the rapid development of many various forms of inter- and multi-modal trip planners, such as widely used: Google Maps[1], Citymapper[2] or Omio[3].

A well designed MaaS system is not only a convenient tool to help with the commute within a city, but also an aswer to a first mile/last mile (FM/LM) problem [5], common mostly for commuters from the sub-urbian areas. An FM/LM problem with relation to the transportation system describes the difficulty in transporting people to their first and final location. Too long walking distance with no or few alternative transportation options works in favor of using private transport, therefore increasing car dependency of commuters, that in turn increases congestion and leads to a number of other problems (Fig. 1) and is in an obvious opposition to the smart city ideas.

Capabilities and flexibility of journey planners can be only limited by the type, extent and,

[1] https://www.google.com/maps
[2] https://citymapper.com/cities
[3] https://www.omio.com/

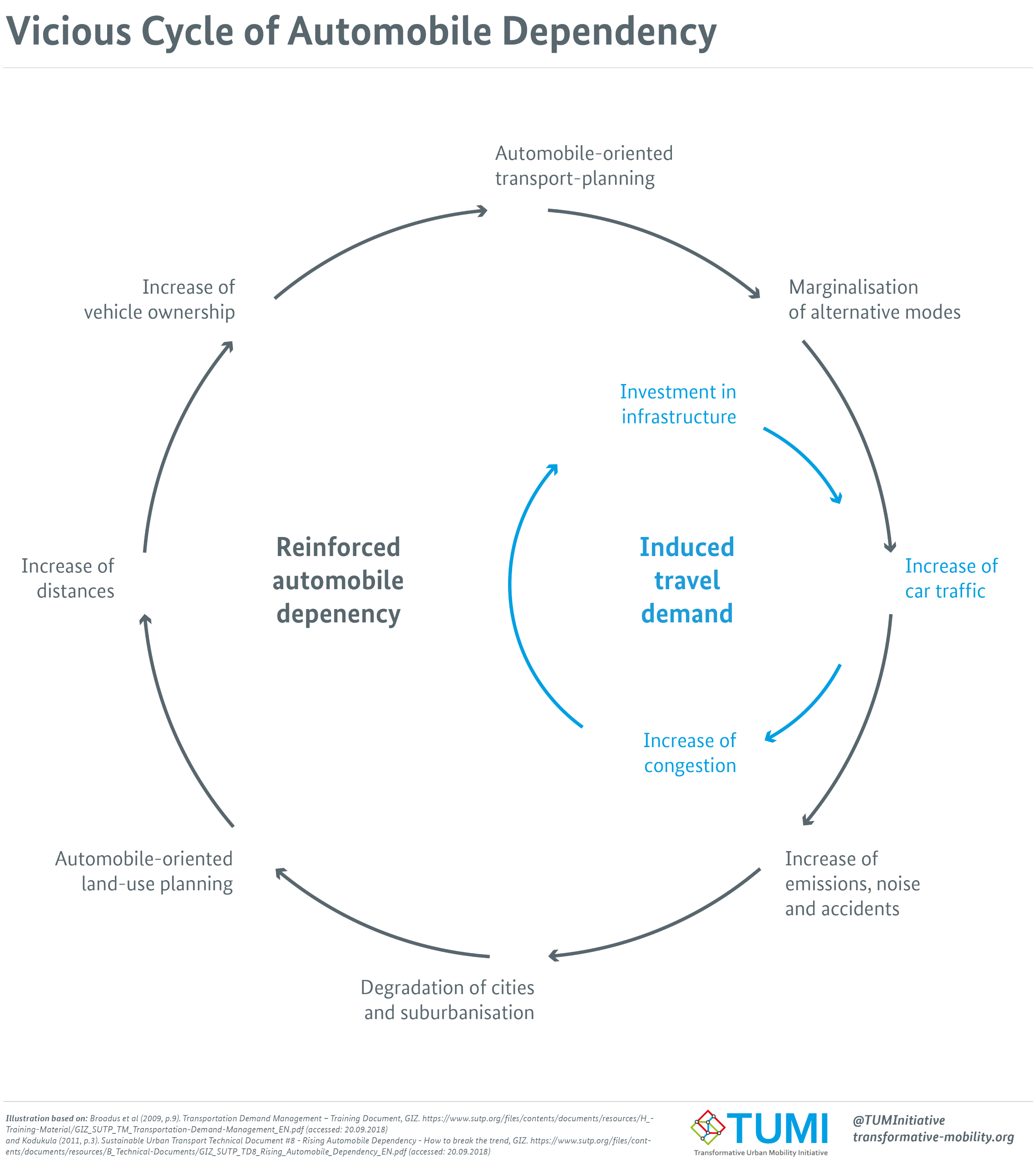


Figure 1: Cycle of car dependency in urban and sub-urban areas. *Source: Transformative Urban Mobility Initiative (TUMI)* [6]

most importantly, the quality of the available data. In city-oriented journey planners, common searches are made basing on such criteria as: commute time, price and number of transfers. However, considering for example an increase of eco-awareness among people or recent restrictions regarding health issues, there is a growing need among users to include also other factors, such as carbon footprint, number and age of co-travellers, passenger limitations or handicapped accessibility. With the increase of smart-phone, availability of the Internet and common trend of metamorphic design [7], consumers demand instant relevance as a service. Therefore the need for a seamless, personalised and optimal travel schedule is now stronger than ever. The perfect journey planner should not only help travellers plan their door-to-door excursions in real-time, but also enable booking, payments and fit to their lifestyle.

The subject of multi-modal planners and MaaS systems in general has been thoroughly investigated and tested both by the academia [2, 8, 9, 10, 11] and business world. According to Rocha *et al.* [12], the division between the groups is rather clear, since one focuses on the designing algorithms to use in mobility assistants, while second—on the development of specific applications. Following chapter describes common problems that occur during designing multi-modal planners with regard to two crucial factors: modes of transport and types of users.

Modes of transportation

Nowadays, people can travel in about a dozen different ways within a city, travelling by foot, shared vehicles, taxis or different modes of public transport. There are even more options to choose from when travelling long distances or in unusual setting, *e.g.* through canals or other waterways. When designing a multi-modal journey planner, each of mode of transport presents us with a set of different factors and issues that have to be taken into consideration.

Public transport

Although public transport consists of various means of transportation, such as buses, trams, trains, *etc.*, technically (from the algorithms' point of view) they are all treated the same way. In the graph-based algorithm, each of them can be viewed as nodes and edges with assigned weights, which could describe distance or duration between them. One uniform feature of all modes of public transport is that each has its own schedule. Although in most of the algorithms it is treated as a fixed, constant value [13, 11, 9], due to multiple different reasons it may not always be true. Therefore some of the MaaS systems take the duration of the trip as a stochastic variable making it possible to analyze the risk of a delay [8, 14]. Searches in multi-modal route planners that do not address this issue, may result in longer unscheduled layovers. When one of the transports is delayed, next can be missed and the, theoretically, quickest path can in fact be much longer or troublesome (Fig. 2). Clever way to decrease the uncertainty of trip duration in traffic dependent modes of transport, *e.g.* buses, is to incorporate traffic speed data [15] to the planner.

Vehicle sharing

With the increasing use of the car-, scooter- and bike-sharing systems [16], there is a growing need to incorporate them into the multi-modal planning systems. They are especially useful

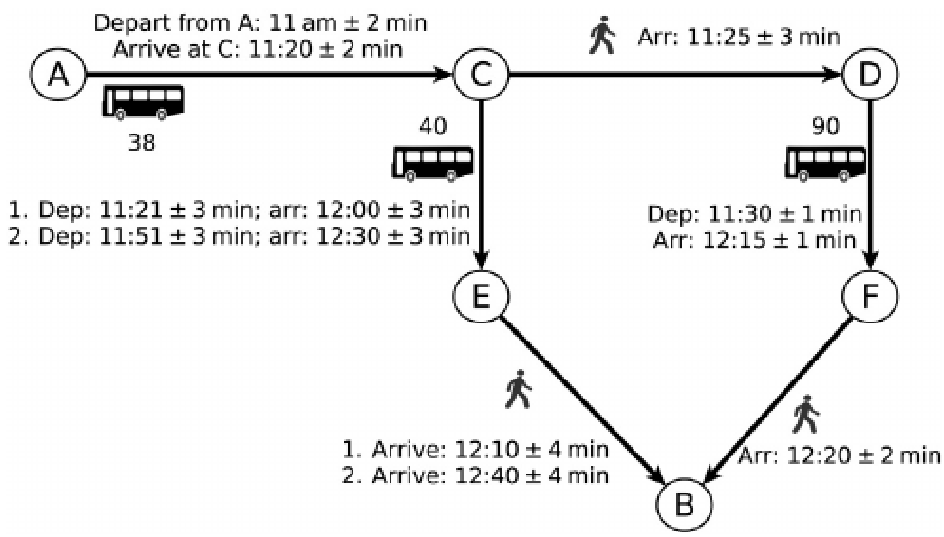


Figure 2: Example of when uncertainty-aware plans, has advantage over fixed time schedules. Quickest path from A to B goes through the point E, but due to uncertainty of arriving time at C, it could be better to go through the points D and F [8].

as a first and last mile modes of transportation. With this type of transport there is a need to model availability of all shared vehicles in the area. It is also necessary to remember, that for more accurate predictions a per-station model has to be built (instead of incorporating a single model for every station [17]) for multiple vehicles stations, such as bikes.

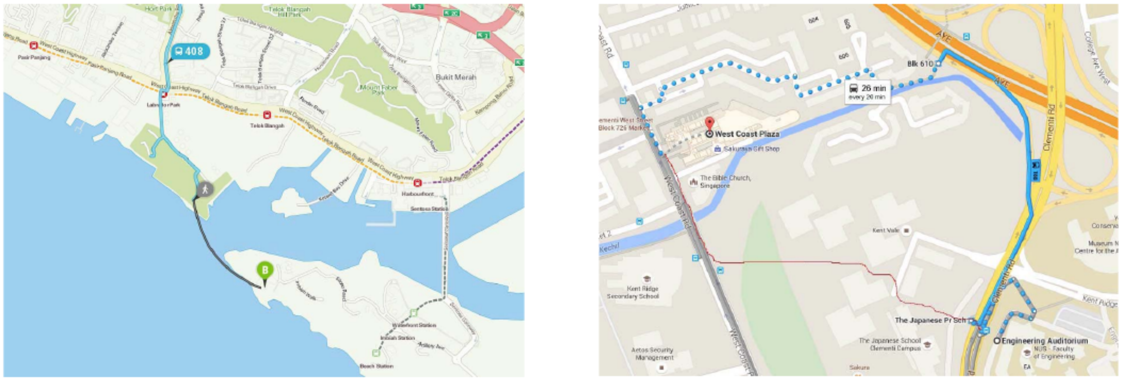
One of the major problems of bike sharing systems is uneven distribution of bikes among the stations during rush hours or as a result of the topography of the area. This issue can be addressed by using a random-walk method to predict bike demand change at the stations [17]. Such model can then be used in a multi-modal planner — after selecting shortest route, it can search for a bike station nearby, and suggest to the user those bike stations that help rebalance the bike station network, but still satisfy user requirements.

Park-and-ride

For multi-modal commuters using their own vehicles for the first leg of the journey, it is crucial that the journey planner suggests not simply the closest station, but one with a nearby parking lot [15]. Even better, when it is known real-time availability of parking spots there [10].

Walk

When all the other transportation modes fail and using a car is for some reasons impossible, or when it is simply the most convenient, people turn to traveling by foot. Although it is the most common way to travel on the first and last leg of the journey, and so seems an easy task, the most popular route planning applications, like GoThere or Google Maps, still have problems with choosing the best (or even realistic) walking path it, as shown in the example from the City of Singapore (Figs. 3a and 3b).



(a) GoThere example

(b) Google Maps example

Figure 3: Examples from two popular journey planners, where the most common solutions fail in determining optimal walking route. In (a) walking path is completely unrealistic, and in (b) Google Maps suggests combination of walking and bus, because it doesn't have the information about walking path trough the park, which is shown by red line. *Source: Yu et al. [15]*

Users

Two main groups of journey planners users in and around the city, are everyday commuters and tourists. While first group density, routes and schedules are usually relatively constant and easy to predict all over the area, the second group can be very changeable, especially in the popular tourists destinations. Massive numbers of tourists can disrupt busy areas, causing transport inefficiency, unbalanced economic growth and nuisance among tourists and citizens [18]. Therefore, it may be reasonable to consider the *Tourist Trip Design Problem*, which is generating personalized tourist itineraries. A Tourist Trip Design Problem is bi-objective, meaning it targets both, the needs of citizens for efficient communication and visitors and their satisfaction. Mrazovic et al. analyzed this problem for the city of Barcelona, proving that it is possible to balance traffic in the city by promoting certain areas for the tourists [18].

Micro-navigation

One of common problems mostly for tourists, but also quite often for everyday commuters, is finding best way from one line or mode of transport to another at the large multi-modal transit interchanges [19]. This problem is especially important for disadvantaged users, such as children, elderly, newcomers, people with poor eyesight or people with impaired cognitive or physical abilities. Non-disadvantaged users also can experience stress during making micro-navigation decisions. Lack of help in this situations, could and very often does lead to reluctance to use public transport. It is most important for buses, as their have the most complex grid connections [20]. Real-time guidance of the passengers is a complex problem, which can be quite easily solved e.g. with the use of Wi-Fi [20], Differential Wi-Fi (DWi-Fi) and RFID technologies [19].

Data

The base of every trip planner is road network data of the area, that can in turn be used to create a connection graph model for the city. Such data can be obtained either from private or public datasets, *e.g.* Open Street Map[4]. The other crucial data used in all journey planners is, of course, public transport timetables. The more advanced journey planner is, the more sources of data it integrates.

Data integration

When variety of mobility options increases, usage of all of the options is more and more complicated. This creates the need for multiple transport data integration [21]. With the increase in use of the IoT (*Internet of Things*) devices in smart cities, types and amount of available data that could be used in trip planning does also increase. This means that modern journey planners should be flexible enough to allow users to utilize that new form of data [22]. To overcome this issue and to deal with the information overload, Kuster et al. propose the Belief-Desire-Intention (BDI) model (Fig. 4), where beliefs are data retrieved from the external services, *e.g.* public transportation schedule, car park occupancy, weather forecast, *etc.*

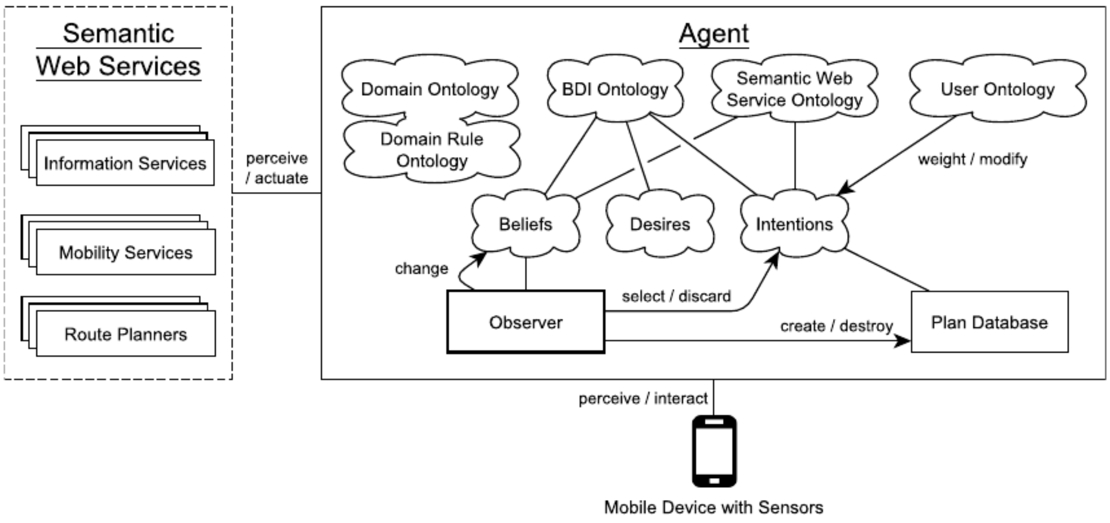


Figure 4: Overview of the BDI (Belief-Desire-Intention) agent's model. *Source: Kuster et al. [22]*

Conclusions and recommendations

Multimodal trip planners are widely used all over the world. In almost every major city travellers, both citizens and tourists, can choose from a number of different applications (both mobile and web-based), helping them in planning and finding their way in and around the area. Trip planners vary from very simple, that base on the schedule from one transport provider, where you can plan

[4]https://www.openstreetmap.org/

transferring only between its lines, to the most advanced, that present such features as nearby parking availability, touristic information services, or additional visualisations regarding real-time human or road traffic congestion [13]. However, to achieve that in a planner, area must be covered by the congestion sensors network, either installed in vehicles [20] or through the crowdsensing, where the data comes from public transport users, through their smartphones [23].

One of the most popular application nowadays, available worldwide is Google Maps[5]. As for now, it supports five modes of transportation: car, public transport, walking, cycling and flights. Unfortunately they are mutually exclusive, meaning, users can plan their trip using only one of them. This way, only public transportation mode could be named multi-modal, as it consist of different types of transportation available in the area: buses, trams, trains *etc*.

Many of the aforementioned and discussed solutions (e.g. [15, 17, 24]) are based on the Open Street Planner[6], an open source multi-modal trip planner, which finds itineraries combining transit, pedestrian, bicycle, and car segments through networks built from widely available, open standard OpenStreetMap and GTFS data[7].

Before creating or choosing one of the already available on the market multimodal route planners for the city, it is crucial to thoroughly analyse and consider all the needs, available data and expected outcome. Key questions to answer will always be:

- Who is the final user? Citizens, tourists or everyone? What are their expectations?
- What transport modes do we want to include or exclude? What data do we have on them so far?
- Is it possible and necessary to integrate payments and bookings?

When approaching the problem of creating a multimodal planning and management system, it is crucial to establish a forum where public and private stakeholders can regularly discuss technical, organisational and legal issues of the creation, implementation and, later, management and usage of the system. We strongly encourage the forum to be open to the public, not only to engage the citizens and private organizations in smart development of their city but also as a source of vital information that may be used in further development.

Although, due to number of reasons, western part of Europe has better coverage of available route planners, there are dozens of different providers and solutions to choose from also in the other parts as well. In 2014 European Commission Directorate General Mobility and Transport under framework contract MOVE/C3/SER/2014-471 commissioned a thorough study on the Intelligent Transport Systems (ITS) Directive, during which a total of 125 provides were found to be offering 160 services (Appendix C in [25]) all over Europe. The final report on the aforementioned project [25], not only gives an overview of the relatively current status of multimodal travel information services in Europe, but also provides a long list of recommendations from the European Commission regarding: legal issues, data and information quality and availability, data standards and interoperability, intra- and interstate cooperation, funding, and many more.

[5] `https://www.google.com/maps`
[6] `http://www.opentripplanner.org/`
[7] General Transit Feed Specification—a common format for public transportation schedules and associated geographic information.

Therefore, we strongly encourage anyone searching for or attempting to create a route planner, to get familiar with the document.

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