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Environmentally Sustainable Transport Planning in the First and Last Mile Section of the Supply Chain

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Background: The article provides a discussion on freight transport planning. The existing solutions applied in this sphere have been compared with the environment-related needs. The concept which has been proposed involves a dedicated travel planner that takes some additional non-standard criteria into consideration. At the same time, the authors have highlighted the necessity to expand the algorithms being applied, and to address the comprehensive nature of the problem. However, it is the first and last mile section of supply chains on which the article focuses. The planner described in the paper is being developed as a part of an integrated platform implemented under the international S-mile project.
Research methodology: The solutions proposed for transport planning purposes include application of ICT. A review of the available solutions has made it possible to indicate one of the planners currently in use as the foundation upon which a more advanced freight transport planning tool dedicated to the first/last mile section can be built. The planner requires application of several optimisation algorithms, including those which consider route parameters, the selection of fleet vehicles available for the given task, cargo distribution over the vehicle etc. The article defines both primary and secondary criteria that such a planner should take into account, including the environmental ones. What the authors have also highlighted is the possibility to make use of open data sources. The approach they have proposed makes it possible to raise the level of environmental awareness at the first and the last mile management stage, and since multiple transport aspects have been addressed, it also increases planning efficiency.
Goals: The purpose of the article has been to discuss an eco-friendly solution which may limit the negative environmental impact of transport.
Conclusions: The solution described in the paper may change the manner in which freight transport is managed in cities. Taking environmental criteria into consideration makes it possible to reduce the negative environmental impact of transport. Planning of freight transport requires that far more criteria should be taken into account compared to route planning for the travelling population. A comprehensive fleet management platform featuring a planning module combined with other modules of the S-mileSys system being currently developed is also aimed at integration of large freight companies with the carriers that service first and last miles.

Keywords: eco-friendly supply chains, freight transport planning, ICT systems in logistic, sustainable development, open data source.

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1. INTRODUCTION

Long-distance freight transport is performed by means of sea, air and rail transport as well as using goods vehicles. This stage of transport management, typically involving the largest distances to be covered, is addressed by many organisational solutions implemented on the level of trans-European networks. The problem of far greater complexity is the need for complete large shipments to be arranged (first mile), and primarily for dividing large cargo into parts and transporting them in an environmentally optimised and cost-effective way between the point of the main transport completion and individual destination points (last mile). This problem is becoming increasingly serious in heavily urbanised areas characterised by variability of road traffic conditions and numerous restrictions in terms of accessibility for freight transport (particularly in city centres). Various European Union documents indicate clear deficiencies in terms of the solutions and growth policies dedicated to urban freight transport (including Urban Mobility – Research Theme Analysis Report, 2016, and White Paper, 2011) as well as excessive dependence on petroleum and insufficiently efficient technological development in the sphere of alternative fuels (including Clean Power for Transport, 2013). What can also be observed is the lack of universal solutions and full information exchange among smaller carriers or traffic administrators. Large transport companies or manufacturers have limited options in choosing the supporting carrier, especially within the last mile. There is also no sufficient IT system linking large transport companies with local carriers [White Paper 2011], as a result of which transport efficiency declines significantly over the last mile. Large transport businesses or production companies storing their goods at logistics centres at the last mile stage also face other issues, including:

- insufficient familiarity with limitations typical of the urban transport network, including local congestion-induced obstacles (dynamics of everyday and periodical changes caused by specific local conditions) or quality of road pavement;
- major restrictions or lack of transport accessibility for large goods vehicles in city centres, assumed to reduce the negative environmental impact of transport in these areas;
- increase of last mile transport costs due to lack of complete information on the market of services rendered in this respect.

Bearing the foregoing problems in mind, an attempt was made under the international project entitled “Smart platform to integrate different freight transport means, manage and foster first and last mile in supply chains (S-MILE)” to develop an integrated tool supporting first and last mile carriers as well as to improve the effectiveness of collaboration between large transport operators and small carriers. At the same time, the system will support local authorities in making freight transport related decisions. The article compares selected research projects related to the development of several components of the S-mileSys system. With reference to the criteria defined under the project, a specific planning tool was chosen, the one which can provide grounds for further development towards the identified requirements connected with efficient and environmentally sustainable freight transport performed inside cities. However, it is the first and last mile section of supply chains on which the article focuses. The above requirements have also been elaborated in the paper.

2. THE REVIEW OF THE EXISTING PLATFORMS PROVIDING BASIC SOLUTIONS FOR THE S-MILESYS SYSTEM

Route planning versus supply chain optimisation.

Representing solutions dedicated to the travelling population, travel planners make it possible to choose, visualise and compare transfer options, but they also support their actual execution in the given transport network between two (or more) pre-defined points using one or more means of transport in the transfer chain. With regard to freight transport, the basic features of a travel planner are insufficient to maintain adequate transport efficiency. Where this is the case, one needs to use a far more extended and integrated platform supporting and optimising the decisions made by a carrier. It is due to incompatibility of the data exchange standard that causes local transport businesses to make use of very diverse systems which hinders freight transport integration in the chosen area and forces large carriers (interested in collaboration within the last mile section) to adapt to different IT systems [Iwan and Małecki, 2012]. However, the lack of integrity among carriers leads to considerable unawareness of the current distribution of transport streams over the road network. In such cases, transport companies use more advanced systems of what is commonly referred to as fleet management. Such solutions enable them to track the location of vehicles and may support route planning, among other features they offer. There are also solutions which carriers can use to optimise their supply chains over the last mile, for instance My Route Online Route Planner that determines optimum sequence of deliveries for a single transport service. Nevertheless, majority of carriers still disregard the environment, as they condition their freight transport services by the cost and time criteria exclusively (or by a criterion based on both these parameters that have been assigned adequate weights), which is clearly visible in the design of most travel planners [Borkowski, 2017], [Iwan et al., 2014], [Esztergár-Kiss and Csiszár, 2015] and [Földes and Csiszár, 2015]. The rare examples of solutions based on an environmentally friendly approach have been described in such papers as [Lewczuk et al., 2013] and [Sierpiński, 2017].

Choice of the planning platform for the system under development.

Since one of the most significant goals of the integrated system being developed under the S-mile project is to improve the manner in which transport companies function by enabling more efficient transport planning, a review of the available solutions was conducted at first. 16 different planning systems were pre-selected for the review (Table 1). However, on account of the project assumptions, the preliminary selection was subsequently limited to open source solutions (marked with an asterisk).

The system being developed is assumed to be universal (irrespective of location of the area it covers or the fleet managed by the given business), and therefore the planner should be based on a platform that enables different variants and modifications to be taken into consideration. The foregoing pertains to the data layer, the API layer as well as the routing algorithms themselves. Another criterion considered under the analysis was availability of the input data fed into the planner, its source code and technical documentation in the public domain. Most travel planners use such formats as Open Street Map (OSM), and so the data availability criterion was successfully met by many of them. Furthermore, according to the project assumptions, the planning system (intended to function as a base for further extension) should be characterised by:

– using public data concerning the transport network,
– openness and public availability of the source code of the routing algorithms,
– publically available data repository comprising a complete platform,
– technical documentation.

Following further analyses, the recommended solution was found to be Open Trip Planner. It features source codes of routing algorithms ([Dijkstra and A*]). Its generally available repository contains source codes and design documentation. The planner also features the implemented WebAPI layer (interface). This solution receives ongoing support and is continuously expanded by teams from all over the world. At the same time, one may point out to its specific practical applications (e.g. [TriMet], [GTAlg], Fig. 1.). Although the chosen platform requires a number of modifications to be introduced, yet it may form a flexible base for further system development. The next section of the paper describes some of the selected requirements for environmentally sustainable transport planning that must be addressed in the system being developed.

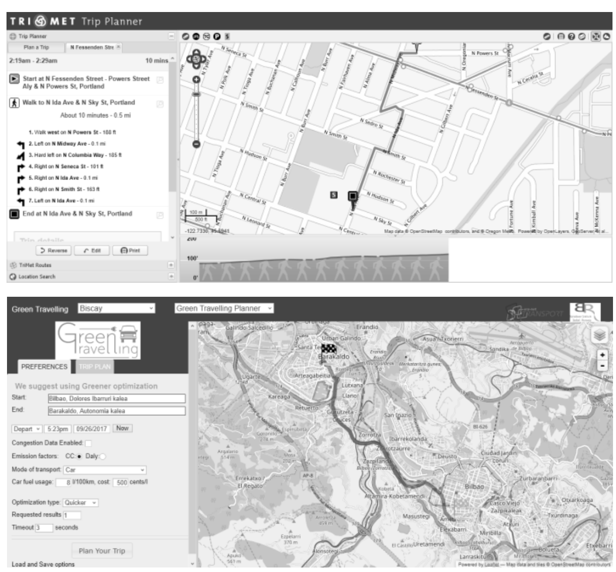

Fig. 1. Travel planners based on Open Trip Planner platform: a/ TriMet (example for Portland, USA), b/ GTPlanner (example for Biscay, Basque Country, Spain).
Source: [TriMet], [GTAlg]

Table 1. The results of preliminary freight transport planners selection.

No.	Name of the planning system	Source
1	My Route Online Route Planner	http://www.myrouteonline.com
2	Freight Journey Planner	http://www.freightjourneyplanner.co.uk
3	Graphhopper *	http://www. graphhopper.com
4	Mapbox *	http://www.mapbox.com/industries/logistics
5	Open Trip Planner *	http://www.opentripplanner.org/
6	Mobycon	http://www.mobycon.com/action/news/item/980/Free/
7	Driving Route Planner	http://www.drivingrouteplanner.com
8	Borusan Guvencesiyle	http://www. etasimacilik.com
9	Truck & Driver	http://www. truckanddriver.co.uk/free-truck-route-planner/
10	Loginext	http://www.loginextsolutions.com
11	Skobbler *	http://maps.skobbler.com/
12	Routinio *	http://www.routino.org/
13	Your Navigation Routing Service *	http://yournavigation.org/
14	Open Route Service *	http://openrouteservice.org/
15	Open Source Routing Machine *	http://project-osrm.org/
16	Reit Und Wanderkarte *	http://www.wanderreitkarte.de/

Source: own research.

* Open source

3. IDENTIFICATION OF REQUIREMENTS FOR EFFICIENT URBAN FREIGHT TRANSPORT PLANNING

Support for first/last mile carriers in the S-mileSys system.

The concept underlying the S-mileSys platform is based on integration of three kinds of stakeholders:

- small urban carries capable of handling the first and the last mile of supply chains,
- large transport companies, manufacturers etc. managing the main part of transport in long distances using their own resources and means of rail, air and water transport as well as large goods vehicles,
- local authorities whose actions affect the way in which traffic streams are managed in cities and who need full information about freight transport in order to make appropriate strategic decisions, also with regard to environmental aspects.

In response to the foregoing needs, S-mileSys comprises several modules. In the article, however, only those requirements which apply to the stage of last mile transport planning by a small carrier have been addressed (Fig. 2). The carrier connects to the system via the *Freighter Tool* module. This system component also enables ongoing monitoring of the fleet in the field, provides insight into the fleet availability across the company and ensures communication with drivers. The basic modules supporting efficient transport planning are *Transport Planner Tool* and *Fleet Management Tool*.

When handled comprehensively in supply chains, freight transport planning differs from that of single transfers between the points of origin and destination. Where the former is the case, efficient

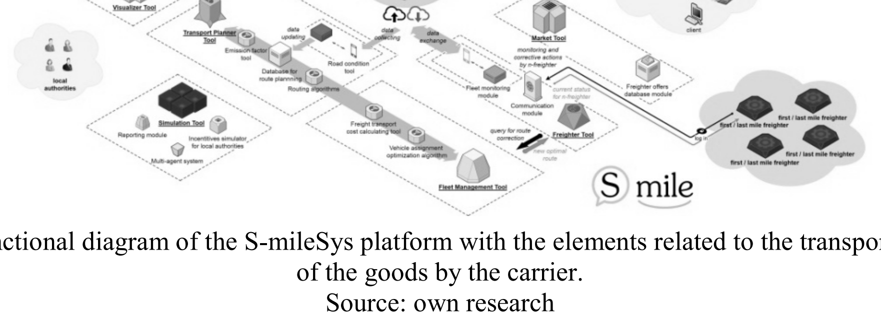

Fig. 2. Functional diagram of the S-mileSys platform with the elements related to the transport planning of the goods by the carrier.
Source: own research

planning should basically take more parameters into consideration. Full integration of individual algorithms will make it possible to provide for the system's support in terms of optimised fleet distribution towards the transport tasks at hand and to establish optimum routes. With that in mind, some of the sub-modules that one can find in the system include:

- *Vehicle assignment optimisation algorithm*
- *Freight transport cost calculating tool*
- *Emission factor tool*
- *Database for route planning*
- *Routing algorithms.*

The above sub-modules address the relevant requirements of sustainable freight transport planning, including environmental requirements. All the aforementioned components operate simultaneously. By way of iteration and by means of analysis of the available combinations and the current transport availability of the road network, the carrier obtains an optimum solution (depending on pre-set primary criteria).

Problem of goods distribution within the fleet.

The first of the above sub-modules (i.e. *Vehicle assignment optimisation algorithm*) is responsible for both optimum distribution of goods in vehicles and optimum assignment to individual vehicles. The optimum distribution of goods in vehicles depends on many factors, including the size and shape of specific elements of the cargo, but also on the sequence of deliveries (see [Mindur, 2012], [Mindur, 2014], [Pisinger and Egeblad, 2006] and [Popiela and Wasiak, 2017], among others). Another aspect to be taken into account is the optimum assignment of cargo to the carrier's fleet vehicles in disposal and currently available (see [Shen et al., 2009] and [Naumov, 2017], among others). Both these aspects must be considered jointly and in line with multiple criteria. For instance, minimisation of the number of vehicles used for transport purposes is not necessarily the most cost-effective and environmentally friendly choice.

Costs in a transport company.

It should be noted that the choice of an appropriate solution is also strongly dependent on some other parameters, including cost. Consequently, another component of the same module is an extended cost calculator (*Freight transport cost calculating tool*) which accounts for such factors as, for instance, operating costs, personnel costs, fleet maintenance related costs, warehousing costs (in cases when goods must be stored) etc. (1):

$$C_{Total}= C_T+C_L+C_A+C_O+C_W+C_S+C_M[\text{cost unit}], \quad (1)$$

where:
C_{Total} – total costs incurred by the transport company [cost unit]
C_T– costs related to transfers made by vehicles in freight transport [cost unit]
C_L– loading/unloading costs [cost unit]
C_A– costs of additional transfers (transport unrelated) [cost unit]
C_O– general facility operation costs [cost unit]
C_W– workshop related costs [cost unit]
C_S– storage costs [cost unit]
C_M– management costs [cost unit]

Each of the cost categories described in (1) is characteristic of a different sphere of transport company's operations. Regardless of the chosen freight transport service, fixed costs are also a fraction of costs that needs to be taken into account. Similar models have also been assumed in such papers as [Bąk, 2010], [Berwick and Farooq, 2003] and [Karoń and Janecki, 2014].

Environmental criteria.

One of the S-mile project goals is to promote environmentally sustainable solutions. What has been identified with reference to various pieces of both European and worldwide literature (including [*The Calculation Of External Costs In The Transport Sector*, 2009], [Maibach et al., 2008], [van Essen et al., 2011], [Becker et al., 2012], [Pawłowska, 2013], [Korzhenevych et al., 2014], [Małecki, 2016], [Turoń and Czech, 2017]) is the need for promoting environmentally sustainable solutions among transport companies, and on such a basis, more than a dozen emission indicators have been defined, including CO (carbon monoxide), CO_2 (carbon dioxide), HC (hydrocarbons), NO_x (nitrogen oxide), N_2O (nitrous oxide), NO_2 (nitrogen dioxide), NH_3 (ammonia), PM (particle matters), Pb (lead), SO_2 (sulphur dioxide), CH_4 (methane), benzene as well as FC (fuel consumption) and WH (energy consumption by electric cars). Since the message to be sent is intended to be fully comprehensible for the carrier, following further analyses extending beyond the domain of traditional route optimisation criteria based on time, distance or cost, three more criteria have been implemented in the system (representing the general environmental impact) with the purpose to seek solutions that reduce the negative environmental impact of transport (the *Emission factor tool* sub-module) [S-mile Report D4.1, 2016]. Consequently, the approach adopted by the authors makes it possible to obtain full information about the scope of environmental impact and fosters application of more environment-friendly means of transport as well as accordingly optimised routes. Values of individual environmental parameters are established with the accuracy of a transport network road section by taking variable traffic conditions into account. For every single parameter, a separate value estimation model has been developed, yet all of them rely on essential variables which determine (2):

$$CC, DALY, NOISE = f(VT, RT, S, TC, G, L, A), \quad (2)$$

where:

CC – impact on climate change [CO_2eq/km],

DALY – indicator of the expected forecasted health or life detriment caused by – as in this case – transport (Disability Adjusted Life-Years) [daly/km],

NOISE – noise emission by the vehicle [dBA],

VT – vehicle type (classification according to vehicle types, e.g. electric passenger car, passenger car, delivery van, lorry etc.),

RT – road type,

S – speed [km/h] in each section of the transport network (with reference to permissible speeds defined for individual sections and speeds recorded by a traffic monitoring system covering the given area of Intelligent Transport Systems (ITS)),

TC – traffic volume [-]; a parameter which takes the current of the forecasted traffic in individual transport network sections into account (based on data extracted by S-mileSys or external data from a traffic monitoring system covering the given ITS area),

G – road inclination [degrees],

L – load [-]; a parameter which defines how much a vehicle is loaded by cargo,

A – residual constant.

The model thus built was based on specific guidelines and databases (including HBEFA, NNSLD). The model required further calibration and implementation to obtain the format of programming libraries [Pijoan et al., 2017].

Optimum route search algorithms regarding eco-friendly means of transport.

Using the described S-mileSys solution, a carrier receives a report with a comparison of optimum solutions matched with different optimisation criteria. The optimum route is established by application of algorithm A*. Depending on the pre-set optimisation, the algorithm will minimise distance, time, costs or negative environmental impact of transport by searching through the R set of routes between individual points defined to complete a supply chain (3) for specific means of transport:

$$R = \{r_i : r_i(T, D, C_T, EI\,(CC, DALY, NOISE))\},$$
$$Opt = \min_{criterion}\left(r_1, r_2, \ldots, r_n\right), \quad (3)$$

where:

R – set of routes between selected points in the transport network,

T – transport time [h],

D – distance [m],

C_T – total cost [cost unit],

EI – environmental impact defined with reference to selected emission indicators,

Opt – goal function.

It should be noted that depending on the vehicle fleet in disposal, the algorithm takes specific additional parameters of the transport infrastructure into account, including availability of individual vehicle types (some elements of the infrastructure may be impassable for specific vehicles), location of parking areas near the destination (for smaller parcels), running range of vehicles or road quality [Staniek, 2017] etc. For instance, considering a route for an electric car (being a solution proposed as a realistic near-future alternative for combustion engine vehicles [Plan rozwoju elektromobilności w Polsce, 2016]) used for transport of small shipments, one may take into account the following additional input parameters:

Ropt_EV = f(O, D, t, T, Wmax, DEV, E, C, Opt, ChS, others), (4)

where:

Ropt_EV – optimum route for an electric car (including the walking distance to reach the destination point),

O – point of origin,

D – destination (or intermediate) point,

t – anticipated date and time of the travel start (or completion),

TJ – logical parameter decisive of whether road network congestion is regarded (or disregarded),

DWmax – maximum walking distance [m],

DEV – maximum forecasted running distance for an electric car [m],

E – electric car's average energy consumption [kWh/100 km],

C – cost of kWh [cost unit],

Opt – optimisation criterion (one of pre-defined criteria),

ChS – charging station location in the transport network of the chosen area (when the vehicle must be recharged on the way).

Potential data sources to support the system under development.

Route planning was based (as described in the previous section) on the generally accessible OSM (Open Street Map) map platform. It is an extensive and frequently refreshed database enabling the transport network to be described as the G directed network graph composed of nodes V and edges E (5):

$$G = \langle V, E \rangle \ . \tag{5}$$

Each edge is described according to the OSM numbering as a pair of nodes $\langle i, j \rangle$ (start and end node) (6):

$$V = \{1,2,...,i,...j,...,m\};\ E \subset \{\langle i, j \rangle : i, j \in V\}. \tag{6}$$

At the same time, the notation sequence defines the direction of motion along the edge. Each arc has additional a set of parameters forming vector X_E (7), the values of which are used to define optimum routes:

$${X_{E_{ij}}}^T = [x_1, x_2, ...x_s]. \tag{7}$$

A network graph thus defined makes it possible to apply optimum route search algorithms. Furthermore, OSM may provide a source of information that considerably supports freight transport planning [Sierpiński, 2018]. The features of OSM components which may be found useful in freight transport planning include the following:

- determination of the road type for linear road section data,
- determination of locations of intersections between a walking path and a vehicle route,
- identification of mini-roundabout intersections,
- identification of road traffic obstacles (including those that only limit access to vehicles of specific height, barriers etc.),
- identification of toll collection points,
- determination of upper and lower speed limits,
- identification of parking places and waiting time restrictions,
- locations of petrol stations and electric car charging stations,
- boundaries of protected areas and accessibility for a specific group of vehicles etc.

Differences in road inclinations (gradient in the algorithm described) may be obtained from open land profile databases, some examples of which may be the National Elevation Dataset and the Shuttle Radar Topography Mission.

4. CONCLUSIONs

A route planning system dedicated to freight transport requires information whose scope extends beyond the one used by traditional navigation systems. In this respect, one should keep in mind the larger number of optimisation criteria, as well as their simultaneous application. There is also a need for combining deliveries into chains, thus triggering further specific needs pertaining to information about the given area and the structures it contains. Reduction of negative environmental impact of transport, including emission of harmful substances, requires technological and organisational changes. The selected planning platform, namely Open Trip Planner, provides solid foundations for the system to be developed. The solution described in the paper may change the manner in which freight transport is managed in cities. Taking environmental criteria into consideration makes it possible to reduce the negative environmental impact of transport. A comprehensive fleet management platform featuring a planning module combined with other modules of the S-mileSys system being currently developed is also aimed at integration of large freight companies with the carriers that service first and last miles.

Integration of the tool being developed into a single system is planned under further research works. This requires combination of transport planning components with the freight exchange as well as data visualisation and simulation modules. The very last stage will be a case study for several chosen areas where the problem of data completeness will be investigated.

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