ANALYSIS OF THE APPLICABILITY OF THE PUBLIC UPPER AUSTRIAN TRANSPORT GRAPH FOR SOLVING A LOCATION-ALLOCATION PROBLEM

Andreas Pell[(a)], Andreas Meingast[(b)], Stefan Rotter[(c)], Markus Pajones[(d)]

[(a) (b) (c) (d)] University of Applied Sciences Upper Austria

[(a)]andreas.pell@fh-steyr.at, [(b)]andreas.meingast@fh-steyr.at, [(c)]stefan.rotter@fh-steyr.at, [(d)]markus.pajones@fh-steyr.at

ABSTRACT

In this study, the applicability of the Austrian national transport graph "GIP.at", which is provided and constantly updated by Austrian public authorities, for a location-allocation problem-solving approach is examined. For this purpose ESRI's ArcGIS Network Analyst™ was applied on the part of the graph which represents the roads of the Province of Upper Austria. Therefore, the geometric network and its attributes are compared with other provider's geographical data. In a second step the street network graphs are used to solve a location-allocation problem in a case study about an Upper Austrian food retailer. The comparison of the results shows, that using diverse geographic data leads to the same facility locations and allocations. Subsequently, the applied geographic data are investigated in more detail. Missing data attributes which are highly relevant for heavy goods vehicles (HGV) routing like vehicle specific restrictions (height, width, weight) or HGV driving bans are depicted.

Keywords: GIS, national transport graph, energy-efficient logistics, location-allocation problem

1. INTRODUCTION

A Geographic Information System (GIS) like ESRI's ArcGIS™ as a computer-based system is able to collect, manage, edit, analyse and visualise spatially referenced information that can be used for different fields of application (Bill 2003). The increasing use of GIS for transportation (GIS-T) in combination with intelligent transportation systems (ITS) raises the demand for specialised and standardized digital maps for the purpose of routing and as a geo-referencing system. Focusing on commercial vehicle operations (CVO), GIS can be used within commercial vehicle preclearance, administrative processes and fleet management to increase the fleet safety and efficiency through routing and location-allocation procedures (Chen and Miles 1999). When it comes to these concrete applications of GIS the users are looking for maps with additional network parameters that are attuned to the commercial vehicle specifications. Heavy goods vehicles (HGV) cannot use all roads because of restrictions in vehicle total weight (e.g. bridges), height (e.g. tunnels, underpasses), width (e.g. narrow roads), severe inclines, narrow bends or sector-related HGV driving bans. To provide sufficiently valid results, it is also necessary to use frequently updated accurate maps.

There are many data suppliers which are anxious to provide their users with up-to-date accurate spatial data either commercially or free of charge. Vendors like NAVTEQ®, TomTom® MultiNet® and ESRI® provide frequent updates for their commercial datasets. Open Street Map (OSM)'s road network data is updated by the OSM-community and is free of charge.

In Austria together local and national authorities and administrations provide and constantly update the Austrian national transport graph (GIP.at) and Basemap.at. The public can use it without a licence fee because it is treated as Open Government Data. The GIP.at's national transport graph is the outcome of a several years lasting process of digitising administrative processes relating to transport infrastructure (Heimbuchner 2013a). "*The GIP.at offers the public administration and authorities an overview of the entire transport infrastructure by furnishing all the essential information in a nutshell. […] The GIP is also necessary to implement the Intelligent Transport Systems Act (IVS), the INSPIRE Directive and the PSI Directive with the local and regional authorities*" (Heimbuchner 2013b). It is the link between historically developed parallel systems. It covers all modes of transport (passenger car traffic, public transport, cycling and walking) on the road. With the help of e-government-processes the platform is continuously updated (Heimbuchner 2013a). The GIP.at graph is used as the basis of traffic modelling in the on-going projects "ITS Austria West" (ITSAW) and "ITS Vienna Region" (ITSVR) to can estimate real-time traffic conditions and short-term traffic predictions. In the project "Traffic Information Austria (VAO)" the GIP.at graph is used to geo-reference traffic information (Heimbuchner 2013c).

The aim of this study is to compare the Upper Austrian's GIP.at transport graph with different maps regarding their included parameters and their routing results. To provide comparable results of applications used these graphs a systematic approach is required. Therefore, a case is solved with each map. The different geographical datasets are integrated in ESRI's ArcGIS® software to analyse the effects of the integrated attributes on route suggestions. The case deals with an actual location-allocation problem of an Upper Austrian food retailer.

Strategic location planning is a quite complex task for companies – especially because decisions cause long-term effects. Retail businesses with lots of supermarkets are regularly faced with this problem. To solve this task, the location planning process needs quantitative as well as qualitative analysis. A location-allocation problem is part of the quantitative analysis and tries to calculate optimal locations while considering weighted customer locations. An analysis with ArcGIS Network Analyst™ provides solutions by using company data and geographical data. Due to the fact, that the same company data is used within each run, the quality do not influence the results and geographic data can be compared in terms of quality and applicability.

Additionally the attributes of the three graphs are analysed regarding their usability for commercial vehicle traffic and road restrictions regarding heavy goods vehicles (HGV), e.g. vehicle weight, height, width or sectoral prohibition on road transport.

2. CASE STUDY

The underlying case study deals with the supply network of a food retailer in Upper Austria. The company plans to strategically select some of the exiting supermarkets as cross-docking stations for unloading incoming merchandise from the central distribution centre and loading outgoing merchandise from regional food producer. This situation correspond to a location-allocation problem, that is, where to locate such cross-docking stations and which regional supermarket should be allocated to which station through minimizing costs within the supply network. The impedance within a network can be indicated differently, e.g. time, money CO_2 equivalents, or distance. The latter holds true for this case study. Furthermore, the food retailer decided to set up 10 cross-docking stations in order to ensure local products (grown locally, produced within the area).

3. METHODOLOGY

An important as well as critical component in the field of logistics represents facility location and allocation problems (Melo 2009). Whilst in early years only geographers had been interested in these problems, facility location and allocation models expanded their acceptance into other research areas, e.g. operations research. The problem is defined as locating "*…a set of new facilities such that the transport costs from facilities to customers is minimized and an optimal number of facilities have to be placed in an area of interest in order to satisfy the customer demand"* (Azarmand and Jami 2009, 93).

Several types of location-allocation problems have evolved over time, for instance, p-Median problem (Weber problem), the p-Center problem, uncapacitated facility location problem, capacitated facility location problem, or quadratic assignment problem (Eiselt and Sandblom 2004). According to Klose and Drexl (2005), respective models differ in space (continuous, discrete), objective (Minsum, Minmax), capacity (capacitated, uncapacitated, echelons (single-stage, multi-stage), product (single-product, multi-product), time (static, dynamic) and data reliability (deterministic, stochastic).

In this case study, a simple p-Median problem is set up which access real world street network data. Given a set of nodes Nwithin a network, consisting of a set of potential facilities $J \in N$ and a set of customer $I \in N$ the following linear optimization model can be formulated:

$$(1.1) \qquad \min z = \sum_{i \in I} \sum_{j \in J} w_i d_{ij} x_{ij}$$

where

$w_i \rightarrow weight\ on\ edge\ (transport\ volume)$
$d_{ij} \rightarrow distance\ between\ customer\ i\ and\ facility\ j$
$x_{ij} \rightarrow binary\ decision\ variable\ equals\ to\ 1$
$if\ a\ customer\ i\ is\ allocated\ to\ facility\ j$
$and\ 0\ otherwise$
$y_j \rightarrow binary\ decision\ variable\ equals\ to\ 1$
$if\ a\ facility\ j\ is\ opened\ and\ 0\ otherwise$

subject to

$$(1.2) \qquad \sum_{j \in J} x_{ij} = 1 \qquad \forall\ i \in J$$

$$(1.3) \qquad x_{ij} - y_j \leq 0 \qquad \forall\ i \in I, j \in J$$

$$(1.4) \qquad \sum_{j \in J} y_j = p \qquad \forall\ i \in I$$

$$(1.5) \qquad x_{ij} y_j \in \{0, 1\} \qquad \forall\ i \in I, j \in J$$

The objective function aims at minimizing the total weighted distance within the network (1.1). Constraints (1.2) guarantee that every customer is served by one facility, whereas Constraints (1.3) couple the location and allocation decision. The last Constraints (1.4) fix the number of selected facilities to p . Constraints (1.5) indicate binary variables for x_{ij} and y_j.

After setting up the mathematical model, data are integrated in ESRI® ArcGIS™ 10.0 software. To start with, all supermarkets' addresses are geocoded by the Address Locator 9.3.1 ESRI Europe Geocode Service (ArcGIS Online). Thereafter, three individual network datasets are created for the location-allocation analysis conducted by the ArcGIS Network Analyst 10.0: (i) national transport graph (GIP), (ii) OpenStreetMap (OSM) and (iii) TomTom MultiNet® 3.6.1 (TomTom).

Besides conducting a location-allocation analysis for the case study, the above-mentioned network datasets are analysed in more detail. Three categories were built to analyse different attributes. Especially data attributes which are required for commercial heavy goods vehicle (HGV) traffic, e.g. restrictions on weight, height, width or sectoral driving bans are investigated. Furthermore, the applicability of the defined network datasets for truck routing is tested.

4. FINDINGS

In the selected case study, the retailer plans to distribute regional products through cross-docking stations at least costs. In the forefront of the analysis, the retailer claimed 10 cross-docking stations for its supply network in Upper Austria. Conducting three different location-allocation analyses yield the following results.

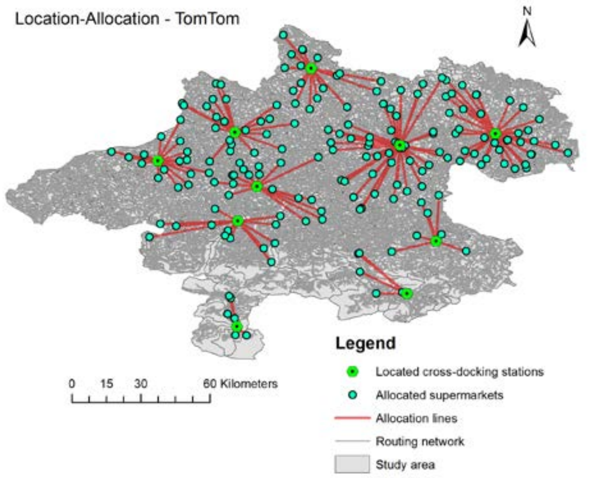

Figure 1: Location-Allocation – TomTom MultiNet®

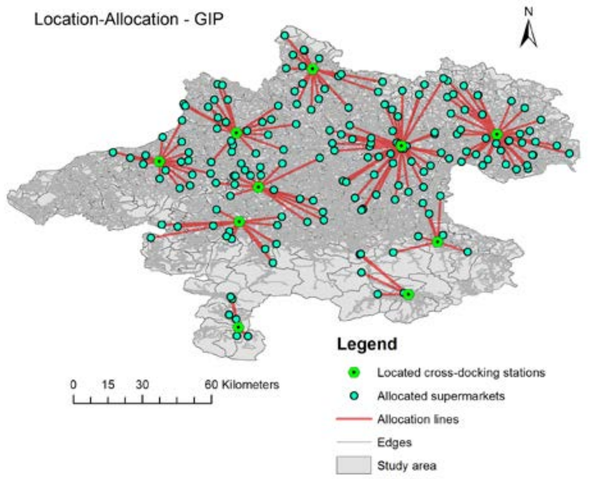

Figure 2: Location-Allocation – GIP

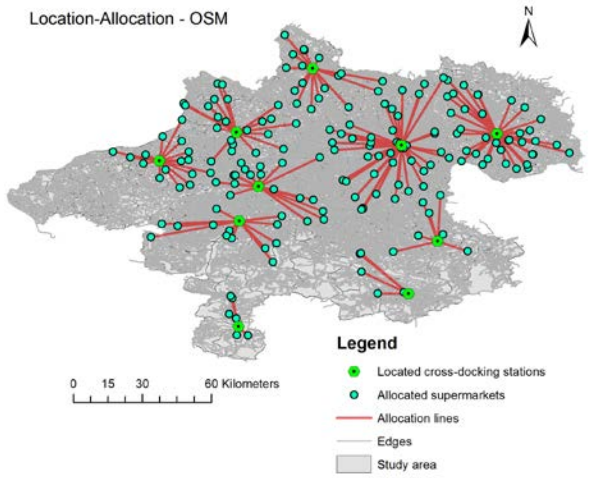

Figure 3: Location-Allocation - OSM

As can be seen in the figures 1-3 the analyses depict the same supply network structure for all three network datasets. It can be concluded that all of the selected spatial data – fee required or free of charge – exhibit sufficient data quality for strategic logistics problems. The following analysis focuses on tactical logistics problems dealing with truck routings and shows the applicability of the selected network datasets for this purpose.

To supply a detailed analysis of the three graphs, network attributes were regarded. Therefore, three categories,

- connections,
- general attributes, and
- HGV specific attributes

were defined and user guides of GIP, OSM (converted by Ramm Frederik) and TomTom were analysed regarding these categories.

- PRISMA Solutions (2012)
- Ramm (2011)
- TomTom (2013a)
- TomTom (2013b)

The findings are summarized below in Table 1 and discussed in the following section.

Table 1: General and HGV-specific attribute analysis

X yes O no	GIP	OSM	TomTom
connections			
road	X	X	X
ferry	O	O	X
congestion charge/ extra tolls	O	O	O
general element attributes			
street name	X	X	X
road category	X	X	X
one way	X	X	X
bridge	X	X	X
tunnel	X	X	X
altitude & grades	O	O	O
road element length	X	O	X
number of lanes	X	O	X
maximum speed limit	X	X	O
travel times	O	O	X
elevation of road elements	X	O	X
HGV-specific attributes			
vehicle height restriction	O	O	X
vehicle width restriction	O	O	X
vehicle weight restriction	O	O	X
low emission zone	O	O	X
HGV load restrictions	O	O	X
restricted manoeuvres	O	O	X
hazardous goods restrictions	O	O	X
time dependent HGV bans	O	O	O
parking space for HGVs	O	O	O
truck diversions	O	O	O
preferred truck routes	O	O	O

Table 1 shows the supported attributes of the compared graphs GIP, OSM and TomTom. Analysing the general attributes of the three network graphs it appears, that all graphs include street names, road categories, one way restrictions, bridges and tunnels. While GIP and TomTom use different attributes to define the road type (e.g. functional road class, form of way), OSM provides only one attribute which gives information about the street category and its use. Due to the fact, that Upper Austria has plain and mountainous regions a categorization of tunnels and bridges is desirable. Within the OSM and TomTom databases bridges and tunnels are entered as Boolean attributes. GIP takes bridges and tunnels into account in the road category using “bridge” and ”tunnel” as string extensions at the end. However, the altitude of road segments and their grade is implemented by none of the graphs.

Analyses of single network elements show that the support of some attributes vary. The element lengths are given as attributes in GIP and TomTom. However, also OSM provides this information indirectly via the elements geographic location. The number of lanes is given in the graphs of GIP and TomTom. Focusing on the availability of the number of lanes, it seems that this information is only available for motorway junctions and a few junctions on primary roads in the TomTom graph. OSM graph doesn’t support this information. The GIP graph seems to provide complete and accurate information about the number of lanes of each road.

All three graphs include the attribute speed. While GIP and OSM take the official speed limit into account, TomTom uses calculated average speeds that seem to be higher than the official maximum speed limit. Nevertheless, TomTom provides estimated travel times for each road element. GIP and OSM can also provide this information by calculating it as far as they provide information on length and maximum speed for the regarded element.

The elevation of roads, which describes the level of an element in relation to another element at junctions without cross traffic or bridges, is implemented by GIP and TomTom.

Taking into account logistic activities it appears, that only TomTom provides specific attributes in an additional package. Examples for included restrictions are:

- vehicle height,
- vehicle width,
- vehicle weight,
- entry in low emission zones,
- HGV load,
- manoeuvres at junctions, and
- hazardous goods.

Specific characteristics like the Austrian time dependent HGV ban at weekends and information about available parking space for HGVs are not integrated in any of the graphs. Also preferred truck routes and diversions are not emphasised in the graphs.

The following section discusses the completeness and accurateness of the three transport graphs in a map extract of the city centre and a highly frequented road junction of the City of Steyr.

Figure 4: City of Steyr with representations of OSM (blue), GIP (green) and TomTom (red)

Figure 4 shows the three graphs for the Upper Austrian City of Steyr lying upon another. The blue network refers to the OSM graph, which looks to be very detailed. A reason for that is the integration of walking and cycling paths and private roads at company sites. However, the red GIP graph and green TomTom graph, which integrate only roads, show that also OSM does not cover all road elements in this area.

Additionally, there are also differences how the nodes and links of streets are located and so the roads and lanes are geometrically recorded in the three graphs. This fact is shown in figure 5, which illustrates a main junction in the City of Steyr and their divergent graphical representations. As shown in Figure 5 access walking paths are implemented in OSM (blue) only.

Figure 5: Imprecise and divergent graphical schematic views of a crossroads in Steyr by OSM (blue), GIP (green) and TomTom (red)

A comparison of web-routing-services based on TomTom, VAO and OSM transport graphs shows, that street restrictions in these spatial datasets may differ. While planning a route through Steyr, it is shown that the TomTom Route Planner (TomTom 2013c) ignores a road closures due to road constructions (figure 6: section S1), which was set up several months ago. The VAO routing planner (VAO 2013), which uses the GIP transport graph, ignores a pedestrian zone (figure 7: section S2) as well as the Open Source Routing Machine (OSRM 2013) does, which uses the OSM transport graph (figure 8: section S3). Summarising the above, it has to be noted that none of the routing services achieved a reasonable result.

Figure 6: TomTom Online Route Planner

Figure 7: VAO Routing Planner (GIP graph)

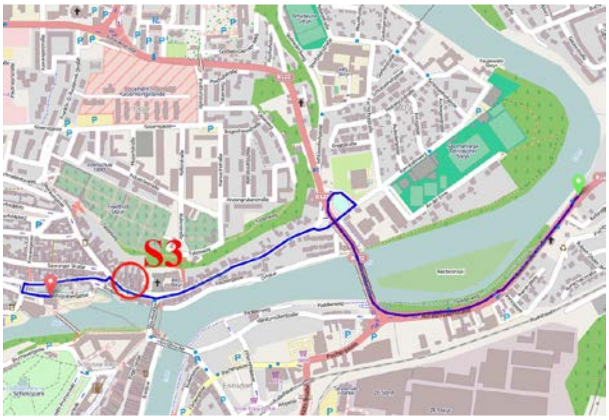

Figure 8: Open Source Routing Machine (OSM graph)

5. DISCUSSION

Research shows, that all three maps are practicable for the location-allocation problem. Further the analyses depict the same supply network structure for all three network datasets. Therefore it can be concluded that all of the selected spatial data – fee required or free of charge – exhibit sufficient data quality for strategic logistics problems in the Upper Austrian territory.

The following analyses focused on tactical logistics problems and on network parameter details revealed, that the considered datasets may differ in how nodes and links are geometrically recorded and attributes like road restrictions are supported or their values are entered.

While all maps seem to be relatively up-to-date, the GIP.at for Upper Austria provides persistently updated maps by the competent administration itself. Furthermore it's free of charge. However, there are missing HGV-specific attributes to use them for a commercial logistics purpose. To become the reference for all commercial or open-source transport graphs the following HGV-specific network parameters should be implemented:

- vehicle height restrictions
- vehicle width restrictions
- vehicle weight restrictions
- entry in low emission zones
- HGV load restrictions
- manoeuvres at junctions
- hazardous goods
- altitude & grades
- curve radius
- time dependent HGV bans
- parking space for HGVs
- congestion charge/ extra tolls
- multimodal/intermodal hubs
- truck diversions and bypasses
- preferred truck routes

The latter is of particular importance to be able to intervene in the road freight transport system and to redirect heavy goods vehicles away from residential areas. The integration of multimodal/intermodal hub data could strengthen the position, attractiveness and ease of use of intermodal transport systems.

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REFERENCES

Azarmand, Z., Jami, E.N., 2009. *Facility location: concepts, models, algorithms and case studies*. Berlin: Springer.

Bill, R., 2003. Grundlagen der Geo-Informationssysteme. University of Rostock. Available from: http://www.geoinformatik.uni-rostock.de/vorlesungdoc/gis-grundlagen2003.pdf [accessed 15 May 2013]

Chen, K., Mils, J.C., 1999. ITS Handbook 2000: Recommendations of the World Road Association (PIARC). Boston: Artech House.

Eiselt, H.A, Sandblom, C.L., 2004. Decision Analysis, Location Models, and Scheduling Problems. Berlin: Springer.

Heimbuchner, K., 2013a. GIP.at.Technical Details. Available from: http://www.gip.gv.at/gipat-technical-details.html [accessed 15 May 2013]

Heimbuchner, K., 2013b. GIP.at.Incentive and Goals. Available from: http://www.gip.gv.at/gipat-incentive-and-goals.html [accessed 15 May 2013]

Heimbuchner, K., 2013c. VAO Technical Details. Available from: http://www.gip.gv.at/vao-technical-details.html [accessed 15 May 2013]

ITSAW, 2013. Factsheet ITS Austria West. Available from: http://www.its-austriawest.at/media/Factsheet_ITS_AustriaWest_engl2.pdf [accessed 15 May 2013]

ITSVR, 2013. About ITS Vienna Region. Available from: http://www.anachb.at/more/its-vienna-region [accessed 15 May 2013]

Klose, A., Drexl, A., 2005. Facility location models for distribution system design. In: *European Journal of Operational Research* 162, pp. 4-29.

Melo, T. et al, 2009. Facility location and supply chain management. A review. In: *European Journal of Operational Research* (196), pp. 401–412.

OSRM, 2013. OSRM Online route planner. Available from: http://map.project-osrm.org/ [accessed 15 July 2013]

PRISMA Solutions (Ed.), 2012, GIP-Datenmodell Physische Ebene. Version 1.3.

Ramm, Frederik, 2011, OpenStreetMap Data in Layered GIS Format. Version 0.6.

TomTom (Ed.), 2013a, MultiNet OSL. Format Specification 4.6. Version 1.4.

TomTom (Ed.), 2013b, MultiNet Logistics 4.4. User Guide v 1.4.6.

TomTom, 2013c. TomTom Online Route Planner. Available from: http://routes.tomtom.com/ [accessed 15 July 2013]

VAO, 2013. VAO Multimodal Route Planner. Available from: http://demo.verkehrsauskunft.at [accessed 15 July 2013]