THE ROLE OF GIS IN PORT HINTERLAND MODELLING BASED ON PORT CHOICE

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Abstract: *Geographic information systems (GIS) play more and more important role in port hinterland modelling. They appear in illustrating and assessing of port hinterlands, and consequently in assisting of port planning and development. Three basic GIS constituent parts of such model are transportation network system, consisting of nodes and weighted links, different kinds of additional spatial data and visualization. In our research we present one option to model port hinterlands, although the conventional representation of port's hinterland has drastically changed in recent years. We introduce a model, which is based on the results of port choice modelling, where shippers' port choice is a trade-off between various objective and subjective factors. We upgrade the model by sophisticated visualization where three-dimensional GIS tools are effectively utilized.*

Key words: *GIS, 3D GIS, port hinterland modelling, port choice, visualization.*

1. INTRODUCTION

Port hinterland presents the inland area surrounding a port from which goods are either distributed, or at which they are collected for shipping to other ports. In other words, the traditional concept of hinterland conceives it as the area whose contour is a continuous line bounding the port economics with influence on the shore (Ferrari, Parola, & Gattorna, 2011). The conventional representation, based on distance decay, is being replaced with spatial discontinuity and clustering (Notteboom & Rodrigue, 2007). Here we find the connection between the definition of the hinterland and the port choice problem. Among the decision-makers belong shippers, forwarders, shipping companies and terminal operators (Sys & Vanelslander, 2013), while some authors indicate also port authorities and government agencies as influencing port choice.

A number of mathematical programming models have been developed, with respect to the many involved factors, in order to minimize the total operation cost by selecting an appropriate port as the most favourable one to call. In general, all models treated the problem of port choice as a multiple criteria decision-making problem.

In this paper we spatially model the port hinterland which is based on port choice problem (Kramberger, Rupnik, Štrubelj, & Prah, 2015). Different authors have also used GIS in modelling

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and visualizing port hinterlands. For example, GIS was used to illustrate and asses captive and contestable port hinterlands, and the results have been recognized as useful in port planning and decision-making (Kronbak & Cullinane, 2011). GIS was also used in studying the port development due to the containerization process, and the methodology was applied in a case study of the port of Rio Grande (Pizzolato, Scavarda, & Paiva, 2010). In another study a multi-layered hinterland classification of major Indian ports for containerized shipments was developed. The approach integrates GIS visualization and data mining methods (Thill & Venkitasubramanian, 2015).

2. PROBLEM DEFINITION

The aim of the paper is to visualize port hinterland modelling in an advanced way. Here we used three-dimensional GIS, since it allows observing the data in true perspective, which consequently allows to make better decisions, and to communicate the ideas more effectively and efficiently.

The problem discussed in the paper focuses on modelling the port's hinterlands and their visualization using GIS. Port hinterland modelling of European ports is done by observing the cargo flow from the origin (Asian) to the destination (European) ports, and from those toward consumption destinations. The question that arises is what hinterland area is covered by which of the destination ports. Using the subjective factors to estimate the preference of individual ports allows for constructing a decision model (Chou, 2010).

The cargo flow follows from production destinations to origin ports using land transport, following shopping via sea routes to destination ports, and land transport from destination ports to consumption destinations across Europe. The focus is on finding out which destination port is optimal for supplying each consumption destination, which represents the hinterland of the respective port. The visualization is then focused on grouping the consumption points supplied by the same destination port.

3. METHODOLOGY

The main idea of the methodology is that if the certain port is port of choice for a certain consumer point, then this consumer point lies within this port's hinterland. As the purpose of the model is to find the hinterlands of destination ports, the only observed cargo shipping direction is in sequence from production points S_K towards consumer points C_L. The model operates on the distances between the elements of each set as well as preference rates of each individual port, both on the origin as well as on the destination side (Kramberger, Rupnik, Štrubelj, & Prah, 2015):

- x_{ki} – edges between production points $S_k \in S_K$ and origin ports $P_i \in P_I$
- x_{ij} – edges between origin ports $P_i \in P_I$ and destination ports $P_j \in P_J$
- x_{jk} – edges between destination ports $P_j \in P_J$ and consumer points $C_l \in C_L$
- PR_i – preference rates of origin ports $P_i \in P_I$
- PR_j – preference rates of destination ports $P_j \in P_J$
- sup_k, $cons_l$ –supply of production points and consumption of consumer points
- $k = 1 \dots K, i = 1 \dots I, j = 1 \dots J, l = 1 \dots L$

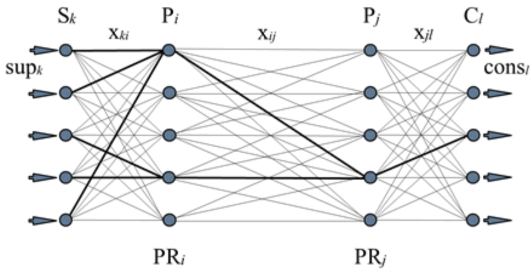

Figure 1. One of the port choice problem solutions (Kramberger, Rupnik, Štrubelj, & Prah, 2015)

The model is presented in Figure 1. The goal is finding the optimal destination ports $P_j \in P_J$ for each of the consumer points $C_l \in C_L$ based on both transportation costs and port preference rates.

As we stated before, consumer point C_l lies within the port's P_j hinterland, when the port P_j is port of choice for consumer point C_l. Let C_L be a set of all consumer points that are uniformly distributed in a predefined geographical area E. Each consumer point $C_l \in C_L$ is connected to the destination ports via railroad connections. Distances d_{jl} are measured as sum of aerial distance from each C_l to the nearest railroad section and from there to the destination ports $P_j \in P_J$ by railroad distances.

The second stage of the methodology consists of three sub-stages as follows: implementation of AHP, definition of the weights and port selection using LP. The methodology with all sub-stages is explained more details in the paper (Kramberger, Rupnik, Štrubelj, & Prah, 2015). Along with the distances, each port is assigned a preference rate, which is calculated using the Analytic Hierarchy Process (AHP) using various subjective factors that are described in greater detail in (Button, Chin, & Kramberger, 2015) .

3.1 Optimal port selection using LP

Figure 1 reveals that the costs for moving goods from S_k to C_l are the sum of land transport cost to move goods along the edge x_{ki}, the costs of maritime transport along x_{ij} and land transport cost along the edge x_{jl}. Therefore the costs of different parts of transport process can be expressed as a sum of weights w_{ki} , w_{ij} or w_{jl} assigned to certain edge respectively. The cost of this situation can be mathematically expressed by Linear Programming model (LP) below:

$$\min W = \sum_{k=1}^{K}\sum_{i=1}^{I} x_{ki}w_{ki} + \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij}w_{ij} + \sum_{j=1}^{J}\sum_{l=1}^{L} x_{jl}w_{jl} \quad (1)$$

$$\sum_{i=1}^{I} x_{ki} \geq \frac{sup_{s_k}}{\sum_{k=1}^{K} sup_{s_k}} \quad k = 1,2,\dots,K \quad (2)$$

$$\sum_{k=1}^{K} x_{ki} - \sum_{j=1}^{J} x_{ij} \geq 0 \quad i = 1,2,\dots,I \quad (3)$$

$$\sum_{i=1}^{I} x_{ij} - \sum_{l=1}^{L} x_{jl} \geq 0 \quad j = 1,2,\dots,J \quad (4)$$

$$\sum_{i=1}^{K}\sum_{j=1}^{L} x_{ij} = \begin{cases} 1; if\ there\ is\ a\ connection\ to\ P_j \\ 0; otherwise \end{cases} \quad (5)$$

$$\sum_{i=1}^{I} x_{jl} \geq \frac{cons_{C_l}}{\sum_{l=1}^{L} cons_{C_l}} \quad l = 1,2,\dots,L \tag{6}$$

The constraints ensure that the flow from S_k to P_i is greater or equal the supply at $S_k$divided by the sum of all supplies (2). Constraints (3) and (4) represent the incoming and outgoing flow at the departure or destination ports, which needs to be greater than or equal to zero. To ensure that only one port is selected at a time, the sum of all x_{ij} in constraint (5) is either 0 or 1 for each destination port, however all the variables are of general type. The port with the sum of 1 appears in the solution. Like supply, the last constraint is required for the flor from destination ports to consumer points, which is greater or equal to the demand of consumer points divided by the sum of all demands. LP set to minimize costs is applied in order to find the optimal destination port.

3.2 Ports' hinterland area calculation and visualization

To present visualization more sophistically, a three-dimensional GIS was used. In this process, the digital elevation model (DEM) for observed part of Europe was prepared first. Further several ArcGIS geoprocessing tools were used (ArcGIS for Desktop: Release 10.2.2., 2014): tool Mosaic Dataset to merge different data sheets, and tool Extract by Mask to cut DEM for observed region. Due to relatively large observed area the size of the raster cells was increased from 25x25 meters to 100x100 meters. Finally the tool Raster to TIN (ArcGIS for Desktop: Release 10.2.2., 2014) was used to convert a raster to a triangulated irregular network dataset. Here the height coordinates were inflated for better visualization. Example of 3D visualization can be seen in figure 2.

4. DATA AND CALCULATIONS

4.1 Data sets

Port hinterlands were modelled using available data that consists of origin ports in Asia (Singapore, Hong Kong, Busan, Kaohisiung, and Port Klang), destination ports in northern (Rotterdam, Hamburg, and Bremerhaven) and southern (Koper, Rijeka, Trieste, Venetia, and Ravenna) Europe. Sailing times between origin ports and destination ports were calculated by assuming the most common cruising speed of 21 knots over the standard sea routes. The sailing days were acquired from a web service (Sea rates, 2011). The data for operating costs was acquired by surveying shippers, logistics providers, and retailers. Preference rates were calculated using analytic hierarchy process (Kramberger, Rupnik, Štrubelj, & Prah, 2015). The preference rates for origin ports can be seen in table 1, and preference rates of destination ports in table 2.

Table 1. Operating costs and preference rates of origin ports (Kramberger, Rupnik, Štrubelj, & Prah, 2015)

Ports P_I	Operating costs (in $)	Preference rate
Singapore	5,420	0.211
Hong Kong	5,820	0.211
Busan	17,004	0.202
Kaoshiung	7,115	0.196
Port Klang	5,275	0.180

Table 2: Operating costs and preference rates of destination ports (Kramberger, Rupnik, Štrubelj, & Prah, 2015)

Ports P_J	Operating costs (in $)	Preference rate
Koper	34,033	0.097
Rijeka	35,814	0.095
Trieste	37,164	0.106
Venice	35,630	0.101
Ravenna	34,095	0.100
Rotterdam	43,052	0.168
Hamburg	35,900	0.167
Bremerhaven	36,350	0.166

4.2 Calculation

LP results are used as input for ArcGis, which is used to construct the Voronoi diagram over consumer points and to assign the Voronoi region of each point to its designated destination port. Further, the Voronoi regions assigned to the same destination ports are merged, forming their hinterlands (Kramberger, Rupnik, Štrubelj, & Prah, 2015). The results can be seen in figure 2.

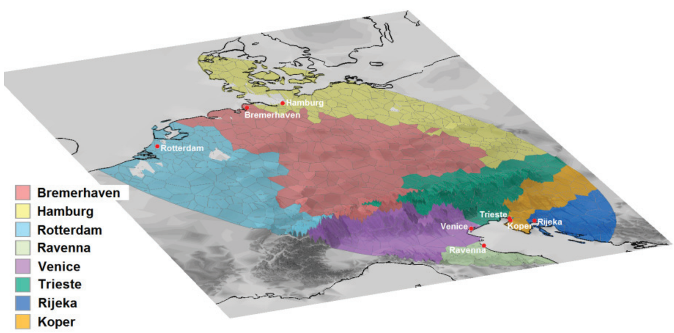

Figure 2. Port hinterlands

3D visualization allows us to see whole area even more plastically. We can recognize Alps as mountain barrier, where hinterlands of Rotterdam, Bremerhaven and Venice meet, while is the hinterland of Trieste focused mainly on eastern alpine and subalpine region.

Undoubtedly, the terrain influences the transportation network significantly. Especially young fold mountains like Alps represent great natural barriers. But, not only natural - Trans Alpine area represents an important example of a physical/political/economic “arena”, and transalpine freight transport represents one of the most challenging operational and policy issues of freight transport development. Freight transport operators are on the one side confronted with a limited capacity of the Trans-Alpine transport infrastructure and with environmental constraints, and on the other hand, there is a permanent need to serve the growing demand in a more efficient manner. This applies even more since we know that the traffic in the Transalpine-chain will continue to grow (Reggiani, Cattaneo, Janic, & Nijkamp, 2000).

5. CONCLUSIONS

The main restrictions of the model are due to the data availability. The hinterlands were modelled based on the surveys that include the three northern and four Adriatic ports. This case only represents the hinterland competition of the stated ports. Other ports also play a role in forming the hinterlands and given the data, the results would differ.

The benefit of 3D visualization is to explain the extension of port hinterlands in connection with terrain characteristics, such as flatlands, mountains, valleys etc. We can do the analysis, which comprises both variables – hinterlands and terrain. Even more since we know that physical characteristics influence political and economic characteristics which overall influence transport and accessibility characteristics in region. The methodology of hinterland modelling, presented in the paper, takes into account many different factors that influence the port choice. The hinterland displayed on the figure 2 is calculated according to present data. The data such as port charges, land transport costs or preference rates can change over time. This should consequently change the shape and size of the hinterland of certain ports. Therefore, the presented methodology could be used to simulate different scenarios and different relations between the influencing factors. The results might send a strong signal to policy decision-makers and their efforts to achieve better results in comparison with competing ports.

REFERENCES

[1] ArcGIS for Desktop: Release 10.2.2. (2014). Redlands, CA: Environmental Systems Research Institute.

[2] Button, K., Chin, A., & Kramberger, T. (2015). Incorporating subjective elements into liners' seaport choice assessments. Transport Policy, 44, 125-133.

[3] Chou, C. C. (2010). AHP model for the container port. Journal of Marine Science and Technology, 18(2), 221-232.

[4] Ferrari, C., Parola, F., & Gattorna, E. (2011). Measuring the quality of port hinterland accessibility: The Ligurian case. Transport Policy, 18, 382-391.

[5] Kramberger, T., Rupnik, B., Štrubelj, G., & Prah, K. (2015). Port hinterland modelling based on port choice. Promet - Traffic & Transportation, 27(3), str. 195-203.

[6] Kronbak, J., & Cullinane, K. (2011). Captive and contestable port hinterlands: modelling and visualization using GIS. V K. Cullinane, International handbook of Maritime Economics (str. 348-361).

[7] Notteboom, T., & Rodrigue, J. (2007). Re-Assessing Port-Hinterland Relationships in the Context of Global Commodity Chains. V :. J. Wang et al. (eds) (Ured.). London: Ashgate.

[8] Pizzolato, N. D., Scavarda, L. F., & Paiva, R. (2010). Zonas de influência portuárias – hinterlands: conceituação e metodologias para sua delimitação (Ports influence zones – hinterlands: concepts and methodologies for their delimitation). Gest. Prod., 17(3), 553-566.

[9] Reggiani, A., Cattaneo, S., Janic, M., & Nijkamp, P. (2000). Freight transport in Europe - Policy Issues and Future Scenarios on Trans-Border Alpine Connections. IATSS Research, 24(1), 48-59.

[10] Sea rates. (2011). Pridobljeno 2015 iz SeaRates.com: http://www.searates.com/reference/portdistance/

[11] Sys, C., & Vanelslander, T. (July 3-5 2013). Port Hinterland Competitiveness: Analysis of a Road Expansion Project, applied to the Port of Zeebruges. Proceedings of IAME 2013 Conference. Marseille, France.

[12] Thill, J.-C., & Venkitasubramanian, K. (2015). Multi-layered hinterland classification of Indian ports of containerized cargoes using GIS visualization and decision tree analysis. Maritime Economics & Logistics, 17(3), 265-291