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PORT HINTERLAND MODELLING BASED ON PORT CHOICE

ABSTRACT

This paper presents a new approach for hinterland modelling based on the results of port choice modelling. The paper follows the idea that the shippers' port choice is a trade-off between various objective and subjective factors. The presented model tackles the problem by applying the AHP method in order to obtain ports' preference rates based on subjective factors, and combine them with objective factors, which include port operation costs, sailing times, and land transport costs using MILP. The ports' hinterlands are modelled by finding the optimal port of choice for different locations across Europe and merging the identical results. The model can be used in order to produce captive hinterland of ports and can also be exploited in order to analyse how changes in the traffic infrastructure influence the size of hinterlands.

KEY WORDS

port hinterland modelling; captive hinterland; contestable hinterland; MILP; GIS; objective and subjective factors;

1. INTRODUCTION

Port hinterland presents the inland area surrounding a port from which the goods are either distributed, or at which they are collected for shipping to other ports. In abstract terms, the traditional concept of hinterland conceives it as an area whose contour is a continuous line bounding port economics with influence on the shore [1]. Although the concept is well known, it is extremely difficult or even impossible to pinpoint the port's hinterland. The conventional representation of a hinterland, often linking the clients of the port with a distance decay perspective, is being replaced with one where spatial discontinuity and clustering prevails [2]. The distance became only one of the factors contributing to the overall problem. In this respect, a fundamental role is played by the effectiveness of inland connections. The better the connection of a port to various inland markets, the bigger the potential to enlarge its overall captive area [1]. However, Haralambides claims that for most ports such captive hinterlands have diminished [3]. In most of the cases the captive hinterlands were downgraded to contestable hinterlands where there is no single port with a clear cost advantage over competing ports. As a consequence of this fact the interport competition has encountered an enormous increase of volume in the last few years [4]. In practice, this means that maritime transport users can choose any feasible port in the area. This fact strongly connects the definition of the hinterland with the port choice problem.

The literature review of port competition reveals a wide range of factors influencing the decision of port choice. The decision makers identified by authors of previous papers are: shippers, forwarders, shipping companies and terminal operators [5]. Some authors indicate also port authorities and government agencies as influencing port choice of those actors. Traditionally, the port authorities generally play a minor role in the port hinterlands development, but shippers, freight forwarders and rail operators have always been involved in the port-hinterland connection [6]. Since contemporary improvements in maritime shipping are mainly based on inland transport system improvements [2] and intermodal hinterland networks became more important than in the past, the port authorities were urged to become active players in the hinterland development. Some researchers still believe that the hinterland is defined by explanatory power of distance [7] while others claim that hinterland is defined by hard competitive game among the top players [8]. Due to these facts it is clear that the definition of hinterland is strongly associated with the port choice.

The attraction of the port choice problem is reflected by the fact that Sargent dealt with it already in 1938 [9]. He claimed: cargo tends to seek the shortest route to access the sea. In the field of research into the Port Choice problem one can find many papers by various authors. A structured review on methodological issues since 1980s can be observed in [10].

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. Some of them use the linear programming technique to determine the optimal location of the port [11], others proposed the weight factor analysis to integrate quantitative data with qualitative rating [12]. Lately, the authors have used Analytical Hierarchy Process and Fuzzy approach to solve the port selection problem [13]. But in general, no matter whether on the basis of two or more factors, they considered the problem of port choice as a multiple criteria decision-making problem.

In this paper the port hinterland is spatially modelled by solving the port choice problem. In the past we already considered the port choice problem as a Discrete Optimization Problem. We follow the idea that the port choice is a trade-off between objective and subjective factors [14] and it is still related to the inland distance, but in this case the distance is only one of the parameters that contribute to the decision.

The paper presents a new hybrid model combining Mixed Integer Programming method (MILP) and Analytic Hierarchy Process (AHP) [14]. For the visualisation of the results the developed model is combined with GIS technology.

The paper is organized as follows. In the first section the background is explained and the essential literature review presented. In the next section we define the problem and explain the model. The fourth section presents the data and calculation results.

2. PROBLEM DEFINITION AND METHODOLOGY

The aim of the present paper is to answer the question whether the port's hinterland can be modelled with the solution of the port choice problem. The working hypothesis is thus as follows: "Port's hinterland can be modelled with the solution of the port choice problem".

The problem discussed in the paper focuses on modelling port's hinterland, when transportation of cargo from one or more production points located in Asia to consumption points located in Europe is considered. In other words, the potential area served from certain port is calculated and visualized. The obvious motive is to find the most economical route from the production point to the consumer point, which can be calculated using the known transportation costs and distances. However, as stated in [14], subjective factors such as quick response to port users' needs, port's reputation for cargo damage, etc. [15] also play an important role and need to be taken into account. Subjectivity in the decision-making process in the model is illustrated by the so-called preference rate [16]. The model takes into account preference rates of both origin ports and destination ports, which also influence the decision of port choice.

The transport starts at the production points from where the cargo is moved using land transport to ports of origin, followed by shipping via sea routes to the destination ports, and finally transport to consumer points, which again takes place using land transport.

2.1 The model

The methodology based on the idea that if a certain port is the port of choice for a certain consumer point, then this consumer point lies within the port's hinterland. In order to solve the problem stated above, the following sets have to be defined:

1. Production points S_K;
2. Origin ports P_I;
3. Destination ports P_J;
4. Consumer points C_L;

where the set indices denote the number of elements. As the purpose of the model is finding the hinterlands of destination side ports, the only observed cargo shipping direction is in sequence from S_K towards C_L. The model operates on the distances between the elements of each set as well as the preference rates of each individual port, both on the origin as well as on the destination side:

- 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

$k = 1 \ldots K$, $i = 1 \ldots I$, $j = 1 \ldots J$, $l = 1 \ldots L$

The situation is displayed in *Figure 1*. Although the model optimizes the whole transport route from the production points to the consumer points, the main purpose of the model is finding the optimal destination port $P_j \in P_J$ for each of the consumer points $C_l \in C_L$ based on transportation costs and port preference rates.

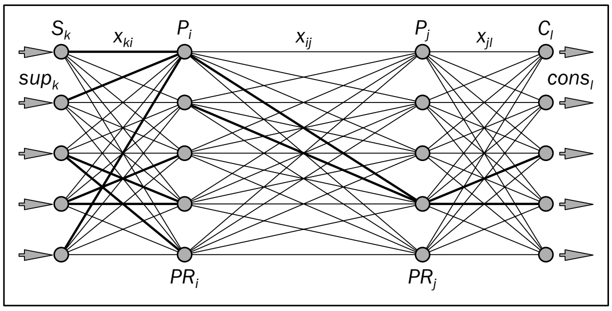

Figure 1 - One of the port choice problem solutions

The presented method consists of the following stages:

1. Consumer points generation;
2. Port of choice calculation per consumer point;
3. Ports' hinterland area calculation and visualization.

2.2 Stage 1: Consumer points generation

As stated before, consumer point C_l lies within the port's P_j hinterland, when the port P_j is the 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.

2.3 Stage 2: Port of choice calculation

The second stage of the methodology consists of three sub-stages as follows: implementation of AHP, definition of the weights and port selection using MILP. The sub-stages are explained in the next three subsections.

AHP implementation

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 further described in the next subsection. The AHP method to identify the stated preference about the port choice was already used by Chou [16]. Data employing AHP were obtained through surveys of several logistics providers, freight forwarders. In the first stage of AHP, the subjective factors are ranked by importance. Each respondent is required to rank the criteria from 1 to 10, where 1 is the highest influence, for each port separately.

In the second stage the ports are compared against each other according to the ranked factors. Based on this, each port is given a preference rate compared to its competitors - PR_i on the origin side and PR_j on the destination side. The subjective factors are described in section 3.1.4.

Weights definition

For the connections between production points and origin ports (Eq. 1), origin ports and destination ports (Eq. 2), and destination ports and consumer points (Eq. 3), the following weights for each are defined:

$$w_{ki} = \frac{1}{PR_i} T_{rail} d_{ki} \tag{1}$$

$$w_{ij} = \frac{1}{\overline{PR_{ij}}}\left(\frac{SC_{ij}}{\overline{ST}} ST_{ij} + \frac{PC_i}{cap} + \frac{PC_j}{cap}\right) \tag{2}$$

$$w_{jl} = \frac{1}{PR_j} T_{rail} d_{jl} \tag{3}$$

Where PR_i and PR_j are the preference rates for ports P_i or P_j, respectively. $\overline{PR_{ij}}$ is the geometric mean of preference rates PR_i and PR_j. $T_{rail} d_{ki}$ is the product of rail tariffs (\$/(TEU*km)) and distances (km) from the production points to origin ports. The destination side is defined by the same principle with the preference rates and distances being replaced by destination ports and consumer points.

ST_{ij} is the sailing time between ports P_i and P_j, and $\overline{ST}$ mean sailing time between origin and destination ports. PC_i and PC_j are port charges for ports P_i and P_j respectively and SC_{ij} represents the overall shipping cost on the route from P_i to P_j, and *cap* denotes the shipping capacity.

The data needed for implementation of the model are presented with the following matrices:

$$W_{KI} = [w_{ki}], \text{ where } k = 1 \ldots K \text{ and } i = 1 \ldots I \tag{4}$$

$$W_{IJ} = [w_{ij}], \text{ where } i = 1 \ldots I \text{ and } j = 1 \ldots J \tag{5}$$

$$W_{JL} = [w_{jl}], \text{ where } j = 1 \ldots J \text{ and } l = 1 \ldots L \tag{6}$$

Optimal port selection using MILP

Mixed Integer Linear Programming (MILP) is an optimization technique where some variables are required to be integer, while others may be continuous. The method relies on setting the proper constraints that describe the optimization problem. Generally speaking from the shippers point of view the most effective port for them is the port which causes the lowest cost. *Figure 1* reveals that the costs for moving goods from S_k to C_l is the sum of land transport cost to move goods along edge x_{ki}, the cost of maritime transport along x_{ij} and land transport cost along edge x_{jl}. Therefore, the costs of different parts of transport process can be expressed as a sum of weights $w_{x_{ki}}$, $w_{x_{ij}}$ or $w_{x_{jl}}$ assigned to certain edge, respectively. The cost of this situation can be mathematically expressed by Eq. 7:

$$W = \sum_{k=1}^{K}\sum_{i=1}^{I} x_{ki} w_{ki} + \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} w_{ij} + \sum_{j=1}^{J}\sum_{l=1}^{L} x_{jl} w_{jl} \tag{7}$$

$$\sum_{i=1}^{I} x_{ki} \geq \frac{sup_{S_k}}{\sum_{k=1}^{K} sup_{S_k}} \quad k = 1,2,\ldots,K \tag{8}$$

$$\sum_{k=1}^{K} x_{ki} - \sum_{j=1}^{J} x_{ij} \geq 0 \quad i = 1,2,\ldots,I \tag{9}$$

$$\sum_{i=1}^{I} x_{ij} - \sum_{l=1}^{L} x_{jl} \geq 0 \quad j = 1,2,\ldots,J \tag{10}$$

$$\sum_{i=1}^{KI} x_{ij} = \begin{cases} 1; \text{if there is a connection to } D_j \\ 0; \text{otherwise} \end{cases} \tag{11}$$

$$\sum_{i=1}^{I} x_{jl} \geq \frac{cons_{C_l}}{\sum_{l=1}^{L} cons_{C_l}} \quad l = 1,2,\ldots,L \tag{12}$$

Here, the left side is the flow from each S_k to all P_i and must be greater than or equal to the supply *sup* of production point S_k divided by the sum of all supplies (Eq. 8). The constraints for departing ports are described as the difference between the incoming and outgoing flow at port P_i which has to be greater than or equal to zero (Eq. 9). Constraints for destination ports representing the difference between the incoming and outgoing flow at port P_j are similar as to those for departure ports (Eq. 10). Here, additional constraints assure that only one port is selected at a time, so the sum

$$\sum_{i=1}^{I} x_{ij}$$

has binary values (Eq. 11). The constraints for the consumer points *cons* are similar to those for production points. On the left is the flow from P_j to all C_l, which is greater than or equal to the demand *cons* of C_l divided by the sum of all demands (Eq. 12).

Finally, the origin-destination cost matrix is calculated for each of the consumer points, and MILP is applied in order to find the destination port that minimizes the costs.

2.4 Ports' hinterland area calculation and visualisation

The computation of port hinterland polygons is based on MILP results. Hinterland polygons are formed by constructing a Voronoi tessellation, which uses consumer points C_L as input. In this way, each consumer point C_l covers the area R_l, in which distance *d* is nearer to C_l than to other point in C_L as depicted in Eq. 13.

$$R_l(C_l) = r \subset R \,|\, d(r, C_l) \leq d(r,h) \quad l,h = 1,2,\ldots L, l \neq h \tag{13}$$

With consumer points being assigned to specific destination ports, the hinterland of each port H_j is defined as a union of all Voronoi regions encompassing a consumer point belonging to the same destination port (Eq. 14). All Voronoi regions reaching outside the selected geographical area of consumer points were clipped against area *E*.

$$H_j = \bigcup R_l, \quad P(C_l) = P_j, l = 1,2,\ldots,L \tag{14}$$

The calculation and visualisation of hinterland areas was done using ArcGis software. Different colours were selected for each destination port. Each Voronoi region that covers a consumer point belonging to the same port is assigned the same colour as its port. In this way the hinterlands of each individual port can be distinguished. Examples can be seen in Figures 2, 3, and 4.

3. DATA AND CALCULATIONS

3.1 Data sets

In order to calculate and visualize the hinterlands of certain ports we have to create certain data sets, such as consumer points, port of origin and destination ports, weighted sea distances and weighted land transport distances.

3.1.1 Ports of origin, destination ports and weighted sea distances

Port hinterlands were modelled using available data that consist 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,

Table 1 - Sailing times (days)

	Singapore	Hong Kong	Busan	Kaohsiung	Port Klang
Koper	21	23	27	28	22
Rijeka	24	26	30	30	25
Trieste	20	22	26	26	21
Venice	22	24	28	29	23
Ravenna	20	25	29	30	24
Rotterdam	24	28	32	31	25
Hamburg	25	29	33	32	27
Bremerhaven	24	30	33	32	27

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 [17] and can be seen in *Table 1*.

The data for operating costs were acquired by surveying shippers, logistics providers, and retailers. Preference rates were calculated using analytic hierarchy process. The preference rates for origin ports can be seen in *Table 2*, and preference rates of destination ports in *Table 3*.

Table 2 - Operating costs and preference rates of origin ports

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 3 - Operating costs and preference rates of destination ports

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

3.1.2 Weighted land transport distances

Side of origin Production points are uniformly distributed over south East Asia. The weighted Origin-Destination Cost Matrix $W_{KI} = [w_{ki}]$ was calculated using railway distances and average tariffs.

Destination side The shortest rail distances to each of the destination ports were calculated using ArcGis. Air distance was used to bridge the gap between consumer points and the railroad network. The weighted Origin-Destination Cost Matrix $W_{JL} = [w_{jl}]$, was created for all ports and consumer points within the constrained area, see subsection 3.1.

3.1.3 Consumer points

Based on our available data, we chose a smaller geographical area of continental Europe rather than the whole region as our modelling area. The constraint area *E* for hinterland modelling was selected to include all of the destination ports and to minimize the potential influence of other ports for which data were not available. For this purpose an ellipse with the centroid set at the geographical centre of all destination ports with northern axis of 1,800 km and eastern axis of 900 km was determined. For consumer points, 1,000 virtual locations were randomly generated within the selected geographical area, with a minimum allowed distance between them set at 50 km. Then the network dataset, consisting of edges and junctions, storing the connectivity of the source features, was created. We used a GIS layer of railroads from the company VDS Technologies GIS & Mapping Components (VDS Technologies) as the basis for the creation of the railroad network.

3.1.4 Ports preference rates

As mentioned in the previous section, the preference rates are acquired by performing surveys among various shippers. The shippers were asked to rank by importance the following factors:
- Connectivity to hinterland,
- Connectivity to feeder ports,
- Frequency of ship calls to and from the desired destination,
- Competitive port charges,
- Quality of human capital,
- Ease of doing business,
- Reliability,
- Safety and security,
- Enforcement of no-show fine,
- Quick turn-around time at port,
- Efficient customs and checkpoints procedure, and
- Quick response to port user needs.

After ranking the importance of factors, the factors were graded per each port individually and the preference rates of ports were calculated using the AHP method.

3.2 Calculation

Using the data described in subsection 4.1, all MILP calculations were performed in Matlab R2013b using the Linear Mixed Integer Program Solver by Thomas Trötscher [18]. MILP 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. The results can be seen in *Figure 2*, while *Table 4* displays the areas of each hinterland.

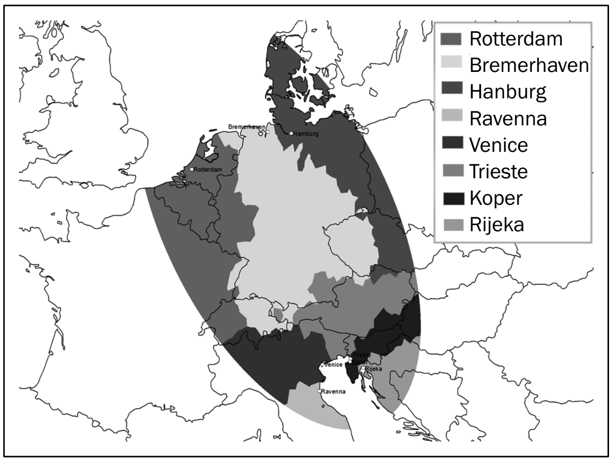

Figure 2 - Port hinterlands

Table 4 - Hinterland areas

Port	Hinterland area (km^2)
Koper	10,690.74
Rijeka	49,028.66
Trieste	117,675.27
Venice	79,620.34
Ravenna	24,755.61
Rotterdam	195,421.13
Hamburg	171,781.43
Bremerhaven	292,343.06

As stated before, the hinterland of ports depends on many factors, among which often dominate transport connections and cost aspect. In *Figure 2* we can see the calculated hinterlands with respect to all mentioned factors.

One can see that the hinterland of the port of Hamburg comprises an area of Denmark and part of Germany, Poland, the Czech Republic and Austria. According to the report of the Hamburg port, its hinterland spreads mainly in the areas of Central and Eastern Europe [19], while [20] also indicates that the hinterland of the port of Hamburg coincides with traffic flows of the city itself, which are strongest in the north and the south-east and of course in the city itself.

The port of Bremerhaven falls under the organization of Bremen ports, which is an association of two ports (Bremerhaven and Bremen). Transport connections of the port reach deep into the interior of Germany, so the hinterland extends to the areas of the Czech Republic, Liechtenstein and part of Switzerland, whereby the port´s report shows that most cargo is transported to the areas of Germany and Poland, while a lot of cargo is also shipped to areas of Russia, Finland and Sweden [21].

The most important port of the Netherlands is the port of Rotterdam. Its hinterland runs south from the port location and comprises the areas of the Netherlands, Belgium, Luxembourg and a partial area of France and Switzerland. Rotterdam's hinterland has, according to the port´s reporting, strong transport connections in these directions, among which dominate rail and road transport, while the hinterland also depends on inland waterways [22].

Compared with North Sea ports, the North Adriatic ports have significantly smaller hinterland areas, so the hinterland of the port of Rijeka comprises an area of Croatia and partly areas of Slovenia and Bosnia and Herzegovina, where the port is an important maritime transport link to Central and Central-Eastern Europe [23] on the basis of European transport corridors, where transport route tends towards Hungary, the Czech Republic, Slovakia, and Serbia. The only important Slovenian port is the port of Koper, its hinterland, in *Figure 2*, covers areas of Slovenia itself and partly Austria and Croatia. Depending on the reporting the port´s hinterland is composed mainly of areas of Slovenia and Austria, but also extends to small areas of Italy, Hungary and Slovakia [24]. Important North Adriatic ports lie in the area of Italy, wherein the hinterland of the port of Ravenna, which lies lowest among the selected ones, represents the part of Italy, while the hinterland of the port of Venice ranges, in addition to the areas of Italy, partly in the areas of Switzerland and Liechtenstein. Main transport connections of this port with the hinterland are via rail and road, which represent the connection all the way to Lyon, Vienna, Rome, Budapest and Palermo. The largest potential hinterland of the North Adriatic ports is connected with the port of Trieste. Its hinterland extends to the eastern area of Italy, throughout Austria and also Hungary and Slovenia, as demonstrated by the port´s record about competitive advantages in these areas, which allow expansion of the port's hinterland in the interior of Central and Eastern Europe and on the Mediterranean market [25].

Practical meaning of the model

By use of the same model it is relatively easy to model the port's captive hinterlands. Post processed data are used to plot Voronoi regions in GIS. The results in *Figure 3* show that captive hinterlands are significantly smaller than the previously calculated areas. Captive hinterlands can be defined as all regions where one port has a substantial competitive advantage because of lower generalized transport costs to these regions. The 'generalised transport costs' are not only influenced by the distance of locations in the hinterland but also by the quality of infrastructure, frequency of services, efficient organization of intermodal transport, and natural or political barriers [26].

The next question that can be answered with the use of our model is the question in what way the substantial improvement in land transport infrastructure

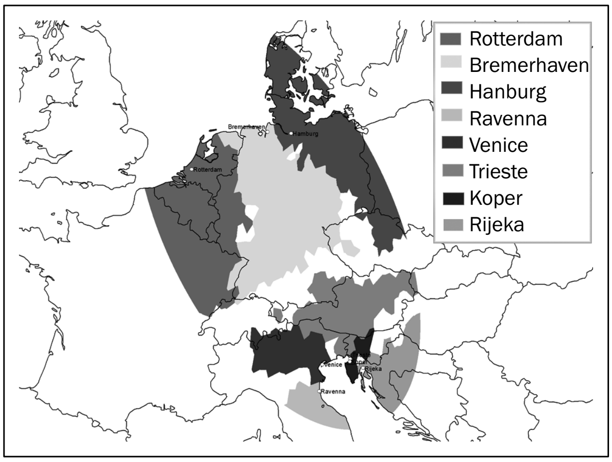

Figure 3 - Port captive hinterlands

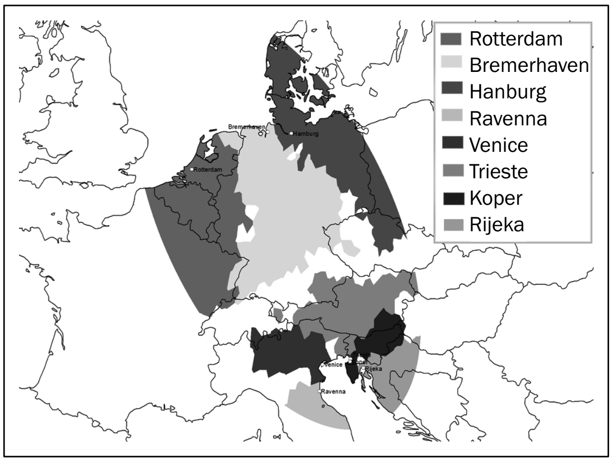

Figure 4 - Hinterland based on 50 km shorter distance to the port of Koper

in the port area contributes to the size of hinterland. For example, in Slovenia the route of the railway dates back over 150 years. Due to this fact the railway is winding and is about 50 km longer than necessary. The calculation of hinterland presented in *Figure 4* is based on 50 km shorter distances to the port of Koper.

4. DISCUSSION

Hinterlands of ports depend on many factors. Historically, the hinterland is defined by explanatory power of distance, but the results of our model showed that the distance is only one of the parameters that contribute to the decision. Let us discuss the results of our model in comparison to the known data. The calculated hinterlands, presented in *Figure 2*, are in line with what the port itself regarded as its hinterland. When we look at *Table 5*, we see that the actual port's throughputs regarding TEU are not linearly connected to the size of the hinterland. In the case of North European ports this is somehow true, but in the case of Adriatic ports, the picture changes. For instance, the port of Koper has a very small calculated hinterland, the captive one is even smaller, but the actual throughput is the highest in the region.

Table 5 - Throughput in thousands of TEUs

	2010	2011	2012
Rotterdam	11,148	11,877	11,866
Hamburg	7,896	9,014	8,864
Bremerhaven	4,889	5,915	6,115
Koper	477	589	571
Venice	394	458	430
Trieste	282	393	408
Ravenna	183	215	208
Rijeka	137	151	172

It seems that Koper is leading the competitive game among the regional players in remote contestable regions. However, this advantage can be void pretty fast if competition improves its image and port efficiency. But on the other hand the calculated hinterland could become bigger with significant improvement of land transport infrastructure in the region.

On the other hand, the introduction of the concept of dry port into the model could change the shape and size of the hinterlands tremendously. The explanatory power of distance would become even smaller in that case. In that case the distance to the port would no longer play the same role as before.

Other approaches predominantly rely on distances in hinterland calculation. For instance, the gravity model [1] is based on traffic flows between ports and geographical regions. The main emphasis is on the number of transports between the ports that diminishes with the increase of distances between regions and ports. Further, the model is calibrated to ensure that the estimated flow is similar to the observed flow. Another example presented by [27], bases the hinterland modelling on distances from the decision point in the English Channel to northern ports and combines it with road traffic. Further, they model captive and contestable parts of the hinterlands by calculating relative transport cost differences between competing ports and comparing the ports that have competitive advantage to second most competitive ports. Observing the visualisations in [27] reveals similarities in hinterland calculations to the results in this paper, despite the fact that their approach is based on road transportation while ours is restricted to railroad transportation. The focus on railroad transportation can be used for analysing the benefits of railroad infrastructure development [28] on the hinterland formation.

The model presented in this paper uses a different approach, although, distance represents one of the main factors here as well. However, other factors can alter the final result. The traffic flow in this case is simulated, and the actual computation is focused on ports properties, which yields results for each consumer point. The actual modelling is then performed from the view of consumer points based on their port choice. Although direct comparison with the results of other models may prove difficult, as different encountered approaches use different input data for calculations of hinterlands, similarities can be observed.

The main restrictions of the model are due to data availability. The hinterlands were modelled based on the surveys that include 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, especially on the borders to other ports' hinterlands.

5. CONCLUSION

The methodology of hinterland modelling presented in the paper takes into account many different factors that influence the port choice. The hinterland displayed in Figures 2, 3, and 4 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 the competing ports. For further research, the model will be extended to analyse the effects of creating a dry-port as well as the improvement of railroad infrastructure on the formation of the hinterlands and competition among ports.

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POVZETEK

MODELIRANJE PRISTANIŠKEGA ZALEDJA Z IZBIRO PRISTANIŠČA

Članek predstavlja nov pristop za modelirane pristaniškega zaledja na podlagi rezultatov izbire pristanišča. Metodologija je osnovana na ideji, da je izbira pristanišča kompromis med raznimi tako objektivnimi kot tudi subjektivnimi dejavniki. Predstavljen model rešuje problematiko z uporabo metode AHP za določitev preferenčnih stopenj pristanišč na podlagi subjektivnih dejavnikov, katere nato združi z objektivnimi izračuni, ki vključujejo operativne stroške, čase plutja ter stroške zemeljskega transporta z uporabo metode MILP. Modeliranje zaledja je izvedeno z določitvijo optimalnega pristanišča za razne lokacije znotraj Evrope in z združevanjem istih rezultatov. Model je možno uporabiti za določanje zajetega zaledja pristanišč, prav tako pa ga je možno uporabiti za razne analize kako spremembe v prometni infrastrukturi vplivajo na obliko zaledij.

KLJUČNE BESEDE

modeliranje zaledja pristanišč; zajeto zaledje; nedorečeno zaledje; MILP; GIS; objektivni in subjektivni dejavniki;

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