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ON DISTANCE DECAY IN PORT CHOICE

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In the paper, a well-known port choice problem using Mixed Integer Linear Programing (MILP) is presented. By applying MILP, the relevant importance of the decision factors is presented. The importance of the decision factors was analysed by several selected examples. First of all, the ports within a narrow region were taken into consideration, and afterwards the ports from different multiport regions were compared. In the first example, the distance between ports have small effect on the choices made by the decision makers, while in the second example, the distances and consequently both the land transport and subjective decision factors play an important role within the decision making process. The analysis therefore indicates that decision factors do not have equal importance depending on the problem perspective.

Keywords: mixed integer linear programming; port choice; decision factors.

INTRODUCTION

Container ports represent important links within the maritime supply chains (Talley, 2013). In today's competitive environment each port wants to be included into the supply chains of shippers (Meersman *et al*, 2010), therefore operational efficiency and location are not the only factors which trigger inter-port competition.

A supply choice is ussualy considered a derived choice from the set of choices made by a shipper, a shipper representative (e.g., a third-party logistics provider or freight forwarder), a shipping line or any other party (Magala and Sammons, 2008). The supply chain that is naturally chosen by the shipper or its representative may be that supply chain for which the logistics costs are minimal. In this case the choice of ports by shippers is influenced by the port charges, port characteristics, and ship-schedule characteristics (Talley, 2013).

Shippers prefer diversified services such as door-to-door service (Hsu *et al*, 2009). In door-to-door liner pricing schemes, shippers are charged independent of port choice, where the rate is the payment for ocean and inland transportation services as well as other costs. That fact basically shifts the port choice decision from the shipper to the shipping line or to the freight forwarder. Therefore when considering the port choice problem, we have to deal the problem from more than one perspective, for instance from carrier's (shipping line's) or freight forwarder's perspective. One has to distinguish port selection from a particular multiport region or port selection from several multiport regions. In the first case ports are located in the near proximity, while in the second case the geographic position of the port plays a key role in the decision making.

Many papers by various authors have been written about port choice. The port choice problem has been studied a lot since Sargent (1938) suggested that cargo tends to seek the shortest route to access the sea. The problem is of particular interest in the multiport regions of North-Europe, the North-Adriatic, the North-Mediterranean and East and Southeast Asia, where the interport competition has intensified in recent years (Garcia-Alonso and Sanchez-Soriano, 2009). Therefore, port choice studies were made mostly for multi-port regions. For instance in Chou (2005; 2010; 2007) ports in a geographicaly connected area were studied. Quite the opposite one can see in Malchow and Kanafani (2004) where the ports from both sides of the US are considered. They are not competitors like in the first instance, but when one considers the land transport cost, they are actually.

In previous papers, the factors which influence the port choice decisions were identified (Tang *et al*, 2011), (Chang *et al*, 2008). The results suggest that high port efficiency, good geographical location and connectivity to other ports are the most important in the port choice process (Kramberger and Chin, 2013; Nazemzadeh *et al*, 2013).

In the present paper, we want to show that decision factors have relative influence on the port choice. We used the model presented in (Kramberger and Chin, 2013) to determine the importance of influencing factors when comparing Western and Central-European ports. In the second case, a comparison is made between Western and Central-European ports on the one hand, and North-Adriatic ports on the other.

LITERATURE REVIEW

A maritime supply chain is a connected set of activities for efficient planning, coordination and control over containerized cargo from the point of origin to the point of consumption (Lam, 2011). Tongzon *et al* (2009) define a maritime supply chain as a network, where carriers, ports and shippers cooperate through a customer-supplier realtionship with the aim of achieving mutually acceptable outcomes. Cooperative agreements and vertical connections among players therefore facilitate reciprocal decisions about shipping route formation and port connections, which consequently reflect the total network configuration.

In the literature, there is a lack of studies about maritime supply chains, focusing into reciprocal choices from all players involved. Talley (2013) seeks the primary reason for non-oriented supply chain decisions in supply chain integration. The latter requires information sharing and mutual trust among all players involved. Since many customers and suppliers enter the relationships just to fulfill a certain job, their common interests are related to the accomplishment of this job. Within a relationship, where players have their own confidential information, it is hard to achieve mutual trust and information sharing. Therefore, the study further focuses on the transport decisions made from the shipper's perspective.

A maritime transport chain represents a "network over which carriers, ports and shippers are involved in the movement of cargo" (Talley, 2013). With respect to the maritime supply chain, players of the transport chain are linked hierarchically. The study of Cullinane and Wang (2012) indicates that "a port hierarchy relies on the existence of mutual relations between ports", where ports with greater importance within the network have stronger connections to other ports.

Ports having a strategic location are privileged to become the main regional ports - gateways or hubs, where the cargo flows may be consolidated and distributed over wide areas. To the opposite, "less atractive" ports are willing to enter into alliances with the near gateways, where both players are delighted with the beneficial effects[i] Similar conclusions may be drawn when observing port attractiveness from the hinterland perspective. The better is a connection of a port to the inland market, the bigger is the potential to enlarge its overall captive area (Ferrari *et al*, 2011).

A number of mathematical programming models have been developed in order to minimize the total operational costs by selecting an appropriate port as the most favourable. Tran (2011) introduces a non-linear model and heuristics for minimizing overall costs in a cargo's journey. The most important claim is that without taking into account inland transport, we cannot fully understand the benefit of the direct call pattern on liner services.

The literature review revealed that port attractiveness is no longer just a cost function depending on travelled distances. With containerisation and intermodality, inter-port competition and consequently the expansion of the catchment areas has started. Road/rail terminals and dedicated tracks have positively influenced the hinterlands to become more discontinuous and easily reachable. Conventional perspectives based on distance-decay have so become "ill-fitted to address this new reality" (Ferrari *et al*, 2011). Hence, the port is just a node in the entire network. Magala and Sammons (2008) indicate that port attractiveness has become more a function of the overall network cost and performance.

Nowdays, the port choice problem is considered a Multiple-Criteria Decision-Making (MCDM) problem, taking into account operational costs, volume of containers, port facility, port location, port operation efficiency and other factors (Chou *et al*, 2010). Veldman *et al* (2011) introduced the demand choice function of a port's services to support the economic and financial evaluation of port investment projects. The outcomes of the linear regression model show that port location is a key decision factor.

Besides the objectivity reflecting the performance of the transport chain, studies show that "bounded rationality, inertia and opportunistic bahaviour are among the behavioural factors that could lead to a deviation from a distance-decay optimal solution" (Ferrari *et* al, 2011). Chou (2005) made a comparative study of models for port choice. He compared the Stackelberg model for port choice (Yang, 1995; Yang, 1996), the Equilibrium model for port choice (Chang, 1974; Zong-Hwa-Consultant, 1978) and a fuzzy MCDM model for port choice (Chou, 2007). The results show that these three models cannot be used to explain adequately the actual port choices, since the modelling approaches consider only objective decision factors. Thus, Chou proposed the Analytic Hierarchy Process (AHP) model for the integration of subjectivity in the container port choice (Chou, 2010). The AHP model yielded promising results.

THE PROBLEM TO SOLVE

In this study the port choice problem is considered a discrete optimization problem. The problem is modelled as a connected weighted graph with the aim of minimizing its total weight. From figure 1 we can see the typical shape of the shipper's supply chain (Talley, 2009). The exporting firm located at point S_k has many options to ship the cargo to the final destination. It has a choice of truck, rail or maybe even inland waterway carriers that link location S_k to the five possible departing ports O_i. The decision-maker also has to choose the destination port D_j in the target region. The port D_j has to be chosen in the way that inland transportation costs between port D_j and consumer points C_l are minimal.

Figure 1 here

As indicated above, costs are not the only criterion in the decision-making process when considering the port choice problem (Spohrer and Kmak, 1984; Chou, 2005; Chou, 2007). Therefore, mathematical programming models that include only costs are not able to explain the actual port choices of decision makers. Factors such as opportunistic bahaviour, preferences about the port location, adequate port infrastructure and others are at least equally important. These factors are considered subjective factors. Their influence on the decision will be quantitatively defined as a preference rate (PR).

In the following research, we are going to compare the relative importance of decision factors for two different port choice problems. The first problem corresponds to the attractiveness of Western and Central-European ports with respect to the choices made by Bavarian shippers. The second case introduces Bavarian shippers who choose the port from two different European regions, i.e. the Western and Central-European region on one hand and the Adriatic region on the other hand. Considering different conditions in terms of distance we would like to test the hypothesis that different decision factors affect the decisions made by the shippers. We suppose that in the port choice problem, where ports are located within a narrow area, the port charges represent an important decision factor. The study further investigates in which case subjective factors have the biggest influence.

Behavioural factors

A preference rate obtained with the AHP method used by Chou in (2010) is one of the most promising criteria in the decision-making process with regard to the port choice problem. The same methodology was applied in our case, where the calculated PRs represent the share of the importance between all destination and all origin ports. Let PR_{O_i} be the preference rate for i-th departure port. Now it can be assumed that PR_{O_i} has an impact on the weight of every edge connected to the port O_i. For instance, the weight of the edge S_kO_i has the following form:

$$w'_{ki} = \frac{1}{PR_{O_i}} \cdot w_{ki}, \tag{1}$$

where w_{ki} is the land transport cost along the edge S_kO_i. When calculating land transport costs, the distance from the port to the Source point or Consumption point is multiplied by the railway tarriff per travelled distance.

On the other hand, there is a difference when calculating the weight of the edge O_iD_j since PRs of both types of ports have an impact on the latter. Therefore, we simply calculate the geometric mean of the rates $\overline{PR_{O_iD_j}}$, which leads to the following expression: $w'_{ij} = \left(\overline{PR_{O_iD_j}}\right)^{-1} \cdot w_{ij}$, where w_{ij} is the sum of maritime transport and port charges.

When calculating weights, there is still some vagueness with respect to PRs and cost integration on the one hand and the influence of the PR on the other. Since we have no information on the percentage of weight influenced by the PR, the equation where the PR has an impact on p per cent of the total weight is introduced. For instance, the weight of the edge S_kO_i is expressed as:

$$w'_{ki} = w_{ki} \cdot \left(1 - \frac{p}{100}\right) + \frac{1}{PR_{O_i}} \cdot w_{ki} \cdot \left(1 - \frac{p}{100}\right) \tag{2}$$

METHODOLOGY

The problem defined in section 3 is formulated as a Mixed Integer Linear Programming (MILP) model.

MILP model

The objective function of the modelling approach consists of the sum of all used edges[ii] x_{ki} between production points and departing ports, edges x_{ij} between departing and destination ports and edges x_{jl} between destination ports and consumer points, all multiplied by their weights defined in the previous section (See eq. 3).

$$W' = \sum_{k=1}^{K} \sum_{i=1}^{I} x_{ki} \cdot w'_{ki} + \sum_{i=1}^{I} \sum_{j=1}^{J} x_{ij} \cdot w'_{ij} + \sum_{j=1}^{J} \sum_{l=1}^{L} x_{jl} \cdot w'_{jl} \tag{3}$$

The aim is to achieve the cheapest solution according to several constraints. We have three sets of constraints: for production points, ports (departing and destination) and consumption points. Production point constraints are formulated as:

$$\sum_{i=1}^{I} x_{ki} \geq \frac{sp_{S_k}}{\sum_{k=1}^{K} sp_{S_k}} \quad , \qquad k = 1,2,\dots,K \tag{4}$$

where the left side is the flow from each S_k to all O_i and is greater or equal than the supply sp of the S_k divided by the sum of all supplies. The constraints for departing ports are described as the difference between the incoming and outgoing flow at the port O_i, which has to be greater than or equal to zero (eq. 5).

$$\sum_{k=1}^{K} x_{ki} - \sum_{j=1}^{J} x_{ij} \geq 0 \quad , \qquad i = 1,2,\dots,I \tag{5}$$

Similarly follows for the destination port constraints. They are representing the difference between the incoming and outgoing flow at the destination port D_j, which also has to be greater than or equal to zero. Here, additional constraints assure that only one destination port is selected at a time, so the sum has binary values (Eq. 6).

$$\sum_{i=1}^{I} x_{ij} = \begin{cases} 1; & \text{if there is a connection to } D_j \\ 0; & \text{otherwise} \end{cases} \tag{6}$$

The constraints for the consumption points cs are similar as for production points. On the left is the flow from D_j to all C_l, which is greater than or equal to the demand of the C_l divided by the sum of all demands (Eq. 7).

$$\sum_{j=1}^{J} x_{jl} \geq \frac{cs_{C_l}}{\sum_{l=1}^{L} cs_{C_l}} \;, \qquad l = 1,2,\ldots,L \tag{7}$$

In order to choose the most effective port from the shipper's point of view, we select the destination port D_j for which the value W' of the objective function is minimal.

Assumptions of the modelling approach

The modelling approach considers assumptions about the vessel, departing and destination ports, and production and consumption points.

Shipping cost. The MILP model is able to simulate costs for many different types of vessels. In this case, a Panamax size type of vessel with a GRT of 50,350 tonnes, a capacity of 4,200 TEU and a cruising speed of 21 knots was selected.

Departing ports. Even though the model is capable of handling several ports on the departure and destination side simultaneously, we have chosen five common ports uniformly distributed over Southeast Asia and East Asia. The ports of Singapore, Hong Kong, Busan, Kaohsiung and Port Klang are often used for transporting goods to Europe.

Destination ports. For the destination port, we have chosen five ports uniformly distributed over the North Adriatic Coast and three ports in Western and Central-Europe. The candidate ports are Koper, Rijeka, Trieste, Venice, Ravenna, Rotterdam, Hamburg and Bremerhaven.

Production points. Virtual production points are uniformly distributed over Southeast Asia and East Asia.

Consumption points. For consumption points, we have chosen four big consumption centres uniformly distributed over Bavaria, i.e. Regensburg, Munich, Ingolstadt and Nürnberg.

Sailing time. We have calculated sailing times expressed in days by using the online distance calculator (Searates). We have considered the most common cruising speed of 21 knots.

Preference rate. The PRs were calculated using AHP presented by Saaty (1980). We have ranked our five departing and eight destination ports according to eleven different criteria, explained in Chou (2010), Bloningen and Wilson (2006), Garcia-Alonso and Sanchez-Soriano (2009), Mangan and Gardner (2002), and Tongzon (2009). To obtain relevant data, a survey among several Bavarian logistics service providers, shippers, shipping lines and retailers was conducted. We used a separate questionnaire for the departing and destination side.

Analysis of the decision factors

With the analysis of decision factors, we would like to determine how each of decision factors influence the objective value and how their influence is related to port selection alternatives. In our study, we tested four different decision factors: preference rate (*PR*), port costs (*PC*), land distance between destination ports and consumption points (*LD*) and sailing time between origin and destination ports (*ST*). The values of each decision factor for selected destination ports were decreased or increased for a certain percentage. By doing so, we were able to observe how much objective value W'changes as the decision factor changes for a certain percentage.

In order to compare results between different port selection alternatives we used standardized decision factor values. The latter were calculated by:

$$SDF_j = \frac{DF_j - DF_{min}}{\bar{D}F} \quad , \tag{8}$$

where SDF_j represents standardized decision factor for destination port j, DF_j original decision factor value, DF_{min} minimal factor value selected among all destination ports and $\bar{D}F$ represents average decision factor value. By using this adjustment, ports with similar values of decision factors (for example ports from the multi-port region) have very low SDF, and consequently decision factors have lesser impact on the objective value. On the other hand, ports from different regions have dispersed values of decision factors and SDF have greater impact on the objective value.

Before this decision factor analysis was carried out for real data, our model was tested on selected examples with simulated data. With the preliminary analysis we were able to test whether our hypothis is true. It can be claimed that decision factors have different influence on the objective value and their influence depends on which group of ports we are choosing from.

Simulated data

Using simulated data, we tested 2 examples with dummy source points, consumption points, and origin and destination ports. In both examples, the PR for origin and destination ports were equally distributed. In the first example, only the PC of destination ports were dispersed, while other decision factor values were close together. This represented a hypothetical case where observed destination ports are very close to each other, but have different PC (Example 1). In the second example, all decision factors were dispersed, and only destination PC had similar values. The latter represented a case where destination ports are very far from each other, but they have similar PC.

In Figure 2, the factor analysis results are presented. A steeper line indicates greater decision factor influence on the objective value and vice versa. As is depicted in Figure 2a, the PR has minor effect or almost no effect on the objective value if other decision factors have similar values. But if destination ports have different values of decision factors, the PR has a great impact that should not be neglected. On the other hand, the PC (Figure 2b) has very low influence if their values are close together and minor influence if their values are spread and other factors are close together. The LD (Figure 2c) has no effect on the objective value in example 1, but in example 2, the LD's influence is greater than that of the PC. For the ST (Figure 2d) we can see that it has great influence on the objective value in both examples. In example 1, we can see that the blue line breaks when the ST decreases by 2%. This occurs due to the fact that the selected destination port ST has the lowest value so its standardized value becomes 0 and does not affect the objective value and by decreasing its standardized value remains unaltered. This could be avoided if we choose another destination port with a greater value of ST, which remains greater than the lowest although it decreases by a certain percentage. But nevertheless, the fact is that the cost of maritime transport plays a very important role in our model so by changing its key parameters, the objective value changes proportionally too.

Figure 2 here

Real data modeling

Using real data we tested how decision factors influence the objective value for different groups of ports. In the first example we were choosing between three Western and Central European ports, while in the second example, only North-Adriatic ports were considered, and in the last example, we included all above-mentioned ports. By doing this, we set two different multi-port regions and one region where ports are very far apart. This was the framework for applying the above-described analysis, the results of which are presented in the following section.

NUMERICAL RESULTS

The results of the decision factor analysis using real data are shown on Figure 3. As the figure depicts, the impact of the decision factor describing port costs is close to a constant value. Nevertheless the impact of this decision factor is greater when ports from the same port region are considered. Also the decision factor describing sailing time has greater impact when concerning ports within a narrow area. As it was seen from a simulated example, the same phenomena occured here, related to points where lines are broken.

Figure 3 here

On the other hand, when considering ports from different geographic regions, land transport costs represents one of the most important decision factors (Figure 3) . When distances between ports are increased, also the subjective decision factors get greater importance.

CONCLUSION

The port choice problem is presented as a discrete optimization problem by combining subjective and objective decision factors. Subjectivity is introduced using the Analytic Hierarchy Process method, while Mixed Integer Linear Programming defines the optimal port of choice according to given constraints and decision factors. Besides the analysis of the selected port choice problem, a substantial part of the paper presents the analysis concerning the importance of the decision factors.

Results discussed in the previous section show that both the preference rate and land transport costs represent the most important factors influencing port choice decisions when considering ports from different geographic regions. To the opposite, when ports within a narrow region are considered, the port costs and sailing time represent the most important factors influencing port choices. The obtained results revealed that approaches concerning distance-decay are not completely ill-fitted. Combining conventional perspectives with the relevant approaches must be the right way within the decision making process.

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[i] For instance, gateways have enlarged capacities to distribute cargo over time more efficiently, while smaller ports are faced with larger throughputs, as if they operate individually.

[ii] Variables x_{ki}, x_{ij} and x_{jl} represent the distribution of cargo sent through the selected ports, where the shares are calculated with respect to the total number of containers in the network.