DETERMINING OPTIMAL SHIPPING ROUTES FOR BARGE TRANSPORT WITH EMPTY CONTAINER REPOSITIONING

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ABSTRACT

Service network design for freight transportation is concerned with the selection and characteristics of routes on which services are provided. An efficient service network design should take empty container repositioning movements into account. These empty container movements are highly interrelated with loaded container transports. Unfortunately, most existing models do not consider both types of movements together. In this paper, a model for service network design in intermodal barge transportation is presented. Both loaded container transports and empty container repositioning movements are taken into account. The model is applied to the Albert Canal which connects the port of Antwerp with four hinterland ports. Several possible assumptions and empty container management scenarios are defined. The optimal shipping route under different demand conditions is calculated and the optimal location of an empty container hub in the hinterland is determined. Finally, the model is extended to a multi period model to cope with transport demand variation over periods.

1. INTRODUCTION

During the last two decades intermodal barge transport has gained market share in Northwestern Europe, with annual growth figures of 10% to 15% (Konings 2003). Currently, barge transport plays an important role in the hinterland access of major sea ports in this region. For the port of Antwerp in Belgium, the share of barge transport in the modal split rose from 22.5% to 34.8% between 1999 and 2009 (Port of Antwerp, 2009). Although many interesting contributions to literature have been made, Caris et al. (2008) indicate several intermodal planning problems that need further research attention, like service network design for intermodal barge transport.

Crainic and Laporte (1997) state that service network design is an important issue at the tactical decision level for intermodal transportation. It is involved with the selection of routes on which services are offered and the determination of characteristics of each service, particularly their frequency. State-of-the-art reviews on service network design in freight transportation are presented by Crainic (2000) and Wieberneit (2008). An overview of models for service network design in intermodal transportation may be found in Crainic and Kim (2007). Research on service network design specifically for intermodal barge transportation is scarce. Groothedde et al. (2005) discuss the design of a hub network for transporting palletized fast moving consumer goods by barge and road transport. Maras (2008) investigates the design of an optimal barge shipping route in a linear network. Caris et al. (2010) study the advantages of cooperation between hinterland terminals and different bundling strategies for barge transportation in the hinterland of the port of Antwerp.

Empty container repositioning is an important aspect that might be taken in to account when creating a service network for intermodal barge transportation and for freight transportation in general (Crainic, 2000). Because of regional imbalances between import and export volumes, some terminals or ports will create a surplus of empty containers, while others will face a deficit. In order to be able to satisfy future requests for empty containers by shippers, empty containers need to be repositioned. In barge transportation, these repositioning movements are made by using excess capacity of container ships (Choong et al. 2002; Maras 2008). Since these movements often represent a large part of the overall movements, they should be taken into account when creating service networks.

Empty container repositioning at a global level, in the context of maritime shipping network design, is studied among others by Shen and Khoong (1995), Cheung and Chen (1998), Lam et al. (2007) and Li et al. (2007). Also a large amount of research exists on empty container repositioning at a regional level, between shippers, consignees, depots and terminals (Crainic et al. 1993; Olivo et al. 2005; Jula et al. 2006; Chang et al. 2008). Unfortunately, all these papers optimize empty container flows without considering loaded container movements or by considering loaded container movements as given. Only a few papers consider the simultaneous optimization of loaded and empty container flows (Erera et al. 2005; Song and Dong 2008; Bandeira et al. 2009; Huth and Mattfeld 2009; Braekers et al. 2010).

Empty container repositioning in barge transportation is studied by Choong et al. (2002) and Maras (2008). Choong

et al. (2002) study the operational side of the empty container repositioning problem in intermodal barge transportation. The authors assume loaded container transports by barge to be known. They formulate a model that minimizes repositioning costs over multiple periods by using excess ship capacity and other uncapacitated, but more expensive transport modes (truck, rail). Experimental results show that a longer planning horizon can give better empty distribution plans because the use of slower but cheaper transport modes like barge is encouraged.

To the authors' knowledge only Maras (2008) investigates empty container repositioning in the context of service network design for barge transportation. Maras (2008) adapts a model introduced by Shintani et al. (2007) for service network design in maritime shipping. In the model of Shintani et al. (2007) the profit maximizing shipping route between a number of sea ports is determined. Not all ports have to be visited, but if a port is visited all transport demand at that port has to be satisfied. Container in- and outflow is balanced at every port, either by empty container repositioning using excess capacity or by leasing and storing empty containers. The problem is solved by a genetic algorithm.

Maras (2008) adapts the model of Shintani et al. (2007) to the context of barge transportation. The author considers the viewpoint of a logistic service provider or shipping company that wants to charter a single ship to offer a roundtrip barge service between a fixed start and end port. The objective is to maximize profit, while it is assumed that non-profitable transport requests may be turned down. The problem is to define which intermediary hinterland ports need to be visited between the start and end port, while taking both loaded container transport and empty container repositioning movements into account. Empty containers may be transported between any pair of ports and leased or stored at every port. Not all transport demand at a visited port has to be satisfied. Instead, it is assumed that any number of containers smaller than the transport demand may be transported between two ports. The model is applied to a sequence of ten ports. Since the number of possible routes is far lower in barge transportation than in maritime shipping because all ports are situated across a single axis, Maras (2008) is able find optimal solutions by using commercial software. The author finds the maximum profit for five types of ships under a single transport demand situation.

In this paper, the model of Maras (2008) is extended in several ways and applied to the management of hinterland transport chains in Western Europe. A dummy port is introduced so that the starting port should not be predefined. More realistic assumptions regarding fulfilling transport demand at hinterland ports are made. The model formulation is adapted to represent the situation of the Albert Canal which connects four hinterland ports with two clusters of terminals in the port of Antwerp. Three possible empty container management scenarios are defined and the optimal location for an empty container hub in the hinterland is determined. The model is tested for all scenarios under different transport demand conditions. Finally, the model is extended to a multi period model,

including storage and leasing options, to handle situations where transport demand is not the same every period. A detailed problem description is given in Section 2. The network structure, adapted to the Albert Canal, is presented in Section 3. The formulation of the single period model and experimental results are presented in Section 4. In Section 5, the multi period model is described. Finally, in Section 6 conclusions are drawn and future research opportunities are identified.

2. PROBLEM DESCRIPTION

In this paper, the viewpoint of a logistic service provider or shipping company that wants to offer a regular barge service between a sea port and some hinterland ports is considered. The decision maker has to determine which loaded containers are to be transported and thus which hinterland ports need to be visited. The objective is to maximize profit. Revenues are generated by loaded container transports. Costs of performing the loaded container transports and empty container repositioning costs are taken into account. Although empty containers may be transported at a marginal cost using excess capacity, these movements cause handling costs, take loading and unloading time and reduce the capacity available for loaded container transports (Choong et al. 2002; Maras 2008). At each port, the total number of containers coming in and going out needs to be balanced. In contrast with Maras (2008), no leasing and storage option is considered in the single period model. Since it is the intention of performing the same route every period, continuously leasing containers at a certain port and storing containers at another port seems not realistic in our problem context.

The ship starts its route at one of the hinterland ports, travels to the port of Antwerp and then returns to the same hinterland port. Along the route, one or more hinterland ports in-between may be visited. The intermediate ports visited upstream may differ from those visited downstream. While in the model of Maras (2008) the starting port is fixed in advance, this is not the case in this paper. A dummy port is introduced as the starting point of the ship, which means that the actual starting port is decided by the model.

As mentioned in the introduction, Maras (2008) assumes that any number of loaded containers may be transported between two ports as long as this number is smaller than the transport demand between these two ports. In this paper, two more realistic assumptions are proposed and the model is tested for both. The first assumption is that all transport demand originating from a hinterland port should be fulfilled when it is visited downstream. Likewise, all transport demand to a port should be fulfilled when it is visited upstream. Upstream and downstream decisions are made separately. The second assumption is that transport demand to and from a certain hinterland port is the sum of the transport demand of several clients. Therefore, the decision maker may choose to serve one, several or all of these clients. This means that the total transport demand at a port is made up of several blocks and that the number of

containers transported should be a combination of these blocks.

Finally, three different empty container management scenarios are considered in this paper. Scenario one represents the case where empty containers may only be transported to and from an empty container hub located in the port area. In the second scenario, an empty container hub is located in one of the hinterland ports besides the hub in the port area. In the third scenario, a hub is located in all ports which means that empty containers may be transported between all pairs of ports.

3. NETWORK

The model presented in this paper is applied to the situation of the Albert Canal which connects the port of Antwerp with hinterland ports in Deurne, Meerhout, Genk and Luik. In the port area of Antwerp, two clusters of sea terminals can be identified, one on the right river bank and one on the left river bank (see Figure 1). Both clusters are separated by three lock systems, which means ships have to pass through a lock in the port area to sail from one cluster to another.
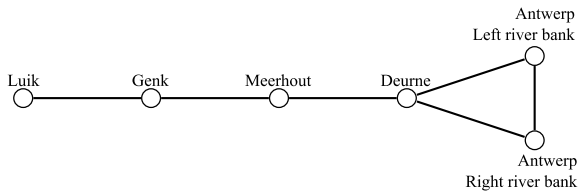
Figure 1: The Albert Canal

Because travelling from one river bank to the other may take two and a half hours, both clusters are considered as a separate port. It is assumed that a ship may visit a river bank only once each roundtrip. If it is decided to visit both river banks, the order of visiting should be free to choose since this may have an impact on the capacity available to reposition empty containers in some of the scenarios described in Section 2. In order to preserve the linear representation of the ports, a duplicate node is created for the cluster at the right river bank. Next, all hinterland ports and the dummy port are duplicated to facilitate the formulation of the problem. The final network representation is shown in Figure 2. The dummy port is represented by nodes 1 and 13, Luik by nodes 2 and 12, Genk by nodes 3 and 11, Meerhout by nodes 4 and 10, Deurne by nodes 5 and 9, Antwerp right river bank by nodes 6 and 8 and finally Antwerp left river bank by node 7. The ship starts and ends at the dummy port (node 1 and 13) and can only travel from a node to another node with a higher number.
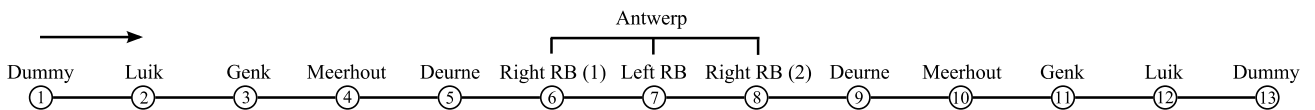
4. SINGLE PERIOD MODEL

4.1 Problem Formulation

In this section the problem formulation for the single period model is presented. The following notation is used:

$$P = 1, \dots, 13 = \text{set of 13 ports}$$
$$L = \{(i,j) \mid i \in P\backslash 13, j \in P\backslash 1, i < j\}$$
$$c_i^e = \text{entry cost at port } i \text{ (€)}$$
$$c_i^h = \text{handling cost at port } i \text{ (€/TEU)}$$
$$t_i^a = \text{standby time for arrival at port } i \text{ (h)}$$
$$t_i^d = \text{standby time for departure at port } i \text{ (h)}$$
$$t_i^h = \text{handling time per container}$$
$$\text{at port } i \text{ (h/TEU)}$$
$$t_{max} = \text{maximum roundtrip time (days)}$$
$$c_{ch} = \text{daily charter costs (€/day)}$$
$$c_f = \text{fuel price (€/ton)}$$
$$c_l = \text{lubricant price (€/ton)}$$
$$sfc = \text{specific fuel consumption (tons/kWh)}$$
$$slc = \text{specific lubricant consumption (tons/kWh)}$$
$$N_{inst} = \text{engine output/propulsion (kW)}$$
$$CAP = \text{ship capacity (TEU)}$$
$$Y = \text{profit (€)}$$
$$R = \text{total revenues (€)}$$
$$C = \text{total costs (€)}$$
$$C_{char} = \text{ship charter costs (€)}$$
$$C_{fuel} = \text{voyage fuel costs (€)}$$
$$C_{lubr} = \text{voyage lubricant costs (€)}$$
$$C_{entr} = \text{total port entry costs (€)}$$
$$C_{hand} = \text{total handling costs (€)}$$
$$T = \text{roundtrip time (h)}$$
$$T_{trav} = \text{total travel time (h)}$$
$$T_{entr} = \text{total time entries (h)}$$
$$T_{hand} = \text{total handling time (h)}$$

For all combinations of ports i and j with $(i,j) \in L$, the following parameters and variables are introduced:

$$r_{ij} = \text{loaded container freight rate (€/TEU)}$$
$$d_{ij} = \text{loaded container transport demand (TEU)}$$
$$t_{ij} = \text{travel time (h)}$$
$$x_{ij} = \text{loaded containers transported (TEU)}$$
$$y_{ij} = \text{empty containers transported (TEU)}$$
$$z_{ij} = \begin{cases} 1 & \text{if ports } i \text{ and } j \text{ are directly connected} \\ 0 & \text{else} \end{cases}$$

Figure 2: Network Representation

The problem is formulated as follows:

$$Max\ Y = R - C \tag{1}$$

Subject to:

$$R = \sum_{(i,j)\in L} x_{ij} \cdot r_{ij} \tag{2}$$

$$C = C_{char} + C_{fuel} + C_{lubr} + C_{ent} + C_{hand} \tag{3}$$

$$C_{char} = c_{ch} \cdot t_{max} \tag{4}$$

$$C_{fuel} = c_f \cdot sfc \cdot N_{inst} \cdot \sum_{(i,j)\in L} z_{ij} \cdot t_{ij} \tag{5}$$

$$C_{lubr} = c_l \cdot slc \cdot N_{inst} \cdot \sum_{(i,j)\in L} z_{ij} \cdot t_{ij} \tag{6}$$

$$C_{entr} = \sum_{\substack{(i,j)\in L \\ i\neq 1}} z_{ij} \cdot c_j^e \tag{7}$$

$$C_{hand} = \sum_{(i,j)\in L}(x_{ij} + y_{ij})(c_i^h + c_j^h) \tag{8}$$

$$x_{ij} \leq d_{ij} \cdot \sum_{q=i+1}^{j} z_{iq} \qquad (i,j)\in L \tag{9}$$

$$y_{ij} \leq CAP \cdot \sum_{q=i+1}^{j} z_{iq} \qquad (i,j)\in L \tag{10}$$

$$x_{ij} \leq d_{ij} \cdot \sum_{q=i}^{j-1} z_{qj} \qquad (i,j)\in L \tag{11}$$

$$y_{ij} \leq CAP \cdot \sum_{q=i}^{j-1} z_{qj} \qquad (i,j)\in L \tag{12}$$

$$\sum_{q=1}^{i}\sum_{s=j}^{n}(x_{qs} + y_{qs}) \leq CAP + M(1 - z_{ij})$$
$$(i,j)\in L \tag{13}$$

$$\sum_{(j,i)\in L}(x_{ji} + y_{ji}) - \sum_{(i,j)\in L}(x_{ij} + y_{ij}) = 0 \qquad i \in P \tag{14}$$

$$\sum_{j=2}^{13} z_{1j} = 1 \tag{15}$$

$$\sum_{i=1}^{n-1} z_{i13} = 1 \tag{16}$$

$$z_{1.2} = z_{12.13} \tag{17}$$

$$z_{1.3} = z_{11.13} \tag{18}$$

$$z_{1.4} = z_{10.13} \tag{19}$$

$$z_{1.5} = z_{9.13} \tag{20}$$

$$\sum_{i=1}^{5} z_{i6} + \sum_{i=1}^{7} z_{i8} \leq 1 \tag{21}$$

$$\sum_{i=1}^{q-1} z_{iq} - \sum_{j=q+1}^{13} z_{qj} = 0 \qquad q = 2,\dots,12 \tag{22}$$

$$T = T_{trav} + T_{entr} + T_{hand} \tag{23}$$

$$T < 24 \cdot t_{max} \tag{24}$$

$$T_{trav} = \sum_{(i,j)\in L} z_{ij} \cdot t_{ij} \tag{25}$$

$$T_{entr} = \sum_{\substack{(i,j)\in L \\ i\neq 1, j\neq 13}} z_{ij} \cdot (t_i^d + t_j^a) \tag{26}$$

$$T_{hand} = \sum_{(i,j)\in L}(x_{ij} + y_{ij}) \cdot (t_i^h + t_j^h) \tag{27}$$

$$x_{ij}\ \text{integer} \qquad (i,j)\in L \tag{28}$$

$$y_{ij}\ \text{integer} \qquad (i,j)\in L \tag{29}$$

$$z_{ij} = \{0,1\} \qquad (i,j)\in L \tag{30}$$

The objective is to maximize profit, represented by revenues minus total costs (1). Revenues are calculated by multiplying the number of loaded containers transported between two ports and the corresponding freight rate (2). Total costs are the sum of ship charter costs, fuel costs, lubricant costs, port entry costs and container handling costs (3). Ship charter costs are determined by the maximum roundtrip time and daily charter costs (4). Fuel and lubricant costs depend on the distance travelled, engine power of the ship and the respective fuel and lubricant prices (5,6). Port entry costs are calculated in equation (7). Handling costs for both loaded and empty containers are calculated in equation (8). Constraints (9), (10), (11) and (12), together with constraint (22), ensure that no loaded or empty containers are transported between two ports when they are not connected. The capacity of the ship is controlled by constraint (13). For each port, container inflow and outflow should be the same (14). The ship must start and end at the dummy port (15,16) and the final real port must be the one corresponding with the first real port (17,18,19,20). The right river bank, represented by nodes 6 and 8, may only be visited once (21) and when a ship enters a port, it should also leave it (22). The total time of the roundtrip is the sum of the travel time, port entry time and container handling time (23) and must be lower than the maximum roundtrip time (24). The travel time, port entry time and container handling time are calculated by equations (25), (26) and (27). Finally, the number of loaded and empty containers transported should be integer values and the linking variables between nodes are binary variables (28,29,30).

Under the assumption that all transport demand at a port needs to be fulfilled when the port is visited, the following constraints are added:

$$x_{ij} = d_{ij} \cdot a_{ij} \qquad (i,j)\in L \tag{31}$$

$$a_{ij} = \{0,1\} \qquad (i,j)\in L \tag{32}$$

Under the assumption that the transport demand at each port is divided into a number of blocks, the following parameters and constraints are added:

B_{ij} = number of demand blocks between i and j
d_{ij}^b = transport demand in block b between i and j (TEU)
    with $\sum_{b\in B_{ij}} d_{ij}^b = d_{ij}$

$$x_{ij} = \sum_{b \in B_{ij}} d_{ij}^b e_{ij}^b \qquad (i,j) \in L \qquad (33)$$

$$e_{ij}^b = \{0,1\} \qquad (i,j) \in L, \ b \in B_{ij} \qquad (34)$$

Finally, for each empty container management scenario, the appropriate values of y_{ij} are set to be zero.

4.2 Experimental Results

Experimental results for the single period model are presented in this section. The model is applied to the situation of the Albert Canal for a ship with a capacity of 120 TEU. Maximum roundtrip time is set at two days. Figures for cost and time parameters are based on real values or found in other research papers (Konings 2007; Maras 2008). The model is solved using Lingo 10.0.

Artificial but realistic data are used for the loaded container transport demand. For each hinterland port, transport demand to and from each cluster in the port area ranges between 20 and 40 TEU, between 50 and 70 TEU or was set to zero. Fifteen different demand situations are defined, varying from each other in terms of:

- balanced or unbalanced distribution of demand over the hinterland ports,
- balanced or unbalanced downstream and upstream demand,
- transport demand to and from one or both clusters at the port.

For each situation, two instances are generated. Together with ten random instances, this results in a set of 40 problem instances.

In Section 2, two assumptions for fulfilling transport demand are described and three empty container management scenarios are presented: an empty container hub in the port area, a hub in the port area and in the hinterland or a hub at every port. A distinction is made whether the hub in the port area is located on the left or right river bank, or on both river banks.

For each of the 40 problem instances, the optimal shipping route is determined for all combinations of demand assumptions and empty container management scenarios. Results are shown in Table 1. The rows represent the different empty container management scenarios. For scenario two the hub in the hinterland may be located in Deurne (2-D), Meerhout (2-M), Genk (2-G) or Luik (2-L). The columns distinguish between the two demand assumptions and the three possibilities for hub location in the port area. Results for the third empty container management scenario are always the best. For the other scenarios the relative gap with the profit of scenario three is shown.

Table 1 shows that results for the first empty container scenario are worse than those of scenarios two and three, especially for the case where all transport demand needs to be fulfilled at a port. When comparing scenarios one and two, it seems that a network with a single empty container hub in the hinterland already gives substantially better results compared with a network with only a hub in the port

area. Results are even better when a hub is located at every port.

The model formulation allows to determine the optimal inland location of an empty container hub. It can be seen that on average Genk is the best location under all circumstances. However, the difference with other locations is often small. When using the model in practice, the decision where to locate a hub should therefore be based on accurate cost and demand information.

An empty container hub on the right river bank in the port area gives on average better results than a hub on the left river bank. Probably this is due to the fact that the travel time from the right river bank to the hinterland ports is smaller than for the left river bank. When a hub is located at both river banks, results are even better.

Table 1: Overview of Results

Scen.	All			Blocks		
	Left	Right	Both	Left	Right	Both
1	16.39	13.05	8.66	8.80	7.78	4.95
2-D	7.14	4.99	4.01	4.85	4.77	3.75
2-M	4.72	3.20	2.10	4.54	4.45	3.39
2-G	4.35	2.74	1.74	3.76	3.88	2.82
2-L	9.66	7.23	5.74	4.24	4.19	3.47
3	-	-	-	-	-	-

No large difference in the average loading degree of the ship is found between the different demand assumptions and empty container management scenarios. When travelling between two ports, on average 70% of the capacity is taken up by loaded containers, while 6% is used for empty container repositioning. The number of hinterland ports visited is on average 2.41. Roundtrip time is almost always equal to the maximum of two days, implying that time represents a restriction on the number of containers that can be transported. Only in 65% of the experiments both clusters in the port area are visited. The time restriction may be a reason for this, since travelling between both clusters takes a considerable amount of time.

5. MULTI PERIOD MODEL

In the previous sections it is assumed that transport demand is the same in every period. A single period model is used since the optimal shipping route does not change and each period the same number of loaded and empty containers are transported. In reality, transport demand will not be constant over periods. For example, some shippers may want containers to be transported every week, while others only require containers to be transported once every two weeks. In order to handle these kind of situations, the model described in the previous sections is extended to a multi period model.

For each period, the optimal shipping route is defined. This route is not necessarily the same for each period. However, if the transport demand of a certain client is fulfilled in one period, it should also be fulfilled in the other periods.

Short term container leasing and storage options are introduced in the multi period model, while they are not

considered in the single period model. Since the number of loaded containers transported between two ports may differ from period to period, empty container repositioning needs will also change. A port may have a surplus of empty containers in one period and a deficit in another. In that case, temporarily storing empty containers at a port and leasing empty containers elsewhere could be an interesting option. Empty container repositioning costs and handling time are saved and more capacity is available to transport loaded containers. The extra costs due to leasing and storing containers are introduced in the model. These costs depend on the duration of the lease and storage. The model decides which option, repositioning empty containers or leasing and storing empty containers, is the best in each situation.

Each port has a starting stock of empty containers available (this can be zero). At the end of the planning period, the same amount of containers should be located at that port. Finally, it is assumed that empty containers can only be leased and returned at ports where an empty container hub is located. Storing containers is possible at every port.

To test the multi period model, ten random two period problem instances are generated with transport demand at each port varying between both periods. The length of a period is assumed to be a single week and empty container inventory at every port is assumed to be zero at the beginning of the first week. Results are obtained for all three empty container management scenarios. The empty container hub in the port area is assumed to be located on the right river bank. For the second scenario the hinterland hub is assumed to be located in Genk, since this gave the best results for the single period model. Only the assumption where all transport demand in a port has to be satisfied is considered.

Results show that on average the relative gap between the profit of the different empty container management scenarios increases substantially. Scenarios one and two are on average respectively 23.10% and 9.96% worse than scenario three, while this was only 13.05% and 2.74% in the single period case. The gap between scenario one and two is 14.59% (10.60% in the single period case), which shows again that a single empty container hub in the hinterland has a large positive effect on profit in comparison with the situation where there is only a hub in the port area.

Another interesting finding is that increasing the planning horizon may offer better results. Choong et al. (2002) show that using a longer planning horizon may offer better empty container distribution plans because slower but cheaper transport modes like barge may chosen over faster but more expensive modes like road transport. The multi period model described in this section shows that a longer planning horizon may also offer benefits when optimizing loaded and empty container movements in barge transportation simultaneously. When the planning period for the two period problem instances is increased to four weeks, with the transport demand of weeks three and four being the same as those of weeks one and two, slightly more profit is generated. Average weekly profit increases for empty container management scenario one by 0.02%,

for scenario two by 1.15% and for scenario three by 0.83%. Further research is needed to investigate the cause of these improvements.

6. CONCLUSIONS

Empty container repositioning should be taken into account when designing a service network for barge transportation. The model presented in this paper simultaneously decides on which loaded container transports and empty container repositioning movements should be performed. The profit maximizing route for a ship is determined while taking time and capacity restrictions into account.

The model is applied to the Albert Canal in the hinterland of the port of Antwerp. Two assumptions regarding fulfilling transport demand and three empty container management scenarios are defined. Finally, the model is extended to a multi period model that can cope with demand variations over periods.

Results clearly show the advantage of an empty container hub in the hinterland, both in the single and multi period case. For the single period case, results for a network with a hub in the port area and one in the hinterland are even close to those of a network with a hub in all ports. Besides, the presented models allow to determine the best location of an empty container hub in the hinterland.

Future research could focus on the effect of changing the maximum roundtrip time of the ship. Also the tradeoff between the capacity of the ship and the frequency of service may be investigated. Finally, more insight in the results of the multi period model may be gained.

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