ANALYZING THE PRACTICAL USE OF LOAD PLANNING MODELS IN INTERMODAL RAIL TRANSPORT

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ABSTRACT
The train loading problem involves determining the positions of outbound containers on trains. This paper analyzes the applicability of load planning models described in scientific literature to the real life situation of an intermodal rail operator. A novel train planning model is presented, combining theoretical models from literature with problem characteristics from practice. Results of the train planning model are compared with the current manual planning process of the intermodal rail operator. Next, the load planning model is adapted to a rolling time horizon. Results demonstrate the added value of an automated planning method as a supporting tool for the planning department of the intermodal rail operator. Applying the train planning model in a rolling horizon approach offers an initial load plan for the whole week and enables the manual planners to have a longer term view.

Keywords: intermodal rail transport, load planning problem, case study, multiperiod planning

1. INTRODUCTION

A further stimulation of intermodal transport is expressed in multiple communications of the European Commission (2009, 2011). An increased use of intermodal rail transport for long-haul transport distances can relieve congested highways and increase the sustainability of our transport system. Bontekoning, Macharis and Trip already emphasized in 2004 the upcoming research field of intermodal rail transport. Many research efforts have been focused on increasing the efficiency and competitiveness of intermodal transport (Caris et al. 2008). An up-to-date overview of current topics in decision making models for intermodal transport can be found in Caris et al. (2013).

According to Boysen et al. (2013) the market share of rail freight transport may be expanded by establishing an efficient freight handling in intermodal terminals. At the operational decision level, the train loading problem involves determining the positions of outbound containers on trains. The following research papers are related to the train loading problem. Feo and González-Velarde (1995) are the first to study the problem of optimally assigning highway trailers to railcar hitches (‘piggyback’ transport) in intermodal transportation. The problem is defined as a set covering problem. The authors apply a branch-and-bound algorithm and a Greedy Randomized Adaptive Search Procedure. Instead of only considering the local trailer assignment problem at a single yard at a single point in time, Powell and Carvalho (1998) introduce network level information to improve decisions made at a local level. The problem is formulated as a logistics queuing network which can handle a wide range of equipment types and complex operating rules. The repositioning of railroad-owned equipment is integrated in this problem formulation. Corry and Kozan (2006) develop a load planning model to dynamically assign containers to slots on a train at an intermodal terminal. The objectives are to minimize excess handling time and optimize the mass distribution of the train. Because truck arrival times are not known in advance, the model needs to be applied over a rolling horizon. The simplifying assumption is made that all containers have equal length. In an adapted version of their model, the authors minimize the weighted sum of number of wagons required and equipment working time (Corry and Kozan 2008). A local search algorithm and a simulated annealing algorithm are proposed to find solutions in a short time span. Constraint programming is applied by Aggoun et al. (2011) to optimize the assignment of containers of various sizes to wagons of a train. Additional constraints related to the handling of dangerous goods and incompatibilities between families of containers are taken into account. Bruns and Knust (2012) introduce additional weight restrictions for the wagons and the whole train in their train loading model. The objective function is a weighted sum which maximizes the utilization of the train and minimizes setup and transportation costs in the terminal. The authors extend their model taking into account uncertainties about input data concerning the wagons of the train and the load units that should be placed on to the train (Bruns et al. (2013). A robust optimization approach is described to increase the reliability of solutions in an uncertain planning environment.

In this paper we analyze the applicability of load planning models described in scientific literature to the real life situation of an intermodal rail operator. Section 2 summarizes factors which determine the efficiency of a load plan. In section 3 a case study is presented in which scientific models are tested and adapted to a practical context in intermodal rail transport. Concluding remarks are given in section 4.

2. EFFICIENT LOAD PLANNING

This section gives an overview of factors that may play a role in drawing up an efficient load plan. First, for each type of wagon, a given number of load patterns are possible (Corry en Kozan, 2008). Each wagon can be divided in a single or multiple slots. The number of slots in a load pattern is equal to the number of containers on the wagon. Each load pattern defines certain length restrictions and weight limits per slot. Also a limit is placed on the entire length and weight of the train. Second, avoiding a double handling of containers can increase the efficiency of a load plan. Double handling arises when a load unit cannot immediately be placed onto another transport mode and needs to be stacked in a temporary buffer location or when changes are made to the load plan in a dynamic context. However, a reduction in double handling may lead to a worse weight balance of the entire train (Corry and Kozan 2006). Thirdly, a load plan may be efficient in terms of wear of the breaks, by minimizing the distance between the centre of gravity and the front of the train.

3. CASE STUDY

The applicability of theoretical models found in literature is explored in a practical case study in which an intermodal rail operator offers daily services along continental connections throughout Europe. In subsection 3.1 the planning context of this intermodal rail operator is first described. Next, in subsection 3.2 a novel train planning model is presented, combining theoretical models from literature with problem characteristics from practice. In section 3.3 this train planning model is applied to the planning operations on a daily and weekly basis.

3.1. Planning context

This case study considers the load planning operations of an intermodal rail operator offering connections between Italy, the Benelux countries, the United Kingdom and the Rhine-Ruhr area. The train planning at a single intermodal rail terminal in their service network is studied.

The company owns and manages its own trains to be able to offer a high service degree to its customers. Only when its own capacity is insufficient or when a certain connection is not offered by the company itself, it will make use of external rail operators. Around 1800 load units of seven different types are available, as summarized in Table 1. The second and third column mention the available number and length of each type of load unit.

Table 1: Type of load units

Type	Nb	Length (metres)
Coil flat – 20 ft and 25 ft	195	6.10; 6.58 or 7.15
Bulk container – 30 ft B	950	9.12
Curtain side swap body – 30 ft	100	9.29
Curtain side swap body – 45 ft	335	13.72 or 13.95
Pallet wide box container – 45 ft	175	13.71
Mega huckepack trailer – 45 ft	10	13.62
Trailer with coil well – 45 ft	15	13.95

For the intermodal connection under study, the company makes use of three different wagon types: 60-feet wagon with four axes, 90-feet wagon with six axes and 104-feet wagon with 6 axes. Each wagon type is characterized by a number of load patterns.

The company offers a daily service on this intermodal connection from Monday until Saturday. The train planning is performed by experienced planners, who take into account the following restrictions. The total weight of a train, including wagons, load units and load content may not exceed 1600 tonnes. The train length is limited to 520 metres. The order of the wagons and wagon types are fixed, as the train is composed first for the intermodal connection in the opposite direction.

The train planners apply a number of rules of thumb. Priority is given to most urgent transport orders with the shortest due dates. Secondly, large transport orders of 45 feet are assigned to 90-feet wagons. Each train also needs to carry a number of containers of a specific customer. These are identical transport orders without a fixed due date. Transport orders for which the load type is not yet known, are planned in advance as a 45-feet load unit and are assigned to a 90-feet wagon. If all 90-feet wagons are already occupied, these transport orders are assigned to 60-feet wagons. If afterwards it appears that these transport orders have been given different load types, the train planning needs to be revised. Bulk containers of 30 feet and 30-feet swap bodies are allocated as much as possible to 60-feet wagons. If this is not possible anymore, they are placed on 90-feet wagons. Load units of 20 and 25 feet are preferably not placed onto 90-feet wagons. The train planning is a dynamic process. The emergence of more urgent transport orders, the fact that planned load units may not arrive in time at the intermodal terminal and new information on the type of load unit of a transport order all lead to changes in the initial train planning.

3.2. Train planning model

In this subsection a binary programming model is proposed for the train planning in this case study. The model formulation is partly based on Corry and Kozan (2008) and is adapted to the specific problem context.

Concerning the objective function, the intermodal rail operator aims to maximize the loading degree of its trains. A minimization of train length is not pursued, as the company prefers to carry an additional transport order with a later due date instead of uncoupling wagons. A minimization of handling costs (cfr. double handlings) is not considered by the planners, as handling operations are the responsibility of the terminal operator and not of the intermodal rail operator. Handling costs are also estimated to be much lower than the cost of an additional wagon set. Therefore the intermodal rail company focuses on the minimization of the number of wagon sets and thus the maximization of the loading degree of each departing train.

The following notation is used to formulate the train planning model:

Indices

i	load unit i ($i = 1,\dots, n$)
j	wagon j ($j = 1,\dots, m$)
a	load pattern a ($a = 1,\dots, c_j$)
k	slots k per load pattern ($k = 1,\dots s_{ja}$)

Parameters

s_{ja}	number of slots in pattern a of wagon j
c_j	number of possible patterns for wagon j
d_{ijak}	equals 1 if load unit i has same dimension as slot k in pattern a of wagon j, zero otherwise
g_i	weight of load unit i (empty weight and weight of the load)
h_j	empty weight of wagon j
mwg_j	maximum allowed weight loaded on wagon j (excluding h_j)
P_{ja}	priority of load pattern a on wagon j

Variables

U_{ijak}	equals 1 if load unit i assigned to slot k in pattern a of wagon j, zero otherwise
y_{ja}	equals 1 if pattern a is chosen for wagon j, zero otherwise

Maximize

$$1000 * \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}} U_{ijak} + \sum_{j=1}^{m}\sum_{a=1}^{c_j}(P_{ja} * U_{ijak})$$

Subject to

$$U_{ijak} \leq d_{ijak} \qquad \forall i, \forall j, a = 1,\dots,c_j, k = 1,\dots,s_{ja} \tag{1}$$

$$\sum_{i=1}^{n} U_{ijak} \leq 1 \qquad \forall j, a = 1,\dots,c_j, k = 1,\dots,s_{ja} \tag{2}$$

$$\sum_{j=1}^{m}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}} U_{ijak} = 1 \qquad \forall i \tag{3}$$

$$\sum_{a=1}^{c_j} y_{ja} \leq 1 \qquad \forall j \tag{4}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{s_{ja}} U_{ijak} \leq s_{ja} * y_{ja} \qquad \forall j, a = 1,\dots,c_j \tag{5}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}} g_i * U_{ijak} + \sum_{j=1}^{m} h_j \leq 1{,}600{,}000 \tag{6}$$

$$\sum_{i=1}^{n}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}} g_i * U_{ijak} \leq mwg_j \qquad \forall j \tag{7}$$

$$U_{ijak} \in \{0,1\} \qquad \forall i, \forall j, a = 1,\dots,c_j, k = 1,\dots,s_{ja} \tag{8}$$

$$y_{ja} \in \{0,1\} \qquad \forall j, a = 1,\dots,c_j \tag{9}$$

The objective function maximizes a weighted sum of the loading degree of the train and the use of optimal load patterns. Optimal load patterns receive a high priority P_{ja}, as they make to a maximum use of the available capacity. For these load patterns, P_{ja} is set to 10, while the train utilization receives a weight of 1000. A high loading degree remains the main objective of the company.

The first group of constraints (1) ensure that a load unit is assigned to a slot with a matching dimension. Constraints (2) and (3) guarantee that slots are allocated to at most one load unit and that each load unit is assigned to a single slot. The next group of constraints (4) state that a single load pattern may be chosen for each wagon. Load units may only be assigned to selected load patterns, taking into account the number of available slots in a selected pattern (constraints (5)). A limit of 1600 tonnes is imposed on the total weight of the train by constraint (6). Furthermore, the total weight of all load units assigned to a wagon should be less than the maximum allowed weight for this wagon type (constaints (7)). Finally constraints (8) and (9) define the decision variables as binary variables.

The intermodal rail operator does not take the balancing of weight on the total train into consideration, as wear of the breaks is seen as of minor importance compared to the cost savings of a higher loading degree. The company realizes that a higher degree of cooperation with the terminal operator could lead to an integrated decision making, taking also the minimization of handling costs at the terminal into account when drawing up a train loading plan. A higher degree of integration with the terminal would offer the opportunity to integrate data flows, leading to real-time information. An online status update of the load units at the terminal can further improve the planning process. Currently, the intermodal rail operator can consult a status update of the terminal only every two hours.

3.3. Case study results

Results of the train planning model are compared with the current manual planning process of the intermodal rail operator. This analysis is performed for the planning process of a random day, with the historic data given in Table 2. The first part of table 2 summarizes the number of wagons of each wagon type available on the train. The composition of the train is fixed and depends on the earlier made composition of the train in the opposite direction along the same transport corridor. The second part of table 2 mentions the type and number of load units which were loaded onto the train in the manual planning process. For each wagon type, multiple load patterns are possible. The available number of slots in each load pattern is also an input into the train planning model. The optimal load pattern *a*, allowing a maximal load on wagon *j*, needs to be identified by setting the corresponding parameter P_{ja} to the value of 10.

Table 2: Data day 1

		Nb
Wagon type	60 ft	13
	90 ft	3
	104 ft	4
	Total	**20**
Type of load unit	20 ft	7
	25 ft	5
	30 ft B	14
	30 ft	2
	40 ft	1
	45 ft	11
	Total	**40**

Table 3 compares the manual train planning of day 1 with the exact solution of the train planning model as described in section 3.2. This automated planning is calculated with the optimization software Aimms (www.aimms.com).

Table 3: Train planning day 1

		Manual			**Automated**			
		Slot			Slot			
Wagon	ft	1	2	Opt	1	2	3	Opt
1	60	20	25	0	45			0
2	60	25	20	0	20	20		0
3	60	30	30	1	30	30		1
4	60	30	30	1	30	30		1
5	60	30	30	1	25	30		0
6	60	30	30	1	30	30		1
7	60	20	25	0	45			0
8	60	20	20	0	30	30		1
9	104	45	45	0	20	25	25	0
10	104	45	45	0	20	25	45	0
11	104	45	45	0	30	45		0
12	60	30	20	0	20	20		0
13	60	30	30	1	30	30		1
14	90	30	20	0	45	45		1
15	90	40	45	0	45	45		1
16	90	45	45	1	45	45		1
17	60	30	30	1	30	30		1
18	60	30	30	1	30	30		1
19	104	45	45	0	20	25	40	0
20	60	25	25	0	45			0

Each line in table 3 represents a wagon. The columns indicate the wagon type expressed in feet (ft) and the type of load unit placed in the first, second and third slot in the manual and automated planning. The columns 'Opt' show whether an optimal load pattern is chosen for this type of wagon or not. As the train planning is based on historic data, the same number of load units is planned in the automated planning as in the manual planning. Thus train utilization remains the same. However, the automated planning chooses the optimal load pattern for 10 wagons, compared to 8 times an optimal load pattern in the manual planning. Also time savings are achieved in the planning operations. The manual planning takes around 30 minutes, whereas the exact solution of the train planning model is generated in a few seconds. In the dynamic context of the intermodal rail operator, this time gain can be crucial when changes in the train planning are required.

In table 4, the same comparison is made for a train with an almost ideal composition and high degree of utilization. Both the manual and automated planning select an optimal load pattern for 15 out of 18 wagons. Results for days 1 and 2 indicate that the binary program of section 3.2 adequately solves the train planning problem and may result in considerable time savings for the intermodal rail operator.

Table 4: Results day 2

		Manual			**Automated**		
		Slot			Slot		
Wagon	ft	1	2	Opt	1	2	Opt
1	90	45	45	1	45	45	1
2	90	45	45	1	45	45	1
3	60	30	30	1	20	20	0
4	60	30	30	1	30	30	1
5	60	30	30	1	25	30	0
6	60	20	30	0	30	30	1
7	60	30	30	1	30	30	1
8	60	30	30	1	30	30	1
9	60	25	20	0	30	30	1
10	90	45	45	1	45	45	1
11	60	30	30	1	30	30	1
12	90	45	45	1	45	45	1
13	90	45	45	1	45	45	1
14	90	45	45	1	45	45	1
15	90	45	45	1	45	45	1
16	60	25	30	0	30	30	1
17	60	30	30	1	25	30	0
18	60	30	30	1	30	30	1

In the previous two examples historic data of a manual train planning is used. No changes in train utilization can be measured as the number of available load units is given. In the next analysis, the load planning model is investigated with a rolling time horizon. Historical data of one week are used as a list of available load units that need to be transported. Priorities PD_i are assigned to each load unit *i*, according to its due date. Load units that need to be shipped on the present day receive a priority value of 100. Load units which have to be shipped one day later, get a priority value of 10. All other transport orders with a later due date in the same week, receive a priority value of zero. The automatic planning is run for each day of the week consecutively and priority values are modified after each day. The objective function of the binary programming model is adapted as follows, to incorporate the handling of these priorities.

$$\text{Maximize} \quad \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}}(l_i * U_{ijak})$$
$$+0.1 * \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}}(PD_i * U_{ijak})$$

In the first part of the objective function the train utilization is maximized. However, in this formulation the sum of the length l_i of all loaded units is maximized. In this way optimal loading patterns are already favoured and the second part of the previous objective function becomes redundant. The handling of priorities is maximized in the second part of the new objective function. A weight of 0.1 is assigned to this priority handling. This implies that only if the priority of a load unit is equal to 100, a larger importance is given to urgent transport orders than to maximizing the loading degree of the train. The rolling horizon model also requires a change in constraints (3). Each load unit should now be assigned to at most one slot, as stated in the new group of constraints (10). All other constraints remain the same.

$$\sum_{j}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}} U_{ijak} \leq 1 \qquad \forall i \qquad (10)$$

Historical data of a single week is used to analyze the use of the train planning model in a rolling horizon approach. Table 5 gives an overview of the number and type of wagons available on each day of this week.

Table 5: Available wagons in rolling horizon approach

Wagon type	Mon	Tue	Wed	Thu	Fri	Sat
60 ft	8	10	14	8	13	11
90 ft	5	7	4	5	5	5
104 ft	5	2	2	5	1	2
Total	18	19	20	18	19	18

The train planning model is run for each day of the week. Load units assigned to a wagon slot are each time removed from the list of available load units for the next planning day. Tables 6 and 7 summarize the results of the manual and automatic train planning. The first row in both tables mentions the number of load units assigned to the train. The unused weight and unused length of the train are given in the second and third row as a percentage of the available capacity. In the automated planning a higher train utilization is realized from Monday to Friday. This results in fewer load units left and thus a high remaining capacity on Saturday (40% unused weight and 70% unused length). The largest difference between both planning methods is observed on Monday. This may be partly explained by the fact that the planners on the first day of the week may not dispose of all information on some load units that will become available later on.

Table 6: Results manual planning of one week

	Mon	Tue	Wed	Thu	Fri	Sat
Nb of load units	31	38	40	36	38	36
Unused weight (%)	22.1	0.7	1.8	10.7	6.3	7.9
Unused length (%)	25.2	8.9	14.1	13.1	9.3	7.1

Table 7: Results automatic planning of one week

	Mon	Tue	Wed	Thu	Fri	Sat
Nb of load units	45	40	42	38	37	17
Unused weight (%)	0.01	0.67	0.48	0.02	0.94	40.29
Unused length (%)	1.7	1.3	1.3	4.1	3.7	70.4

Table 8 gives a detailed analysis of the number of assigned load units in each priority class on each day.

Table 8: Number of assigned load units

Day	PD_i	Manual	Automated
Mon	100	18	24
	10	10	10
	0	3	11
Tue	100	11	23
	10	24	12
	0	3	5
Wed	100	22	14
	10	0	0
	0	18	28
Thu	100	26	18
	10	7	7
	0	3	13
Fri	100	15	15
	10	15	17
	0	8	5
Sat	100	18	7
	10	16	0
	0	2	10

In current practice, the manual planners only look two days ahead. Therefore, fewer load units with a zero priority are observed in the manual planning. Only on Wednesday less urgent load units are shipped to guarantee that these will arrive at the latest on Saturday. Table 8 also shows that the automated planning assigns a higher number of urgent load units to trains on the first days of the week. Results in tables 6, 7 and 8 demonstrate the added value of an automated planning method as a supporting tool for the planning department of the intermodal rail operator. Results should still be interpreted with care, as in reality the planning is highly dynamic. New transport orders may be placed on the same planning day and other load units may not reach the terminal in time to be put on the departing train. However, applying the train planning model in a rolling horizon approach offers an initial load plan for the whole week and enables the manual planners to have a longer term view.

4. CONCLUSIONS AND FUTERE RESEARCH DIRECTIONS

In this paper the applicability of train planning models from scientific literature is tested on a case study of an intermodal rail operator in Europe. The company focuses on maximizing the train utilization, at the expense of handlings costs at the terminal. Load patterns and weight restrictions are taken into account. The company does not consider double handlings, transportation costs of rolling stock at the terminal or changes in pin settings of wagons. A new train planning model is proposed and compared with the manual planning method currently in practice. The new train planning model can provide the train planners with an immediate and efficient solution.

In future research, the use of this train planning model in a dynamic setting should be further investigated, as the planning operations are continuously subject to changes. Another research opportunity lies in the integration of train planning decisions with the other operational decisions at the intermodal terminal, taking into account the cost of handling material. A final research track identified in the case study is the joint planning of multiple trains departing from different nearby terminals from which the intermodal rail operator offers services.

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