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LOADING OPTIMIZATION OF PALLET UNITS IN RAILWAY WAGONS[1]

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Abstract

The pallet is a loading unit with which a forklift can easily and quickly manipulate. One of the important services provided by the railways is transportation of freight in pallets. Loading pallets in railway wagons must satisfy numerous constraints related to: the order of packing both horizontally and vertically, the balanced load and characteristics of freight wagons (volume, carrying capacity, tare weight, length, number of axles, number of openings for loading, etc.). A number of constraints comes from the category of railway line by which the goods will be transported. The problem falls into the category of combinatorial optimization problems which is complex both for modeling and for solving due to the large number of constraints and numerous exceptions. In the paper, one model for the problem has been proposed. This paper also presents a few examples on which the proposed optimization model and its corresponding software have been tested.

Keywords - loading pallets; optimization; Cutting and Packing problem; railway wagons

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[1] Original scientific paper

INTRODUCTION

Under the term of pallet we consider an object that is used for packing multiple pieces of freight until it reaches certain weight or height in order to protect and create a unified loading unit which can be easily manipulated by a forklift (to lift it up, put it down, carry it and pack). One of the most important services which are provided by a railway company is transport of freight packed in pallet units. The goal of each railway operator is to offer high quality of this service and to gain as much profit as possible by its realization.

When loading the pallet units in railway wagons certain constraints such as the order of loading the units both vertically and horizontally, the wagon carrying capacity, the available floor surface, the available volume of loading space, balancing the freight in wagons, must be satisfied. There are the freight wagons different volumes, carrying capacity, weight, length, number of axles. They differ in type (open closed, special, tanks), number of openings for loading and unloading the freight, the way of loading and unloading, etc. Certain constraints are in connection with the freight which is being transported, e.g. certain types of freight are sensitive to pressure, so that it must be loaded on the top level. Variety of pallets of different types, dimensions, weight and useful capacity are being used in railway transport too. In case if there are used two different types of pallets in the same wagon certain rules that refer to vertical and horizontal loading must be obeyed. Naturally, the problem becomes more complex, if we bear in mind, that large number of wagons that have the same or different destination and are being loaded in the same cargo center can be loaded simultaneously. A number of the constraints refer to the type of railway line by which the goods will be transported.

This problem falls into category of combinatorial optimization problems which have complex way of modeling and solving due to the large number of constraints and because these constraints are usually difficult to formulate due to many exceptions. Nowadays we can overcome the volume and complexity of these tasks by using computer software. The power of modern computers offers the opportunity of transferring from imperative to declarative programming and from textual to graphic and multimedia presentation of the solutions that we have come to.

The rest of the paper is organized as following: The section 2 reviews the literature dealing with packing optimization. The section 3 describes motivation for our research in this filed. The fourth, key section sets constraints and objective function for pallet loading problem. Before the conclusion, section 5 shows chosen numeric examples.

BACKGROUND

Packing optimization of different packages into cargo space of some transport vehicle is basically the cutting and packing (C&P) problem. C&P problem appear under various names in literature: vehicle, pallet or container loading problem, knapsack problem, rucksack problem, nesting problem, bin or strip packing problem, cutting stock or trim loss problem, etc. Basic structure of C&P problem is as follows: given are two sets of elements, a set of large objects (input) and a set of small items (output), which are defined in one, two, three or alarger number of dimensions [1]. Select some or all small items, group them into one or more subsets and assign each of the subsets to one of the large objects such that all specified constraints are respected and a given objective function is optimized. We note that a solution of the problem may result in using some or all large objects, and some or all small items.

In the nineties Dyckhoff has first systemized the difference in terminology, types and potential applications in his comprehensive survey [2]. According to Dyckhoff, the basic classification of C&P problems is to C&P in narrow sense and abstract C&P, Fig. 1.

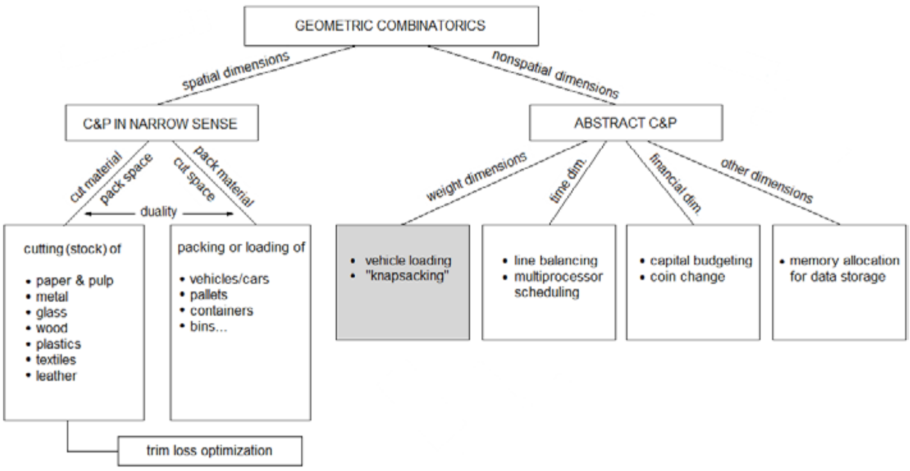

Fig.1.Types of cutting and packing problems

Our problem is to load a wagon as good as possible and position of the problem in the classification which Dyckhoff has proposed is shaded on the Fig. 1. In the trading of goods, weight is taken to mean the same as mass, and this concept has been adopted in this paper.

Even though C&P problems grabbed the attention of researchers for more than fifty years, in recent period of time there were numerous researches which have tried to find the solution in this field by using different techniques. At this point we will present a brief review of couple most recently published papers that were interesting for our research.

The study described in [3] proposes a hybrid approach that integrates the genetic algorithm and fuzzy logic in order to assist in the generation of an optimal pallet loading plan. In this paper, the term "pallet" is synonymous with the term "cargo space". The proposed model enables the maximization ofprofits for freight forwarders through the most efficient use of space and weight in pallet loading. In order to demonstrate the benefits of the hybrid model, metaheuristics simulated annealing and tabu search are used to benchmark the results. Also, the application of the proposed hybrid approach is discussed.

Combination of vehicle routing problem and vehicle loading problem is a recent domain of research [4]. In packing literature, weight distribution of the cargo inside the vehicle is achieved by appropriate positioning the center of gravity of the load and by balancing over the axles of the vehicle. Since weight distribution varies with every pick up or delivery, this should be monitored not just at the point of departure but throughout the journey.

MOTIVATION FOR THE RESEARCH

The previous section clearly indicates that researches have shown an interest for the problem of packing and loading. It is not necessary to explain too what practical significance the railway operator has from loading optimization. The question arises: What is the point of such a research when tens of software companies claim that they have developed programming systems that solve the problem: "how to" load the trucks, containers, pallets, wagons, boxes, ... with single and mixed size products? At this point we are going to mention only several available systems for loading optimization: CubeDesigner.NET (http://www.logensolutions.com/ VMS/CubeDesigner/ Palletizing_Package_Design_Software_Overview.html),CubeMaster (http:// www.logensolutions.com/VMS/CubeMaster/Cargo_Load_Plan_Optimization _Software_Overview.html), StackBuilder (https://stackbuilder. codeplex.

com/) and Ortec Load Building (http://www.ortec.com/loadbuilding.aspx).

The following lines should provide the answer to this question.

Namely, it has proved that the effort to apply commercially available optimization system in practice may be important. Pinedo considers Generic Systems vs. Application-Specific Systems [5] and concludes that code that has been developed for acceptanceof generic system sometimes may be bigger than the half of code of final version of the system. The most common reason for this is that the environment where the optimization should be implemented has certain constraints or limits which are very hard to “join” with generic software system. General valid constraints may have “special cases” where process of coding can be that comprehensive that it would be more useful to build up the system “from scratch”. It may happen as well that commercial optimization software does not have necessary interface to make connection with already present information system of real environment. E.g. software system predicts the reception of input data from Oracle database (it is common because generic systems are usually build up as a system upgrade for database management systems, e.g. Access or Oracle), and the data has been already saved in Excel worksheets. The following reason to develop its own system is if the user insists on source code so that it could be possible to maintain the system autonomously. To represent the solutions in an unusual form may demotivate the user from using the generic software package at all. User-planner often likes to compare different solutions and to conduct “what-if” analysis.

Now then, in many cases, commercial optimization software simply is not suitable and specific system intended for the environment where the optimization is being done must be developed.

PALLET LOADING AS CUTTING AND PACKING PROBLEM

International Union of Railways, UIC (French:*Union Internationale des Chemins de fer*)recommends the usage of pallets that have base dimension800x1200mm (UIC 435-2), 1000x1200mm (UIC 435-5)and box pallets that have base dimension800x1200mm (UIC 435-3). EPAL (*European Pallet Association*) refers to these pallets as EPAL, EPAL 3and EPAL-box pallets, in this order [6]. The standard dimension of 800x1200mm was adopted in Serbian Railways, even though it is allowed to use pallets of different dimensions when transporting certain products.

The palletized goods can be transported in closed and opened railway wagons. The usage of closed wagons is more frequent considering that the goods that are being transported in pallets are not usually resistant to atmospheric changes. The Serbian Railways use following types of pallets: flat pallet, box pallet, column pallet and special pallet.

The subject of this paper is packing the box pallets in single closed railway wagon, that has to fulfill following constraints:

1. The number of available levels N^hdetermined by the height of pallet and height of the wagon. Similarly, the number of pallet units lengthwise the wagon N^ldetermined by length of the wagon and length of the pallet, whereas the number of pallet units in wagon width N^w in width of the wagon and the pallet.The number of pallets that can be loaded into wagon

is:$n=N^h \cdot N^l \cdot N^w$.Our model implies that the wagon is loaded at departure station, in term of volume, to full extent.

2. The forklift loads the pallet units in closed railway wagon starting from the front towards the middle and from bottom to top (“vertically”) in order from the position 1 to the position$n$,Fig. 2and 3.
3. The unloading of the pallets is done in reverse order to loading, thus from position $n$to position 1. All the pallets are unloading at the same station.
4. The max wagon carrying capacity must not be exceeded.

4	6	5
1	3	2

82	84	83
79	81	80

Fig. 2. The position arrangement on first and last vertical that is being loaded for $N^h=2$, $N^l=14$ and $N^w=3$

Level I

2	8	14	20	26	32	67	69	68	62	56	50	44	38
3	9	15	21	27	33	73	75	74	63	57	51	45	39
1	7	13	19	25	31	79	81	80	61	55	49	43	37

Level II

5	11	17	23	29	35	70	72	71	65	59	53	47	41
6	12	18	24	30	36	76	88	77	66	60	54	48	42
4	10	16	22	28	34	82	84	83	64	58	52	46	40

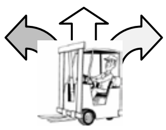

Fig.3. The position arrangement in the first and the second level for$N^h=2$, $N^l=14$ and $N^w=3$

5. The max axel weight must not be exceeded.
6. The axel construction (left/right) weight ratio has to be respected, Fig 4. This ratio defines the allowed deviation of freight center of gravity in transverse direction and depends on both whether the wagon is fully or partially loaded and the category of railway line for which loading is done. In this model the axel construction weight ratio can be at most 1:1.25.

$$R_1 = \sum_{j=1}^{n}\sum_{i=1}^{m}\frac{s-r_j}{s}x_{ij}\cdot weight_i + \frac{W}{8}$$

$$R_2 = \sum_{j=1}^{n}\sum_{i=1}^{m}\frac{r_j}{s}x_{ij}\cdot weight_i + \frac{W}{8}$$

$$0.8R_1 \le R_2 \le 1.25R_1$$

W - weight of wagon

$weight_i$ - bruto weight of pallet type i

$$x_{ij} = \begin{cases} 1, \text{ if pallet type } i \text{ is assigned to position } j \\ 0, \text{otherwise} \end{cases}$$

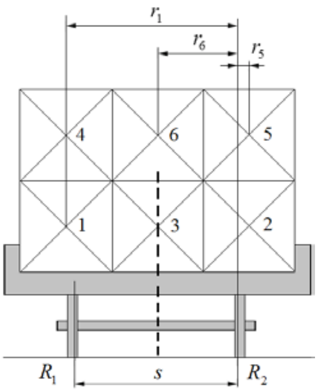

Fig. 4. Axel construction weight ratio

7. In case of wagon with bogies, the bogie weight ration can be up to 3:1.
8. The weight of loaded wagon by meter can increase up to the determined value.

The most frequent optimization criteria when transporting goods is profit maximization. Therefore, we have chosen this objective function in our research.

The described problem has been formalized as zero-one linear programming task. Mathematical model has been coded using OPL (*Optimization Programming Language*) and then solved by using CPLEX Optimizer,a solver for mathematical programming (http://www-01.ibm.com/ software/websphere/products/optimization/cplex-studio-community-edition/).

Declarative nature of OPL, modeling language, has been used in order to formulate the constraints and objective function with ease. E.g. the constraint concerning the axel construction weight ratio is simply coded in OPL:

```
0.8*((sum (i in pallets, j in positions)((s-r[j])/s)*weight[i]*x[i][j])+W/8)<=
((sum (i in pallets, j in positions)(r[j]/s)*weight[i]*x[i][j])+W/8) &&
((sum (i in pallets, j in positions)(r[j]/s)*weight[i]*x[i][j])+W/8) <=
1.25*((sum (i in pallets, j in positions)((s-r[j])/s)*weight[i]*x[i][j])+W/8);
```

NUMERICAL EXAMPLES

The box pallets should be loaded in one closed wagon of H_{bs}(“Habis”) type. Characteristics of H_{bs}wagon [7] and box pallets are represented in Table 1. The door of ”H” wagon series can be opened up to 2/3 of side surface which leaves forklift to enter the wagon and manipulate with goods. All of the box pallets have the same volumeand bruto weight which depends of the weight of the goods, Table 2. We will consider that box pallets are homogeneous bodies, i.e. their center of gravity is in volume center of gravity, in diagonal cross-section. By transporting the goods the railway companies make profit which depends of the weight and type of goods. The goods are going to be transported by means of C2 railway line category, where the top allowed one axel weight is 20t and the top allowed weight by meter is 6.4t/m, in case of standard track width of 1.435m.

Table 1. Wagon and box pallet characteristics

Characteristic	**Habis wagon**	**Box pallet**
length [m]	18.54	1.240
width [m]	2.66	0.830
height [m]	2.50	0.970
carrying capacity [t]	53.50	0.900
volume [m^3]	113.40	0.750
weight [t]	26.50	0.085

Table 2. A task of packing optimization with 10 box-pallet types

	Pallet type									
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
Weight of the goods [kg]	200	455	555	505	615	665	695	715	765	895
Profit [mu]	152	230	320	310	350	220	280	330	350	650

Therefore, the number of pallets that can fit in is: $n=N^l \cdot N^w \cdot N^h$=[18.54/1.24]·[2.66/0.83]·[2.50/0.97] = 14 ·3 ·2 = 84 (14 by length and 3 by width, in two levels). The wagon is being loaded in order, starting from position 1 to position 84 (Fig. 2 and 3), up to full volume occupancy.

Example 1. There are no constraints in number of pallet units for any type of pallets which are waiting to be loaded.

The optimal solution has been found with a profit of 33852 monetary units [mu]. The wagon has been filled-up with weight of 53.485t i.e. 99.97% of carrying capacity. The arrangement of pallets in the first and the second level has been represented in Fig. 5. Taking into account that arrangement of loading position is represented in Fig. 2 and 3, the arrangement that the forklift will use while loading is the following: P1, P1, P1, P1, P1, P1, ..., P10, P10, P10, P10, P10, P10.

Level I

P1	P1	P1	P10	P10	P10	P10	P10	P10	P10	P10	P10	P1	P1
P1	P1	P1	P1	P10	P10	P10	P10	P10	P10	P10	P1	P1	P1
P1	P1	P1	P1	P10	P10	P10	P10	P10	P10	P10	P1	P1	P10

Level II

P1	P1	P1	P1	P10	P10	P3	P10	P10	P10	P10	P10	P1	P1
P1	P1	P1	P1	P10	P1	P1	P10	P10	P10	P10	P1	P1	P1
P1	P1	P1	P1	P10	P1	P10	P10	P10	P10	P10	P1	P1	P1

Fig. 5. Optimal pallet arrangement for Example 1.

The number of suitable pallet types that are due to be loaded has been in the Table 3.

Table 3. The number of pallets by type in solution of Example 1.

	Pallet type									
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
Number	41	0	1	0	0	0	0	0	0	42

of pallets										

Example 2. The number of pallet units of P4 and P10 type which are waiting to be loaded is 10, whereas for the rest of the types there are no constraints.

The optimal solution has been found with a profit of 28664 monetary units. The wagon has been filled-up with weight of 53.495t i.e. 99.99% of carrying capacity. The arrangement of pallets in the first and the second level has been represented in Fig. 6. The arrangement that the forklift will use while loading is the following: P5, P5, P5, P1, P5, P5, ..., P4, P1, P1, P5, P5, P5.

Level I

P5	P1	P5	P1	P5	P4	P5	P1	P1	P5	P5	P5	P10	P10
P5	P4	P1	P5	P5	P5	P5	P5	P1	P5	P3	P5	P10	P5
P5	P10	P1	P1	P5	P5	P4	P1	P1	P5	P4	P5	P10	P10

Level II

P5	P5	P1	P5	P5	P4	P5	P1	P1	P5	P4	P5	P4	P5
P5	P1	P1	P5	P5	P5	P5	P4	P5	P5	P4	P5	P10	P5
P1	P10	P1	P5	P5	P5	P5	P5	P5	P5	P5	P5	P10	P10

Fig. 6. Optimal pallet arrangement for Example 2.

The number of suitable pallet types that are due to be loaded has been in the Table 4.

Table 4. The number of pallets by type in solution of Example 2.

	Pallet type									
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
Number of pallets	17	0	1	9	47	0	0	0	0	10

By transporting the goods in Example 2. the company would make 15.4% less total profit (5208 monetary units) in comparison with transport of goods in Example 1. The restricted number of pallet units of P4 and P10 type, has caused both different optimal solutions and different transport income. Thus, the Railways income depends on both the optimal arrangement of freight in the wagons and keeping optimal supplies at place of loading.

CONCLUSION

Loading pallets in railway wagons must satisfy numerous constraints related to: the order of packing both horizontally and vertically, the balanced load, characteristics of freight wagons and characteristics of pallets. A number of constraints comes from the category of railway line by which the goods will be transported.

In this paper, the problem of loading the pallets in single railway wagon is being dealt with as C&P problem. The mathematical model in zero-one programming terms has been formulated and implemented for its solution.

We tested our model and originally developed software on a number of examples and only several are presented in the paper.

The directions for further research are numerous and they lead to the significantly more complex model: solving the problem of simultaneous loading of multiple wagons in the same cargo centre; possibility to load/unload at intermediate stations while each loading/unloading on the way requires checking of balance constraints; relaxation from constraints by which the wagon has to be loaded up to its full volume; using heuristics in order to find the good solutions faster, etc.

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