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Economic Impact of Container-Loading Problem

Alen Jugović

Thousands of containers with different types of cargo are loaded every day in multiple manufacturing and logistics centres in the world. The main problem arising from these handlings is how to make the maximum use of all the available container capacities, while keeping the overall costs of transport per cargo unit as low as possible. The previous research mostly focuses on studying different algorithms for optimising container loading with cargo that has already been assigned based on its dimensions and weight. However, this paper will emphasise the importance of using algorithms in the planning and preparation of the cargo itself during the manufacturing processes before it is dispatched for loading into containers. Besides the length, width, height, and weight of the cargo itself, a fifth component influencing the overall transport costs will be considered, i.e. the manner of loading a container. The research will be carried out on an example of a container shipment of wooden sawn timber materials.

KEY WORDS

~ Container-loading problem
~ Cargo packing
~ Cost optimisation
~ Efficiency of container capacity

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1. INTRODUCTION

Planning and loading cargo into modes of transport or containers represent the most important link in the flow of transporting processes. The efficiency of a particular transport is directly dependent on the optimal cargo loading plan and therefore dependent on the entire transport system.

With respect to loading cargo into containers, the problem is the optimal placement of as many small cargo units as possible into one large storage unit, i.e. container. Therefore, the main goal is to achieve the maximum efficiency of the available capacity of a particular container (Moura and Oliveira, 2005).

A container as a transport unit is defined by three-dimensionality, i.e. defined by its length, width, height, and permissible load-bearing capacity. During the loading process certain cargo first fills the container's available volume, while heavier cargo first fills the container's permissible load-bearing capacity. It follows that planning the loading of a container has limitations deriving from the volume and the load-bearing capacity; however, many other factors also influence the cargo stowage plan such as the possibility of cargo rotation, required level of cargo stability, exposure of cargo to possible damages, time required for loading a container, etc.

In this paper, the research on the topic of cargo loading problems is focused on setting up an algorithm which prioritises the importance of the initial cargo preparation in the manufacturing plants given that the limiting parameters of the storage unit, i.e. the container, are predefined. Moreover, manufacturing assortments are also mostly predefined, thus finding the optimal cargo unit and container loading plan which will economically be the most satisfying for all the participants in the international trade to be the greatest challenge.

The rest of this paper is divided in several, mutually connected chapters. A cross-section of the available literature on the topic of cargo loading issues is presented in the second chapter. The problem with conducting research is defined in the third chapter. The fourth chapter elaborates on the topic of the algorithm that has been set up, while in the fifth chapter the accuracy of the algorithm is tested on an example of a container dispatch of wooden sawn timber materials. The final, sixth chapter lays down the conclusion of the research carried out and confirms the hypothesis put forward, which states that timely planning of cargo packing and a sophisticated preparation of the cargo stowage plan may significantly lower the costs of transport per cargo unit and improve transport processes.

2. PREVIOUS STUDIES

The basic ideas of the researchers mentioned will be analysed through a review of relevant literature related to the topic. Framework guidelines will be indicated as the foundation of this paper.

The correct layout of the goods, the objects or the cargo in the available container space presents a very difficult task. The available capacities end up unused, and the cargo in the containers is frequently damaged because of inadequate layout and the implementation of inadequate stowage models. In order to make the maximum use of the container capacities and lower the rate of cargo damage in the containers, Patil and Patil (2016) propose creating optimising algorithms for planning the loading. They propose using a simple algorithm, a LAFF (Largest Area First-Fit) algorithm, and a LAFF algorithm with an additional weight variable as new algorithms. These algorithms use heuristic method, which first places the biggest cargo at the bottom of the container and gradually decreases the height available for stowing the cargo. They introduce a new weight variable that specifies that the heavier cargo is to be stowed at the bottom of the container to avoid possible cargo damage. A comparative analysis of the results obtained shows that the LAFF algorithm achieves greater efficiency and that it is more efficient than the other two above-mentioned algorithms.

According to Bortfeld and Wascher (2012), container loading represents the focal point of an efficient flow of the supply chain. For this reason, they thoroughly analyse the available literature on this topic, identify all the factors influencing the issue of loading cargo into containers, and analyse their prevalence in the models that offer solutions to certain problems. They also indicate all the tasks that must be considered while choosing a particular method of loading cargo into containers, and they analyse the achievements and the flaws of previously conducted studies and of the algorithms used.

The literature analysed very often adopts the application of algorithms that use a three-dimensional approach to the loading problem. Every package is placed in its optimal position and so the container is filled to its maximum capacity. The lost container space is minimised, and the number of containers used for shipping larger quantities of cargo is lowered. Layeb et al. (2017) studied the problem of loading a container with square boxes considering multiple realistic limitations of the algorithm regarding weight distribution, positioning of the boxes, and limitations of stowage. Zhao et al. (2016) focused on the evaluation of designing and implementing a methodology with an experimental comparison with different algorithm performances with reference to data sets. They concluded that the studies conducted were mostly based on one loading and much less based on multiple container loadings. They did not consider all the real limitations arising during the process of container loading.

The second group of studies is characterised by the application of a genetic algorithm (GA) which is used for finding precise or approximately precise solutions for optimisation problems. Pino et al. (2013) applied the genetic algorithm to solve the cargo distribution problems of multiple clients and reduce problems to a minimal number of containers while meeting a few basic constraints regarding stowage and balance. The procedure used included basic stowing of the largest and heaviest packages, while the smaller packages were used for filling the gaps. This way the requirements to decrease the time spent planning and to achieve the average occupancy of 85% of the available capacities have been fulfilled.

Other than the application of the genetic algorithm itself, many authors use hybrid approaches by combining various methodologies. Nepomuceno et al. (2007) apply Integer Linear Programming (ILP) and Genetic Algorithms (GAs) to offer competitive solutions for optimising the container loading process. In the study conducted, they integrated two different conceptual components. The first component consists of a generator of reduced original instances, which defines the problems arising during container loading, while the second component is a decoder of reduced instances that interprets and solves any of the generated problems coming out of the generator.

However, the majority of scientists deal with container loading optimisation problems with cargo that has its dimensions and weight already defined, while this paper will emphasise the importance of setting up an algorithm that will be focused on an initial preparation of cargo units in manufacturing plants. Besides the four basic parameters comprising length, width, height, and weight of the cargo, the manner of loading the container will also be considered.

3. DEFINING THE PROBLEM

The problem of loading a container presents a complex problem in logistics processes that aims to lower the unused free space within a container and make maximum use of the available capacities. The existing limitations are defined as follows (Gehring and Bortfeld, 1997):

- orientation limitation - each cargo cannot be rotated in all directions and, accordingly, cannot be loaded in all the positions;
- limitation to placing cargo in the upper rows - not all types of cargo can withstand the weight of the cargo placed above them, therefore there is a limit to maximum cargo stowage upwards, i.e. heavier cargo is stowed in the lower rows, and lighter cargo in the upper rows;
- volume limitation - a container is limited by its maximum volume;
- weight limitation - a container is limited by its maximum load-bearing capacity;
- stability limitation - refers to the ratio of surface on which the loaded cargo leans on one another by comparison with the total surface, which directly demonstrates the stability of the loaded cargo;
- balance limitation - refers to an even distribution of the load on the surface of the container in accordance with the position of the loaded cargo.

Moreover, the very container loading problem is directly affected by the basic characteristics of the cargo set for shipping, namely its length, height, width, weight, shape, etc. Previous studies of this problem consisted of solving scenarios for cargo that was already prepared for shipping; however, the results of cargo-stowage optimisation plan in this paper will be applied to the preparation of the cargo units in the manufacturing plants for that cargo to which this option can be applied. It follows from the above mentioned that the basic problem of the planned research is finding an optimal cargo unit which will make maximum use of the existing container capacities while maintaining a minimal number of cargo handlings.

4. SETTING UP THE ALGORITHM

In this chapter, the input parameters that determine the set-up of the basic algorithm will be defined. As the process of handling the loading of the container consists of three reciprocally connected elements, i.e. the type of container in which the cargo is meant to be loaded, the type and quantity of cargo meant for shipping, and the planned manner of loading the cargo into the container, the basic algorithm includes all three parameters determined with these three elements of the loading process. The specification of the input parameters is shown in Figure 1.

The basic algorithm arising from the above input parameters aims to find the optimal cargo unit with which maximum use of the container capacity will be achieved (Figure 2).

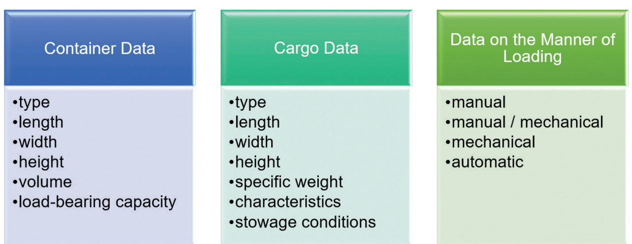

Figure 1.
Input parameters for developing the basic algorithm.

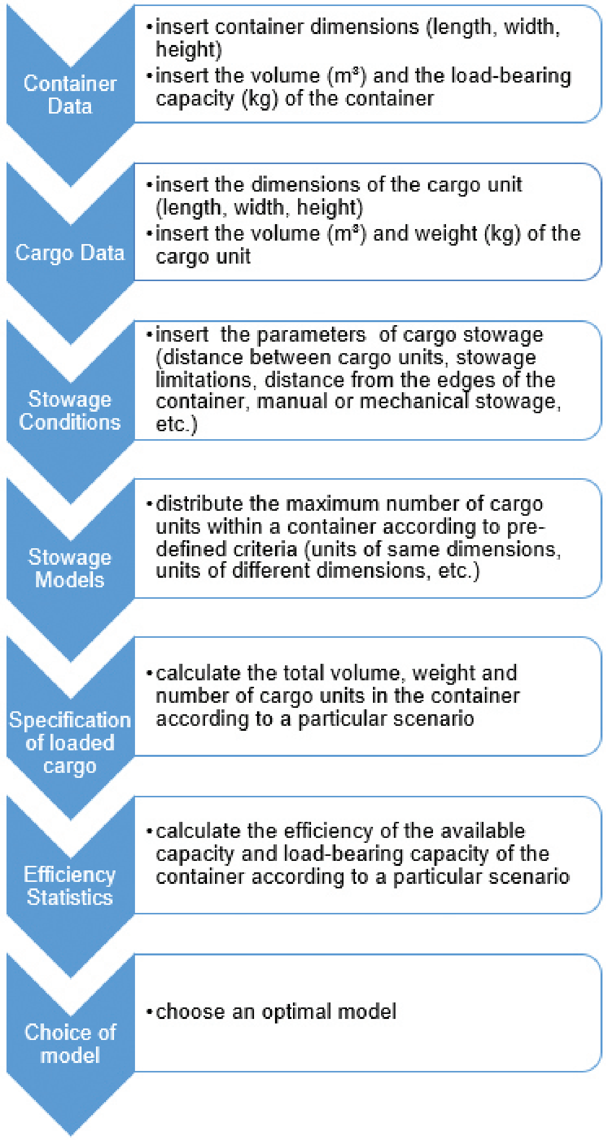

Figure 2.
Scheme of the algorithm developed.

According to the scheme in Figure 2 above, it is possible to achieve different scenarios for loading cargo into containers by inserting different values of particular parameters. A model optimal for the type of cargo tested is chosen depending on the initially set-up requirements.

5. TESTING OF THE ALGORITHM

The testing of the algorithm set up will be performed on an example of a preparatory plan for loading a container of wooden sawn timber materials. As the wooden sawn timber materials are standardized according to the HRN D. C1 022 standard, i.e. based on their thickness, width, length and class, the basic dimensions and the classes determining the criteria for preparing the basic cargo units are the following:

- thickness: 18, 25, 32, 38, (45), 50, 60, 70, 80, 90, and 100 mm;
- width: 8 - 12 cm, and more 12 cm;
- length: very short (50, 55, 60, 65, 70, 75, 80, 85, 90, and 95 cm), short (100, 110, 120, 130, 140, 150, 160, and 170 cm), and long (180, 190, 200, 210, 220, 230, 240, onwards for more than 10 cm);
- class: I, II, (I/II), M, and III.

According to the algorithm set up, a research has been conducted on the optimal dimension of a cargo unit with which maximal use of the volume and load-bearing capacity of a container can be achieved. A simulation was performed on an example of 20’ containers and a model for filling the total volume of the container with cargo units of the same dimensions in a variant of mechanical and automatic loading. A unit of wooden sawn timber materials of 50 mm in thickness, ultra-short dimensions in length, varying width and height, and of a specific density of 700 kg/m3 was used as a representative sample. The data was analysed with a programme for optimising cargo stowage in a container, packVol version 3.6.2. Standard, and the results of the analysis are shown in Table 1. packVol uses an algorithm developed in many years of license ownership research, and is based on the implementation of a set of different rules that allow the application of a large number of different conditions when planning the stacking of cargo in a container. The programme is applied to different types and dimensions of cargo, and allows you to set different stacking conditions such as maximum height and width of cargo, maximum allowed weight, loading packages according to the list of priorities or sizes of packages, allowed orientation and position of each package, spatial separation of packages, and many other conditions and restrictions of stacking. In addition to the automatic stacking plan, the program also allows the user to manually create their own cargo-stacking plan in the container. The applied program was used in a free version that provides full functionality over a period of 30 days. After the expiration of the free trial period, the packVol programme is charged in an amount that depends on individual types of packages and the possibilities it provides. The program is applied to all forms of loading when smaller units of cargo are loaded into one larger unit such as containers, trucks and alike.

The applied conditions for stacking sawn timber in a 20' container for the purposes of proven simulation were length, width, and height of the container, permissible load capacity of the container, certain distances between individual packages and between the package and the container side, machine loading package, automatic package-stacking plan in the container, and packages of the same dimensions and weights with the same priority level.

According to Table 1, the unit with 550 mm in length, 1,900 mm in width and 1,100 mm in height, with a volume efficiency coefficient of 83.08% and load-bearing efficiency coefficient of 68.36% (Figure 3) has the highest efficiency while stowing cargo units of wooden sawn timber materials in a 20’ container. The other data in the table shows the optimal dimensions of the cargo unit in all the lengths of the ultra-short class (500, 550, 600, 650, 700, 750, 800, 850, 900, and 950 mm) based on which the cargo units can be prepared if one wants to use the maximum efficiency of the capacity of a 20’ container.

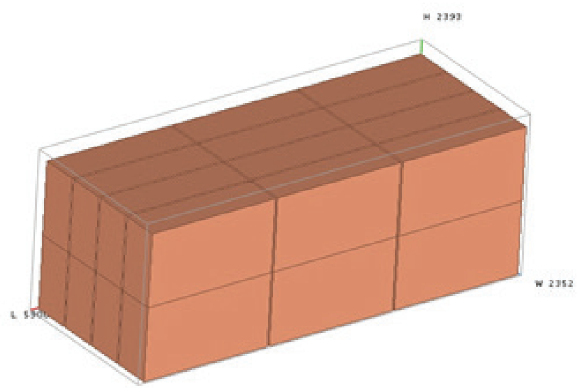

Figure 1.
Configuration of a 20’ container with cargo units sized 550 x 1,900 x 1,100 mm.

Given that the majority of the optimal cargo units in Table 1 differ in width, and because of the setting up of a unified model for the preparation and stowage of cargo units, Table 2 shows the results of the analysis of the dimensions of cargo units with a maximum average efficiency of the container’s capacity.

Table 1.
Dimensions of an optimal cargo unit for stowing wooden sawn timber materials into a 20' container.

No.	LENGTH (mm)	WIDTH (mm)	HEIGHT (mm)	NUMBER OF UNITS (PCS)	VOLUME EFFICIENCY (%)	WEIGHT EFFICIENCY (%)
1	550	1,900	1,100	24	83.08	68.36
2	800	2,200	2,200	7	81.62	67.16
3	800	1,400	2,200	11	81.62	67.16
4	800	2,200	1,100	14	81.62	67.16
5	800	1,100	2,200	14	81.62	67.16
6	700	2,200	1,100	16	81.62	67.16
7	800	1,400	1,100	22	81.62	67.16
8	800	1,100	1,100	28	81.62	67.16
9	700	1,100	1,100	32	81.62	67.16
10	700	800	1,100	44	81.62	67.16
11	500	2,200	1,100	22	80.16	65.96
12	500	1,100	1,100	44	80.16	65.96
13	750	700	1,100	46	80.00	65.82
14	600	1,000	1,100	40	79.50	65.42
15	600	800	1,100	50	79.50	65.42
16	850	1,400	1,100	20	78.84	64.87
17	850	500	1,100	56	78.84	64.87
18	900	2,200	1,100	12	78.71	64.76
19	900	1,100	1,100	24	78.71	64.76
20	650	900	1,100	40	77.51	63.78
21	650	500	1,100	72	77.51	63.78
22	950	1,200	1,100	20	75.53	62.15
23	950	400	1,100	60	75.53	62.15

Table 2.
The average volume efficiency of a 20' container during the loading of a full container with cargo units of the same width and height, but different length.

		LENGTH										
WIDTH	**HEIGHT**	**500**	**550**	**600**	**650**	**700**	**750**	**800**	**850**	**900**	**950**	**AVERAGE (%)**
300	**1,100**	76.52	76.52	75.13	76.22	77.91	76.02	77.91	74.33	75.13	73.64	**75.93**
400	**1,100**	75.53	77.25	77.91	75.79	77.91	69.56	74.20	72.08	76.32	75.53	**75.21**
500	**1,100**	72.88	78.34	79.50	77.51	81.16	72.05	74.20	78.84	71.55	69.23	**75.53**
600	**1,100**	79.50	78.71	64.40	69.76	75.13	74.53	73,14	74.33	75.13	75.53	**74.02**
700	**1,100**	76.52	81.62	75.13	72.35	77.91	80.00	77,91	70.95	75.13	74.90	**76.24**
800	**1,100**	76.85	81.62	79.50	75.79	81.62	55.65	59,36	63.07	66.78	70.49	**71.07**
900	**1,100**	71.55	78.71	75.13	77.51	75.13	62.61	66,78	60.82	64.40	67.97	**70.06**
1,000	**1,100**	72.88	76.52	79.50	73.21	74.20	69.56	74,20	67.58	71.55	62.94	**72.21**
1,100	**1,100**	80.16	80.16	78.71	75.79	81.62	76.52	81,62	74.33	78.71	69.23	**77.69**
1,200	**1,100**	75.53	74.33	62.01	67.18	72.35	65.59	69,96	74.33	71.55	75.53	**70.84**
1,300	**1,100**	68.90	75.79	67.18	67.18	72.35	71.05	75,79	73.21	77.51	73.64	**72.26**
1,400	**1,100**	74.20	81.62	72.35	72.35	77.91	76.52	81,62	78.84	66.78	70.49	**75.27**
1,500	**1,100**	69.56	76.52	71.55	71.05	76.52	74.53	55,65	59.13	62.61	66.09	**68.32**
1,600	**1,100**	74.20	75.79	76.32	75.79	74.20	55.65	59,36	63.07	66.78	60.42	**68.16**
1,700	**1,100**	78.84	80.53	67.58	65.89	70.95	59.13	63,07	57.44	60.82	64.20	**66.85**
1,800	**1,100**	65.59	78.71	64.40	69.76	75.13	62.61	66,78	60.82	64.40	67.97	**67.62**
1,900	**1,100**	69.23	83.08	67.97	73.64	79.30	66.09	70,49	64.20	67.97	71.75	**71.37**
2,000	**1,100**	72.88	80.16	71.55	68.90	74.20	69.56	74,20	67.58	71.55	62.94	**71.35**
2,100	**1,100**	76.52	76.52	75.13	72.35	77.91	73.04	77,91	70.95	75.13	66.09	**74.16**
2,200	**1,100**	80.16	80.16	78.71	75.79	81.62	76.52	81,62	74.33	78.71	69.23	**77.69**

According to Table 2, the cargo units with the highest container volume-efficiency coefficient regardless of length are 1,100 mm in width and 1,100 mm in height, and 2,200 mm in width and 1,100 mm in height. Their average container volume efficiency is 77.69 %. While choosing one of the two optimal models, the complexity of stowing cargo units and their stability must be considered. Given the above-mentioned criteria, the most acceptable size of a cargo unit is 1,100 mm in width and 1,100 mm in height.

6. CONCLUSION

The maximum efficiency of the available container capacity in the international trade presents a continuous challenge for logistics planning of transport processes. The problem of loading a greater number of smaller cargo units into a single storage unit, i.e. container, always presents a complex problem for which there is no unique solution.

Therefore, many authors analyse the topic of solving container-loading problems with the help of different methods and algorithms. In these studies, the cargo units are known in advance, and the optimal models of loading plans are analysed based on the limitations and the conditions set up. However, the emphasis in this paper is placed on the application of a new algorithm that, besides the basic data on the container and the cargo, also introduces a new parameter referring to the planned manner of loading the cargo units into the container. The basic goal of the algorithm set up is to find the optimal cargo unit and its preparation in the manufacturing plants before the dispatch of the whole shipment for handling during container loading.

Through seven steps, the algorithm arrives to an optimal cargo unit that achieves the maximum efficiency of the available container capacity. The algorithm contains basic data on the container and the cargo as well as the conditions and the models of loading and stowage. The results obtained are compared with the different loading specifications obtained, and the optimal model of a cargo unit is chosen based on the statistical data on maximum efficiency.

The suggested algorithm model was tested on the example of loading wooden sawn timber materials into containers and, with the help of the programme packVol version 3.6.2. Standard, the optimal size of the cargo unit was analysed. The result of the conducted analysis for the ultra-short class of wooden sawn timber materials showed that the optimal package for stowage into a 20' container is 1,100 mm in width and 1,100 mm in height. In this case, the average efficiency of the container volume is 77.69%.

The conclusion of the conducted research shows that the container-loading problem is solved in a high-quality way if sophisticated methods and advanced algorithms are used in the initial stages when the cargo units are prepared in the manufacturing plants.

REFERENCES

Bortfeldt, A. & Wäscher, G., 2013. Constraints in container loading – A state-of-the-art review. European Journal of Operational Research, 229(1), pp.1–20. Available at: http://dx.doi.org/10.1016/j.ejor.2012.12.006.

Feng, X., Moon, I. & Shin, J., 2013. Hybrid genetic algorithms for the three-dimensional multiple container packing problem. Flexible Services and Manufacturing Journal, 27(2-3), pp.451–477. Available at: http://dx.doi.org/10.1007/s10696-013-9181-8.

Gehring, H. & Bortfeldt, A., 1997. A Genetic Algorithm for Solving the Container Loading Problem. International Transactions in Operational Research, 4(5-6), pp.401–418. Available at: http://dx.doi.org/10.1111/j.1475-3995.1997.tb00095.x.

Gürbüz, M. Z., Akyokuş, S., Emiroğlu, I., Güran, A., 2009. An Efficient Algorithm for 3D Rectangular Box Packing, Proceedings of Selected AAS 2009 Papers, Ohrid 26-29. September, Society for ETAI of Republic of Macedonia, Skopje. Available at: https://www.parkbeachsystems.com/images/usps/An_Efficient_Algorithm_for_3D_Rectangular_Box_Packing.pdf.

ISO 668, 2013. Series 1 freight containers – Classification, dimensions and ratings. Available at: https://www.sis.se/api/document/preview/916460, accessed on: 5 September 2018.

Patil, J.T. & Patil, M.E., 2016. Cargo space optimization for container. 2016 International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC). Available at: http://dx.doi.org/10.1109/icgtspicc.2016.7955271.

Kanniga, E., 2014. Optimization Solution of Equal Dimension Boxes in Container Loading Problem using a Permutation Block Algorithm. Indian Journal of Science and Technology, 7(is5), pp.22–26. Available at: http://dx.doi.org/10.17485/ijst/2014/v7sp5.5.

Kothawade, A.R., Patil, M.E., 2017. Review on Cargo Space Optimization Methodologies. International Journal of Computer Applications, 162(3), pp.31–34. Available at: http://dx.doi.org/10.5120/ijca2017913323.

Layeb, S. B., Jabloun, O., Jaoua, A., 2017. New Heuristic for the Single Container Loading Problem, International Journal of Economics & Strategic Management of Business Process (ESMB), 8 (1), pp. 1-7. Available at: https://www.researchgate.net/publication/309731780_New_Heuristic_for_the_Single_Container_Loading_Problem.

Liang, S. C., Lee, C. Y. and Huang, S. W., 2007. A Hybrid Meta-heuristic for the Container Loading Problem, Communications of the IIMA, 7(4), pp. 73-84. Available at: https://scholarworks.lib.csusb.edu/ciima/vol7/iss4/9.

Moura, A. & Oliveira, J.F., 2005. A GRASP Approach to the Container-Loading Problem. IEEE Intelligent Systems, 20(4), pp.50–57. Available at: http://dx.doi.org/10.1109/mis.2005.57.

Nepomuceno, N., Pinheiro, P. & Coelho, A.L.V., 2007. Tackling the Container Loading Problem: A Hybrid Approach Based on Integer Linear Programming and Genetic Algorithms. Lecture Notes in Computer Science, pp.154–165. Available at: http://dx.doi.org/10.1007/978-3-540-71615-0_14.

Parreño, F. et al., 2008. A Maximal-Space Algorithm for the Container Loading Problem. INFORMS Journal on Computing, 20(3), pp.412–422. Available at: http://dx.doi.org/10.1287/ijoc.1070.0254.

Patil, J.T., Patil, M.E., 2016. Review on Cargo Space Optimization, International Conference on Global Trends in Engineering, Technology and Management, 4.-6. January, Jalgaon, India, pp. 188-191. Available at: http://www.ijettjournal.org/Special%20issue/ICGTETM-2016/ICGTETM_2016_paper_57.pdf.

Patil, J.T. & Patil, M.E., 2016. Cargo space optimization for container. 2016 International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC). Available at: http://dx.doi.org/10.1109/icgtspicc.2016.7955271.

Pino, R. et al., 2013. Application of Genetic Algorithms to Container Loading Optimization. International Journal of Trade, Economics and Finance, pp.304–309. Available at: http://dx.doi.org/10.7763/ijtef.2013.v4.306.

Raidl, G.R., 1999. The multiple container packing problem. ACM SIGAPP Applied Computing Review, 7(2), pp.22–31. Available at: http://dx.doi.org/10.1145/335527.335530.

Ramos, A.G., Oliveira, J.F. & Lopes, M.P., 2014. A physical packing sequence algorithm for the container loading problem with static mechanical equilibrium conditions. International Transactions in Operational Research, 23(1-2), pp.215–238. Available at: http://dx.doi.org/10.1111/itor.12124.

Thapatsuwan, P., Chainate, W. and Pongcharoen, P., 2007. Improving Packing Efficiency for Shipping Container, Special Issue of the International Journal of the Computer, the Internet and Management, 15(4), pp. 26.1-26.6. Available at: https://pdfs.semanticscholar.org/1aa5/c05be2ed03f2fddbb79ec16d8fd05ed6686d.pdf?_ga=2.123865417.2103835026.1599322871-1634521767.1599322871.

Zhao, X. et al., 2014. A comparative review of 3D container loading algorithms. International Transactions in Operational Research, 23(1-2), pp.287–320. Available at: http://dx.doi.org/10.1111/itor.12094.