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Solving Cargo Loading Problem Using Simulated Annealing Technique

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Abstract:

Based on the statistical report for logistics and transportation field in port and airport Malaysia, there shows a significant increment in the total cargo handling for last few years. The prevalence of online shopping and e – commerce also contribute to the development of the logistics and transportation field. This study aims to contribute mathematical model for maximizing the utilization of space in the container and handling the cargoes systematically in column by using simulated annealing in order to fulfill the demand of public in logistics and transportation field. The study is conducted by using the benchmark dataset published in journal article which was written by Bischoff & Ratcliff in 1995. This weakly homogenous cargo dataset is used for examining the column cargo arrangement by using simulated annealing method. The difference parameters of simulated annealing are used to obtain the near optimal solution that maximizing the utilization of space in the container. The near optimal solution is 126,928 cm² in area that indicates the coverage of cargoes in the container. This near optimal solution is obtained by applying the parameters for number of iterations, temperature and constant factor as 1500, 500 and 0.99. In conclusion, the objectives of this study are achieved by applying the mathematical model, column layout design for cargo arrangement and simulated annealing method. The systematic column cargo arrangement achieves a high efficiency cargo loading in maximizing utilization in the container space and stability of cargo.

Keywords: Weakly homogenous cargo, column cargo arrangement, parameter, simulated annealing

1. Introduction

The development of online shopping is prevalence in the worldwide. Businessman tends to expand their business to whole of the world through the e - commerce. According to Vladimir (1996), the definition of e – commerce is a telecommunication network which acts as platform for sharing business information, conducting business and maintaining business relationship. Through Internet and Web, the digital business or commercial transactions are undergone between organization and individual (Bhalekar & Pathak, 2014). Based on explanation from Nanehkaran (2013), the main function of e – commerce is supporting of consumers, service and commodities supplying, portion of business information, management of business transaction and bond building between suppliers, consumers and retailers through telecommunication network.

The tendency of online shopping raises up due to the convenience of Information Computer Technology (ICT). The rapid development of ICT contributes variety devices such as desktop and mobile phone which enable to access the internet easily. Thus, the convenience of ICT triggers to transformation of conventional business from brick – and - mortar to the brick – and - click mode. Taobao owned by Alibaba and Amazon are the example for the transformation of business mode. E – commerce is a potential market to the businessman proven by the exponential growth of the retail sale (Lim *et al.*, 2016).

The phenomenon of online shopping reflected that public tend to buy item from online shopping website instead of buying in the shop or mall and the country trading statistics reports also showed a significant contribution of e - commerce to the logistics and transportation field. Therefore, the logistics and transportation field need more advanced algorithm to achieve the high efficiency of transportation in order to cater demand of the public in the country.

The development of logistics and transportation field is triggered by the phenomena of online shopping and e – commerce that encourage public to trade through online due to the popular of internet network and electronic gadgets. But the transportation cost holds high percentage of operation cost compared with others cost therefore organization

concerns the effectiveness of transportation (Can & Sahingoz, 2014). Wang, et. al., (2012) stated that the efficiency of cargo loading depends on the utilization of space and the handling cost as well as the time in arranging cargoes in the container.

The method of the study is simulated annealing which is categorized as meta - heuristics method. Meta - heuristics method is derived from the heuristic method. According to Blum & Roli (2003) and Yang (2014), heuristic is derived from verb 'heuriskein' which means 'to find' or 'explore by trial and error'. It is a method that provides good quality solution which approaches to the exact solution of the optimization problem. It emphasizes on finding near optimal solution by trial and error and the process of algorithm is necessary with the expertise knowledge related with the specific optimization problem to explore search space and obtain the near optimal solution (Gavrilas, 2010).

The loaded cargoes can be categorized as homogenous and heterogenous. Homogenous indicates the similarity cargo type while the heterogenous indicates the assortment of different cargo type (Bischoff & Ratcliff, 1995). Whilst, the cargo loading problem can be 2D and 3D for visualization purpose.

Most of the researcher focus on maximizing the utilization space of container in cargo loading problem. This study concerns about the maximum the utilization space of container as same as other researcher at the same time the cargo arrangement also is concerned to minimize the wasted unused gaps between cargoes in order to obtain the maximum utilization space of container and stability of cargoes.

This study focuses on the goal that applying a mathematical model in cargo loading problem. And, the mathematical model is applied on weakly homogenous cargo dataset for obtaining the layout of cargo arrangement with maximum utilization space of container. By applying simulated annealing algorithm which is one of the meta - heuristic, this algorithm is used to search near optimal solution in randomization and local search. The randomization is to diverse optimal solution while the local search is to exploit the neighbourhood solution from current solution Yang (2014).

The data set of this study obtains from the journal article 'Issues in the development of approaches to container loading' (Bischoff & Ratcliff, 1995) Due to this study only focus on 2D cargo loading problem, the length and width of cargoes are considered with the total area of container as 136771 cm² in term of length (587 cm) and width (233 cm). The data set has 8 types of cargoes with different quantity and the total quantity of cargoes is 105 with their length, width and height. Only the length and width of cargo and container are considered in this study.

2. Methodology

The method of this study is simulated annealing for searching near optimal solution in total coverage area of cargoes in the container. In the concept of simulated annealing, it imitates the metal annealing process for searching the near optimal solution. Therefore, simulated annealing method consists of 3 critical elements as temperature, cooling schedule and Metropolis's criterion to control the execution time of algorithm and evaluate the performance of neighbourhood solution that obtained through local search. This main function of simulated annealing is to escape from trapping in local maxima or minima by accepting the inferior neighbourhood solution for reaching the global solution.

2.1. Exponential Cooling Schedule

For each iteration of algorithm, the exponential cooling schedule is used for cooling the temperature parameter as annealing process (Nourani & Andresen, 1998, Pham & Karaboga, 2000). The temperature is decreased with a constant factor along the algorithm and the constant factor is limited between 0 and 1. The equation (3.1) shows the exponential cooling schedule:

$$T(r) = T_0 \alpha^r \quad (3.1)$$

where

T_0 = initial temperature

α = constant factor, $0 < \alpha < 1$

r = number of outer iterations, $r > 0$

2.2. Metropolis's Criterion

Dealing with main function of simulated annealing, Metropolis's criterion uses Boltzmann probability and cooling schedule for escaping from local optima (Hillier & Lieberman, 2010). Boltzmann probability evaluates the neighbourhood solution, S_{i+1} if it is worse than current solution, S_i . The equation of Boltzmann probability is shown as in equation (3.2),

$$\text{Prob}\{\text{acceptance}\} = e^x, x = \frac{S_{i+1} - S_i}{T} \quad (3.2)$$

2.3. Mathematical Model for Cargo Loading Problem

The cargo loading model is formulated for the near optimal solution of cargo coverage area in the container. This model concerns the length and width of both container and cargo as well as the arrangement way in order to obtain the near optimal solution in area for the maximum utilization of space in the container. The model is constructed by objective function, decision variable and constraints of model.

2.3.1. Objective Function

The objective function is to compute the near optimal solution for maximizing the utilization space in the container by computing the area of cargoes that are filled into the container. Before filling cargo into the container, the cargo is evaluated in term of length and width in order to justify whether to fill it into the container. Thus, the objective

function of cargo loading problem is influenced by size of incoming cargo which is justified by decision variable. The equation (3.3) shows how to compute the objective function of the cargo loading model by referring Wei *et al* (2009) and Yeo (2019).

$$\text{Maximize } f = \sum_{j=1}^n a_j \times x_j \quad \forall j = 1, 2, 3, \dots, n, x_j \in \{0, 1\} \quad (3.3)$$

where

f is the maximum utilization space of container

j is the index of incoming cargo in the cargo list

n is the total quantity of cargoes in the cargo list

a_j is the area of incoming cargo with index j in the cargo list

x_j is decision variable for selecting the incoming cargo with index j in the cargo list

2.3.2. Decision Variable

The decision variable of cargo loading problem is to decide whether the cargo being selected and filled into the container. The decision variable considers the summation of width of all selected cargoes in i column, W_i and the length of incoming cargo with index j in the cargo list, l_j . The decision variable is denoted as x_j , and $x \in \{0, 1\}$. When $x_j = 0$, it indicates that j cargo is not selected to fill into the container and vice versa when $x_j = 1$, it indicates that j cargo is selected to fill into the container.

2.3.3. Constraints of Model

The constraints of model focus on the length and width of container for preventing the overfilling issue in the container. According to Moura & Oliveira (2005) and Parreño *et al.* (2008), the constraints of model are modified as shown in below:

$$\text{If } l_j \leq l_k \text{ then } x_j = 1 \quad (3.4)$$

$$\text{If } W_i + w_j \geq W \text{ then } i = i + 1 \text{ and } l_i = l_j \quad (3.5)$$

$$L_i \leq L \quad (3.6)$$

$$i = 1, 2, 3, \dots, k = 1, 2, 3, \dots$$

where

l_j is the length of the incoming cargo with index j in the cargo list

l_k is the length of the selected cargo with index k in the selected cargo list

w_j is the width of the incoming cargo with index j in the cargo list

W_i is the summation of width of all selected cargoes in i column

W is the total width of container

i is the index of columns in the container

l_i is the length of i column

L is the total length of container

Equation (3.4) limits the length of incoming cargo must be smaller and equal to the length of latest selected cargo in order to ensure a systematic cargo arrangement in a column way. Equation (3.5) and (3.6) focus on the limitation of total length and width of selected cargo that are not exceed the length and width of container in order to prevent the overfilling issue. Equation (3.5) ensures total width of selected cargo in each column not exceed the width of container by creating new column.

2.3.4. Mathematical Model for Cargo Loading Problem

By summarizing the decision variable and constraints of model, the completed mathematical model for this 2D cargo loading problem is listed as below:

$$\begin{aligned} &\text{Maximize } f = \sum_{j=1}^n a_j \times x_j \\ &\quad \forall j = 1, 2, 3, \dots, n, x_j \in \{0, 1\} \\ &\text{Subject to} \\ &\text{If } l_j \leq l_k \text{ then } x_j = 1 \\ &\text{If } W_i + w_j \geq W \text{ then } i = i + 1 \text{ and } l_i = l_j \\ &\quad L_i \leq L \\ &i, j = 1, 2, 3, k = 1, 2, 3, \dots \end{aligned} \quad (3.7)$$

3. Result and Discussion

The result of analysis for 2D cargo loading problem is the total area of cargo coverage in the container by considering the length and width of cargo. By experimental way, the highest near optimal solution obtains is 126,948 cm² by using column cargo arrangement and simulated annealing for maximizing the utilization space of container. This near

optimal solution is obtained by using the parameters of number of iterations, temperature and constant factor, α as 1500, 500 degree Celsius and 0.99.

Figure 1 shows that the near optimal solution is obtained after the iteration run around 600th. By comparing between previous near optimal solution, the difference of both is around 10,000 cm² in the increment of coverage area of cargo. The search space of algorithm accepts worse neighbourhood solution as solution due to the high constant factor that slow down the decreasing rate of temperature. Moreover, the 1500 number of iterations is quite large for the search space to extend the local search and increasing the possible of obtaining near optimal solution.

By verifying the appropriateness of parameters in simulated annealing, 10 trials are run for obtaining the average of near optimal solution when the parameters of number of iterations, temperature and constant factor are 1500, 500 degree Celsius and 0.99. Table 1 shows the average of near optimal solutions for 10 trials.

Table 1 shows the average of near optimal solution for 10 trials is 119917.4 cm². The average of near optimal solution is around 120,000 cm² therefore it provides a high-quality near optimal solution by comparing with the near optimal solution obtained by other parameters.

In conclusion, the near optimal solution is 126,948 cm² because it is the highest value of near optimal solutions within 10 trials therefore the appropriate parameters for this weakly homogenous cargo are 1500 number of iterations, 500 degree Celsius and 0.99 constant factor.

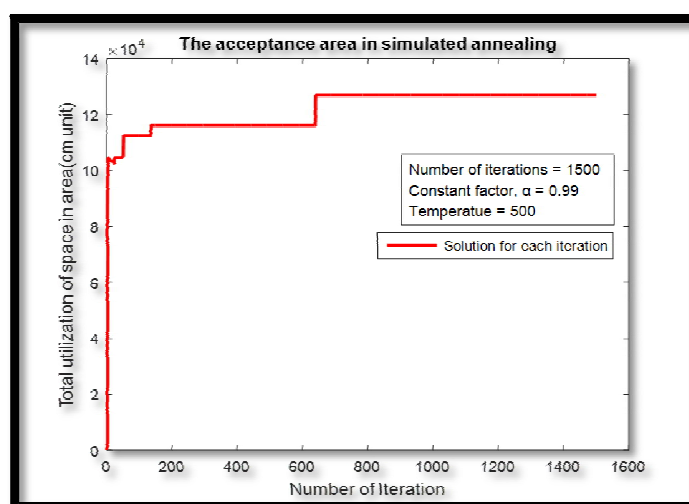


Figure 1: The Change of Solution in Search Space for Searching the Near Optimal Solution by Using 0.99 Constant Factors

Figure 2 shows a colourful layout of cargo arrangement and those colours represent the corresponding type and size of cargoes. There shows similar colour of cargoes are arranged nearby each other and the first item in each column is the large size of cargo compared to the rest of cargoes in that same column. Those are the factors that influencing the total area of cargoes occupied in the container.

The similar type and size of cargo increase the utilization space of container with small wasted gap between cargoes. Whilst the cargoes that are arranged after first's cargo of each column must smaller than size of first cargo also contributes a systematic cargo arrangement in order to ensure the rest of cargoes are arranged in that limited column. Therefore, this layout shows a high percentage of occupation in the total area of container with total area of 136771 cm². The occupation of the near optimal solution is around 93%.

Trial	Optimal Solution
1	126,928
2	124,285
3	116,201
4	122,720
5	118,651
6	116,950
7	117,830
8	118,496
9	118,235
10	118,878
Average	119,917.4

Table 1: Near Optimal Solutions for 1500 Iterations, 500 Degree Celsius and 0.99 Constant Factor in 10 Trials

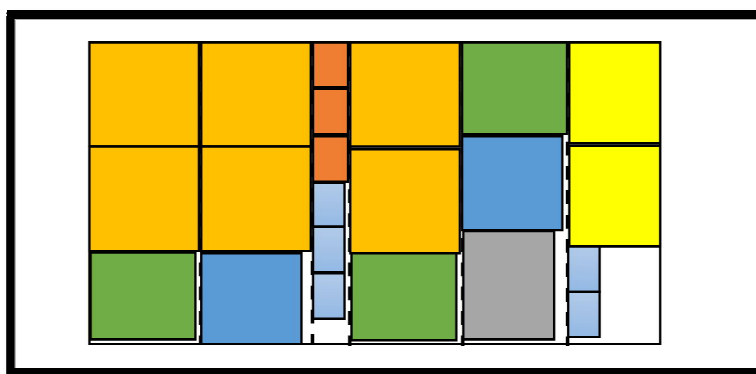


Figure 2: The Cargo Arrangement of Near Optimal Solution

4. Conclusion

The objectives of this study are to apply the mathematical model of cargo loading problem, determining the layout of cargo arrangement and achieving the near optimal solution in the cargo coverage area in the container. First objective is achieved by applying the mathematical model which concerns the length and width of container as well as the column cargo arrangement whilst the second objective is to determine the cargo arrangement into column way. The last objective is the near optimal solution of 126,948 cm² for the area that covered by cargoes in the container. The near optimal solution is obtained with the parameters of number of iterations, temperature and constant factor are 1500, 500 degree Celsius and 0.99 which are proven as appropriated parameters for this weakly homogenous cargo data set.

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