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CLUSTERING BASED HEURISTICS FOR ALIGNING MASTER PRODUCTION SCHEDULE AND DELIVERY SCHEDULE

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Abstract:
Making a Master Production Schedule (MPS) is a very important activity for a manufacturing industry. This is due to the fact that MPS serves as an input for material and production planning. Between the years 2020 and 2022, there were significant fluctuations observed in container freight rates. As response, a lot of manufacturing industry focus on optimizing their container delivery schedule. Hence, there is a need for aligning the master production schedule with the delivery schedule. This paper presents the development of a novel heuristic approach to address problems with the creation of MPS. Specifically, the focus is on the situation where container delivery schedules are prearranged and serve as a main input for creating the MPS. There are two objective functions that are going to be reached: 1) minimize the total number of product variations or Stock Keeping Units (SKU) per month; and 2) minimize the number of SKU per container. The proposed heuristic approach uses the similarity concept to group objects in a clustering technique. It is then implemented in a real-world case of a furniture manufacturing company. Further results were obtained and then compared to the heuristic technology that had previously been used by business entities. The results show that the number of product variations (SKU) that must be performed per month is 10% lower than that of the existing heuristic. In addition, the ratio of SKU variations per container is 9% lower than that of the existing heuristic. The time required to complete the task of creating MPS is less than one minute, as opposed to the one working day required by the company's existing heuristic.

Key words: *clustering technique container, heuristics, master production schedule, similarity concept*

INTRODUCTION

To fulfill consumer orders on time and with a fixed quantity, companies need to manage their production management activities [1]. One of the production management activities is making the Master Production Schedule (MPS) [2]. For a company that produces products with many variations and many processes, the complexity of production planning is higher. Moreover, the complexity of making a production plan increases if the company's production plan requires input, where the input is the output from other activities [3, 4, 5].

Container freight rates fluctuated dramatically between 2020 and 2022, in which the maximum ratio of the highest and lowest rate is more than eight [6]. In reaction to the high container freight rate, manufacturers who utilize containers to distribute their products, such as for export to foreign countries, are attempting to optimize their container loads. As a result of the high cost of container freight rates, all of the export-oriented Asian manufacturing enterprises observed by the authors during that period optimized their container delivery schedules.

Direct effects of the optimized container delivery schedule without changing the way of creating the master production schedule are the finished good inventory and tardiness of delivery. In an observation at the beginning of that period in an export-oriented manufacturing enterprise, its finished goods warehouse is expanded since many of the planned delivery containers are still waiting for their contents to be completed. As a consequence, many of deliveries also missed the schedule. This facts motivate the need for aligning the master production schedule with the delivery schedule.

As result of the optimized delivery schedule, the enterprise need to adjust its master production schedule. This kind of adjustment to the MPS is still required several main ideas to make the production smooth and efficient. Minimizing number of product variation during certain period, for example, it is preferable since minimizing setup of machine. Therefore, the time spend for setup also can be minimized, time available for processing is increase. As consequences, number of production is increased.

This article is trying to contribute to the process for creating the master production schedule that is aligned with the container delivery schedule. The proposed heuristic method for creating the MPS while considering container delivery schedule is inspired by concept in the clustering technique, which is to the best of our knowledge, never been done before in the literatures. To illustrate the applicability of the proposed heuristic, it is implemented in a real-world case study in a furniture manufacturing company. In addition, to check the performance of the proposed algorithm, the result of the proposed algorithm is compared with the result of the heuristic algorithm used by the company.

LITERATURE REVIEW

A manufacturing company can use a variety of order fulfillment strategies, including make-to-stock, make-to-order, assembly-to-order, and engineer-to-order. In companies with a make-to-order strategy, companies need to require a series of activities starting from managing orders, making a MPS, and carrying out production based on the MPS to produce the products desired by consumers. Production is carried out by utilizing existing resources in the company, such as materials, machines, or human labor. Therefore, it is necessary to balance activities between capacity requirements to meet consumer demand and the capacity owned by the company, or what is often called MPS. The MPS is a process carried out by the production system manager to facilitate marketing interests with manufacturers [7,8, 9]. The nature of this MPS is balancing between capacity and demand [10, 11, 12]. MPS is a mechanism to balance the capacity owned by a company with capacity requirements to meet consumer demand [8, 9, 10, 11, 12, 13]. Therefore, MPS is very important, especially for companies with a make-to-order fulfillment strategy [14, 15, 16, 17, 18, 19, 20, 21, 22, 23].

Several previous studies related to the link between MPS and other activities include the following:

1) The creation of a MPS requires input from forecasting activities carried out by the Marketing Department [7], requiring input in the form of a container delivery schedule [24];
2) Making a MPS produces output that is used for other activities such as capacity planning, production planning and scheduling, and material requirement planning [12, 25].

Previous researchers have proposed a variety of methods for producing MPS. There are those that can be applied in general to MPS-making problems in general, but there are also those that can be applied to certain specific cases. The complexity of the problem of making MPS increases when there are several objectives that need to be met [26]. Making MPS increases in difficulty along with the number of resources considered, the number of products, and the time period, so that the problem of determining the optimal MPS is an NP-hard problem [13, 27, 28].

Several approaches to solving these problems have been proposed by several researchers, ranging from analytic approaches, heuristics, metaheuristics, simulations [29, 30, 31, 32, 33, 34], and machine learning [35, 35, 37]. One of the machine learning methods is clustering.

Clustering is an unsupervised learning technique in machine learning used in data mining to identify patterns and structures [37, 38, 39, 40, 41, 42, 43, 44]. Using the clustering technique, similar objects are grouped together while dissimilar objects are separated. Clustering techniques have numerous applications in a variety of fields [38, 45, 46, 47, 48, 49, 50], including:

1) marketing [51, 52, 53, 54];
2) grouping similar images or videos together [55];
3) manufacturing [50, 56].

Subramaniyan et al. [56] used the agglomerative hierarchical clustering technique for determining bottlenecks in manufacturing systems. Ahn and Chang [57] discussed agglomerative hierarchical clustering in the design and management of manufacturing processes.

Based on the explanation above, it can be seen that, to the best of our knowledge, there has been no research that discusses the use of the clustering concept in making the MPS, especially taking into account the container delivery schedule. Therefore, the research presented in this paper is trying to fill that gap. In this paper, a heuristic-based algorithm for solving production planning problems using clustering principles and considering container delivery schedules is developed. To illustrate the applicability of the proposed heuristic algorithm, it is implemented in a real-world case study in a furniture manufacturing company. In addition, to check the performance of the proposed algorithm, the result of the proposed algorithm is compared with the result of the heuristic algorithm used by the company.

METHODOLOGY

A. Problem Description

The MPS problem addressed in this paper is based on an application case that originated with a furniture manufacturer that exports its products abroad. This company uses a make-to-order (MTO) order fulfillment strategy. Orders are received by the marketing department. Stock Keeping Units (SKUs) represent the finished product that is produced by the company to be delivered to the customer. Finished products (SKUs) will be sent to consumers via containers. SKUs are stored in the appropriate container before being delivered to the customer in such a way that the variety of products present in one container is not too great.

The marketing department makes a delivery schedule per container. This delivery schedule per container is then given to the Production Planning and Inventory Control (PPIC) Department to prepare the MPS. The MPS made by PPIC has several objectives, namely: 1) the delivery schedule as written in the container delivery schedule document is fulfilled; 2) not too many product variations are made in a certain period of time to minimize setup costs and changeover costs. Or, in other words, the objective of the company is to minimize the variance of the SKU stored in the container so that the variety of the products produced by the production department can also be minimized and the delivery due date can be fulfilled.

Different from other companies that use input sales forecast results or input orders to make production plans, the heuristics-based algorithm proposed in this paper uses the product allocation or arrangement per container as an input for making a master production schedule (MPS). The product arrangement per container has been made by the marketing department and is not the focus of this research considering that there is software for container optimization on the market. So the focus of this research is on how to get a MPS that can then be executed by the production department.

B. Proposed Algorithm

The framework of the proposed algorithm to solve a production planning problem using clustering principles while considering the container delivery schedule problem can be seen in Figure 1.

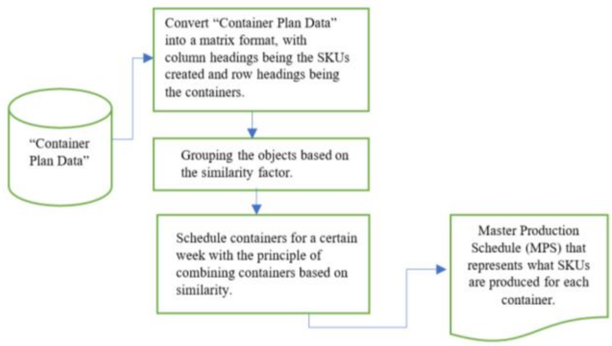

Fig. 1 Framework of the Proposed Algorithm

Based on Figure 1 it can be seen that the proposed algorithm has several steps as follows:

1. The input of the system is "Container Load Plan". "Container Load Plan" is the product allocation or arrangement per container, where this arrangement is performed by the Marketing Department using the software for container optimization available in the market. "Container Load Plan" is retrieved from the container optimization software in Microsoft Excel format.
2. After step 1 is performed, the "Container Load Plan" data can be converted into a matrix format, with column headings being the SKUs created and row headings being the containers dedicated to each SKU. The pseudocode for this step is presented as follows:
   a. Identify the name or ID of the SKUs.
   b. Identify the name or ID of the containers.
   c. For each row in the container load list, read the number of quantity SKUs *i* being loaded in the container *j*. Add this number to the existing quantity of SKU *i* being loaded in the container *j*.
   d. Write the total quantity of SKU *i* being loaded in the container *j* in the matrix format.
   e. Convert the matrix format resulted at Step d into 0–1 matrix form. A cell in the matrix is set to 0 if the SKU was not created for the container and to 1 if the SKU was created for the container.
3. The next activity is grouping the objects based on similarity factors. This proposed algorithm is inspired by the clustering technique in multivariate analysis, where objects with similar characteristics can be placed in the same group. In each group, there are three pieces of information available: They are the type of SKU, quantity, and container used to send the SKU. The basic idea is to check the similarity of products produced per container. This check is carried out for every two containers, namely container *i* and container *j*. This concept is similar to the calculation of similarity in non-metric data clustering, namely the proximity matrix. For the proposed algorithm, the object is a container. The container contains the product that has to be delivered to the customer. In this framework, the similarity is calculated based on the 0-1 matrix. The similarity of two containers is defined as the ratio of the total number of SKUs with similar values in the 0–1 matrix to the total number of SKUs. The clustering concept proposed in this paper is different from other clustering techniques [37, 38, 39, 40, 41, 42, 43, 44], where the clustering technique usually tries to find similarity among objects using distance measurement. In the proposed algorithm, each container is said to be similar to another container if both containers have the same variety of SKU. The proposed algorithm is then performed in order to minimize the ratio of the number of containers to the total number of SKUs during a certain period. By grouping it, it is hoped that the needs of the production department will be met so that in one period, not many variations of the product can be produced.
4. Schedule containers for a certain week with the principle of combining containers based on similarity. Since the goal is to create a master production schedule (MPS) so that it is known per week what SKUs are produced for each container, the groups formed reflect the weekly period of the master production schedule. To obtain the schedule container for a certain week, follow the steps as follows:
   a. The similarity value obtained from Step 3 is then sorted from largest to smallest.
   b. Calculate the total order quantity, for example, *Order = Q*
   c. Calculate the average order quantity per week.
   d. Set the production capacity limit per week (*Qmax*)= (1+ *p*) x *Q/number of weeks*, where *p* is the tolerance
   e. For each pair of containers in the list of *i-j* combinations sorted from the highest similarity, check the case in which case combination

There are 4 possibilities:

(1) *i – j* equally has not entered the weekly group. If *i – j* equally has not entered the weekly group, then:

- Check the quantity of container *i* plus the quantity of container *j*. If, it is less than *Qmax* then, put containers *i* and *j* into one week group

(2) *i* has entered, *j* has not entered the weekly group. If *i* has entered, *j* has not entered the weekly group then:
- Check where the week group *i* belong to, for example, the m^{th} week group. Then, calculate the quantity of containers that enter the m^{th} week.
- Add up with the quantity of container *j*. If the quantity of container group - *m* is added to the quantity of container *j* is less than *Q max*, then container *j* is added to the group – *m*.

(3) *i* have not entered yet, *j* has entered the weekly group. If *i* have not entered yet, *j* has entered the weekly group then:
- Check which container *j* belongs to which week group, for example the n^{th} week group.
- Calculate the quantity of containers that enter the n^{th} week.
- Add up with the quantity of container *i*
- If the container quantity for the n^{th} week group is added to the quantity of container *i* which is less than *Qmax*, then put container *i* in the n^{th} week group.

(4) *i* and *j* have both joined the weekly group. If *i* and *j* have both joined the weekly group, then:
- Check that container *i* has entered which week group, for example the m^{th} week group.
- Check that container *j* has entered which week group, for example the n^{th} week group.
- If the quantity of the m^{th}-week group is added to the n^{th}-week group quantity is less than *Qmax* then combine the *m*-week group with the *n*-week group

This proposed algorithm is then written in Visual Basic for Application in Microsoft Excel (VBA Excel), since the data is originally in Microsoft Excel worksheet format.

RESULTS

To illustrate the applicability of the proposed algorithm, it is applied to a manufacturing company that produces furniture products. This company exports its products to consumers abroad. The order fulfillment strategy applied to this company is make-to-order (MTO). One order from a consumer can consist of several SKUs (stock-keeping units). Shipping orders are carried out via containers. One container sent in order to fulfill consumer orders can consist of several SKUs. Different from its production planning, which is generally based on the results of the demand forecast, this company determines the production plan based on the container load plan.

After the marketing department receives orders from consumers, it makes a load plan for containers. The container load plan contains the division of containers that are used to store the finished products (SKU) and also the SKU quantity per container at a certain time period, for example, weekly. An example of a container load plan can be seen in Table 1.

From Table 1, there are two containers assigned, C-1 and L-1. Container plan data consists of the types of products that can be stored in each container. From the example of Container Plan Data, it is known that in Container C-1, it consists of 4 types of products, which are XXX1, XXX2, XXX3, and XXX4, while in Container L-1, it consists of 2 types of products, which are XXX4 and XXX5.

Table 1
Container Load Plan

Product (SKU)	Quantity	Container
XXX1	2	C-1
XXX2	6	C-1
XXX3	6	C-1
XXX4	13	C-1
XXX2	60	C-1
Total C-1	**87**	
XXX4	47	L-1
XXX5	30	L-1
Total L-1	**77**	

The load plan is converted into a matrix format with column headings being the SKUs created and row headings being the containers, as shown in Table 2.

Table 2
Matrix Format of Load Plan

SKU	**Container**	
	C-1	**L-1**
XXX1	2	0
XXX2	66	0
XXX3	6	0
XXX4	13	47
XXX5	0	30
XXX6	0	0
XXX7	0	0
:	:	:
XXX32	0	0
XXX33	0	0
XXX34	0	0
Total per container	**87**	**77**

Furthermore, the container load plan is used as the basis for the Production Planning and Inventory Control Department to make a weekly production plan to determine which SKUs must be produced to meet the required quantity in the container load plan.

Table 3
Matrix 0-1 Container SKUs

SKU	**Container**	
	C-1	**L-1**
XXX1	1	0
XXX2	1	0
XXX3	1	0
XXX4	1	1
XXX5	0	1
:	:	:
XXX33	0	0
XXX34	0	0

After that, the data in Table 2 is converted into a 0-1 matrix. Then, the data as it has been made, as shown in Table 2, is changed to form 0-1, where 0 means the SKU was not created for the container and 1 means the SKU was created for the container. The result is presented in Table 3.

For the case study presented in this article, there are 47 containers, so there are 1081 pairs of containers *i* and *j* that must be investigated to measure the similarity. To investigate the similarity, follow Step 3 in Section 3. After running the VBA Excel program, the result is presented in Table 4.

Table 4
Result of Calculating Similarity

No	*i*	*j*	Similarity
1	1	2	0.882353
2	1	3	0.911765
3	1	4	0.852941
:	:	:	:
1080	45	47	0.794118
1081	46	47	0.882353

After obtaining the similarity, the next step, according to the proposed algorithm presented in Section 2, is finding the schedule containers for a certain week with the principle of combining containers based on similarity. At this stage, the similarity calculation, as shown in Table 4, is then sorted from the largest to the smallest. The result is shown in Table 5.

Table 5
Sorted Similarity Result

No	*i*	*j*	Similarity
196	5	23	1
221	6	7	1
487	13	14	1
:	:	:	:
933	30	35	0.676471
1009	35	41	0.676471
939	30	41	0.647059

After that, Step 4, as explained in Section 2, is performed, where the idea is to schedule containers for a certain week with the principle of combining containers based on similarity. The result of VBA Excel is presented in Table 6.

Table 6
Schedule Containers Results

Week	No Container	No Product Code (SKU)	Production Quantity
1	11	7	1240
2	11	17	1074
3	6	5	1211
4	11	9	1325
5	8	9	1365
Total	**47**	**47**	**6215**

From Table 6 for the Container Plan Data provided by the Marketing Department, the Master Production Schedule created with the proposed algorithm can provide recommendations for the type of product that must be made per container and the quantity of production made. In addition, the time needed to perform the algorithm is less than 1 minute.

DISCUSSION

Based on the discussion above, it can be concluded that the proposed algorithm can be implemented in the real-life case study. To compare the proposed algorithm, the result from it is compared with the heuristics algorithm performed by the company. Recently, the heuristics algorithm performed by the company was explained as follows:

1. Sort SKUs according to collection, material, color, and product type.
   It is noted that the information on collection, material, color, and product type can be found in the first, second, third, and fourth parts of the SKU code, respectively. For example, a SKU with code AWO1 represents the collection A, material wood, color orange, and product type 1.
2. Based on the total order monthly, that total order is divided by the number of weeks in a particular month to find the weekly maximum number of productions. For example, if the total order is 10,000 units and the total number of weeks in a particular month is 4, then the weekly maximum number of productions is 2,500 units.
3. Provide the tolerance of the weekly maximum number of production quantities. For example, the tolerance is 25%; therefore, the weekly maximum number of production units is now 2,500 units + (0.25·2,500) = 3,125 units.
4. Start with the first week's schedule: add one SKU at a time to the list resulting from step 1 until the total number of productions is closest to the maximum number of production quantities. Once it reaches that situation, the step is continued for the second week's schedule, and so forth.

Using the same data set as is used in Section 3, the result of the existing heuristic performed by the company can be seen in Table 7.

Table 7
Result from the Existing Heuristics Performed by the Company

Week	No Container	No Product Code (SKU)	Production Quantity
1	5	5	1015
2	14	11	1087
3	12	16	888
4	8	8	1614
5	8	10	1611
Total	**47**	**52**	**6215**

It is noted that the existing heuristics algorithm is performed by the staff manually; therefore, on average, it takes 1 working day. According to Tables 6 and 7, there is a comparison between the proposed algorithm and the existing heuristic algorithm used by the company.

The comparison that can be seen is the total number of SKU variations per month and the ratio of SKU variations per container, including the time needed to solve the problem, as shown in Table 8.

Table 8
The comparison of total number of SKU variations per month and the ratio of SKU variations per container

	Total number of SKU variations per month	Ratio of SKU variations per container	Time needed to solve the problem
Proposed algorithm	**47**	**1**	**< 1 minute**
Existing heuristics algorithm applied by company	52	**1. 1**	**1 working day**

Based on the comparisons in Table 8, it is possible to conclude that the algorithm described in this article can generate a smaller variety of SKUs than the algorithm used by the company at the time. Aside from that, the ratio of SKU variation to container size indicates that the algorithm described in this article is superior to the algorithm used by the company at the time. Furthermore, the proposed algorithm can obtain the schedule much shorter than the existing algorithm.

CONCLUSIONS

Based on the information provided in this article, it is possible to conclude that the development of MPS is related to other activities that exist within the company [18, 30, 31]. According to the research presented in this article, there is a situation in which the development of MPS necessitates involvement from the marketing department, particularly in the case of a company conducting a product launch and requiring a container.

In addition, throughout the MPS development process, it is discovered that there are other techniques that can be used to create MPS [35, 36, 37, 38, 39, 40], as well as the machine learning technique [41, 42, 43].

During the research described in this article, the concept of similarity in the clustering technique is used to solve the problem of building MPS based on the characteristics of the company described in the previous paragraph. Based on a real-life case study presented to illustrate the applicability of the proposed algorithm, the similarity concept proposed in this article can be used to solve MPS problems with a better result than the existing algorithm used by the company.

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