Proceedings of the 2022 Winter Simulation Conference
B. Feng, G. Pedrielli, Y. Peng, S. Shashaani, E. Song, C.G. Corlu, L.H. Lee, E.P. Chew, T. Roeder, and P. Lendermann, eds.

PRODUCTION SCHEDULING FOR PARALLEL MACHINES USING SIMULATION TECHNIQUES: CASE STUDY OF PLASTIC PACKAGING FACTORY

Jiratsaya Panasri
Nara Samattapapong
Sathitthep Sangthong

Department of Industrial Engineering
Suranaree University of Technology
111 University Road, Suranaree Subdistrict, Mueang District
Nakhon Ratchasima, 30000, THAILAND

ABSTRACT

The purpose of this study is to use simulation techniques to examine the production scheduling process for parallel machines. This examination focuses on improving the work sequence in the machine and making the most cost-effective use of raw materials, as well as delivering goods on time to customers and reducing total uptime. After examining and collecting data on the planning and sequencing operations, it was discovered that there was a problem in determining how to assign work to the machines due to a lack of systematic analysis of production scheduling, so scheduling systems and tools cannot tell if the current sequence is the best one. The researchers then used simulation techniques to create all possible alternatives and identify the best solution for the sequencing process on the machine. The simulation results showed that sequencing using simulation techniques can reduce the total working time to 112,831.99 seconds by 54%.

1 INTRODUCTION

Plastic manufacturing is an important part of the Thai economy because it adds value to the system and its economy is worth hundreds of billions of baht each year. According to the statistics of the plastic products industry insights analysis center in 2020, Thailand has a value from the plastic product processing industry for domestic use of over 8.4 hundred thousand million baht. It has a growth rate of 0.9 percent from the previous year. In addition, the plastic packaging industry, the country's main plastic product processing industry, generates a value of more than a 200-billion-baht, accounting for 24.3 percent of the total value, and has a growth rate of 4.5 percent compared to the previous year, which was predicted. This is expected to result from the coronavirus disease 2019 epidemic that has resulted in changes in consumer behavior, with consumers paying more attention to health and hygiene. In addition, the level of competition in the plastic products industry is expected to rise. Therefore, in order to maintain the business and strengthen its competitiveness, the strategy must be modified to the present circumstances to satisfy the demands of consumers. The most important factors that affect production and business operations include timely deliveries of goods, resources, and raw materials, etc. These factors are critical because they will enable the company to accomplish its goals. The production planning and scheduling processes are tools that play a big role in managing production factors and making it easier for businesses to adapt to changes in the market.

This study focuses on the plastic packaging factory, which is a medium-sized industry that makes on-demand products for customers. It produces a wide variety of plastic trays for automotive, electronics, consumer, medical devices, and hard disk drives in various forms and quantities at a certain time under the same production line. In addition, there are five production bases in 3 countries, resulting in 200 full-time employees, 15 production machines, and a monthly production capacity of up to 1.5 million plastic trays. The study found that the production scheduling problem in this research is very complicated because plastic tray packaging has a different number of cavity, production materials, and sizes. Due to the demand of customers who need a variety of products, plastic packaging factories face problems in the production scheduling process. It was found that the planning employees did not study how to organize the production systematically. The production order depends mainly on the experience of the planning employees in the production planning department who decided to set the machines based on the delivery date of the products to the customers. As a result, the total working time is large, the production of products is not in time to meet the needs of the customers, and the utilization of materials is lower than the organization's target. As the production scheduling problem is a complex process, it needs different techniques or methods to help optimize work priorities. In addition, the current production scheduling tool from microsoft office excel is inefficient because it cannot verify that the current planning and scheduling process is producing the proper results.

Therefore, this research was conducted to arrange production scheduling on parallel machines by using simulation techniques and Flexsim to find the most suitable alternative to sequencing production on machines according to practical conditions and constraints without compromising on the actual work system. Some other advantages include knowing what will happen in the future, using production sequencing choices efficiently, and delivering products to consumers on time.

2 RELATED THEORIES AND STUDIES

2.1 Related Theories

Production scheduling is a decision-making process for allocating tasks to limited resources such as people, machines, and equipment, as well as the time it takes to complete tasks (Sriphol 2017). It is a process with different characteristics according to limitations and process conditions that make up a scheduling system. They are produced in a variety of styles and are very complex (Kurukidcumchorn 2013). Therefore, business organizations need to find techniques and methods to enable production scheduling to achieve their goals (Lalitaporn 2002). This research aims to study the production scheduling of parallel machines with the same operating characteristics and working patterns but different production rates (Chutima 2003). Computer simulations are used to mimic the behavior or operations of various operating systems, such as industrial production systems, services, transportation systems, etc. (Thongprasert 2001) It is beneficial to analyze current operations and find the most efficient operation method without affecting the actual operation (Jongkol and Paramorn 2010).

Parallel machine scheduling is a scheduling solution with a variable number of jobs, production time, and delivery deadlines for different customers (Sudpum and Limnorarat 2008), including constraints of Limited production machinery. The capacity of existing production machines has the same or different performance depending on the service life or technology of the machines (Wongkrue and Wangwatcharakul 2021). Suppose the parallel machines used in production have different performances. In that case, it will result in different work completion times, which may result in the production of products that cannot keep up with customers' needs. Therefore, the production scheduling of parallel machines requires efficient tools and systematic management to respond to customer needs on time.

2.2 Related Studies

Caputo, Mose and Guizzi (2009) used a simulation to help schedule production, using OptQuest in Arena software to analyze possible sequences in the production process. The operation procedure began with allocating resources to various workstations, followed by writing commands to process production data using VBA code in the database, and finally bringing the processed data into the simulation model. According to research, Arena software can assess the best solution for the production scheduling model.

Cheng and Chan (2011) used simulations to assist in production planning to find the minimum total working time using the Flexsim simulation program. It starts with taking production data from a Microsoft Office Excel spreadsheet and processing it into a Flexsim model by grouping the data as much as possible and sorting the data group that gives the highest Slack time to production first. According to the simulation, improving production sequences resulted in decreased slack time values but longer model processing times to select the optimal solution.

Tharana, Chukijrungrog and Wiriyaphong (2012) developed a production scheduling method of printer machine in corrugated boxes industry to minimize the total working time by using a two-step solution as follows: work grouping, which uses a mathematical model to optimize work for machines; and 2) a work sequence applied based on the earliest deadlines and time-consuming tasks. According to the findings of the study, the production scheduling method can boost production scheduling efficiency by 7.83 percent when compared to traditional production scheduling.

Kongsomboon (2012) developed a method for scheduling the production of plastic injection molding factories to reduce the number of delays (products that are not produced in time for delivery). Since the case study factory does not have a plan to purchase raw materials and relies on the employee's experience in scheduling production, it results in the wrong delivery date with the customer. This research has developed a computer program to help estimate the production time and find a method for forecasting the appropriate number of raw materials. It is also used in the planning and scheduling of production using the heuristic method using the fastest delivery time priority rule. The study's results showed that the number of factory delays in the case study was reduced from as much as 39.93% to 16.87%.

Pushpakom (2014) presents a production schedule to produce printed plastic bottles in order to minimize the total untimely delivery by using a 2-step production scheduling method as follows: 1) work segmentation where tasks are set to machines using the earliest delivery date prioritization rules taking into account production constraints and customer priorities. 2) sequencing tasks to machines using a Tabu method to find the best results. From the study, it was found that such production scheduling gave the total late delivery times less than the old production scheduling by using the first-come-first-make rule by about 95% and the production scheduling time was shorter than the old production scheduling method using a first-come-first-make rule by about 80% in every stage of work.

According to Leawin (2017), a mathematical model called Mixed Integer Linear Programming was used to identify the shortest system shutdown time by transmitting it to the NEOS Server for processing. Because the data is big and there are numerous variables, the software CPLEX with a larger server is applied to assist the analysis. Studies demonstrate that using CPLEX on NEOS servers reduces system shutdown times by 17.49%. This research focused on reducing system shutdown time and avoiding other production costs.

Chaiyacod (2018) presented a method for scheduling the production of machinery for forming tires to reduce the total cost of labor and electricity costs using Mixed Integer Linear Programming, which is a mathematical model. It was used to solve problems using OpenSolver and Gurobi 7.5.2. The manufacturing process has its limitations. Some machines cannot handle specific sizes of work, and the order in which they are made has an impact on how long it takes to set up the machine. The study found that the total cost could be reduced by 328,848 baht per month, or 13.3%.

Wongkrue and Wangwatcharakul (2021) have proposed a strategy for scheduling production to minimize the number of machines used, boost machine utilization efficiency, and reduce the system's overall cost. This study used mathematical modeling to find optimally appropriate alternatives. The research indicated that combining heuristic scheduling with traditional production scheduling methods produces better results. Compared with the overall system, it was 13.43%.

A review of the relevant literature reveals that the production scheduling problem of parallel machines is a given problem. Methods for determining the minimal total uptime and the best solution have been developed continuously. Furthermore, computer simulations are used to assist in managing production scheduling issues and determine the most suitable solution. Therefore, this research applied Flexsim (3D simulation modeling and analysis software) to develop the production scheduling of parallel machines in a plastic packaging factory.

3 RESEARCH METHODOLOGY

The first step in the implementation process was to look at how the plastic packaging factory planned and sequenced its work. Then the environment of the current operation was analyzed and collected data in the scheduling process. The results of the collection and analysis of such data were used to create the current production sequencing model. The model's validity and accuracy were then examined, and a sequencing design based on the factors in the production process was created to develop the model for identifying the appropriate sequencing. Finally, the results obtained from the experiment were analyzed and summarized. The procedures for conducting this research are shown in Figure 1.

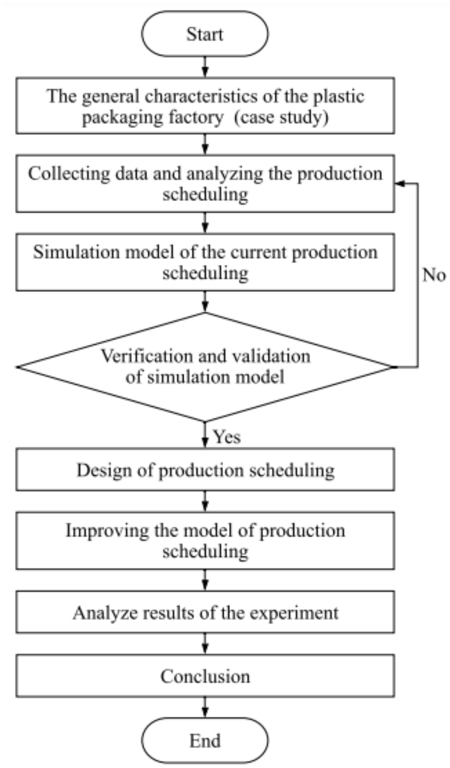

Figure 1: Procedures for conducting this research.

3.1 The General Characteristics of Plastic Packaging Factory (Case Study)

The case study of this research was a factory that manufactures vacuum-formed plastic packaging, primarily producing products according to customer demand. The production process in this case study is complicated because there are so many different types and quantities of goods being made. The planning and production scheduling procedures depend on the expertise of the production planning staff, who prioritize production based on customer delivery schedules to satisfy customer demands quickly, and they would like to earn consumers' trust and loyalty. In addition, there are two machines used in vacuum forming plastic packaging that have the same function but different production rates. The process of planning and sequencing for the factory case study is as follows:

1) Receive orders from customers.
2) Search for data and record production rates in the Master List on Microsoft Office Excel.

3) Plan production by taking into account the delivery schedule, products, and mold sizes.
4) Examine the materials used in the production process.
5) Record the production scheduling plan.

Note: If an operation is urgent, the staff will change the production plan to meet the customer's needs.

3.2 Collecting Data and Analyzing The Production Scheduling

The data collecting phase started with interviews with employees in factory case study. The data collection started with interviews with employees in the factory. In addition, the researcher also asked for samples of products produced for customers to use as samples in the research. There were eight samples of products used in the experiment with the ability to be produced on different machines. Examples of products used in the study are shown in Table 1.

Table 1: Examples used in this study.

Product	Production time (seconds)	Number of Cavity	Production rate (pcs per day)	Machine
Product 1	18.8	1	3,000	6
Product 2	12.0	2	4,900	6
Product 3	11.6	2	1,000	6
Product 4	11.6	2	440	6
Product 5	27.0	1	1,000	3
Product 6	27.0	2	3,000	3
Product 7	23.9	2	10,000	3
Product 8	22.1	2	1,000	3

Note: The machine setup time is one hour for each product.

From Table 1, the production of plastic tray packaging will have cavities for food or others. In the production of plastic trays, customers make production requirements, including the number of cavities. For example, if the customer wants one cavity, it means that the plastic tray must be produced with only one cavity per plastic tray. However, the customer wants two cavities, which means that the plastic tray must be produced with only two cavities per plastic tray.

3.3 Simulation Model of The Current Production Scheduling

Modeling simulation with Flexsim software for the sequencing process starts with defining all the units used in the model. It would then be crucial to design the machines and tools that were utilized in the experiment. In the next step, parameters were defined to assign different properties to the simulation model. Once the simulation was complete, the program would be run to view the results of the experiment. Following that, the simulation model's validity and validation were checked, as shown in Figure 2.

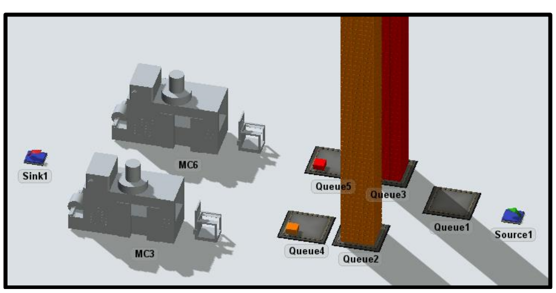

Figure 2: Simulation of current production scheduling.

3.4 Verification and Validation of Simulation Model

Computer simulations should first be checked to make sure they are accurate and work as close to reality as possible. Based on the validation of the simulation model, it was found that the model can operate in the actual operating environment and has no error notifications. For the model validation process, the researchers compared the current total working time and the model total working time using the Minitab program to calculate the statistical values. It started with checking the distribution of the data by using the Normality Test to see if the data set has a normal distribution (Thongman and Samattapapong 2021) as shown in Figures 3 and 4. The test results showed that the current sequencing process P-value was 0.200 and the simulation model was 0.359, where the P-value of both sets was higher than the significance level determined in the test, 0.05. It shows that the distribution of the two sets of data is normal. It is then examined whether the simulation model can be representative of the current scheduling process using the Paired T-Test. The test hypotheses are:

H0 = The model can represent the current sequencing process.
H1 = The model cannot represent the current sequencing process.

The result of the Paired T-Test to compare the current sequencing process with the simulation model is shown in Figure 5. It was found that the P-value was 0.748, which was higher than the significance level determined in the test, 0.05. The developed sequencing process model was found to be acceptable and capable of representing the functionality of the current sequencing process.

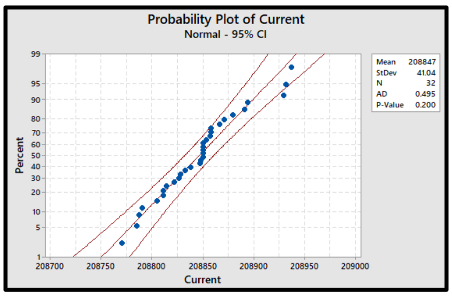

Figure 3: Results from the Normality Test of the current scheduling process.

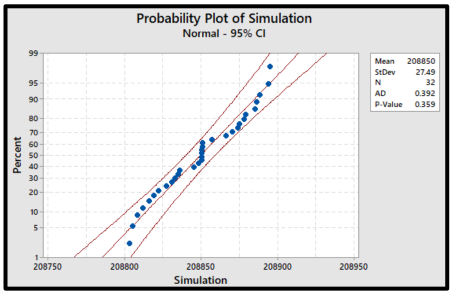

Figure 4: Results from the Normality Test of the simulation model.

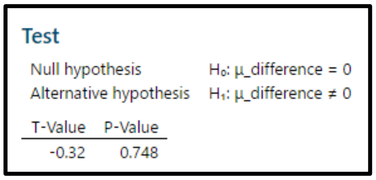

Figure 5: Results from the Paired T-Test.

The number of replications was then determined (Noinual and Wasusri 2012), such that the model processing errors could not exceed 10% of the mean (Christopher 2004). The formula is as follows:

$$N = \left(\frac{t_{1-\frac{\alpha}{2},n-1} * s}{e}\right)^2,$$

$$Standard\ Error = t_{1-\frac{\alpha}{2},n-1} * s/\sqrt{n}$$

where
N = Number of replications
n = Amount of data for replications
t = Use the t-table to find t-values for a confidence interval.
s = The standard deviation of ten initial processing replications
e = Acceptable Error Value is defined as being less than 10% of the average.

According to Table 2, a preliminary simulation result with 10 cycles and a number of rounds of 10 cycles gave an error value of 16.17. This is higher than the acceptable error value. Therefore, the appropriate number of replications must be recalculated as shown in Equation 1.

Table 2: At 10 cycles, the model error is calculated.

Mean	208851.40
Standard Deviation	22.60
t for alpha = 0.05, 9 d.f.	2.26
Standard Error	16.17

$$N = \left(\frac{2.26\ x\ 22.60}{10.00}\right)^2 = 26.13 \approx 30 \tag{1}$$

The result of the calculation using the number of repetitions of 30 showed that the error value was 10.31, which was higher than the acceptable error value as shown in Table 3. Therefore, the appropriate number of replications must be recalculated as shown in Equation 2. And after 32 repetitions, it was found that the error value was 9.91, which was less than the acceptable error value of 10% of the mean, as shown in Table 4. Therefore, the number of replications was 32.

Table 3: At 30 cycles, the model error is calculated.

Mean	208849.47
Standard Deviation	27.61
t for alpha = 0.05, 29 d.f.	2.05
Standard Error	10.31

Table 4: At 32 cycles, the model error is calculated.

Mean	208849.66
Standard Deviation	27.49
t for alpha = 0.05, 31 d.f.	2.04
Standard Error	9.91

$$N = \left(\frac{2.05\ x\ 27.61}{10.00}\right)^2 = 31.89 \approx 32 \tag{2}$$

3.5 Design of Production Scheduling

For the current production schedule of the case study, the production planning department will plan the production. The planning staff receives orders from customers, and then they will plan the production about a day in advance. The capacity of the machine was then determined by considering the machine's size. The production plan will be then forwarded to the production team, who are responsible for producing the work each day under the purchase orders. From the study of the planning and production scheduling of the plastic packaging factory, it was found that the problem was caused by not systematically studying the method of sequencing the production. The production order is based on the expertise of the production planning team, who assign jobs to machines based on the customer's delivery schedule. As a result, the use of raw materials is lower than the goals of the organization. As well as the production sequencing tools that use Microsoft Office Excel, it isn't possible to see if the current planning and sequencing processes are working well.

So, this research has planned and sequenced production to find a way to arrange the production order that is best for the most cost-effective use of raw materials and the fastest delivery of products. Additionally, it minimizes overall uptime. The design of the production sequencing is divided into three major processes.

- Step 1 the ability to form a pair of products.
- Step 2 Machine Productivity
- Step 3 Scheduling the work into the machine

A computer program called VBA (Visual Basic for Applications) is used to make decisions and find possible alternatives in Microsoft Office Excel. The design takes into account factors and limitations in the production process of all eight samples of the product. All possible alternatives were imported into the Flexsim software.

Step 1: The ability to form a pair of products from 8 samples.

It can be considered by the factors of production, including mold area, type of material, and material thickness, as well as mold height. It can be derived from the aforementioned production factors, resulting in the grouping of all four workgroups. For example, product 1 cannot be molded with another product, so it is in workgroup 1. Products 2, 3, and 4 can be molded together on the same machine and at the same time, so they can be in workgroup 2, etc. The results of the decision in step 1 are shown in Table 5.

Table 5: All workgroup information was obtained from step 1.

Workgroup	Product	Production time (seconds)	Number of Cavity	Production rate (pcs per day)
1	1	18.8	1	3,000
2	2, 3, 4	12.0	6	6,340
3	5, 6	27.0	3	4,000
4	7, 8	23.9	4	11,000

Step 2: Machine Productivity of four workgroups

From the factors and limitations of production, it can be considered as follows:

- Machine 3: The mold area can be less than / or greater than the area of the sixth machine's printing plate.
- Machine 6: The mold area must be less than the area of the sixth machine's printing plate only.

Based on the factors and conditions of production, workgroups 1 and 3 can produce work on machines 3 and 6, whereas workgroups 2 and 4 can only produce work on machine 3, as indicated in Table 6. It was also discovered that the number 1 represents workgroups that can be produced on that machine, while the number 0 represents workgroups that cannot.

Step 3: Scheduling the work into the machine

The permutation and combination approaches were used to determine all possible workgroup sequences based on the machine characteristics. As a result, it came up with 40 alternatives.

Table 6: Limitations of workgroup-producing machines.

Workgroup	Available Machines	
	Machine 3	Machine 6
1	1	1
2	1	0
3	1	1
4	1	0

3.6 Improving The Model of Production Scheduling

From the design of the production sequence, all possible alternatives were pulled into the Flexsim simulation software. The schedule of production by using the experiment tool is shown in Figure 6. Performance measurement tools and parameters were used to set up production parameters and conditions. The work being done on the machine includes figuring out how long the production system has been running. Then, the software was run to examine the Flexsim simulation program's findings.

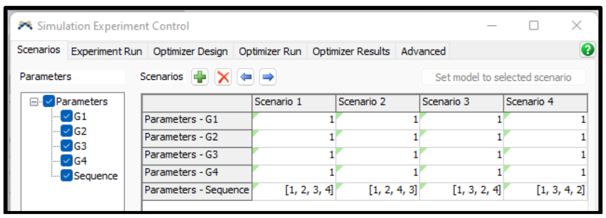

Figure 6: All alternatives were defined using the experiment tool.

The production sequence in the Flexsim simulation program starts by importing the production data processed in Microsoft office Excel into the Flexsim database. Next, set the production machine data and all possible production sequences using the Parameter tool. After that, set all possible alternatives obtained from the microsoft office excel processing on the Experiment tool, as shown in Figure 6. Then use the optimizer run tool to process the lowest total run time of the model.

4 RESULTS

Creating all possible options for the lowest total uptime of sequencing on parallel machines involves three sequencing steps. They include the ability to form a pair of products, machine manufacturing capabilities, and the ability to schedule work on machines. It was discovered that all four workgroups can be grouped by eight product samples, and each workgroup can produce jobs differently. Furthermore, the order of workgroups influences the overall uptime of the different systems. Therefore, this research generated a total of 40 potential sequencing alternatives for two machines. The result of simulation with Flexsim software is shown in Table 7.

From the simulation results using Flexsim 2021 version 21.0.7, it was found that workgroup 2 and workgroup 4 were produced on machine 3, and workgroup 1 and workgroup 3 were produced on machine 6 were the most suitable choices. This is because the production time is as low as 96,018.01 seconds compared to all possible alternatives, and the total uptime of the current sequencing system was lowered. Originally, the total working time was 208,850 seconds, which was reduced to 112,831.99 seconds, or 54.03 percent. A great production scheduling process can also result in the timely delivery of products to customers and the utilization of material of plastic packaging factories increased to 88.23% from 61.25%, resulting in meeting organizational goals.

Table 7: Examples of experimental results from simulation.

Alternative	Machines		Total time (second)
	Machine 3	Machine 6	
25	2, 4	1, 3	96,018.01
26	2, 4	3, 1	99,591.01
27	4, 2	1, 3	96,018.01
28	4, 2	3, 1	99,591.01
29	1, 2, 4	3	141,997.01
30	1, 4, 2	3	142,009.01
31	2, 1, 4	3	145,597.01
32	2, 4, 1	3	145,597.01
33	4, 1, 2	3	145,609.01
34	4, 2, 1	3	145,597.01

5 DISCUSSION OF RESULT

This research studied the production scheduling process by using simulation techniques with Flexsim to find the appropriate workflow for the production on machines according to the conditions and constraints of the actual production process, to find the lowest total uptime and be able to deliver the product on time. According to the study of plastic packaging factories, it was found that the problem is from the planning employee, who did not know how to arrange the production order systematically. Moreover, the production order is based on the experience of the planning employee, resulting in large total working time and insufficient production of products according to customer requirements. In addition, the current production scheduling tool from microsoft office excel is inefficient because it cannot verify that the current planning and sequencing processes are producing optimal results. Therefore, this research has designed a total of 3 new production sequence steps as follows: product matching capability, machine productivity, and machine work ordering. The experiment's results using simulation techniques showed that the program was able to sequence the tasks that reduce the total working time. Therefore, having the right techniques or methods will increase the efficiency of production scheduling as well as being able to deliver products to customers on time.

6 CONCLUSION

Flexsim simulation techniques were used in this study to schedule production on parallel machines and figure out the best total uptime for each machine. After analyzing the planning and scheduling processes of the plastic packaging factory, it was found that there was no systematic strategy for sequencing production since sequencing depends only on the experience of the production planning staff. In addition, the tools for sequencing production are ineffective because it isn't possible to make sure that the current planning and sequencing processes are getting the best results. As a result, the researcher has considered three phases of the production scheduling process: the ability to make products, machine capacity, and the sequence of work that enters into the machine. Its purpose is to create all possible alternatives for ordering production on a machine and use the Flexsim to achieve the best results. Following that, the best outcomes from the simulations were compared to the current production schedule. The results of the experiment with eight product samples showed that the work can be grouped for production on the same machine and at the same time; in other words, the ability to produce pairs of products based on factors in the production process for a total of four workgroups. However, each work group has limitations on production time, production volume, and the number of cavities. Furthermore, some workgroups are limited to producing work on specific machines, resulting in a total of 40 production sequencing alternatives. When all of the alternatives were run through the Flexsim software, it was discovered that the best alternatives were Workgroup 2 and 4 (machine 3) and Workgroup 1 and 3 (machine 6). They had the shortest total working time of 96,018.01 seconds, compared to the original time of 208,850 seconds, for a total working time reduction of 54.03 percent to 112,831.99 seconds.

ACKNOWLEDGMENTS

Thank you to the plastic packaging factory for providing information and giving interviews on various aspects of the planning and sequencing process, as well as for taking the time to provide useful advice to researchers in this implementation.

REFERENCES

Caputo, G., G. Mose, and G. Guizzi. 2009. "Optimization of Production Plan through Simulation Techniques". *Wseas Transactions on Information Science and Applications* 3(6):352–362.

Chaiyacod, A. 2018. "Parallel Machine Scheduling with Sequence Dependent Setup Time for Tire Building Process". Department of Industrial Engineering, Mueang, Chonburi.

Cheng, H. C., and D. Y. K. Chan. 2011. "Simulation Optimization of Part Input Sequence in a Flexible Manufacturing System". In *Proceedings of the 2011 Winter Simulation Conference*, edited by S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, 2374–2382. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Christopher, A. C. 2004. *Simulation Modeling Handbook: A Practical Approach*. Boca Raton, London, New York, Washington: CRC Press LLC.

Chutima, P. 2003. *Techniques for Scheduling Operations*. Bangkok: Chulalongkorn University.

Hammersley, J. M., and D. C. Handscomb. 1964. *Monte Carlo Methods*. London: Methuen.

Jongkol, P., and T. Paramorn. 2010. "Run Length Analysis for Queueing Simulation Model". *UBU Engineering Journal* 3(1): 12–19.

Kongsomboon, W. 2012. "Reduction of the Tardy Jobs in the Plastic Injection Molding Factory". In *Proceeding of the 50th Kasetsart University Annual Conference: Architecture and Engineering*, January 31th-February 2nd, Thailand, 315–321.

Kurukidcumchorn, P. 2013. "Comparison Unrelated Parallel Machines Scheduling of Result from Scheduling Program and Assignment Problem". Department of Industrial Engineering Management, Silpakorn University, Mueang, Nakhon Pathom.

Lalitaporn, P. 2002. *Production Planning and Control System*. Bangkok: Technology Promotion Association (Thailand-Japan).

Leawin, N. 2017. "Heterogeneous Parallel Machine Scheduling of a Packing Department: The Case Study of Pharmaceutical Factory". Department of Industrial Engineering and Management, Silpakorn University, Mueang, Nakhon Pathom.

Noinual, P., and T. Wasusri. 2012. "An Improvement of Transportation in Warehouse with Simulation a Case Study of Soft Drinks Industry". *KMUTT Research & Development Journal* 35(3):323–334.

Pushpakom, P. 2014. "Job Shop Scheduling for Color Printing of Plastic Bottom Production". *MUT Journal of Business Administration* 11(1):27–42.

Sriphol, N. 2017. "Scheduling for Number of Tardy Job Improvement: A Case Study". Department of Industrial Engineering, Thammasat University, Khlong Luang, Pathum Thani.

Sudpum, N., and S. Limnorarat. 2008. "Production Scheduling for Parallel Machines with Dependent Setup Times". In *Proceedings of the 46th Kasetsart University Annual Conference: Architecture and Engineering and Natural Resources and Environment*, January 29th-February 1st, Thailand, 329–336.

Tharana, W., T. Chukijrungrog, and M. Wiriyaphong. 2012. "Production Scheduling of Printer Machine in Corrugated Boxes Industry". *Conference of Industrial Engineering Network*, Phetchaburi: Sripatum University, 339–345.

Thongman, P., and N. Samattapapong. 2021. "Production Sequence using Simulation Techniques: Case Study of Mineral Production Plants for Dairy Cow". In *Proceedings of the 11th Annual International Conference on Industrial Engineering and Operations Management*, Singapore: IEOM Society International, 650–659.

Thongprasert, S. 2001. *Simulation*. Bangkok: Chulalongkorn University Printing House.

Wongkrue, T., and W. Wangwatcharakul. 2021. "Parallel Machine Scheduling in the Integrated Circuits Testing Process". *Thai Journal of Operations Research* 9(1):153–162.

AUTHOR BIOGRAPHIES

JIRATSAYA PANASRI is a master's degree student in Industrial Systems and Environmental Engineering at Suranaree University of Technology. She holds a bachelor's degree in Industrial Engineering from Suranaree University of Technology. Her research interests include modeling and simulation optimization, as well as production planning and control. Her email address is jiratsaya.panasri@hotmail.com.

NARA SAMATTAPAPONG is an Assistant Professor in the Department of Industrial Engineering, Faculty of Engineering at Suranaree University of Technology. He holds a bachelor's degree in Industrial Engineering from Suranaree University of Technology and holds a Master's and Ph.D. in Mechatronics from the Asian Institute of Technology. His e-mail address is nara@sut.ac.th.

SATHITTHEP SANGTHONG is a lecturer in the Department of Industrial Engineering, Faculty of Engineering at Rajamangala University of Technology Rattanakosin. He holds a bachelor's degree in Industrial Engineering from Naresuan University and a Master's degree in Industrial Engineering from Chulalongkorn University. He has special expertise in production planning control and sequencing and scheduling. His email address is sathitthep.san@rmutr.ac.th.