A Simulation Approach for Determining Delivery Time in a Waste Materials Based Make-To-Order Manufacturing Company

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Abstract

This study aims to determine delivery time of a set of customer orders in a repetitive make-to-order (MTO) manufacturing company that utilizes recycled waste products as raw materials. A simulation approach and flow-shop dispatching rules are applied to find minimum total flow time or makespan taking materials supply uncertainties into account which is then used to determine the delivery time of each order. As an industrial case study we consider a small medium repetitive MTO company that produces multiple products from plastic waste. The result of the study shows that in a flow-shop manufacturing system with probabilistic arrival time and quantity of materials shortest processing time rule does not always result in minimum makespan.

Keywords
make-to-order, recycled materials, flow-shop, delivery time, simulation

1. Introduction

Sustainable development is described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WECD, 1987). The strategy to achieve the goal of sustainable development in the industrial sector is sustainable manufacturing. It can be implemented by closing the loop of product lifecycle by utilizing industrial waste streams as alternative sources of other needed material. In this regard, industry has a responsibility to provide sustainable goods by using waste materials, which can lead to technically and economically competitive products.

Closed material cycle can reduce the use of virgin materials as resource inputs and reduce the volume of waste products requiring disposal. However, in practice the utilization of waste materials is limited by several factors. The factors include waste collection and transportation, the scale of the business, the industrial sector in which the company operates, the amount and type of waste produced, environmental regulations, and the level of development within a particular country (Linton et al., 2007).

Waste collection and transportation can bring about the issues on the uncertainty associated with the recovery process with regards to quality, quantity, and timing of returned products (Corbett and Klassen, 2006). The uncertainties will indeed noteworthy in the production planning and control activities. Likewise, uncertainty is very important concern in make-to-order (MTO) company since it complicate the estimation of production lead time.

In MTO situation, manufacturing activities are based on the order received. There are two situations of MTO system i.e. repetitive and nonrepetitive. In nonrepetitive MTO systems, orders are treated as new jobs which have not been done previously so they require manufacturing engineering including design and process planning. While in repetitive MTO system orders are not treated as new jobs as they are produced repetitively, so there is no requirement of new design.

Competitive keys of MTO manufacturing system include technical ability, delivery time, and price. Consequently, aside from price and product design, meeting customer's demand within shortest time becomes an important issue in MTO system. When receiving orders from a customer, MTO company offers price and delivery time. The orders will be executed if the customer agrees with the proposed price and delivery time. Delivery of orders exceeding the promised delivery time may cause penalty to the company. Therefore, MTO company must able to estimate order manufacturing lead time accurately.

Manufacturing lead-time (MLT) is defined as time between the arrival time of material used for product development and product completion time (Chang et al., 1998). It is made up of material handling and non-production (wait or queue) time as well as real production activities (Turbide, 2016). From a customer perspective, lead time can be translated into delivery time. It is affected by many factors including capacity, loading, batching and scheduling, and themselves affect many aspects of costs, and control (Mourtzis et al., 2014). As supply uncertainties influences production planning and scheduling, it will indeed have an effect on MLT. Moreover, waste materials may pass through several stages of process including cleaning operation. Variability in the condition of the materials may increase the accuracy problem of the estimation of production lead time. Therefore, developing methodologies for feasible, robust, and optimal process scheduling under uncertainty is necessary (Li and Ierapetritou, 2008).

Various methods have been proposed for the estimation of lead time (Mourtzis et al., 2014) such as simulation (Chryssolouris et al., 2008) queuing theory (Karmarkar, 1993), logistic operating curves (Nyhuis et al., 2005), statistics (Cheng and Duran, 2004), stochastic analysis (Wiendhal and Toenshoff, 1988), artificial intelligent methods (Negnevitsky, 2005) and hybrid methods (Rao and Gu, 1994). While the previous works concerned with discrete MTS manufacturing lead time with deterministic materials supply, this study is intended to determine production lead time in a repetitive MTO situation, in particular processing industry, where they use recycled waste products as raw materials. In contrast to (Indrianti and Toha, 2006) that developed analytical MLT model for nonrepetitive MTO with single order, this study deals with simulation model for repetitive MTO where recycled materials are used to produce multi products.

The contents of the paper are organized as follows. Section 2 explains manufacturing with recycled materials. In Section 3 we explain the methodology of the study. Section 4 explores industrial case study while the results of the study is discussed in Section 5. Conclusions and directions for further research are summarized in Section 6.

2. Manufacturing with Recycled Materials

Inverse manufacturing and reverse logistics have been developed as strategies to close the loop of product lifecycle. Inverse manufacturing is developed based on the concept of prolonging the life of a product and its constituent components. In addition, reverse logistics is developed based on the concept that manufacturers are forever responsible for their products. The implementation of the strategies involves recycling and remanufacturing products.

Recycling can be defined as the process of converting waste materials into reusable materials. Meanwhile, a remanufacturing process rebuilds a unit or machinery to restore its condition to as "good as new" (European Commission, 1998).

In remanufacturing company, Guide (2000) clearly stated that there are seven characteristics that significantly complicate production planning and control activities. Those include the uncertain timing and quantity of returns;

the need to balance returns with demands; the disassembly of returned products; the uncertainty in materials recovered from returned items; the requirement for a reverse logistics network that concerns with how products are collected from the end user and returned to a facility for repair, remanufacturing or recycling; the complication of material matching restrictions; and the problems of stochastic routings for materials for remanufacturing operations and highly variable processing times.

Furthermore, Guide (2000) described that uncertainty in the timing and quality of returns is a reflection of the uncertain nature of the life of a product and technological change. Whereas the product returns process is highly uncertain with respect to timing depending on the cores available for remanufacturing both in terms of quantity and quality. So it is necessary that core availability be forecast for planning purposes, for both quantities available and the timing of availability.

In remanufacturing systems the uncertainty of the quality level of recycled products will affect the recycling rate, the buyback, cost, and remanufacturing cost. If the quality level of recycled products is very low, then the recycling rate will be high and the buyback cost will be low. This situation motivated (Guo and Ya, 2015) to study the optimal recycling production strategy considering the minimum quality level of the recycled products in the manufacturing and remanufacturing system. He concluded that the optimal manufacturing and remanufacturing strategy is to take the reasonable arrangement of remanufacturing and manufacturing batch to reduce the average total cost.

3. Model and Methodology

This study deals with a repetitive MTO flow shop manufacturing system that produces multiple products with recycle waste products as raw materials. All products are produced in the same serial machines with the same processing sequence as shown in Figure 1. The problem is to determine production sequence so as to minimize production lead time. With regards to Ioannou and Dimitriou (2012), lead time in this study represents the amount of time allowed for orders to flow through the production facility and measured by the amount of completion time of all jobs or makespan.

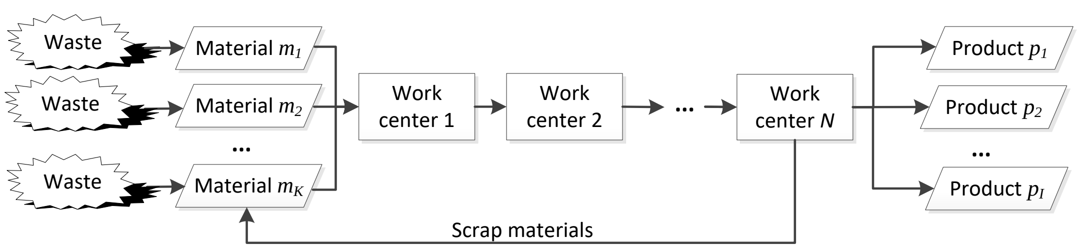


Figure 1. Production process diagram

Because the materials are recycled from almost the same type of product waste and there is no need for high specification of the material, we assume that the quality of waste products is good enough and meets the requirement of the materials so there is no disposal of the incoming materials. Order quantity of each product is known. Due to the uncomplicated production process the processing time of each product at each work centre is assumed to be known and deterministic. Recycling rate of waste materials is probabilistic in regard to the timing and quantity of returns. The production process is started after materials are arrived and reach the quantity required. We used simulation approach using Arena software to solve the problem.

The simulation model was built based on the following steps: (1) Description of the current production system, (2) Description of the material structure of each product; (3) Data acquisition and analysis, including collecting data and defining the probability distribution of each materials; (4) Development of simulation model, started from individual production process followed by the entire process model that was built by combining the individual models; (5) Running the simulation with dispatching or scheduling rules; and (6) Verification and validation.

4. Industrial Case Study

As a case study we consider a small medium MTO company located in Purwokerto, Central Java, Indonesia. The company uses recycled plastic products as raw materials. We focus on three types of products which are often ordered by customers. The products and materials can be seen in Figure 2. Nail products are used as cracks barriers of wood logs as raw material for furniture. The products are made of various materials and scrap combined with indirect materials such as glossy and coloring agent with a specific composition as listed in Table 1.

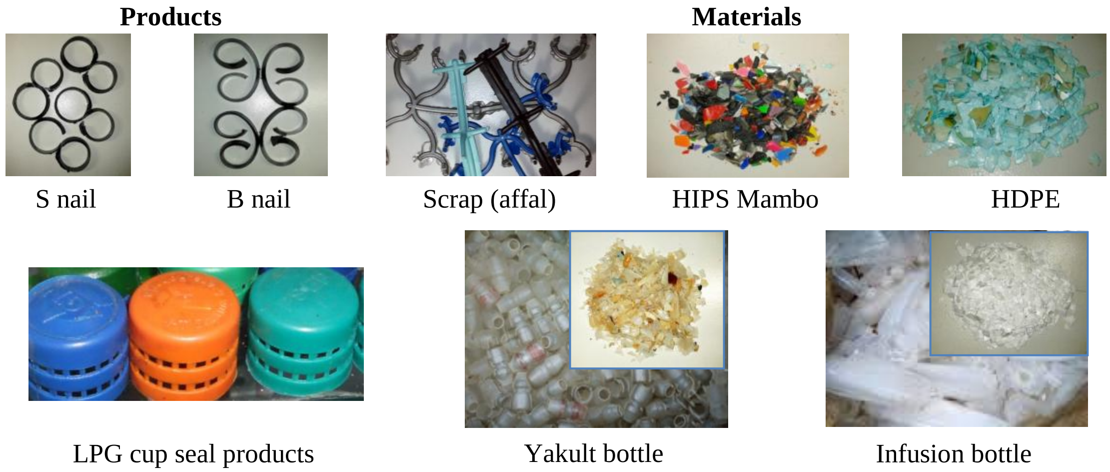


Figure 2. Products made from recycled plastic products

Table 1. Material composition of each product

Product	Material composition		
	Type	Main Material	Additional Material
All nail products	High impact proof polystyrene	• 30% HI Mambo • 60 % Affal (by colour)	• 10% yakult plastic
All LPG cup seal	Poly ethylene	• 30% HDPE (Naso) • 60% Affal (by colour)	• 10% Infusion plastics • Glossy 2 gr per kg of product • Colouring agent (1gr per kg of product)

The production process is done in three work centers: mixing, moulding or injection, and finishing. The Finishing process includes product-scrap separation and products weighing, packaging, and storage. Processing time (tp_i) of each product at moulding work center is determined based on production cycle time (tc_i) and production quantity per cycle (qc_i). Table 2 shows production time and historical production data for five months.

The distribution function of arrival time and the quantity of the waste materials are determined based on 40 consecutive data of time of arrival of materials in the warehouse. The distribution test was done using Input Analyzer program of Arena software and the result is shown in Table 3.

Finishing processing time was determined based on 60 samples taken using a stopwatch. Statistical tests were done for uniformity and adequacy. With regards to Nunally (2002), for a 95% confidence level and 5% accuracy level (k=2, s=0.05) at least 46 samples were required. This means that the number of the data points is enough. The result of uniformity test shows that all the data are uniform. The calculation resulted in 1.68 minutes/kg and 1.612 minutes/kg of finishing time for nail and cup seal products respectively.

Table 2. Processing time and production quantity

p_i	Description	Processing time						Monthly production				
		Mixing			Moulding			Month (kg)				
		tc_i (min)	qc_i (kg)	tp_i min/ kg	tc_i (min)	qc_i (kg)	tp_i min/kg	1	2	3	4	5
1	Black B nail	15	50	0.3	0,23	0.06	3.83	5511	294	0	2170	767
2	Black S nail	15	50	0.3	0.23	0.03	7.67	120	1870	275	24	2068
3	Green S nail	15	50	0.3	0.25	0.05	5.00	545	249	292	432	925
4	Green LPG cup seal	15	50	0.3	0.3	0.05	6.00	361	0	225	359	42
5	Red LPG cup seal	15	50	0.3	0.3	0.05	6.00	237	238	392	242	281
6	Silver LPG cup seal	15	50	0.3	0.3	0.05	6.00	464	153	164	492	76
7	Blue LPG cup seal	15	50	0.3	0.3	0.05	6.00	282	0	0	324	338

Table 3. Distribution function of material arrival time

Materials		Distribution Function	Expression value
m_k	Description		
1	HI mambo	Beta	-0.001 + 555 * BETA(0.324, 4.27)
2	HI white	Exponential	-0.001 + EXPO(64.5)
3	Black affal	Exponential	-0.001 + EXPO(31.2)
4	Red affal	Weibull	-0.001 + WEIB(17.2, 0.384)
5	Green affal	Exponential	-0.001 + EXPO(155)
6	Silver affal	Exponential	-0.001 + EXPO(70.9)
7	Blue affal	Weibull	-0.001 + WEIB(40.1, 0.365)
8	Naso	Weibull	-0.001 + WEIB(16.6, 0.32)
9	Yakult bottle	Exponential	-0.001 + EXPO(101)
10	Infusion bottle	Exponential	-0.001 + EXPO(87.7)

To execute the model, we considered the quantity of each ordered product as follows: 1220 kg of p_1, 550 kg of p_2, 550 kg of p_3, 900 kg of p_4, 500 kg of p_5, 350 kg of p_6, and 150 kg of p_7. The simulation model was initially developed for individual products. For example, Figure 3 shows production process model for black B and S nail products. As described in Table 1 all nail products use the same materials, which are HI mambo, black affal, and yakult plastics.

As is shown in Fig 3, “Decide” module is based on “2-way by condition”, in which the production of black B or S nail products depends on the priority. “Assign” module is for replacing and adding attribute value, i.e. “weight” and “priority”. Production process for other products is composed using the same way as B and S products. After all individual production process are composed, we then created model for the whole process.

The next step was a validation process which aimed to define if the simulation model behaves just like the actual system. The validation process was done by comparing the number of products resulted from the simulation model and real production. In this case we used Paired-t Confidence Interval (ProModel, 1998) with α=0.05 and the following hypothesis:

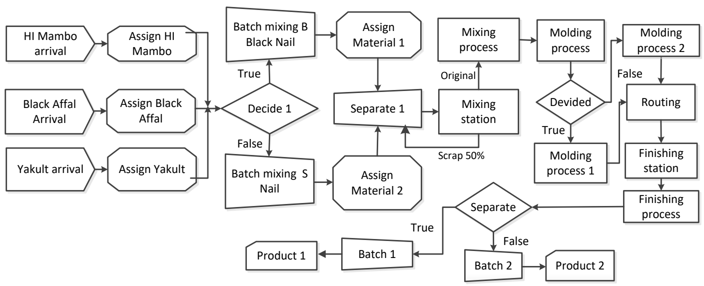
$$H_0 : \mu_1 - \mu_2 = 0 \qquad (1)$$

$$H_1 : \mu_1 - \mu_2 \neq 0 \qquad (2)$$

Table 4 shows the simulation result of the production of green S nail product for five months. Using 5% accuracy level and 95% level of confidence, the number of data (n)=5, standard deviation (S)=125.23, and $t_{n-1,\ \alpha/2}$ = 2.776 (from t Table), according to (Law and Kelton, 2000), the half width (hw) can be calculated as follows:

$$half\ width\ (hw) = \frac{(t_{n-1,\alpha/2})S}{\sqrt{n}} = 155.47 \quad (3)$$

Figure 3. Production process model of B and S black nails



The value of *confident interval* is calculated as follows:

$$CI_a = \bar{X}_{(1-2)} + hw = 23.6 + 155.47 = 179.07 \quad (4)$$

$$CI_b = \bar{X}_{(1-2)} + hw = 23.6 - 155.47 = -131.87 \quad (5)$$

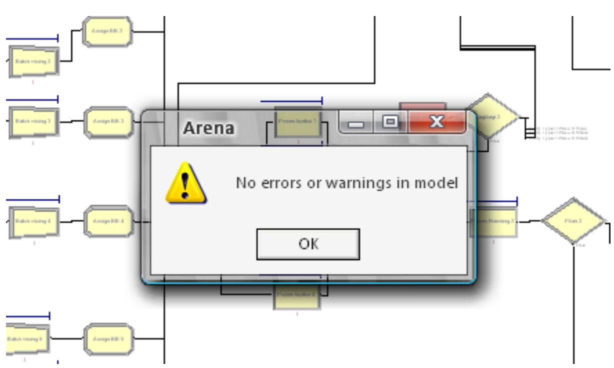
Because 0∈ [CI_b, CI_a], *Ho* is accepted. It means that at 95% of confidence level the developed model is not different from the real system. In other word, the simulation model is valid.

The next step was verification process. It was made with the purposes of detecting errors using the embedded debugging tool of the software. Figure 4 shows the verification result.

Table 4. Validation result of green S nail product

Month	Actual production (kg)	Simulation result (kg)	The difference
1	545	450	95
2	249	225	24
3	292	450	-158
4	432	450	-18
5	925	750	175
Average			23.6
Standard Deviation (S)			125.23
Variance			15682.3

Figure 4. Verification result



In this study we considered six flow shop dispatching rules, i.e. Shortest Processing Time (SPT), Longest Processing Time (LPT), First Come First Serve (FCFS), and three random sequences. Jobs sequence of each rule are 7-6-3-5-2-4-1 for SPT, 1-4-2-5-3-6-7 for LPT, 1-2-3-4-5-6 for FCFS, 3-2-1-5-4-6-7 for Random 1, 4-5-6-7-3-2-1 for Random 2, and 1-3-5-7-2-4-6 for Random 3.

To get good result, the simulation must be done in *n* replications. Initial run was done for green S nail product with 5 replications. The result is shown in Table 5. The minimum number of replications ($n_r{}^*(\gamma)$) can be calculated as follows (Law & Kelton, 2000)

$$n_r{}^*(\gamma) = \min\left\{i \geq n: \frac{t_{(i-1,1-\alpha/2)}\sqrt{S^2/i}}{|\bar{X}(n)|} \leq \gamma'\right\} \tag{6}$$

$$n_r{}^*(\gamma) = \min\left\{i \geq 5: \frac{2.776\sqrt{186.75/i}}{465} \leq 0.0476\right\} \tag{7}$$

We then tried some values for *i* as shown in Table 6. We can see from the table that the minimum number of replication is 4. Thus replication used in the simulation is sufficient.

Table 5. Initial replication

i	1	2	3	4	5	Total	Avg	Conf. level	95%
Simulation result X_i (kg)	450	225	450	450	750	2325	465	α	5%
a= (X_i – Avg)	-15	-240	-15	-15	285			$S^2(n)$	186.75
a^2	225	57600	225	225	81225	139500		γ'	0.0476

Table 6. Calculation of replication

i	i = 8	i = 7	i = 6	i = 5	i = 4	i = 3	i = 2	$S^2(n)$	186.75
$(t_{n-1,\alpha/2})$	2.365	2.447	2.57	2.776	3.182	4.303	12.706	Average	465
$n_r{}^*(\gamma)$	0.0246	0.0272	0.0308	0.0365	0.0467	0.073	0.264		

Simulation results for each dispatching rule can be seen in Table 7. It is shown that the Random 3 dispatching rule resulted in minimum makespan or total flow time.

Table 7. Simulation results

p_i	Flow time (hours)					
	SPT	LPT	FCFS	Random 1	Random 2	Random 3
1	105.13	87.91	87.87	93.18	105.13	87.91
2	97.06	94.43	93.13	92.55	99.60	97.69
3	60.15	65.85	62.78	58.40	62.31	59.95
4	216.75	213.91	211.12	213.98	214.29	217.39
5	125.25	123.22	125.80	123.22	125.09	119.65
6	197.20	204.85	204.94	204.80	192.51	211.78
7	175.98	193.37	193.05	193.09	179.96	173.38
Total	977.52	983.54	978.69	979.22	978.89	967.75
Average	139.65	140.51	139.81	139.89	139.84	138.25

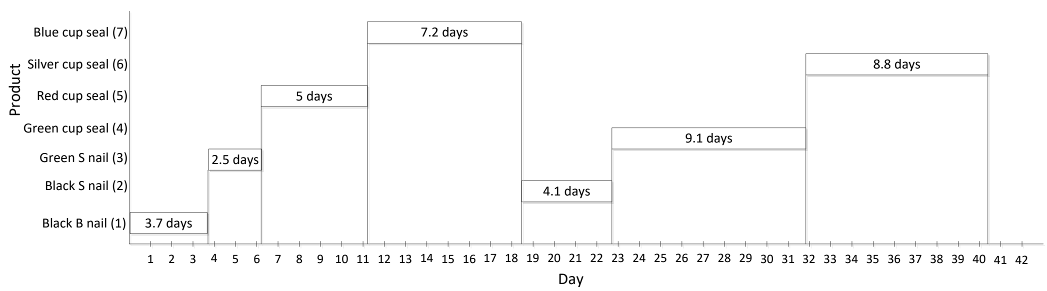
5. Discussion

We have developed a simulation model for determining production lead time in a repetitive single line process MTO company that uses recycled waste materials to produce multiple products with probabilistic arrival time and quantity of materials. The objective of the model is to determine jobs sequence so as to minimize makespan. The results show that Random 3 dispatching rule generated minimum makespan, i.e. 967.75 hours or 40.32 days if the production runs continuously (24 hours a day). The Random 3 rule executes the production based on the following sequence: black B nail - green S nail – red cup seal – blue cup seal – black S nail - green cup seal – silver cup seal.

In flow shop serial machines, shortest processing time rule oftentimes results in minimum makespan and average completion time. However, that situation does not happen in this case study. This is because the starting time of each production is based on the probabilistic arrival time and quantity of the materials.

Flow time resulted from the simulation can be used to determine order delivery time. Figure 5 shows 24-hours production schedule based on Random 3 dispatching rule. It can be seen that delivery time of each product offered to the customer are: 4 days for black B nail, 7 days for green S nail, 12 days for red cup seal, 19 days for blue cup seal, 23 days for black S nail, 32 days for green cup seal, and 41 days for silver cup seal.

Figure 5. Production schedule based on Random 3 dispatching rule



6. Conclusion

The result of the study shows that simulation approach can be used to determine orders' delivery time in a repetitive flow-shop MTO manufacturing system that utilizes recycled waste products as raw materials. Unlike flow shop manufacturing in which SPT rule oftentimes resulted in minimum makespan, in this study SPT rule did not arrive at the minimum makespan. This is because the production will start just after the incoming materials are sufficient. The simulation procedure used in this study can be applied in the order management phase when the company must make offer of price and lead time for the order received.

Further research direction includes the situation with more dispatching rules and multi resources. Inventory costs can be also taken into account when deciding production sequence.

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