SIMULATION MODELLING FOR LEAN PRODUCTION: CASE STUDY

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ABSTRACT: This article presents the simulation results of using Arena software in investigating the influence of lean production that depend on sequencing techniques in a manufacturing firm which operates based on engineer-to-order. By using the actual data collected from a case study, two sequencing techniques, Johnson Rule's and Critical Ratio were applied. The result showed that the use of sequencing techniques in an engineer-to-order operation was beneficial in optimising the operating time, and increasing output number. The finding will benefit manufacturing firms in making strategic decision to implement lean production in engineer-to-order operations.

KEYWORDS: *Simulation; Sequencing Techniques; Lean Production; Engineer-to-Order*

1.0 INTRODUCTION

Lean Production (LP) is a social-technical approach that offer various tools and techniques for greater benefits to improve manufacturing operations and production processes [1]. This subsequently encourages manufacturers around the world to adopt LP practices as a strategic part to improve productivity. Nevertheless, LP practices implementation in project-based operations was perceived to be more difficult. Operation based on engineer-to-order (ETO) is more complicated to manage and create more challenges as compared to the other operating segments. The variety of works, high degree of customisation in product and processes, and uncertainty of environment have created critical constraints for manufacturing firms to manage the manufacturing operations, mainly in fulfilling customers' needs [2-3]. These encompasses the product quality , pricing, production time delivery time [4]. Driven by demand, the product is only designed, engineered, and built according to specification once the order is received and confirmed by customer. Therefore, it is decisive to have an effective approach in streamlining the manufacturing activities in this type of operations, primarily to achieve a higher sustainability in manufacturing [5-6].

The main objective of this case study is to investigate by using a simulation on how LP practices implementation, through sequencing techniques, will influence the manufacturing responsiveness and economic performance to improve productivity in a project-based manufacturing operation that operates based on ETO oriented, as shown in Figure 1.

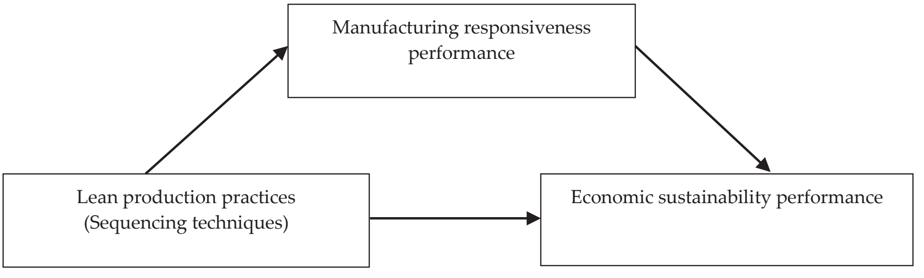

Figure 1: Research model

2.0 FINDINGS AND DISCUSSION

A case study was conducted at one of the local manufacturing firms that manufactures switchboard panels, in Kluang, Johor, Malaysia. Based on the interchangeability of operations by using a wide range of in-house facilities to customise the design of switchboard panels according to customer specifications, this manufacturing firm was selected. In general, the operations in this firm were separated into four main stages of activities, namely designing, fabricating, assembling and testing. In calculating time required for simulation, the time study technique, called Maynard's Operation Sequence Techniques (MOST), was chosen. This was because the number of products manufactured by this firm was small, limited and unique. Moreover, MOST technique is simpler and easier to implement as compared to other MTM techniques that require greater observational details [9]. By focusing on work motion, involving general move, control move and tool use, MOST technique is also useful in analysing and improving working method [10].

As practised, the allowance related to an individual, nature of work and environment were considered in estimating the standard time. By referring to the recommended allowance by the International Labour Organisation, or also known as ILO [11], constant allowance (personal allowance and basic fatigue allowance) and variable allowance were determined. All work activities in this firm were executed by male employees, and based on the nature of work performed, a total of 11% of allowances (personal allowance = 5%, basic fatigue allowance = 4% and variable allowance based on working position = 2%) were set by referring to the recommended allowances by ILO. By applying MOST technique, the standard time for each activity was later calculated.

To identify the simulation scopes, the Critical Path Method (CPM) Analysis was conducted. From observations, the fabrication section was identified as the main area that produce a bottleneck process, involving five sub-processes, i.e., pre-marking, shearing, stamping, bending and welding, particularly in fabricating the seven sub-components of sub-box assembly for switchboard panels, i.e. a wall mounted bracket-**G**, shield cover support bracket (A & B)-**H**, Neutral link support bracket-**I**, miniature circuit breaker (MCB) support bracket-**J**, divider bracket-**K**, moulded case circuit breaker (MCCB) support bracket-**L** and housing box-**M**. The plan layout of manufacturing process flow for switchboard panels is depicted in Figure 2. To achieve the study objective, two simulation analysis stages were executed. The first simulation was used to analyse the performance of current practices, and the second simulation was used to predict the operational performance after the sequencing techniques were applied.

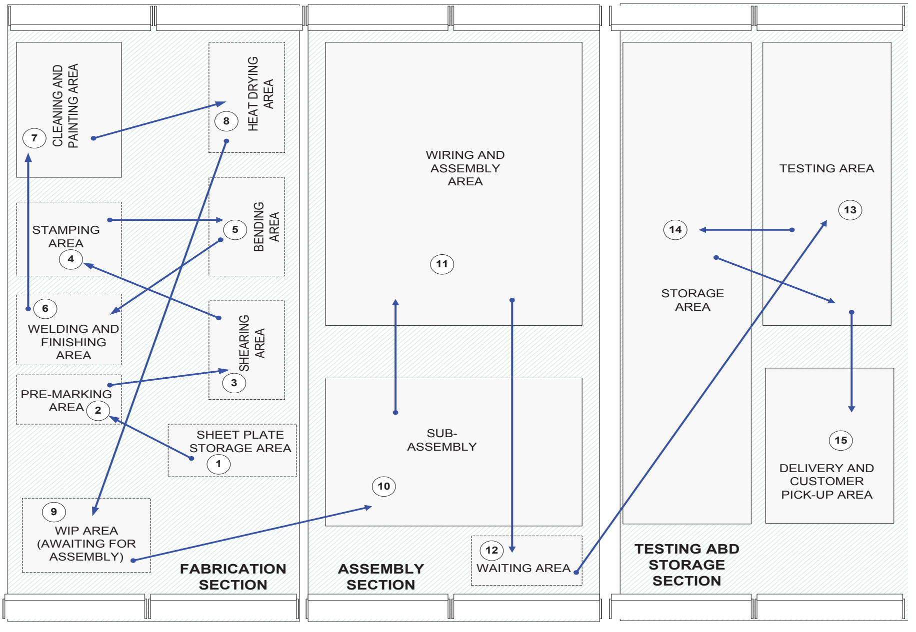

Figure 2: Plan layout of manufacturing process flow for switchboard panel

2.1 Current Operational Practices

In normal practices, three employees are assigned to fabricate all components in the fabrication section. Worker A is responsible for stamping and welding operations, while Worker B is for pre-marking and shearing operations, and Worker C is for bending operations. By using the ARENA software, a model for current operational practices was simulated based on five assumptions. Assumption was used to predict the time required to fabricate all the components for 1 unit of sub-box assembly. Assumption 2 and Assumption 3 were used to predict the number of components that can be fabricated for one working day. Meanwhile, Assumption 4 and Assumption 5 were used to predict the number of components that can be completed for a half working day (from 8.30 am to 1 pm), as recorded in Table 1. Based on the result in Table 1, the current operations potentially produces at least three units of WIP (work-in-progress) if Assumption 3 was chosen, and 1 unit of WIP if Assumption 5 was implemented, specifically in the welding area.

Table 1: Results of simulation analysis for current operations

	Assumption	Assumption 1	Assumption 2	Assumption 3	Assumption 4	Assumption 5
	Replication Length	100 minutes	540 minutes	540 minutes	270 minutes	270 minutes
	Input	1	9	10	4	5
	Output	1	9	7	4	4
	WIP	-	-	3(M5)	-	1(M5)
Utilization (Resource) (%)	Worker A	27.63	33.32	20.56	24.21	33.42
	Worker B	27.94	60.52	72.28	61.71	74.51
	Worker C	40.69	23.38	21.13	19.77	22.35
	Bending MC	40.69	23.38	21.13	19.77	22.35
	Shearing MC	13.20	28.31	29.88	24.43	30.89
	Stamping MC	12.59	21.70	17.63	11.75	23.57
	Welding MC	15.04	11.62	2.93	12.46	9.85

Note: WIP = work in progress MC = machine
Break time: Morning: 10:00H – 10:30H (30 Mins); Lunch: 13:00 – 14:00H (60 Mins);
Tea Break: 15:00H – 15:30H (30 mins)

2.2 Alternative Operational Practices

By referring to the CPM analysis, the scheduling technique was engaged to schedule the sequence of serial work processes. In operational management, the most popular approach in scheduling the ***n*** jobs for ***m*** machines was the Johnson's Rule that was introduced in the 1950s [12]. This alternatively provides the opportunity to optimise the sequence of work process to reduce make span (the total amount of time to complete all processes), and balance the utilisation of resources based on flow shop scheduling.

Based on the initial data analysis as recorded in Table 2, the scheduling of ***n*** job for more than 2 machines was unsuitable for implementation. This is based on the findings from initial analysis that showed the data did not meet any of the following rules as a condition that must be met before applying the Johnson's Rule scheduling [13].

$$\text{Rule 1} : \text{Tmin}_{(m1)} \geq \text{Tmax}_{(m\text{-}1)} \tag{1}$$

or

$$\text{Rule 2} : \text{Tmin}_{(m)} \geq \text{Tmax}_{(m\text{-}1)} \tag{2}$$

Therefore, the Johnson's Rule was only used to test the two processes, involving pre-marking and shearing process. By using the Johnson's Rule procedure in scheduling ***n*** jobs for two machines, a new sequence was suggested, namely **G-I-J-K-L-H-M** as depicted in Figure 3.

Based on this alternative, the assignments of employees were rearranged for Worker B, who had the highest utilisation percentage, and Worker C who recorded the lowest utilisation percentage.

According to these new work assignments, Worker B was only responsible for pre-marking operations, and Worker C was responsible for shearing and bending operation. The test result is recorded in Table 3.

Table 2: Time required in fabricate the seven critical component for sub-box assembly

Jobs / Components		Process					Due time
		Pre-Marking (m_1)	Shearing (m_2)	Stamping (m_3)	Bending (m_4)	Welding (m_5)	
G	Wall mounted bracket	121.1	91.7	231.8	-	-	444.6
H	Shield cover support bracket (A&B)	261.7	146.3	90.7	-	-	498.7
I	Neutral link support bracket	155.4	123.5	-	104.7	-	383.6
J	MCB support bracket	155.4	123.5	-	104.7	-	383.6
K	Divider bracket	155.4	123.5	-	104.7	-	383.6
L	MCCB support bracket	155.4	123.5	-	104.7	-	383.6
M	Housing box	157.4	95.3	220.2	306.9	490.3	1270.1

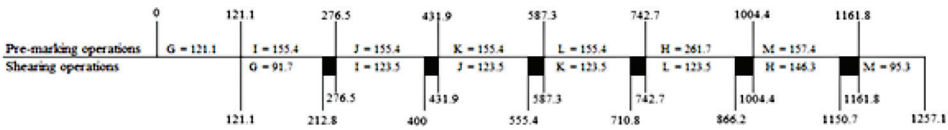

Figure 3: Sequencing for Pre-Marking and Shearing Operation using Johnson's Rule

Table 3: Results of simulation analysis for first alternative
(sequencing using Johnson's Rule)

	Assumption	Assumption 1	Assumption 2	Assumption 3	Assumption 4	Assumption 5
	Replication Length	98 minutes	540 minutes	540 minutes	270 minutes	270 minutes
	Input	1	11	12	5	6
	Output	1	11	11	5	4
	WIP	-	-	1(M5)	-	2(M4)
Utilization (Resource) (%)	Worker A	24.10	38.73	38.63	23.43	33.13
	Worker B	15.42	43.26	52.59	50.32	35.23
	Worker C	59.75	54.80	63.26	57.54	77.36
	Bending MC	46.25	21.41	33.17	32.01	26.00
	Shearing MC	13.50	33.39	30.09	25.54	51.36
	Stamping MC	8.75	26.03	18.76	19.15	21.08
	Welding MC	15.35	12.70	19.86	4.28	12.06

Note: WIP = work in progress MC = machine
Break time: Morning: 10:00H – 10:30H (30 Mins); Lunch: 13:00 – 14:00H (60 Mins);
Tea Break: 15:00H – 15:30H (30 mins)

In comparing the suitable sequence for all processes, scheduling of work processes based on critical ratio (CR) was also considered. This technique was used in setting the priority of processes based on priority index through a simple function of time to complete the job that was close to the deadline [14]. This technique was commonly used in arranging the sequence of work in a job shop-based manufacturing, in which the ideal jobs were assigned to resource at a particular time [15-16]. Referring to the scheduling procedure, the new scheduling sequence based on CR technique was identified as **M-H-I-G-J-K-L.** The simulation result based on CR scheduling technique was recorded in Table 4. The employees assignments in this simulation were maintained as decided in Alternative 1 (based on Johnson's Rule).

Table 4 Results of simulation analysis for second alternative
(sequencing using Critical Ratio technique)

	Assumption	Assumption 1	Assumption 2	Assumption 3	Assumption 4	Assumption 5
	Replication Length	74 minutes	540 minutes	540 minutes	270 minutes	270 minutes
	Input	1	11	12	6	7
	Output	1	11	7	6	4
	WIP	-	-	2(K2), 3(K3)	-	1(J3), 2(K3)
Utilization (Resource) (%)	Worker A	8.89	46.86	61.99	32.12	62.93
	Worker B	44.38	37.52	33.33	53.74	54.21
	Worker C	46.20	63.17	58.75	77.68	60.31
	Bending MC	14.71	31.74	23.23	35.66	23.69
	Shearing MC	31.49	31.43	35.52	42.02	36.62
	Stamping MC	7.51	21.87	25.66	13.61	36.36
	Welding MC	1.38	24.99	36.33	18.52	26.57

Note: WIP = work in progress MC = machine
Break time: Morning: 10:00H – 10:30H (30 Mins); Lunch: 13:00 – 14:00H (60 Mins);
Tea Break: 15:00H – 15:30H (30 mins)

Referring to the simulation results, time required to fabricate a set of components for 1 unit sub-box assembly was 100 minutes (based on current operational practices), 98 minutes (if operate based on Alternative 1), and 74 minutes (if operating based on Alternative 2). The results from the simulation showed that if this firm operates for one full working day and for a period of 540 minutes (9 hours), they will potentially fabricate the components for at least 11 units of sub-box assembly through Alternative 1 and Alternative 2, as compared to only 9 units if operate based on current operational practices. In the meantime, the comparison of simulation results demonstrated that this firm potentially fabricated a maximum of 4 units of sub-box assembly under current operational practices, at least 5 units if implemented under Alternative 1, and a maximum of 6 units through Alternative 2 if operate for half-day of work for a period of 270 minutes or 3 hours (from 8.20 am to 1.00 pm). In fact, the percentage of resource utilisation, in terms of workers and machine, were more balanced through considerations of strategy as proposed in Alternative 1 and Alternative 2 as compared to current operational practice, except for Worker C. However, it varies depending on the period of working hours and the number of work orders. The results showed a similar situation with the study by Ramasesh [16] where the implementation of work scheduling that operated based on job shop process flow had greatly influenced time and resources.

3.0 CONCLUSION

The findings from this case study showed that the LP practices can be implemented in a manufacturing firm that operates based on ETO that corresponds with current operational practices by a case study firms. This showed that the implementation of scheduling techniques provide a valuable approach in increasing value added activities (part of lean techniques that focus on controlling the workflows), and bring a vital impact to the manufacturing firms that operate based on ETO concept with a unique set-up and a specific work sequence to complete each work order. Scheduling techniques are also found to contribute significantly in managing the resources, strategically for operational advantages as suggested by Vlajic et al. [17]. As a result, a better economic performance, i.e. minimise production cost, efficient equipment utilisation, efficient resources utilisation, reduction in processing time and production lead time can be achieved.

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