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The Institution of Engineering Designers

ABOUT THE CONFERENCE

The conference aims to provide a forum for the exchange of ideas on the latest development in the field of industrial engineering and management system among researchers and engineers in universities and industries, and to seek opportunities for collaboration among the participants. The conference is also expected to foster networking, collaboration and joint effort among the participants to advance the theory and practice as well as to identify major trends in Industrial Engineering and Management System. The past APIEMS conferences had been very successful in attracting participants from all over the world.

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Production Systems Design, Planning & Control

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The Effect of Product Structure Complexity and Process Complexity on Optimum Lot Size in Multilevel Product Scheduling

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Abstract - *It is difficult to justify the scheduling result before creating the schedule itself. In the other hand, for practical purposes it is important to make scheduling decision immediately to respond the orders. This research concerns to find a short-cut justification of lot size in order to minimizing makespan for scheduling of multi-level products in job shop environment. It was hypothesized that as the complexity of scheduling problem, the lot size decision is a function of operations complexity. In this research, operation complexity is presented by product structure complexity and process complexity. Number of level, number of part in each level, and total number of part in each product are the parameters representing product structure complexity. Setup time, run time, time variations, number of operation applied on each part, and routing complexity are the parameters corresponding to process complexity. Up to now the research still has not covered yet the evaluation of routing complexity. The analysis was based on a set of hypothetical data, those are limited up to 5 levels of product structure, up to 5 items in each level, up to 21 items in each product, setup time-unit run time ratio up to 10, and number of operations up to 5 for each item. Several lot size decisions are applied in the scheduling of some replicated cases, and the lot size giving the minimum makespan is pointed as optimum lot size. To get a general parameter for lot size, the term "setup time-total run time" ratio (R) was formulated, and optimum lot size is represented by R*. The result showed that number of levels, average number of item in each level, setup time-unit run time ratio, and variation on number of operations are the factors affecting R*, as proved by these respective correlation coefficients: 0.26; -0.21; 0.43; 0.30. The value of most R* (91.09%) is varied from 0.1 to 0.4.*

Keywords: *short-cut justification, lot size, setup time-total run time ratio, product structure complexity, process complexity.*

1. INTRODUCTION

Recent researches about lot size and lot sizing were done related to recent issues such as lean manufacturing, agile manufacturing, and supply chain management. Munson et al (2003), Tang et al (2004), and Jiang et al (2006) are some examples of those. Most of them concerned to cost minimization, as well as the previous researches such as Anwar and Nagi (1997), Lovell (2000), Friend et al (2001), Ghomi and Torabi (2001), Chubanov et al (2006), Marinelli et al (2007), and Liu et al (2008), or mathematical models and approaches such as Ghomi and Torabi (2001), Friend et al (2001), Loparic et al (2003), Tang et al (2004), Guan et al (2006), Beraldi et al (2006), Vyve (2006) Chiu et al (2006), Hwang (2007). However, for practical purposes, it is important to make short-cut justification for immediate lot size decision making, one point-of-view which is still rarely discussed in previous papers. This paper present a study on that aspect, i.e. how to make a short-cut justification of lot size in order to minimizing the total time for scheduling of multi-level products, in make-to-order and job shop environment.

Scheduling problems are NP-hard problems (Pinedo, 2002), especially in job shop environment. It is difficult to justify the scheduling result before creating the schedule itself. In the other hand, it is important to decide scheduling or planning parameters such as lot size as soon as possible to immediately respond to the orders. The main objective of this study is to find a short-cut justification of appropriate lot size decision based on some parameters of product structure complexity and process complexity. The expected result of the study is a general empirical formula to decide

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an optimum lot size, i.e. a lot size giving minimum makespan, to help a production planner deciding the production lot size immediately and simply. This paper presents a particular result of the study.

2. METHOD

A preliminary study showed that the makespan in multilevel product scheduling is affected by several parameters, i.e. product structure complexity (number of levels, number of parts in one level, total number of parts) and process routing complexity (setup time and run time, number of operations, operation sequences). Patria (2006) and Rinawati (2007) had conducted case studies in different manufacturing companies. Their studies had shown that there was a specific lot size resulting minimum makespan in operations scheduling for producing a number of multilevel products.

2.1. Concept and Idea

Based on the preliminary studies, it is hypothesized that:

1. The optimum lot size decision can be affected by the level of product structure, because the higher the level, the operations sequence will be longer, and it means that the variation of operations and operation time may be higher also.
2. The optimum lot size decision can be affected by number of parts in one level, because the possibility of parts to wait one to another for the next operation becomes higher if the number of parts in one level is increase.
3. The optimum lot size decision can be affected by number of parts included in a product, because both reasons mentioned in point 1 and 2 will come together if the number of parts is increase.
4. The optimum lot size decision can be affected by the ratio of setup time to unit run time, because as usually mentioned in many research, higher setup time will lead to larger lot size decision.
5. The optimum lot size decision can be affected by the variation of operation time, both setup time and run time, because the wide variation of time will lead to unbalanced load among the machines.
6. The optimum lot size decision can be affected by number of operations applied for each part, and the impact is similar with the one mentioned in point 1.
7. The optimum lot size decision can be affected by the variation of number of operations applied for each part, because the wide variation of number of operations may lead to unbalanced load among the machines.
8. The optimum lot size decision can be affected by the complexity of operation sequence, because the complex combination of operation sequence will lead to unbalanced load among the machines.
9. The optimum lot size decision can be affected by number of machines used, because the scheduling problem becomes more complicated if the number of machines is more.

The hypothesis leads to the following general empirical formula to make a short-cut justification of lot size decision:

$$L_s^* = f(H, W, N, T_s, t_r, \sigma_s, \sigma_r, P, \sigma_p, S, M) \quad (1)$$

where:

- L_s^* = optimum lot size,
- H = number level of product structure,
- W = maximum number of parts in one level,
- N = total number of parts,
- T_s = average setup time of all operations,
- t_r = average unit run time of all operations,
- σ_s = relative standard deviation of T_s
- σ_r = relative standard deviation of t_r
- P = average number of operations for each part,
- σ_p = relative standard deviation of P
- S = sequence complexity parameter
- M = maximum number of machines used

Lot size decision actually depends on the ratio of setup time and run time, not on the values of the time itself. Several experiments using different values of setup time and run time gave similar optimum lot sizes if the ratios of setup time to run time are similar. An un-dimensional number called setup time-run time ratio then generated as follows:

$$R = \frac{T_s}{L_s . t_r} \quad (2)$$

and a new parameter presented setup time and unit run time is defined as follows:

$$r = \frac{T_s}{t_r} \quad (3)$$

Where:

- R = setup time-run time ratio
- r = setup time-unit run time ratio

The function presented in equation (1) then could be re-formulated as:

$$R^* = f(H, W, N, r, \sigma, P, \sigma_p, S, M) \quad (4)$$

Where:

- R* = optimum setup time-run time ratio
- σ = relative standard deviation of r

2.2. Scope

The scope of this study is shown in Table 1. The study was divided to several sub-studies. Each of those was conducted by different co-researchers who created their own hypothetical cases as presented in each cell of Table 1. The variation of all the parameters resulted by the different cases represents the parameters of the real cases which could not be controlled. By this condition, the final result of this study is expected to be a generic approach for all possible case.

Table 1: Scope of Study

		W				
		1	2	3	4	5
H	2	2;5-7	2;3-5	1;5	1;5	1;5
	3	1;7	3;3	6;5	11;5	18;3
	4	1;7	6;3	18;3	10;4	12;5
	5	1;7	10;3	10;5	20;3	30;3
Note: [number of BOM variation];[number of replications]						

This particular study consider the variation of H, W, N, r, σ, P, and σ_p, but still has not consider yet the variation of S and M.

2.3. Design

Analysis steps for each cell is shown in Figure 1. Different number of BOMs for each cell was generated because each cell has its own characteristic. The higher the H and W, the possible variations of BOM will be larger. Total of 164 BOMs had been generated. The example of generated BOM can be seen in Figure 2.

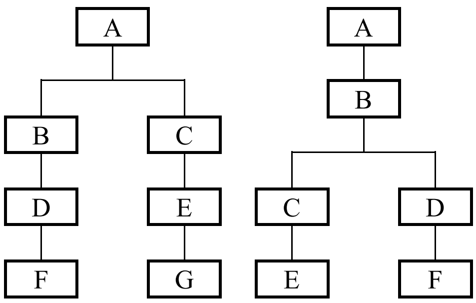

Figure 2: Two Examples of Possible Generated BOM for H = 4 and W = 2

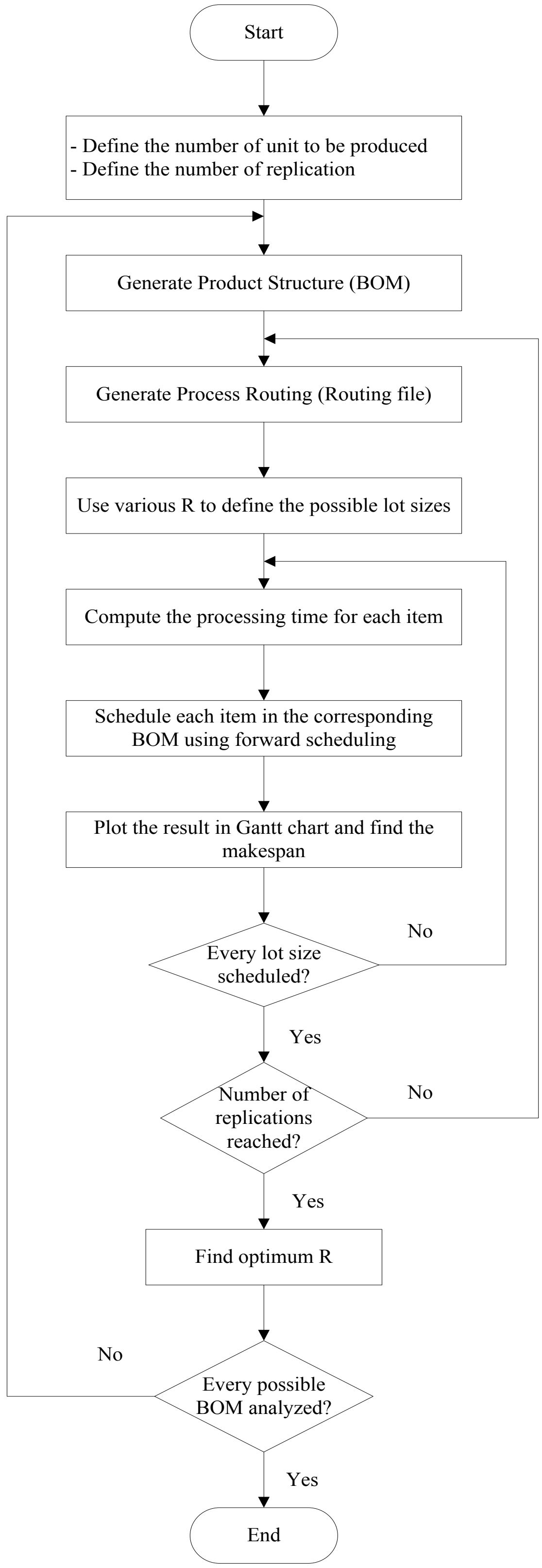

Figure 1: Analysis Steps for Each Cell

The number of machine was limited up to 3 machines and the number of operations applied for each part was limited up to 5 operations. A three to seven replications of routing file were generated for each BOM with the setup time varied between 1 to 10 minutes for each lot and run time varied between 1 to 10 minutes for each unit. The example of generated routing file can be seen in Table 2.

Table 2: Example of Generated Routing File

Item	Machine	Setup time (minutes/lot)	Run time (minutes/unit)
A	Y	7	5
	Z	6	2
	X	9	3
	Y	6	5
	Z	6	1
B	X	6	3
	Y	10	1
	Z	8	1
	X	8	2
	Y	8	3
C	Z	6	5
	Y	10	1
	X	7	2
	Z	9	2
D	X	6	4
	Z	8	3
	Y	7	2
E	X	8	2
	Z	7	3
	X	6	4
	Y	9	1

Using the generated routing files, we use different R to define the various lot sizes possible for each cell. For example, refer to Table 2, the unit to be produced is 30, the average of setup time is 7.476 minutes, and the average of run time is 2.619 minutes. Then the possible lot sizes to be used for specific R are calculated as shown in Table 3. From Table 3, for the 30 units to be produced, we scheduled using 5 lot sizes, 3, 5, 10, 15, and 30.

Table 3: Possible Lot Size for Various R

R	Lot Size	Possible Lot Size
0.1	28.5453	30
0.2	14.2726	15
0.3	9.5151	10
0.4	7.1363	
0.5	5.7090	
0.6	4.7575	5
0.7	4.0779	
0.8	3.5681	
0.9	3.1717	3

The R that yields the minimum makespan is called optimum R or R*. To find the minimum makespan in each BOM and each replication, these following steps are used:

1. Compute the processing time for each item: processing time = setup time (minutes/lot) + run time (minutes/unit) x lot size (unit).
2. Use forward scheduling to schedule each item in the corresponding BOM, starting from the lowest level.
3. Plot the result in Gantt Chart, the example is shown in Figure 3.
4. Find the makespan and identify which lot size that yields minimum makespan.
5. Find the optimum R using equation 2.

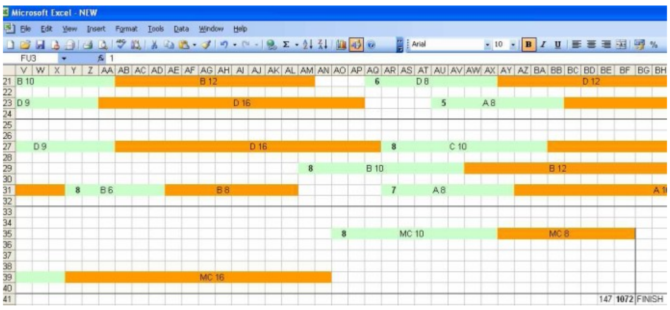

Figure 3: Part of Gantt Chart

As mentioned previously that this study is related with the make-to-order environment, the purpose of deciding the optimum lot size is to achieve the minimum total time to process the orders. That is why one of relevant objective function to be minimized is makespan. Assume that all the ready times are at time zero, makespan is equivalent to the completion time of the last job to leave the system (Pinedo, 2002).

Forward scheduling assumes that procurement of materials and operations start as soon as the requirements are known. The events or operations are scheduled from this requirements point of view (Narasimhan et al., 1995). As well as makespan, the forward scheduling approach is chosen related with the make-to-order environment, in which the goal is how to complete all the operations as soon as possible. However, this study actually do not concern with the scheduling method because as mentioned previously, in the real cases, as well as the parameters, there are many possible method used in practice. The various details in scheduling priority run by the different co-researchers is expected to represented the various methods used in practice.

3. RESULT

The values of R* taken from 606 total replications (164 BOMs with number of replications varies from 3 to 7) is presented in Figure 4. The range of R* is from 0.059 to 0.567. Mostly of R* values (91.09%) is between 0.1 and 0.4.

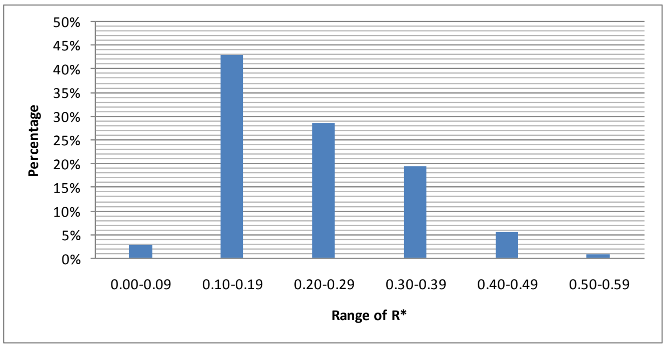

Figure 4: Distribution of R*

To evaluate the effect of H, W, N, r, σ, P, and σ_p on R*, a correlation analysis was done and the result is shown in Table 4.

Table 4: Correlation Between the Factors and R*

Factor	Correlation coefficient to R*
H	0.2569
W	-0.2102
N	0.0451
r	0.4346
σ	0.0963
P	-0.1465
σ_p	0.2958

According to Table 4, there are no strong correlation between R* and all the factors. However, if the correlation coefficient of all the factors with R* is relatively compared, it could be conclude that H, W, r, and σ_p are the factors gave stronger effect on R* as shown by the darkened cells.

The four strongest correlated factors then analyze by scatter diagrams presented in Figure 5, 6, 7, and 8. The diagram shown that, although not really clear, the four factors are affecting the value of R*.

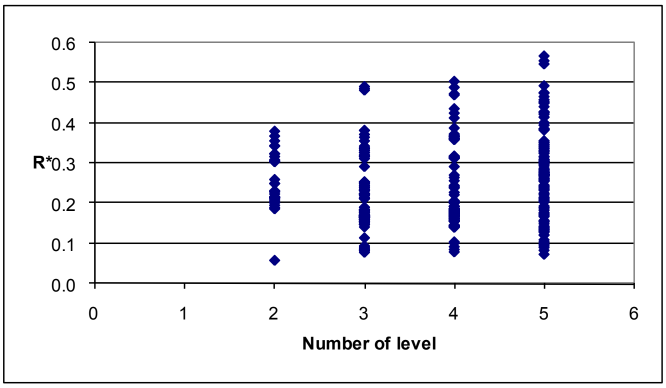

Figure 5: The Effect of H on R*

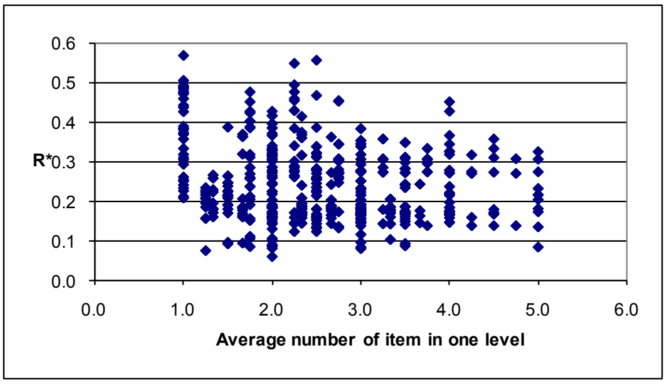

Figure 6: The Effect of W on R*

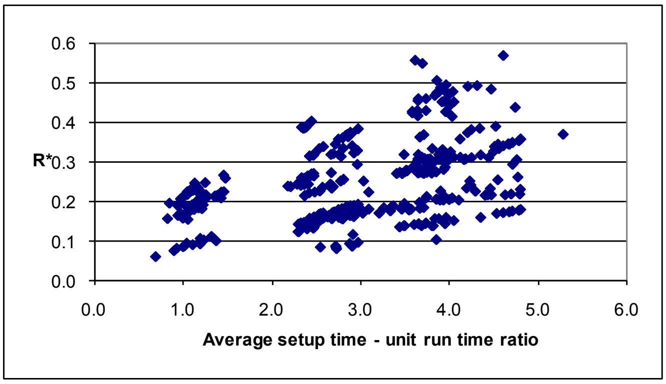

Figure 7: The Effect of r on R*

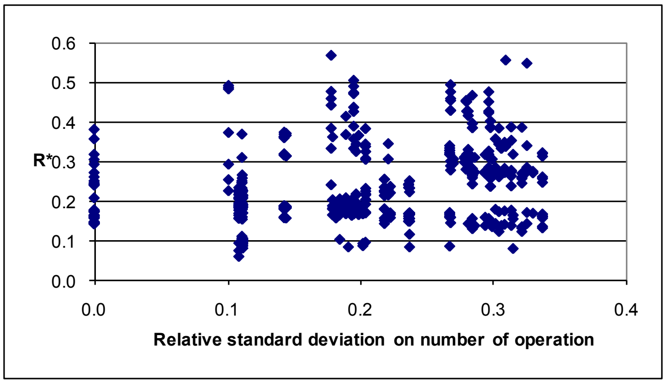

Figure 8: The Effect of σ_p on R*

If a linear regression applied, the following equation presenting R* as the function of H, W, r, and σ_p can be generated.

$$R^* = 0.108 + 0.013H - 0.036W + 0.046r + 0.165\sigma_p \quad (5)$$

Although Equation 5 still has to be observed evaluated further, the result has a close relation with the real case. A research on a garment factory done by Patria (2006) yields 25 as the best lot size between two possible lot size 25 and 50. If the mechanism proposed in this study is applied, the L_s* = 14.0555. It means that the lot size larger than 25 (the minimum possible lot size) is not recommended. The other research on a glove factory done by Rinawati (2007) yields 10 as the best lot size among these possible lot size: 30, 15, 10, 5. The result from this proposed approach is 9.4498. Table 5 shows the summary of these calculations.

Table 5: Application of Proposed Approach on Real Case

Factor	Case of Patria (2006)	Case of Rinawati (2007)
H	6.0769	6
W	3.5385	2
r	5.1205	4.2614
σ_p	0.4360	0.8687
R*	0.3643	0.4510
Ls*	14.0555	9.4498

6. CONCLUSION

The particular study showed that the optimum lot size in scheduling of multilevel product in make-to-order and job shop environment is affected by the number of level in product structure, the average number of part in one level, the setup time-unit runtime ratio, and the variation of number of operations applied on each part. However, further observation and evaluation is still needed to sharpen the final result.

The next study will be done to extend the evaluation of the effect of process complexity on R*.

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