Makara Journal of Technology

Volume 20 | Issue 1 Article 3

4-1-2016

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Recommended Citation

Farizal, Farizal; Rachman, Amar; Tandean, Tifani; Sudarto, Sumarsono; and Takahashi, Katsuhiko (2016) "Multi-Project Scheduling Cost Optimization in a Machine Manufacturer Engineer-to-Order," *Makara Journal of Technology*: Vol. 20: Iss. 1, Article 3.
DOI: 10.7454/mst.v20i1.3050
Available at: https://scholarhub.ui.ac.id/mjt/vol20/iss1/3

Makara J. Technol. 20/1 (2016), 13-18
doi: 10.7454/mst.v20i1.3050

Multi-Project Scheduling Cost Optimization in a Machine Manufacturer Engineer-to-Order

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Abstract

This paper discusses the utilization of mixed integer linear programming (MILP) model to optimize cost for multi-project scheduling in a machine maker company. The objective is to minimize total project's penalty cost and labor cost. The model formulated shows how to achieve the objective i.e. whether to use outsourcing or overtime to finish all projects. The model of multi-project scheduling was solved by Branch & Bound algorithm coded in Lingo 14.0 software. The case study shows that if a company wants to minimize lateness, it should use overtime instead of outsourcing, which minimize total lateness of projects by 144 days or 73.5%. Whereas, if a company wants to optimize cost, they should use outsourcing instead of overtime, which reduces total cost of about 10,873,000 IDR or 28.5%. These results indicate that the model developed is applicable for optimizing multi-project scheduling.

Abstrak

Optimasi Biaya Penjadwalan Multi-Proyek pada Industri Pembuatan Mesin berbasis *Engineer to Order*. Paper ini membahas tentang penggunaan model *mixed integer linear programming* (MILP) untuk mengoptimalkan biaya dari problem penjadwalan multi-proyek pada industri pembuatan mesin. Industri ini dicirikan dengan adanya keterlambatan dalam memenuhi pesanan sehingga menyebabkan adanya biaya pinalti dan tambahan biaya pekerja. Karena itu tujuan dari studi ini adalah meminimalkan kedua biaya tersebut. Model yang dibangun dan dipecahkan dapat menunjukkan bagaimana mencapai tujuan tersebut yaitu melalui *outsourcing* (alih daya) atau melalui lembur. Model penjadwalan multi-proyek ini dipecahkan dengan menggunakan algoritma *Branch & Bound* yang telah di-*coding* dalam *software Lingo* 14,0. Hasil dari studi kasus yang menggunakan model ini menunjukkan jika sebuah perusahaan ingin menekan keterlambatan maka sebaiknya digunakan lembur bukan alih daya. Penggunaan lembur pada studi kasus dapat menekan keterlambatan multi-proyek hingga 144 hari atau 73,5%. Tetapi, jika perusahaan ingin menekan biaya maka alih daya harus digunakan. Dengan jalan ini perusahaan dapat mengurangi biaya sebesar 10.873.000 IDR atau 28,5%. Hasil ini menunjukkan model yang dibangun dapat digunakan sebagai model *generic* pada penjadwalan industry multi-proyek pembuatan mesin.

Keywords: Branch & Bound, outsourcing cost, overtime cost, mixed integer linear programming, multi-project scheduling, penalty cost

1. Introduction

Machine manufacturer is classified as Engineer-to-Order (ETO) company based on manufacturing type. ETO or project based manufacturer is usually called "custom" manufacturer. This term refers to manufacturers that produce products that are unique and often complex because they are designed to follow specifications from customers and may require unique engineering design or significant customization. As a result, each customer's order will have a unique set of item numbers, material requirements, and different activities. Table 1 shows some differences in the characteristics of ETO manufacturing compared with Make-to-Stock (MTS).

Due to the different nature of ETO manufacturer, it uses project management for the planning approach [2]. Various orders in ETO companies are seen as a number of projects running simultaneously. Problems that often occur in ETO companies are delay in the completion of the project. It has been found that less than 10% of engineering projects finished on time, and over half took twice as long as the original schedule [3]. This symptom also occurs in a machine manufacturer, and it is described in Table 2.

Table 2 shows that the percentage of late projects is more than 50%. Delay in completion of projects which deviates from target will affect on-time delivery (OTD) for customer. When there is delay in project completion, and it exceeds the deadline agreed, late penalty fee is be charged by customer. This cost is unnecessary loss for the company.

Delay always exists because each project is uncertain and variations will undoubtedly occur [4]. Manufacturing process of a production ETO company, which is viewed as project-based manufacturing, also has uncertain duration [5]. Indeed, variations always occur in the system, but they can be overcome by scheduling and control [4].

Companies often face problems of project delays because they are working on several projects at once (multi-project). Scheduling and resource allocation for multi-project companies are more difficult than a single project. Computation time increase quite significantly in a multi-project scheduling or when there is a big scheduling problem. In common practice where project scheduling exists, some occurring problems include limited resources and multiple active projects at the same time. Therefore, multi-project scheduling has the potential to be optimized.

Regarding the problems described, there are some studies that have tried to optimize multi-project scheduling with different methods and objectives. A study by [6] optimized scheduling to minimize delays with heuristic priority rules method. However, rules of priority will obtain not necessarily optimal result.

Other studies also optimized scheduling with the objective to minimize makespan and delay, which uses meta-heuristic method of Ant Colony Algorithm [7] or by creating their own heuristic method [8]. The use of meta-heuristic method was expected to obtain optimal scheduling approach with shorter time. But to use a meta-heuristic method, companies must invest in the creation of a network model, which is required to apply meta-heuristics method [6]. Therefore, the method is not applicable to most companies that deal with complex multi-project. Moreover, meta-heuristic method does not guarantee that the results obtained are the most optimal.

Other studies by [9] did scheduling optimization with different objectives, which was to minimize completion time of all projects and the cost of outsourcing. It means companies need to minimize the completion time of the project at the lowest cost of outsourcing using a created heuristic algorithm.

By reviewing and comparing some literatures, it was found that there is a lack of research on the loss of company in scheduling, especially at the cost of lateness penalty fee and labor cost (outsourcing or overtime cost). When a company is overloaded with projects, the company usually uses overtime or outsourcing to finish it. By using overtime, the company must pay employees overtime cost, which is higher than standard salary during regular working hours.

With outsourcing, the company must pay outsourced employees fee which is higher than company’s employees fee. Therefore, the company needs to decide on an option, whether to use overtime or outsourcing or just let projects delay, which can save the cost of company. The goal is to minimize the losses suffered by the company.

Table 1. Differences of Make-to-Stock and Engineer-to-Order [1]

MST	ETO
Standard Products	Unique Products
Flat Bills of Material	Deep and Unique Bills of Material
Product Lead Times in Days/Weeks	Product Lead Times in Weeks/Months/Years
Focus on Material Planning	Focus on Production Scheduling
Plan with Master Schedule	Plan with Project Management

Table 2. Project Lateness in an ETO Manufacturer

Year 2013	Number of projects	On Time Delivery	Late Delivery	Late Projects Percentage
Jan-Mar	20	9	11	55%
Apr-Jun	15	5	10	67%
Jul-Sept	25	4	21	84%
Oct-Dec	14	2	12	85%

In short, cost optimization scheduling model is needed to minimize company cost, both lateness penalty cost and total cost of using overtime or outsourced employees.

Engineer-to-Order (ETO). Engineer-to-Order (ETO) is one of manufacturer types to produce goods. ETO company produces high customization of products which need to be designed and made in detail as per the specifications of customer orders. Therefore, the production process lead time is relatively longer than other manufacturing type such as Make-to-Stock, Assemble-to-Order, and Make-to-Order.

Multi-project scheduling. Scheduling is one of the steps in project management. Project scheduling is the process of allocating available resources to the project activity to determine the start and finish of each activity [10].

Project scheduling in literature mostly concentrates on making the sequence of activities and schedules that optimize resource scheduling and most often to minimize the duration of the project. The optimized schedule should serve as a basic schedule for implementing the project [11]. Initial schedule has important roles in a project. The first role is to allocate resources to activities that exist in the project. The second is as a basis for the planning of external activities such as procurement of materials, preventive maintenance and delivery of goods to external or internal customers. Initial schedule serves as a basis for communication and coordination with external parties in the supply chain stakeholder. Based on the initial schedule, the committed delivery date of material is asked to subcontractors and the due date is set for the project.

From the viewpoint of modeling, many scheduling problems in real life, such as lecture scheduling, sport scheduling, train and flight scheduling, can be modeled as a variation of project scheduling problem with limited resources. In limited resources condition, carrying out activities based on the basic schedule is a necessity, even though sometimes activities will possibly deviate from the schedule.

During project implementation, however, uncertainties of project activities can lead to schedule delay. This uncertainty may be derived from a number of causes such as activity may take more or less time than expected, the resources may be unavailable, the materials may arrive behind schedule, due dates may be changed, a new activity should be added or discarded because of changes in the scope of project, weather conditions, etc. Disturbed schedule can cause higher company's costs due to lateness penalty fee incurred, human resources were idle, high inventory work in process and system's nervousness happens in frequent rescheduling.

Managing multiple projects simultaneously is quite common in modern industry. Some projects are processed in parallel and use limited resources. Multi-project scheduling doing general assignment of resources to activities from time to time. Most projects in the industry have limited resources. If they have multiple projects and each project has a priority level, it makes the problem becomes complex. This problem should be solved by considering a few things to get near-optimal result [10].

One method to find the optimal solution of scheduling problems is named mathematical programming [12]. To use a mathematical approach, the existing problems will be modeled in a mathematical model. The created mathematical model will be solved using exact or non-exact method. Mathematical programming can be considered as a linear programming (LP) in general.

Sequence based mixed integer linear programming for scheduling. Based on two studies that have been conducted by [13] and [8] about mathematical modelling for sequential scheduling, the model of mixed-integer linear programming (MILP) is compiled as follows:

Definition:

i = subscript for job, i = 1, 2, ..., I;
j = subscript for operation , j = 1, 2,.., N;
k = subscript for work stations in each operation, k = 1, 2, ..,K;
$C_{i,j}$ = Completion time of job i operation j.
$Y_{i,j,k}$ = 1 if job i operation j is done i workstation k; 0 otherwise.
$Z_{i,r,j}$ = 1 if job i was processed before job r at operation j; 0 otherwise.
$W_{i,j}$ = processing time of job i at operation j.
M = A large positive number

Constraints:

$$\sum_{k=1}^{K} Y_{i,j,k} = 1 \forall i, j \quad (1)$$

$$C_{i,j} \geq C_{i,j-1} + \sum_{k=1}^{K} Y_{i,j,k} * W_{i,j} \forall i, j \quad (2)$$

$$C_{r,j} \geq C_{i,j} + W_{r,j} + M\left[3 - Y_{i,j,k} - Y_{r,j,k} - Z_{i,r,j}\right] \forall i, r, j, k \text{ dan } i \neq r \quad (3)$$

$$C_{i,j} \geq C_{r,j} + W_{i,j} + M\left[Z_{i,r,j} + 2 - Y_{i,j,k} - Y_{r,j,k}\right] \forall i, r, j, k \text{ dan } i \neq r \quad (4)$$

$$C_{i,j} \geq 0 \quad (5)$$

$$Y_{i,j,k}, Z_{i,r,j} \in \{0,1\} \quad (6)$$

Equation (1) makes sure that all job i operation j can be processed in any work station k but limited to only one work station. This equation is also called mutually exclusive constraint: one decision must be chosen from a number of K. Equation (2) makes sure it is not allowed to do the job on the next stage of the operation (j) if it has not completed the previous operation (j-1). This equation is called a precedence constraint. Equation (3) and (4),called either or constraint, are to ensure that a job i and r can not be processed simultaneously for each stage of the operation. The second thing is also to comply with the requirements of work order in each operation. For this constraint, only one equation is active. Equation (5) ensures that the completion time of each job i, operation j must be positive numbers. Equation (6) ensure that both variables are binary 0 or 1.

2. Methods

Mathematical modelling for outsourcing. Based on the problem setting and data, mathematical modelling for outsourcing can be described as follow:

Definition:

i = subscript for project number, i = 1, 2,..... , I ; I = number of projects

j = subscript for activity number, j = 1, 2,...., N; N = number of activities

k = subscript for workstation number in each activity, k= 1, 2, ... , K; K = number of workstations

Variable:

$C_{i,j}$ = Completion time of project i activity j.

E_i = earliness of project i

L_i = lateness of project i

M = A large positive number

$Y_{i,j,k}$ = 1 if project i activity j is done in workstation k; 0 otherwise.

$Z_{i,r,j}$ = 1 if project i was processed before project r at activity j; 0 otherwise.

Parameter:

$W_{i,j}$= processing time of project i activity (day)

D_i = due date project i (day)

P_i = penalty fee per day of project i (IDR)

O_{jk} = outsourcing fee per day per one additional workstation of activity j (IDR)

Objective function:

$$Min\, z = \sum_{i=1}^{14} P_i * L_i + \sum_{i=1}^{14}\sum_{j=1}^{11}\sum_{k=1}^{6} Y_{i,j,k} * O_{j,k} * W_{i,j}$$

Constraints:

1) $Y_{i,j,1} = 1 \forall i, j = 1$

$$\sum_{k=1}^{6} Y_{i,j,k} = 1\ \forall i, j \geq 2$$

2) $C_{i,1} \geq \sum_{k=1}^{K} Y_{i,1,k} W_{i,j} \forall i$ dan $j = 1$

3) $C_{i,j} - C_{i,j-1} \geq \sum_{k=1}^{K} Y_{i,1,k} W_{i,j} \forall i$ dan $j \geq 2$

4) $M\left[3 - Y_{i,j,k} - Y_{r,j,k} - Z_{i,r,j}\right] + C_{r,j} - C_{i,j} \geq W_{r,j}\ \forall i,r,j,k\ \ dan\ \ i \neq r$

$$M\left[2 - Y_{i,j,k} - Y_{r,j,k} + Z_{i,r,j}\right] + C_{i,j} - C_{r,j} \geq W_{i,j}\ \forall i,r,j,k\ \ dan\ \ i \neq r$$

5) $C_{i,11} + E_i - L_i = D_i \forall i$

Mathematical modelling for overtime. Mathematical modelling for overtime scenario is similar to outsourcing. The difference is only the elimination of the outsourcing factor in the objective. Besides that, the limit number of work station in each activity phase is also modeled in constraint 1.

Objective function:

$$Min\, z = \sum_{i=1}^{14} P_i * L_i$$

Constraints:

1) $Y_{i,j,1} = 1 \forall i, j = 1{,}9{,}10{,}11$

$$\sum_{k=1}^{Z} Y_{i,j,k} = 1\ \forall i,\ j = 3{,}6{,}7$$

$$\sum_{k=1}^{4} Y_{i,j,k} = 1 \text{ untuk } j = 5\ \forall i$$

$$\sum_{k=1}^{3} Y_{i,j,k} = 1 \text{ untuk } j = 8\ \forall i$$

$$\sum_{k=1}^{6} Y_{i,j,k} = 1 \text{ untuk } j = 2{,}4\ \forall i$$

2) $C_{i,1} \geq \sum_{k=1}^{K} Y_{i,1,k} W_{i,j} \forall i$ dan $j = 1$

$$C_{i,1} - C_{i,j-1} \geq \sum_{k-1}^{K} Y_{i,j,k} W_{i,j} \forall i \text{ dan } j \geq 2$$

3) $M\left[3 - Y_{i,j,k} - Y_{r,j,k} - Z_{i,r,j}\right] + C_{r,j} - C_{i,j} \geq W_{r,j}\ \forall i,r,j,k\ \ dan\ \ i \neq r$

$$M\left[2 - Y_{i,j,k} - Y_{r,j,k} + Z_{i,r,j}\right] + C_{i,j} - C_{r,j} \geq W_{i,j}\ \forall i,r,j,k\ \ dan\ \ i \neq r$$

4) $C_{i,11} + E_i - L_i = D_i \forall i$

3. Result and Discussion

Each project received passes through 11 (eleven) phases of activity and each activity has a number of different work stations as illustrated in Figure 1.

Optimization Result and Analysis. Based on the result given, there are two points that can be analyzed. First is to compare results before and after the optimization with overtime and outsourcing option, and second is to create sensitivity analysis of the model.

From Table 3, it can be seen clearly that optimization model with outsourcing can reduce lateness by 51 days (26% of 196 days total project delay) and reduce cost by IDR 10,873,000 or 28.5% of total cost IDR 38.14 million. On the other hand, optimization model with overtime can reduce lateness by 144 days (73.5% of 196 days total project delay) and reduce cost by IDR 3,205,500 or 8.4% from IDR 38.14 million.

If it needs to reduce lateness, then optimization with overtime gives less lateness than with outsourcing. In contrast, when viewed from total cost, optimization with outsourcing has more minimum cost than with overtime.

4. Conclusion

This paper has created a multi-project scheduling model that can minimize the total cost of lateness penalty fee and employee fee, either with outsourcing or overtime. If lateness is needed to be minimized, then it should use overtime rather than outsourcing, which the numerical example shows to improve lateness by 144 days. In contrast, when concerning total cost, outsourcing would be better than overtime, which reduces total cost by IDR 10,873,000. The results of sensitivity analysis of the model obtained can be described as follows: a) When lateness penalty fee increases, the cost of outsourcing increases; on the other hand, lateness declines as the penalty increases 20%; b) When lateness is lowered, the penalty fee reduces, while the cost of outsourcing increases significantly. As a result, lowering lateness increases total cost.

This research can be further developed in the future for improvement. Some areas of improvement that can be made are followed: a) Expansion of the problem by considering multi-objective optimization model; b) Developing the scheduling problem that more similar to multi-project conditions such as nondeterministic processing time (stochastic), combining outsourcing and overtime in one optimization model; c) Using metaheuristic algorithms that may get nearly optimal result with more time efficiency.

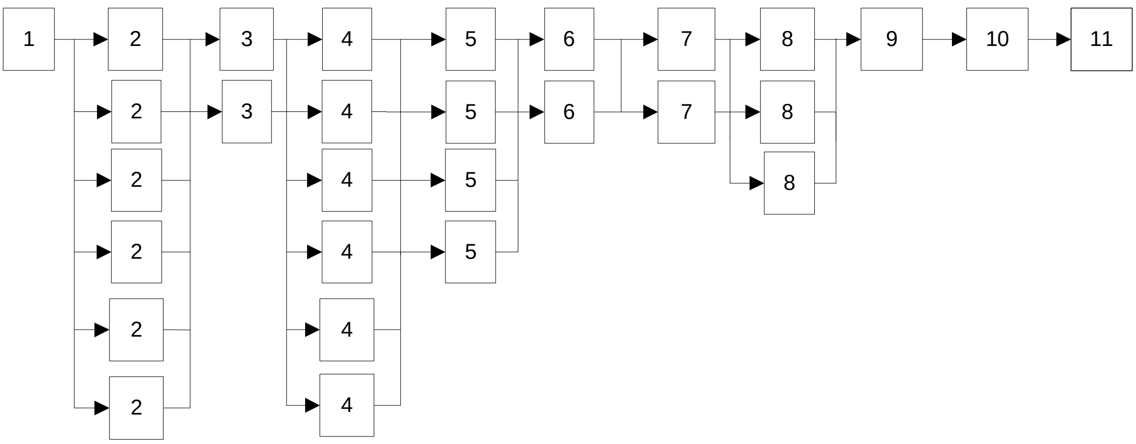

Figure 1. Project Activity Route

Table 3. Comparison Lateness and Total Cost Before and After Optimization

Comparison	Before Optimization	Result After Optimization		Improvement thru Optimasi	
		With Outsourcing	With Overtime	With Outsourcing	With Overtime
Lateness (days)	196	145	52	51	144
Total Cost (IDR)	38,140,000	27,267,000	34,934,500	10,873,000	3,205,500

References

[1] Brian & Watson Associates, *http://www.bwatson associates.com/man.overview.php*, 2013.

[2] Pennsylvania Project Management Institute, Inc. A Guide to The Project Management Body of Knowledge. Project Management Institute, Inc. 2013.

[3] S. Dalgleish, Understanding Why Project Schedules Always Slip and Go Late. *http://www.90percentdone.com*, 2011.

[4] P. Schneider-Kamp, An Analysis of Critical Chain Concepts in the Context of Their Possible Application to Traditional Project Management. Electronic Theses and Dissertations, 2002.

[5] C. Earl, D.P. Song, C. Hicks, in: G. Gogu, D. Coutellier, P. Chedmail, P. Ray, (Eds.), Recent Advances in Integrated Design and Manufacturing in Mechanical Engineering. Kluwer, Netherlands, 2003, p.463.

[6] T.R. Browning, A.A. Yassine, Int. J. Prod. Econ. 126/2 (2010) 212.

[7] B. Skolud, B. Marcinczyck, J. Mach. Eng. 12/3 (2012) 80.

[8] I. Mahdavi, V. Zarezadeh, P. Shahnazari-Shahrezaei, J. Ind. Eng. Int. 7/13 (2011) 74.

[9] H. Mokhtari, I.N.K. Abadi, Computers & Operations Res. 40 (2013) 234.

[10] A. Singh, Proceeding of the 24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013.

[11] W. Herroelen, R. Leus, Eur. J. Oper. Res. 165 (2005) 289.

[12] J. Meredith, S.Jr. Mantel, Project Management: A Managerial Approach, 7th John Wiley & Son Edition. United States, 2009, p.600.

[13] V. Roshanaei, Ph.D Thesis, University of Windsor, Canada, 2012, p.157.