Orders Acceptance Model for Practical Purpose in Make-to-Order Manufacturing

Muhammad Akbar, Diandra Ayasa Anandipa, and Anas Ma'ruf

***Abstract*—Order acceptance in make-to-order industry is critical because the high variety among orders. Decision whether to accept or reject an order depend on several factors such as resources capacity and potential profit of each order. In this research, a heuristic order acceptance model has been developed to support quick decision making for order acceptance. The heuristic approach is conducted due to unreasonable computation time of analytical approach. Numerical example is elaborated in the paper for a case study at a make-to-order industry manufacturing mold and dies. The proposed model results in a reasonable computational time while having a near optimum solution.**

***Index Terms*—Order acceptance, make-to-order, order selection, production capacity.**

I. Introduction

Make-to-Order (MTO) manufacturers have a basic problem which is challenged by the high variety of orders. When a customer request an inquiry, manufacturer will respond by a quotation consisting: order completion time and order cost. Completion time and cost will be negotiated by both parties and finally be analyzed for order acceptance. If the lateness has a positive value or the profit has a negative value, manufacturer will reject the order.

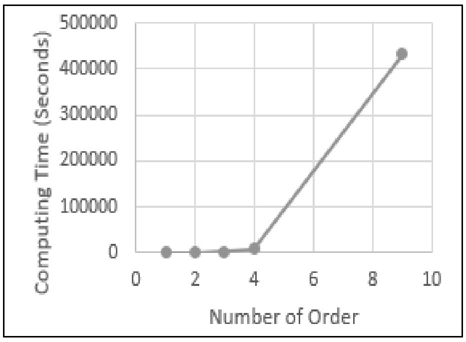
Evaluation of lateness of an order is based on capacity planning. Capacity planning could be conducted by using analytic model or heuristic model. Lewis and Slotnick presented a profitability model of job selection decisions over a number of periods when current orders exceed capacity with the objective of maximizing profit [1]. An optimal dynamic programming approach is proposed in this model. Reference [2] presented a model to examine order acceptance decision when capacity is limited, customer receive discount for late delivery, but early delivery is neither penalized nor rewarded. An optimal branch-and-bound procedure is implemented in this approach. Another research developed a mathematical model to select a set of potential customer orders to maximize the operational profit such that all the selected orders are fulfilled by their due date, as in [3]. Ron developed a heuristic model to solve the order-acceptance problem with tardiness penalties [4]. The heuristic model proposed a genetic algorithm to solve the problem. Maestry presented a Mixed-Integer Linear Program (MILP) to decide which orders to accept and how to allocate resources such that the overall profit is maximized [5]. To solve the MILP effectively, the model use a branch-and-price (B & P) algorithm. For further discussion, this model will be referred as Maestry model.

Preliminary experiments of Maestry model has been conducted for 9 orders having 5 processes with production capacity of 5 days per period and 2 shift per day. Table I depicts the computational time of Maestry model. It took about 5 computational days for processing 9 orders.

TABLE I: Computational Time of Maestry Model

Number of Order	Computing Time (Seconds)
1	0
2	12
3	2460
4	9000
9	432000

GRAPHICAL RESULT



This research has been initiated as a case study at a MTO industry manufacturing mold and dies for automotive industry. Variety of mold and dies ranges from 5-10 units per week while order respond should be conducted less than 2 days. The objective of this research is to propose a heuristic algorithm for order acceptance in MTO manufacturing. A reasonable computational time is expected for practical implementation, while maintaining near optimal solution.

II. Maestry Model

The heuristic model proposed in this research is developed based on Maestry model. The model is used for further

Manuscript received June 10, 2013; revised September 3, 2013.

Muhammad Akbar is with the Department of Industrial Enginnering and Management of Institut Teknologi Bandung, Indonesia (e-mail: muhammad.akbar.abay@gmail.com).

Diandra Ayasa Anandipa is with the PT Astra Internasional Tbk. (e-mail: diandra_anandipa@yahoo.com).

Anas Ma'ruf is with the Department of Industrial Enginnering of Institut Teknologi Bandung, Indonesia (email: maruf@ti.itb.ac.id).

DOI: 10.7763/IJIMT.2013.V4.466

development because the model fit to the case study being researched. The mathematic model of order acceptance proposed by Maestry is as follow:

Set

Resource, $\{r \in R\}$;

Time period, $\{t \in T\}$;

Work shift, $s \in S = \{1 - \mathrm{Re}\,gular; 2 - Overtime\}$;

Customer Order, $\{j \in J\}$;

Operation, $\{o \in O\}$;

Parameter

l_{ts}, length of each shift.

b_{rts}, capacity of a resource *r* at shift *s* in the period time *t*

P_{jor}, processing time of operation *o* of job *j* on the resource *r*

d_j, due date of job *j*

q_j, price of job *j*

c_{rs}, operating cost of resource *r* at shift *s*.

Decision variables

X_{jorts} = Number of hours allocated to operation *o* of job *j* on resource *r* at shift *s* in period time *t*.

$$Y_{jorts} = \begin{cases} 1, \text{if job } x_{\text{jorts}} > 0 \text{ chosen} \\ 0, \text{otherwise} \end{cases}$$

$$U_j = \begin{cases} 1, \text{if job } j \text{ chosen} \\ 0, \text{otherwise} \end{cases}$$

Model Formulation

$$Maximize\ Z = \sum_{j \in J} q_j U_j - \sum_{j \in J} \sum_{0 \in O_j} \sum_{r \in R} \sum_{t \in T} \sum_{s \in S} c_{rs} X_{jorts} \quad (1)$$

s/t

$$\sum_{j \in J} \sum_{o \in O_j} X_{jorts} \le b_{rts} \qquad \forall r \in R, t \in T, s \in S \quad (2)$$

$$\sum_{s \in S} \sum_{t \in T} X_{jorts} = p_{jor} U_j \qquad \forall r \in R, o \in O, j \in J \quad (3)$$

$$\sum_{s \in S} \sum_{t \in T} X_{jorts} \le l_{ts} \qquad \forall j \in J, t \in T, s \in S \quad (4)$$

$$X_{jorts} \ge \tau Y_{jorts} \qquad \forall j \in J, o \in O_j, r \in R, t \in T, s \in S \quad (5)$$

$$X_{jorts} \ge P_{jor} Y_{jorts} \quad \forall j \in J, o \in O_j, r \in R, t \in T, s \in S \quad (6)$$

$$\sum t Y_{j|o_j|rts} \le d_j U_j \qquad \forall j \in J, t \in T, s \in S \quad (7)$$

$$\sum_{s \in S} \sum_{t'-1}^{t-1} X_{j(o-1)rt's'} + \sum_{s'=1}^{s} X_{j(o-1)rts'} \ge P_{j(o-1)r} \sum_{r' \in R} Y_{jor'ts}$$

$$\forall j \in J, o \in O_j \setminus \{1\}, r \in R, t \in T, s \in S \setminus \{|S|\} \quad (8)$$

$$\sum_{s \in S} \sum_{t'-1}^{t-1} X_{j(o-1)rt's'} \ge P_{j(o-1)r} \sum_{r' \in R} Y_{jor'|S|t}$$

$$\forall j \in J, o \in O_j \setminus \{1\}, r \in R \quad (9)$$

$$X_{jorts} \ge 0 \qquad \forall j \in J, o \in O_j, r \in R, t \in T, s \in S \quad (10)$$

$$Y_{jorts} \in \{0,1\} \qquad \forall j \in J, o \in O_j, r \in R, t \in T, s \in S \quad (11)$$

$$U_j \in \{0,1\} \qquad \forall j \in J \quad (12)$$

Objective function in equation (1) is to maximize total profit during the planning horizon. Total profit is the difference between total revenue and total production cost. Equation (2) ensures the capacity allocated on resource *r* at shift *s* in time period *t* does not exceed the available capacity. Equation (3) ensures all allocated operation time are equal to the processing time. Equation (4) ensures each operation in each shift does not exceed the length of shift (l_{ts}). Equation (5) and (6) ensure the binary value of $Y_{jorts.}$ Equation (7) ensures all orders selected will be finished before its due date. Equation (8)-(9) ensures operation *o* of job *j* could be started in time period of *t* at the regular/overtime shift only after preceding operation has been accomplished. Equation (10)-(12) are non-negative constraints.

III. The Proposed Heuristic Model

Based on Maestry model, it could be extracted that there are two types of data being processed. First type of data is data related to manufacturing capacity and second type of data is related to customer order. Manufacturing capacity related data are number of machine (unit), machine operation cost (rupiahs per hour), length of shift (hours), and machines capacity (hours). Meanwhile customer order related data are cost of order (rupiahs), due date, and operation routing of the order. Fig. 1 depicts the proposed heuristic model. The model is based on priority logic where profitable orders are to be scheduled as much as possible during regular shift and allocate least profitable order during overtime. The proposed model consists of 7 steps as follow:

Step 1–Compute profit of each order at regular shift. Assume that all order could be finish at regular shift. Each job profit is computed by reducing each total operating cost from order cost as in the equation (13).

$$q_j - \sum_{o \in O_j} \sum_{r \in R} P_{jor} \times C_{r1} \qquad \forall j \in J \quad (13)$$

Step 2–Eliminate non-profitable jobs. Eliminate jobs having negative profit. Otherwise, set *N* equal to the number of profitable job.

Step 3–Sequence jobs from the highest profit to the lowest. Sequence the jobs from a highest profit to the lowest profit. Set $N^* = 1$.

Step 4–Check finish time of job *N.** If N* > N, then stop. Else, compute the total operation time of job *N** based on the job routing using equation (14).

$$\sum_{o \in O_j} \sum_{r \in R} P_{jor} \qquad \forall j \in J \quad (14)$$

If the total time exceeds the due date, reject job *N**. Set $N^* = N^* + 1$, go to step 4. Else, go to step 5.

Step 5–Allocate all operation of job *N to regular shift.** Job *N** is scheduled to regular shift using forward scheduling from the earliest start time while considering precedence constraint of job *N**. If all operation of job *N** has been allocated to regular shift, go to step 7. Otherwise, for unallocated operation of job *N**, go to step 6.

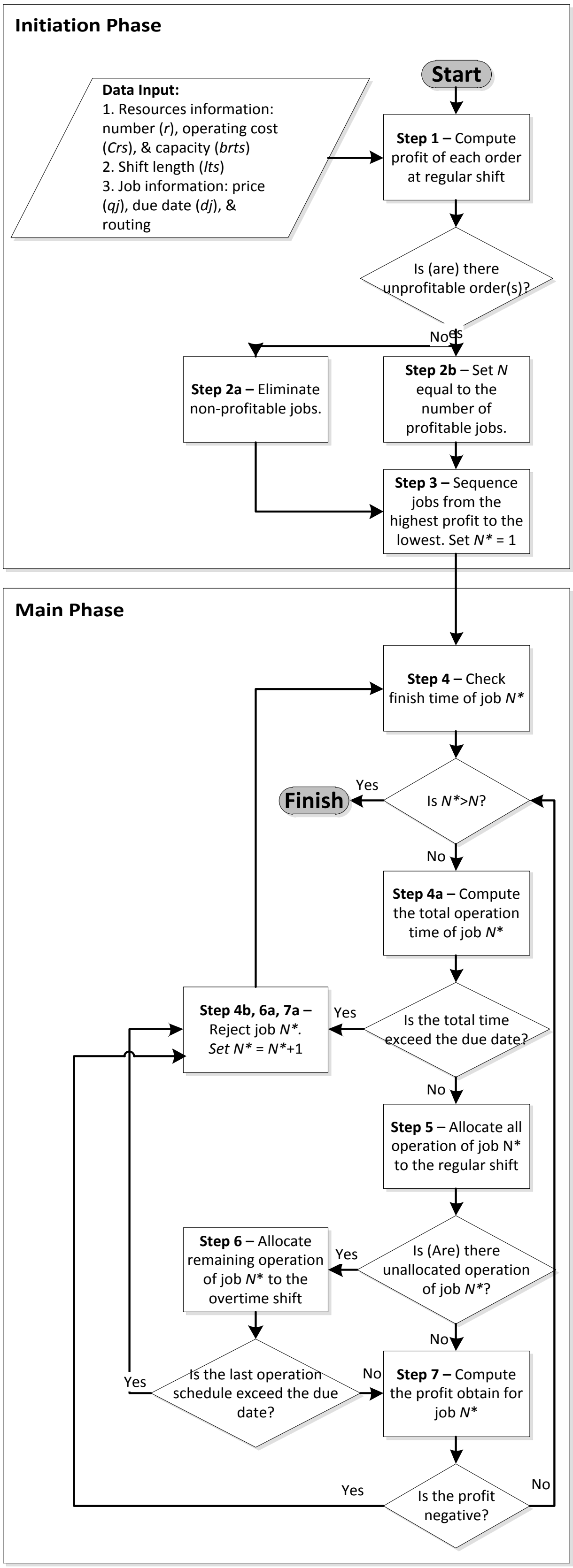


Fig. 1. The proposed heuristic algorithm.

Step 6–Allocate remaining operation of job N^* **to overtime shift.** Allocate operation of job N^* using a semi active schedule. To perform the allocating process, an algorithm of left-shift is implemented as shown in Figure 2.

If the last operations of job N* exceed due date, then reject order N*; Set $N^* = N^*+1$ and go to step 4. Otherwise, go to step 7.

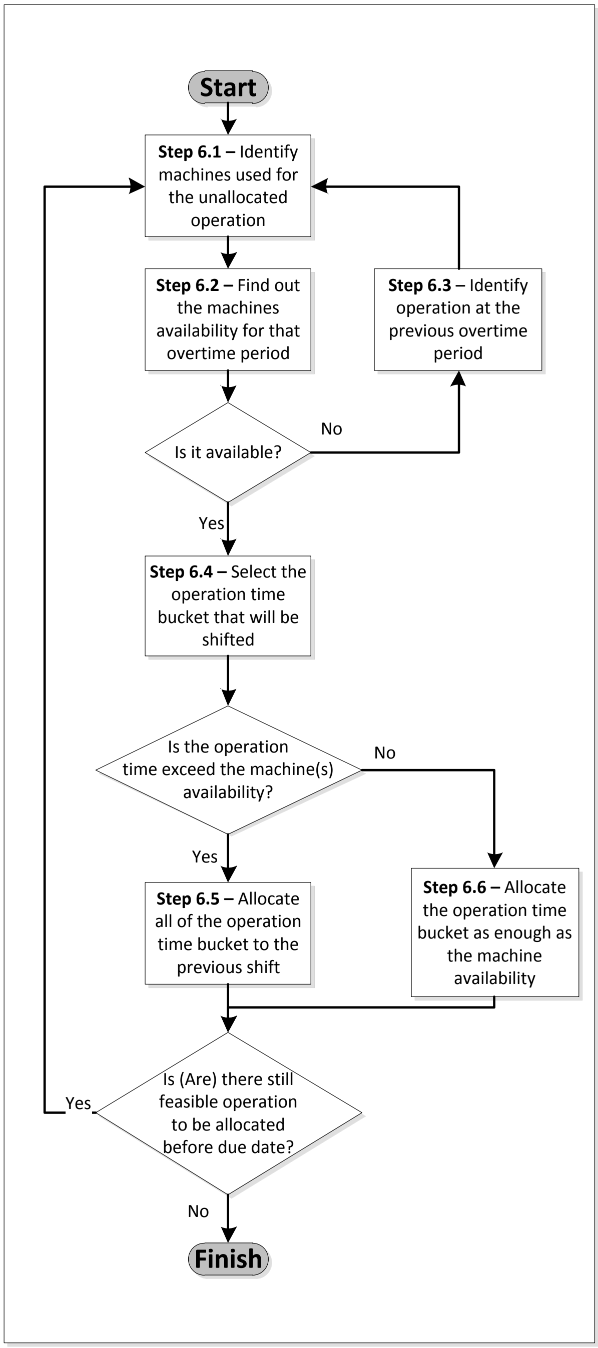


Fig. 2. Left-shift procedure algorithm.

Step 7–Compute the profit obtain for job N^***.** Calculate profit by equation (15). If negative profit is obtained, then reject job N^*. Set $N^* = N^*+1$ and go to step 4.

$$q_j - \sum_{o \in O_j} \sum_{r \in R} P_{jor} \times C_{rs} \qquad \forall j \in J \tag{15}$$

IV. Numerical Example

A case study for order acceptance at a MTO industry for manufacturing mold and dies has been conducted to analyze the performance of the proposed model. Data used in this example are collected at the last week on February 2013.

Capacity information include machine types, machines operation cost (rupiahs per hour), and machine capacity (hours/day) is shown in Table Ⅱ. Regular time is 16 hours per day and overtime is 4 hours per day. Each machine has a full capacity equal to the total shift time which is 20 hours per day per machine. Actual capacity is calculated based on the remaining capacity after subtracting workload currently in process from previous planning period. Table III depicts the current workload for each machine.

TABLE II: MACHINE CAPACITY AND OPERATION COST

ID	Machine Type	Potential Capacity (Hours/day)		Operation Cost (Rupiahs/hour)	
		Regular Shift	Overtime Shift	Regular Shift	Overtime Shift
1	Milling machine	64	16	35000	43750
2	Surface grinding	16	4	25000	31250
3	Turning	16	4	30000	37500
4	Band saw	16	4	120000	150000
5	Bench work	16	4	15000	18750
6	CNC milling	16	4	180000	225000
7	CNC turning	16	4	100000	125000
8	Laser Cut	16	4	80000	100000
9	Wire Cut	16	4	267300	334125
10	Teflon Coated	16	4	300000	375000
11	Welding	16	4	5000	6250
12	Hobbing	16	4	40000	50000
13	Surface Treatment	16	4	30000	37500
14	Cyclical Grind	16	4	75000	93750
15	Heat Treatment	16	4	100000	125000
16	Engineering	16	4	50000	62500

TABLE III: ACTUAL WORKLOAD FROM PREVIOUS PERIOD

Machine	Actual machine capacity (Hours)				
	Day-1	Day-2	Day-3	Day-4	Day-5
Milling machine	16	36	38	51	24
Surface grinding	0	0	0	1	0
Turning	11	16	8	11	0
Band saw	0	1	0	0	0
Bench work	16	16	8	8	5

Order related data such as job quotation, due date, routing, and operation time are shown in Table IV.

TABLE IV: JOB INFORMATION

ID	Job Number	Job Price (Rupiahs)	Due date	Operation Routing (ID Machine [hours])
1	12050	1.300.000,00	Day-17	1 [2] – 3 [2]
2	12050	5.800.000,00	Day-17	1 [2] – 3 [4]
3	12057	909.300,00	Day-13	1 [4] – 1 [5] – 5 [2] – 1 [2] – 6 [2]
4	12058	3.553.980,00	Day-7	4 [5] – 10 [16] – 11 [16]
5	12063	2.153.791,00	Day-11	1 [8] – 1 [8] – 6 [2]
6	12064	2.351.250,00	Day-12	12 [16] – 14 [16] – 9 [16] – 6 [5] – 6 [1] – 6 [4] – 5 [2] – 5 [8]
7	12065	1.444.000,00	Day-12	8 [4] – 6 [1] – 14 [24] – 3 [8] – 4 [1] – 2 [2]
8	12067	2.900.000,00	Day-19	1 [6] – 3 [3] – 6 [1]
9	12080	359.955,00	Day-14	4 [8] – 1 [8] – 6 [4]

A. Solving Using Maestry Mathematic Model

The case study was applied to the Maestry model by using mathematical program software. The model obtained an optimal total profit Rp. 10.628.090. Orders accepted are order ID 1, 2, 3, 5, and 8 as shown in Table V. Computational time took about 5 days.

B. Application of the Proposed Heuristic Model

In the following numerical example, the proposed heuristic model generated the same solution as the Maestry model with total profit Rp 10.628.090. The processing time of the proposed model was less than 5 seconds. Illustration of the proposed heuristic model will be explained in the following.

TABLE V: CAPACITY PLANNING RESULTS

Order (j)	Operation (o)	Machine (r)	Period (t)	Shift (s)	Time Allocated (X_{jorts})
1	1	1	17	1	2
1	2	3	17	1	2
2	1	1	2	1	2
2	2	3	2	1	1
2	2	3	17	1	1
3	1	1	1	1	4
3	2	1	2	1	2
3	2	1	3	1	3
3	3	5	3	1	2
3	4	1	3	1	2
3	5	6	8	1	2
5	1	1	8	1	8
5	2	1	8	1	6
5	2	1	9	1	2
5	3	6	11	1	2
8	1	1	12	1	6
8	2	3	12	1	1
8	2	3	13	1	1
8	2	3	17	1	1
8	3	6	19	1	1

The first step, compute the profit of each job (see in Table VI). The next step is to eliminate non-profitable jobs, which are job 4, 6, 7, and 9. The third step, sequence the profitable jobs from the highest profit to the lowest profit, which are 2-8-5-1-3. The sequenced job order is then schedule by proceeding step 4 to step 7. The case study scheduled all jobs in 5 iterations.

TABLE VI: JOB'S POTENTIAL PROFIT

ID	Job Number	Job Profit (Rupiahs)
1	12050	1.170.000
2	12050	5.670.000
3	12057	134.300
4	12058	-1.926.020
5	12063	1.233.791
6	12064	-5.715.550
7	12065	-1.266.000
8	12067	2.420.000
9	12080	-1.600.045

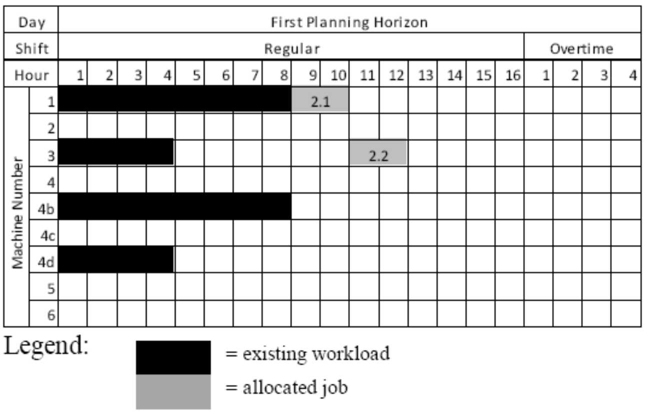


Fig. 3. Gantt chart for first iteration.

A. 1st Iteration – Allocating Job Number 2

The first step is to conduct capacity planning for job number 2. The total processing time is 4 hours, while its due date is 17 days or equal to 340 hours. Job 2 is feasible to be processed, so the next step is to allocate all of its operation to the regular time period using forward scheduling (see Fig. 3).

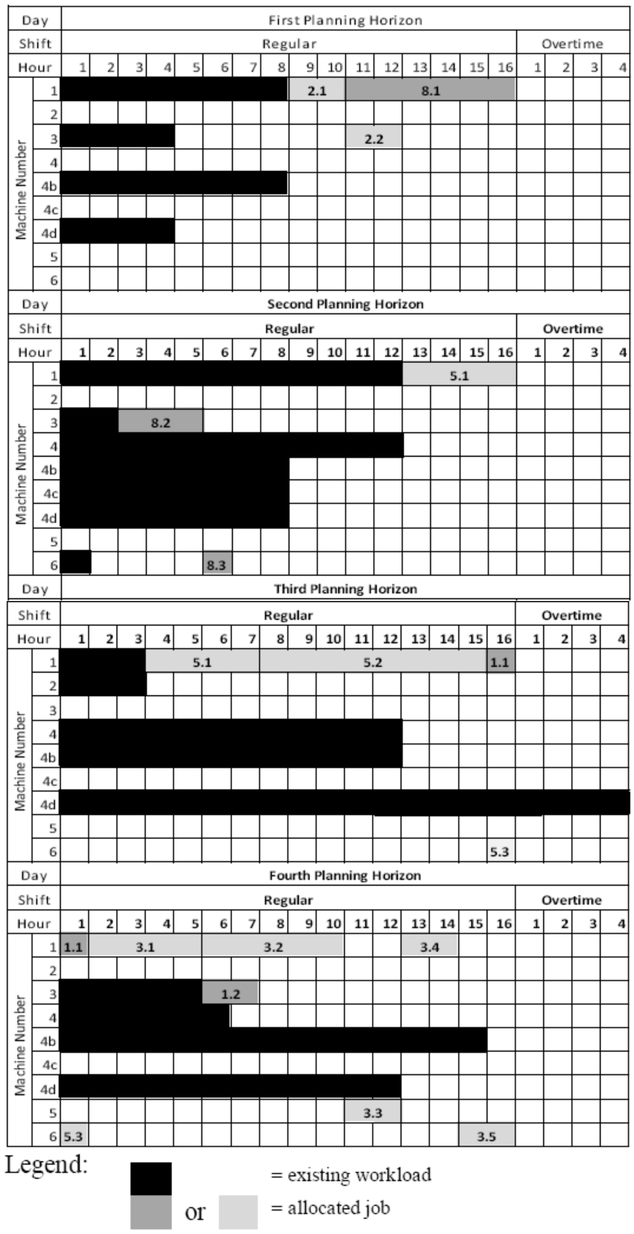


Fig. 4. Gantt chart for final iteration.

B. 2^{nd} – 5^{th} Iteration – Allocating Job Number 8, 5, 1, and 3

Using same approach in the first iteration, job number 8, 5, 1, and 3 is also allocated at regular shift. The gantt chart of the final schedule could be seen in Fig. 4.

Several sets of numerical implementation of the proposed algorithm have been conducted. The schedule are not guaranteed optimal but still maintaining a reasonable computational time

V. Conclusion

This research proposed a heuristic algorithm for order acceptance in MTO manufacturing. The main purpose of the development is for practical application. Order acceptance decision is expected less than 2 days. Analytic model for processing 9 jobs took 5 days of computational days. The computational time of the proposed model took less than 5 seconds. The solution of the proposed model is not guaranteed optimal even though from the numerical example it obtained the same value of the analytic model.

References

[1] H. F. Lewis and S. A. Slotnick, "Multi-Period job selection: Planning workloads to maximize profit," *Computers & Operation Research*, vol. 29, pp. 1081-1098, 2002.

[2] T. E. Morton and S. A. Slotnick, "Order acceptance with weighted tardiness," *Computers & Operation Research*, vol. 34, pp. 3029-3042, 2007.

[3] C. S. Chen, S. Maestry, P. Damodoran, and C. Wang, "The capacity planning problem in Make-To-Order-Enterprises," *Mathematical and Computer Modeling*, vol. 50, pp. 1461-1473, 2009.

[4] W. O. Rom and S. A. Slotnick, "Order acceptance using genetic algorithm," *Computers & Operation Research*, vol. 36, pp. 1758-1767, 2009.

[5] S. Maestry, P. Damodaran, and C. S. Chen, "A branch and price solution approach for order acceptance and capacity planning in Make-To-Order operation," *Production, Manufacturing and Logistics*, vol. 211, pp. 480-495, 2011.

Muhammad Akbar is a master degree student at the Department of Industrial and Manufacturing Engineering and Management-Institut Teknologi Bandung. He received the Bachelor degree in Industrial Engineering at Institut Teknologi Bandung, Indonesia, in 2010. His email address is muhammad.akbar.abay@gmail.com.

Diandra Ayasa Anandipa received the bachelor degree in Industrial Engineering at Institut Teknologi Bandung, Indonesia, in 2012. He is a warehouse analyst at PT Astra Internasional Tbk. His email address is diandra_anandipa@yahoo.com.

Anas Ma'ruf received doctor degree in Mechanical and Structural Engineering from Toyohashi University of Technology, Japan, in 2000. Since 2007 he is Associate Professor at the Manufacturing System Research Group, Institut Teknologi Bandung. His research interest is in the field of CAD/CAM, intelligent manufacturing system and production planning and control for MTO industry. His email address is maruf@ti.itb.ac.id.