Production Planning under Hierarchical Workforce Environment

Sujan Piya, Nasr Al-Hinai

Abstract— **In a make-to-order system, orders are scheduled for production based on the agreed due date with customer and the strategy of company. Production planning of such system includes scheduling of orders to the production periods and allocation of workers at different work centers. Complexity in the system arises when the operation to perform next and its processing time is skilled dependent where a higher qualified worker type can substitute a lower qualified one, but not vice-versa. Under such working environment, efficient scheduling of orders and allocation of workers at different work center play a major role to improve system performance. This paper develops a mathematical model for make-to-order flow shop system that helps to identify optimum schedule of orders and allocation of workers, under hierarchical workforce environment, with an objective of minimizing the weighted average earliness and tardiness of orders. A heuristic method is also proposed to reduce the complexity and solve the model efficiently.**

***Index Terms*— Worker allocation, Scheduling, Hierarchical workforce, Make-to-Order, Flow shop.**

I. Introduction

Due to fierce competition in the market there is an increasing trend of company moving from Make-to-Stock (MTS) model of production system towards Make-to-Order (MTO) system. The main reason for the popularity of MTO system is that the firm can offer a product which is unique and customized in nature [1]. Also, due to the success of Dell Corporation, many firms seek to offer greater product variety at a low cost by eliminating finished goods inventory using MTO production model [2]. In MTO system, company starts production only after getting confirmed orders from the customers and each order will be for a unique product. The scheduling of orders for production depends on the due date attached to the order and the strategy of company. The complexity in the production of orders occur when the operations to be performed depends on the level of skill that the workers posses, where a higher qualified worker type can substitute for a lower qualified one but not vice-versa. This hierarchical nature of workforce will affect the time at which order once scheduled will be finished. It will have direct implication on when to start production and who should be allocated to produce it because neither producing earlier than the due date (holding cost of inventory) nor producing late (tardiness cost) is desirable to the manufacturer.

We can find number of literatures dedicated to production scheduling i.e., scheduling of job to the machines for production. To name few of them are [3], [4], [5], [6], [7], [8], [9], [10]. These literatures have developed new approaches/ heuristics to solve scheduling problem either in a flow shop or job shop settings with different objective functions such as minimizing makespan, mean flow time, weighted tardiness / earliness, total ideal time and so on. In these literatures, scheduling is done by considering the number and capacity of available machines. But, if the industry is labor intensive, then only considering the number and capacity of machines is not enough. In such situation, the capability of worker for performing a specific job, rather than the capacity of available machine, will determine the duration on which the job can be completed. Since each worker will have their own capability, forming a hierarchical nature of workforce, scheduling order based on the capability of workers is another challenging task for such system. Therefore, together with scheduling and sequencing of orders to the machines, proper allocation of worker is also important to optimize available resources. According to [11] there are very few published papers that have dealt on hierarchical workforce problem and more research is needed in this area.

Research on hierarchical workforce using combinatorial method can be traced back to [12]. The paper developed an algorithm which generate feasible schedule under the assumption that each worker must have 2 off-days per week. In the same line of research [13] discusses necessary and sufficient condition for a labor mix to be feasible and presented one-pass method that gives the least labor cost. [14] shows that integer programming approach is well suited for solving the problem studied by[13]. [15] presented an optimal algorithm for multiple shifts scheduling of hierarchical employees on four days or three days workweeks. [11] introduced the concept of compressed workweeks in the model of [14]. The work of [11] is further extended by [16] by introducing the concept of suitability of task assignment to individual employees. Recently, [17] extended the model of [14] and [11] by developing mathematical models under the assumption that the work is divisible. The models proposed in these literatures give the optimum number of workforces with different hierarchies needed to satisfy customer order. However, in Make-to-Order production system each order will have certain due date attached to it. Hence, it is necessary for the company to identify the sequence on which order to produce first and then which next together with identifying optimum numbers of workers with different hierarchies to minimizing the total

Manuscript received March13, 2014. This work was supported in part by Sultan Qaboos University under grant IG/ENG/MIED/14/05.

S. Piya and N. Hinai are with the Department of Mechanical and Industrial Engineering, Sultan Qaboos University, Muscat, Sultanat of Oman. (Corresponding author phone: +968 97256293; e-mail: sujan@ squ.edu.om; nhinai@squ.edu.om).

cost of production. Furthermore, reviewed literatures on hierarchical workforce neglect the precedence relationships that exist between the operations in the order, which is a critical issue when job needs to be processed at different work centers.

From the literature review it can be seen that there are many papers published on production scheduling and hierarchical workforce planning separately. However, many manufacturing companies have to deal with both of these factors simultaneously, especially when the company is labor intensive. This research aims at developing a mathematical model by integrating hierarchical workforce planning with order scheduling problem with an objective of minimizing weighted average earliness and tardiness, which as far as we know is the first attempt in this area of research.

The rest of the paper is structured as follows. Section 2 addresses the problem description. Section 3 explains the proposed mathematical model in detail. Section 4 discusses a heuristic method developed to reduced the complexity and solve the proposed mathematical model efficiently. Finally, concluding remarks and future research directions are highlighted in section 5.

II. Problem Statement

Scheduling of orders and allocation of workers to the available resources are some of the most important and widely researched issues in the field of production planning and control as these issues have direct impact on the productivity and/or cost of production. This paper has considered the integration of aforementioned issues in a periodic setting where all of the orders that arrived on a given period will be produced in the next succeeding period. Once the order arrives with certain due date attached to it, order will remains in a pre-shop pool till the next period. Company will accumulate all the orders of a given period plus any backlog of past period to make schedule for next period, depending on which the order will go for production. To minimize the weighted average earliness and tardiness of orders, which is the objective function here, it is necessary during scheduling to consider the hierarchical nature of workforce. Three different levels of workers hierarchy are considered, namely level 1, level 2 and level 3. Workers in these levels differ in terms of their capability to operate various machines and in the speed with which the worker can perform a certain operation. Level 1 represents the most efficient group of workers who can do all types of tasks that are necessary to be performed in the order or it is the group of worker who can operate all of the machines. Plus, this group of workers can perform the operation faster (less processing time) than any other groups. On the other hand Level 3 represents the group of workers who can work only on fewer machines and takes more time to finish job. Capability of workers that fall on Level 2 lies in between level 1 and level 3 in terms of number of machines they can operate and the speed at which they can perform the assigned operation. Here, the problem is to identify the required number of workers of each level, allocate these workers to different work centers and schedule the orders on the basis of capability of identified numbers of workers of various levels.

The paper assumes this problem in a flow shop environment. The shop basically consists of various work centers. An order consists of batch of one product type that will enter from the initial work center and exit through the last work center. Each order involves operations at all the work centers. The objective is to develop order scheduling model by taking into account the hierarchical nature of work force in such a way as to minimize the weighted average earliness and tardiness. Following assumptions are used for developing mathematical model:

- Same order cannot be processed on more than one machine at a time.
- The processing time of operation of an order on a given machine by the given level of worker is predefined.
- Preemption of order is not allowed.
- Each machine can process at most one operation at any time.
- Due date of orders are known and fixed.
- Allocation of workers in the work center for the given order remains fixed once the work is started.
- Allocation of workers in the work center for different order may be different.
- Set up time is considered negligible.
- All orders are available for processing at the beginning of period.

III. Mathematical Model

This section discusses the proposed mathematical model developed to solve the problem described in Section 2. All indexes, parameters, and decision variables used in the model are listed below.

Index

i Work center, $i = \{1,\ldots, m\}$
o Customer order, $o = \{1,\ldots, O\}$
k Worker level, $k = \{1,\ldots,K\}$
f Unit in the order, $f = \{1,\ldots,F\}$
v Position of order in the sequence, $v = \{1,\ldots, V\}$

Parameter

q_o Total number of units in order o
d_o Due date of order o
t_o Time at which production of order o can be started
Δ_{oi} Waiting time for operation in work center i of order o
p_{iok} Processing time worker level k takes to process one unit of order o in work center i
Cap Capacity of work center in a period
CT_{iok} Completion time of a batch of order o in work center i by worker level k
ST_{iof} Starting time of f unit of order o at work center i
w' Earliness penalty of order o for each time unit of earliness
w'' Tardiness penalty of order o for each time unit of tardiness

Decision Variable

CT_{mo} Completion time of order o at work center m
E_o Earliness time of order o
T_o Tardiness time of order o
X_{iov} 1 if at machine i order o is assigned to v^{th} position in the sequence; 0 otherwise

ISBN: 978-988-19253-5-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Y_{iok} 1 if in work center i order o is processed by worker level k; 0 otherwise

The Model:

$$\min z = \sum_{o=1}^{O}\left(w_o^{'} E_o + w_o^{''} T_o\right) \quad (1)$$

Subject to:

$$E_o \geq d_o - CT_{mo} \quad (2)$$

$$T_o \geq CT_{mo} - d_o \quad (3)$$

$$CT_{mok} = CT_{(m-1)ok} + p_{mok} \qquad o = 1,\ldots\ldots\ldots, O; \quad k = 1,\ldots\ldots\ldots, K \quad (4)$$

$$CT_{iok} = ST_{iof} + p_{iok} \qquad i = 1,\ldots\ldots\ldots, m-1; \quad o = 1,\ldots\ldots\ldots, O;\ k = 1,\ldots\ldots\ldots, K;\ f = 1 \quad (5)$$

$$\sum_{k=1}^{K} Y_{iok} = 1 \qquad i = 1,\ldots\ldots\ldots, m; \quad o = 1,\ldots\ldots\ldots, O \quad (6)$$

$$\sum_{o=1}^{O} X_{iov} = 1 \qquad i = 1,\ldots\ldots\ldots, m \quad (7)$$

$$Cap_i \geq \sum_{o=1}^{O} q_o\, p_{iok}\, Y_{iok} \qquad i = 1,\ldots\ldots, m;\ \forall k \quad (8)$$

$$ST_{i(o+1)f} \geq CT_{iok} \qquad o = 1,\ldots\ldots\ldots, O; \quad k = 1,\ldots\ldots\ldots, K;\ f = 1 \quad (9)$$

$$ST_{(i+1)of} \geq CT_{iok} \qquad o = 1,\ldots\ldots\ldots, O; \quad k = 1,\ldots\ldots\ldots, K;\ f = 1 \quad (10)$$

$$CT_{mo}, E_o, T_o \geq 0 \qquad o = 1,\ldots\ldots\ldots, O; \quad (11)$$

$$Y_{iok}, X_{ior} = \{0,1\} \qquad i = 1,\ldots\ldots, m; \quad o = 1,\ldots\ldots\ldots, O;\ k = 1,\ldots\ldots\ldots, K \quad (12)$$

The objective function, shown in Equation (1), is to minimize the weighted average earliness and tardiness. While developing the current model it is assumed that all the orders that arrive in previous period can be completed within the next period with the regular production time of workers. Equation (2) calculates the earliness of an order o which is greater than or equal to the difference between its due date and completion time at the last work center m. Similarly, Equation (3) calculates the tardiness of an order. Completion time of an order at the last work center will determine the earliness and tardiness of an order. This can be calculated by Equation (4). However, completion time of order at the last work center depends on its completion time at the preceding work center, which is calculated by Equation (5). It indicates the completion time of an order in a given work center by worker level k. Equation (6) is a binary variable to ensures that in each work center i order o will be processed by one worker level k. The value of Y_{iok} equals 1 means that worker level k is assigned to work center i to process order o. Otherwise, the value of it will be zero. Similarly, equation (7) is also a binary variable to ensure that each order is assigned only once in the given machine. The capacity constraint is represented by Equation (8) and indicates that the total processing time for orders with a given worker type must be less than or equal to the available capacity within a period. Constraint that a machine can operate only one operation of an order at a time is indicated by Equation (9). Equation (10) is a precedence constraint. Equation (11) is non-negative constraint and Equation (12) is binary variable.

The starting time in the above equations can be calculated by using iterative method as follows.

When i = 1 and f = 1

$$ST_{iof} = \max\,[t_o, \Delta_{io}] \quad (13)$$

When i = 1 and f = 2, 3,……., F

$$ST_{iof} = ST_{io(f-1)} + p_{iok} \quad (14)$$

When i = 2, 3, …., m and f = 1

$$ST_{iof} = \max\,[ST_{(i-1)of} + p_{(i-1)ok}, \Delta_{io}] \quad (15)$$

When i = 2, 3, …., m and f = 2, 3,……., F

$$ST_{iof} = \max\,[ST_{io(f-1)} + p_{iok}, ST_{(i-1)of} + p_{(i-1)ok}] \quad (16)$$

IV. PROPOSED HEURISTIC

Flow shop scheduling problem with the objective function considered in this paper is NP-hard [18]. The complexity of the problem is exacerbated by hierarchical nature of workforce that we have considered here. Therefore, in order to solve industrial size problem a heuristic method is proposed by assuming that at least one level of worker (Level 1) can work on all the machines and they are the most experienced group of workers thus resulting into less working time as well in all the work centers. Let So be the set of orders to be produced in any given period. Proposed heuristic works as follow:

Step 1: Generate sub-sets of order by selecting any two orders from the set (So). The total number of sub-sets (z) will be equal to $\sum_{a=1}^{n-1}(n-a)$ where, n is the total orders in the set So.

For eg.: Let, So =(o1,…..,o6) and assume that these orders have to be processed in 6 different machines ($m1$, …, $m6$). Also, let's assume that there are three levels of workers (l1, l2, l3) out of which level 1 can work on all the machines, level 2 on machines $m3$, $m4$, $m5$ and $m6$. However, level 3 can work only on machines $m5$ and $m6$.For this example, the sub-sets are (o1, o2), (o1, o3), …, (o5, o6).

Step 2: Select any sub-set and define the possible sequence. Here, since each sub-set will have two orders, the total number of possible sequences will be equal to $2z$. For sub-set (o2, o6) the possible sequences will be (o2-o6) and (o6-o2).

Step 3: For any possible sequence of orders allocate Level 1 worker on all the machines as it has been assumed that worker that falls in this level can work on the entire machines. Then,

3(a): Identify the number of different levels of workers who can work on same sets of machines and allocate the worker on those machines accordingly. This results into $3y^r$ different possibilities on worker allocation where, y is the number of different levels of workers that can work

ISBN: 978-988-19253-5-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

on same sets of machines and r is the number of machines on which y can work.

For our example, in *m1* and *m2* only worker with level 1 can work. So, for any sequence of order in these machines, assign worker with level 1 and fix it. Then, for machines *m3* and *m4*, workers with level 1 and 2 can work. So, one possible allocations for order sequence (o2-o6) on these machines will be [o2(*m3*/*l1*);o2(*m4*/*l1*)-o6(*m3*/*l1*;o6(*m4*/*l2*)]. The total possibilities for worker allocations here will be equal to 12.

3(b): Repeat Step 3(a) for the remaining sequence. This results into $6y^r$ different possibilities on worker allocation for orders (o2, o6).

3(c): For each possibility, calculate the objective function and then select the one that gives the minimum value of objective function. Here, it should be noted that while calculating the objective function, for remaining machines *m5* and *m6*, still worker belonging to level 1 will be allocated.

Let the best possibilities for our example be [o2(*m3*/*l1*);o2(*m4*/*l2*)-o6(*m3*/*l2*;o6(*m4*/*l1*)].

3(d): Similarly, repeat the steps from step 3(a) for remaining machines by fixing worker level on machines based on the result of Step 3 (c).

For the example, remaining machines for worker allocation are *m5* and *m6* and all level of workers can work on it. The total possible solution for worker allocations here will be equal to 27. These situations will be enumerated by fixing worker level 1 in *m1*, *m2* for o2 and o6. Also, worker level 1 at *m3* and *m4* for o2 and o6, respectively. However, at *m4* and *m3* of o2 and o6 respectively worker with level 2 will be fixed.

Step 3 results into $\sum_{\forall s \in S} 3y_s^{r_s}$ different possibilities on order sequencing and worker allocation for a set of order where $s = (1,\ldots, S)$ represents set of worker level who can work on specific set of machine. 2 sets of workers for the example are (*l1*, *l2*) and (*l1*, *l2*, *l3*) who can work on machine sets (*m3*, *m4*), (*m5*, *m6*) respectively.

The outcome of Step 3 will be the best sequencing of orders and allocation of workers at all the machines for orders (o2, o6).

Step 4: Repeat steps from *step 2* for all the remaining sub-set of orders and select the sub-set with the sequence and allocation that results into minimum value of objective function. This results into $\sum_{\forall s \in S} 6y_s^{r_s}(z)$ possibilities of order sequencing and worker allocations for all the sub-sets generated in step 1. The outcome of Step 4 will be the best sequencing of orders and allocation of workers at all the machines for the pair of order that must be scheduled first for production.

Step 5: Next, repeat steps from step 1 for the remaining orders in the set (*So*) until the set remains empty. While repeating the steps it should be noted that the order pair that has been selected in Step 4 with their sequence and worker allocation should be fixed and the sequencing of new order pair will start after the selected order pair.

Proposed heuristic results into $\sum_{\forall s \in S} 3y_s^{r_s}\left[\sum_{a=o}^{x}(n-2a)\{n-(2a+1)\}\right]$ possible solutions on order sequencing and worker allocations for all the orders in the set *So* instead of $\prod^{\forall s \in S} 3y_s^{r_s} n!$.

V. CONCLUSION

This paper developed a mathematical model to allocate hierarchical nature of workforce to different orders at various work centers in a flow shop environment. This allocation problem is integrated with order scheduling problem. The problem that the paper dealt with is strongly *NP*-hard. Therefore, a heuristic method is also proposed to address industrial size problem efficiently. The proposed heuristic method reduces the number of possible combinations of order sequence and worker allocation drastically. The developed model helps a company to identify required number of workers with different level of hierarchies, order processing sequence, and allocation of different workers to the available work centers. As far as we know this is the first attempt to integrate order schedule problem with worker allocation under the situation where different levels of workers exists. In the near future extensive numerical analysis will be conducted to see the performance of proposed model and check its sensitivity.

Even with the proposed heuristic, if the numbers of orders are very high, with many levels of worker hierarchy, then it may be difficult to solve the problem in a reasonable timing. Therefore, introduction of intelligent method such as GA, PSO, TS can be considered as an extension of present research. Also, the next avenue for the research expansion may be to consider the constraint on working hours of workers for eg. each worker works only 8hrs per day and max 5 days a week with 2 day rest period.

ACKNOWLEDGMENT

The participation of the author in this conference has been made possible through the partial contribution from Sultan Qaboos University. This support is gratefully acknowledged.

REFERENCES

[1] J. Gallien, Y.L. Tallec, and T. Schoenmery, “A model for make to order revenue management”, *Sloan School of Management, Massachusetts Institute of Technology*, Cambridge, MA, 2004 (Working Paper).

[2] K.L. Kreamer, J.Dedrick, and S. Yamashiro, “Refining and extending the business model with information technology: Dell computer corporation”, *The Information Society*, 2000, Vol. 16, pp. 5-21.

[3] I.Lee, and M.J. Shaw, “A neural net approach to real time flow shop sequencing”, *Computers and Industrial Engineering*, 2000, Vol. 38, pp. 125-147.

[4] I. Kacem, S. Hammadi, and P. Brone, “Approach by localization and multi-objective evolutionary optimization for flexible job-shop scheduling problems”, *IEEE Transactions on Systems, Man and Cybernetics*, 2002, Vol. 32 (1), pp.1-13.

[5] B. Toktas, M. Azizoglu, and S.K. Koksalan, “Two machine flow shop scheduling with two criteria: Maximum earliness and makespan”, *European Journal of Operation Research*, 2004, Vol. 64, pp. 278-285.

[6] L. Tang, J. Liu, and W. Liu, “A neural network model and algorithm for the hybrid flow shop scheduling problem in a dynamic environment”, *Journal of Intelligent Manufacturing*, 2005, Vol. 16, pp. 361- 370.

[7] L. Liu, H. Gu, and Y.Xi, "Robust and stable scheduling of a single machine with random machine breakdowns", *International Journal of Advanced Manufacturing Technology*, 2007, Vol. 31, pp. 645-654.

[8] B. Yagamahan, and M. Yenise, "Ant colony optimization for multi-objective flow shop scheduling problem", *Computers and Industrial Engineering*, 2008, Vol. 54(3), pp. 411-420.

[9] Y. Xia, B. Chen, and J. Yue, "Job Sequencing and due date assignment in a single machines shop with uncertain processing times", *European Journal of Operational Research*, 2008, Vol. 184, pp. 63-75.

[10] N. Al-Hinai, and T.Y. El Mekkawy, "Robust and stable flexible job shop scheduling with random machine breakdowns using a hybrid genetic algorithm", *International Journal of Production Economics*, 2011, Vol. 132, pp. 279-291.

[11] S.U. Seckiner, H. Gokcen, and M. Kurt, "An integer programming model for hierarchical workforce scheduling problem", *European Journal of Operational Research*, 2007, Vol. 183, pp. 694-699.

[12] H. Emmons, and R.N. Burns, "Off-day scheduling with hierarchical worker categories", *Operations Research*, 1991, Vol. 39, pp.484-495.

[13] R. Hung, "Single-shift off-day scheduling of a hierarchical workforce with variable demands", *European Journal of Operational Research*, 1994, Vol. 78, pp.49-57.

[14] A. Billonnet, Integer programming to schedule a hierarchical workforce with variable demands, *European Journal of Operational Research*, 1999, Vol. 114, pp.105-114.

[15] R. Narashiman, "An algorithm for multiple shift scheduling of hierarchical workforce on four-day or three-day workweeks", INFOR, 2000, Vol. 38, pp. 14-32.

[16] R. Pastor, and A. Corominas, "A bicriteria integer programming model for the hierarchical workforce scheduling problem", *Journal of Modeling in Management*, 2010, Vol. 5, pp. 54-62.

[17] C. Ozguven, and B. Sungur, "Integer programming models for hierarchical workforce scheduling problems including excess off-days and idle labor times", *Applied Mathematical Modelling*, 2013, Vol. 37, pp. 9117-9131.

[18] C. Koulamas, "The total tardiness problem: Review and extensions", *Operations Research*, 1994, Vol. 42(6), pp. 1025-1041.

ISBN: 978-988-19253-5-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)