A Study of Workforce Assignment Problem in Lean Factory on Machine Tool Industry

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Abstract

For a company in the traditional manufacturing environment, such as a machine tool industry, how to adjust the workforce assignment during adopting lean production is a key issue. Consiering the complexity in manufacutirng various machine types, each requires a combination of the expertise in multiple techniques for one specific technician, arrange appropriate workforce is therefore not an easy job for the shop floor manager. This work proposes a systematic method, based on the mathematical programming, to resolve the issue of workforce assignment when receiving small-volume, large-variety orders in the machine tool industry. A case company is used to demonstrate the feasibility and effectiveness of this method. The proposed method starts with the drawing of Value Stream Mapping (VSM) and applies the seven principles of lean to design the to-be production system. An interger programming (IP) model is formed to find the optimal workforce assignment in re-designing the manufacturing process when various orders are received for the future VSM. Simulation results illustrate the potential performance of the model. A typical company which was quite representive in the machine tool industry was selected and its shop floor information was collected. For the case company, it was found out that the makespan could be reduced from 28.03 days to 12.5 days without additional manpower for a series of five orders with four machine types. The emprical results clearly demonstate that the proposed method is feasible and could be extended to other companies.

Keywords: Lean Manufacturing, Value Stream Mapping (VSM), Integer Programming, Workforce Assignment

1. Introduction

A machine tool is, in usual, heavy, large and difficult to move. It is assembled at a fixed position and the technicians work in turn according to their specific techniques such as scarping, accurate calibration, and laser calibration. It takes a while for a novice engineer to learn and practice the skills and act like an experienced worker. There are huge differences on the performance of workforces based on their experiences. Since the machine tool industry has the characteristics of multi-specification, small batch production model, and make to order, automation is therefore very difficult. On the other hand, lean production is a common practices in this type of the industry. Considering a company that is transforming toward lean manufacturing, this work proposes a systematic method, based on the integer programming model and lean thinking, to resolve the issue of workforce assignment in the machine tool industry.

Value Stream Mapping (VSM) is a tool that assists managers to understand the situation of the production line. The VSM can be used to improve the flow of information and materials thereby improvement in the productivity eliminating wastes (Gunaki et al., 2015). Using this tool, Rother & Shook (2003) plotted the future VSM based on the seven principles of lean thinking on a specific organization. Wang et al. (2014) applied the VSM for the operation room arrangement. It is found out that the operation room should be assigned based on the time required for the operation instead of pathology to prevent long overtime work. IP (Integer Programming) was formed to find the optimum to arrange the operating room that could reduce the overtime hours of the medical staff.

Andrade *et al.* (2016) aims at applying the concepts of VSM in an auto-parts company in the ABC region of Sao Paulo. By mapping the state of art, it was possible to identify the waste present in an assembly line of clutch discs. Results showed that VSM combined with simulation is a good alternative in the decision-making for change in production process. Atieh *et al.* (2016) introduces a condensed version of lean manufacturing implementation toward improving manufacturing processes in a small to midsize glass fabrication company in Jordan. The results of the simulation is then used to identify all the possible primary and secondary bottlenecks using multiple approaches such as utilization method, waiting time method, and scenario-based method.

2. Methodology

This work considers the characteristics of the machine tool industry, where lean production is a common practice. Starting from the process information collection, it is proposed to draw the VSM firstly, and use the seven principles of lean thinking as the baseline to re-design the shop floor. Due to the complexity of workforce arrangement, IP is suggested to formulate in order to enable the future VSM works out for the practices.

The model of IP is shown in Figure 1. Considering there are O orders, J processes and I employees. Let's define the the objective function and constraints to optimize the workforce assignment by solving X_{ij}、 S_j、 f_j.

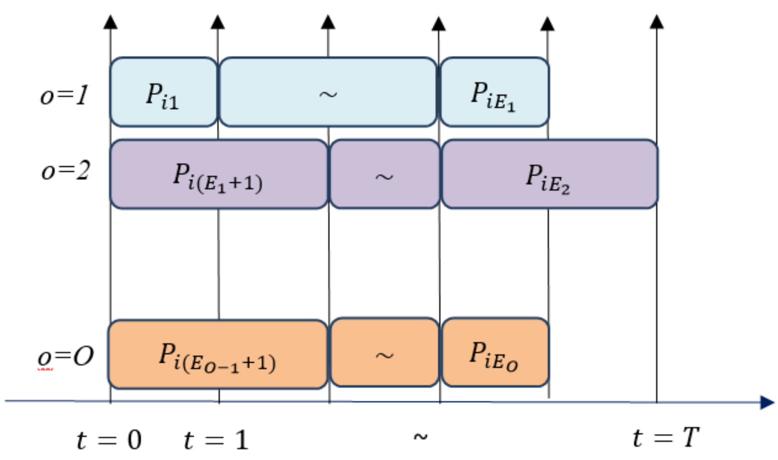

Figure 1. Work process and related unit time

Notations:

$i \in I$: index on employee, number of employees is I.

$j \in J$: index on process, number of processes is J.

$k \in \{1, \dots, K\}$: index on finish time of process, the max. number is K.

$P_{ij} \in \{1, \dots, K\}$: number of process time where employee i doing process j.

$t \in \{0,1, \dots, T\}$: index on unit time, number of unit time is T.

$o \in O$: index on order, number of orders is O.

$E_o \in J, \forall o \in O$: the last process index of each order.

$F_o \in \{1, \dots, T\},\ \forall o \in O$: the finish time of each order.

$h \in \{0,1\}$: binary variable with value 1 if the $P_{ij} \geq k$; 0 otherwise.

M: maximum.

Decision variables:

$X_{ij} \in \{0, 1\}$: binary variable with value 1 if the employee i doing process j;
0 otherwise.

$Z_{ij}^t \in \{0, 1\}$: binary variable with value 1 if the employee i doing process j in time t; 0 otherwise.

$y_{ij}^t \in \{0, 1\}$: binary variable with value 1 if the employee i doing process j after unit time t; 0 otherwise.

$S_j \in \{0,1, \dots, T\}$: number of begin time in process j.

$f_j \in \{1, \dots, T\}$: number of finish time in process j.

Objective function:

$$\min \ \{ \max_{o \in O} F_o \}$$

Subject to:

1. Each process must be assigned exactly one person to execute.

   $\sum_i X_{ij} = 1,\ \forall j \in J$ -- (1)

2. Each process must be executed just once during the whole time.

   $X_{ij} - \sum_t Z_{ij}^t = 0,\ \forall i \in I\ \forall j \in J$ -- (2)

3. The same person can only execute one or less process work at the same time.

   $\sum_j y_{ij}^t \leq 1,\ \forall i \in I\ \forall t \in \{0, \dots, T\}$ -- (3)

4. The working time of each process is determined by the assigned staff's ability to work.

   $\sum_t y_{ij}^t = P_{ij} X_{ij}\ ,\ \forall i \in I\ \forall j \in J$ --- (4)

5. Each process must be completed independently by the same assignee. The staff working time in this process is P_{ij}. The process must be executed by the same person

throughout the P_{ij} time.

$k \leq P_{ij} + M \cdot h$ -- (5.1)

$Z_{ij}^{t} \leq y_{ij}^{t+k-1} + M \cdot h$ -- (5.2)

$P_{ij} \leq k + M \cdot (1 - h),$ -- (5.3)

$y_{ij}^{t+k-1} \leq Z_{ij}^{t} + M \cdot (1 - h)$ -- (5.4)

$\forall i \in I\ \forall j \in J\ \forall t \in \{0, \dots, T - k + 1\}\ \forall k \in K\ \forall h \in \{0,1\}\ M \gg 1$

6. The start time of each process is the accumulation of upstream process time.

$S_j = \sum_i \sum_{t=0}^{T} t Z_{ij}^{t}, \forall j \in J$ -- (6)

7. The completion time of each process is the start time of the process plus the processing time.

$f_j = S_j + \sum_i P_{ij} X_{ij}, \forall j \in J$ -- (7)

8. Define the order of each process by order O.

$S_j \geq f_{j-1}, \forall j \in \{E_{o-1} + 2, E_{o-1} + 3, \dots, E_o\}\ \forall o \in O$ -------------------------------- (8)

9. The completion time of order O is exactly the completion time of the process E_O.

$F_o = f_{E_o}, \forall o \in O$ --- (9)

3. Results and Discussion

Considering a machine tool company that is that already adopting lean production. This company adopts the make to order production process and there are information of the five orders are collected where the demands are four types of the machines.

Figure 2 is the VSM of a specific machine in the case company. Applying the IP model shown in the previous section and the workforce is arranged based on model suggested. The managers then applied the seven principles of lean thinking to transform the shop floor and the future VSM is shown in Figure 3.

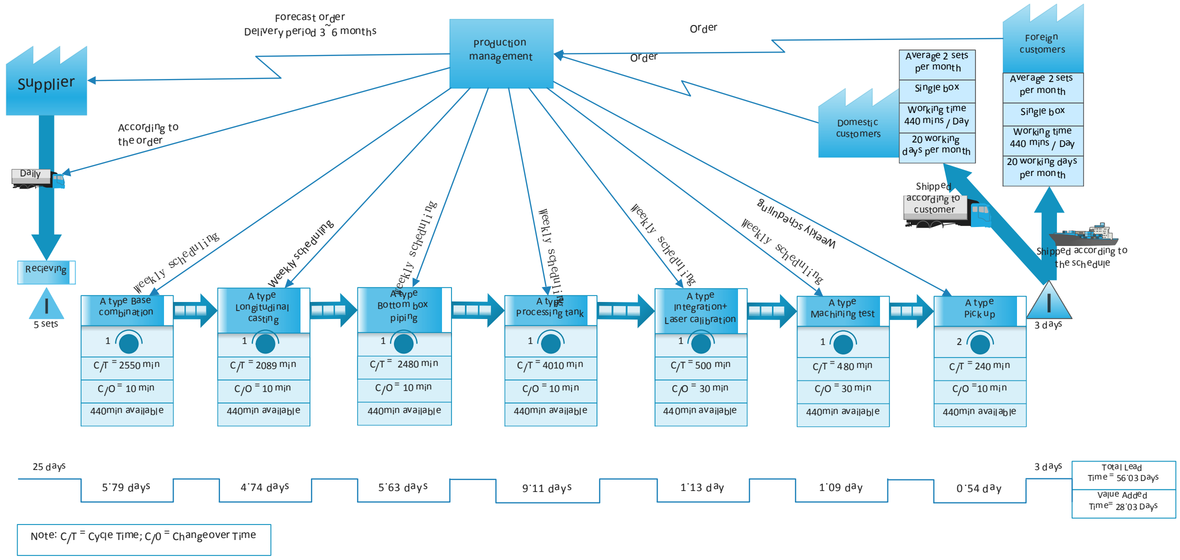

Figure 2. VSM of the case

The simulation results of future VSM showed that should the workforce assignment were arranged as planned, the employee utilization rate could be improved from 41.4% to 91.6% and the make-span could be reduced from 28.03 to 12.5 days. This demonstrates the importance to apply the IP model in making lean production practical in the machine tool industry.

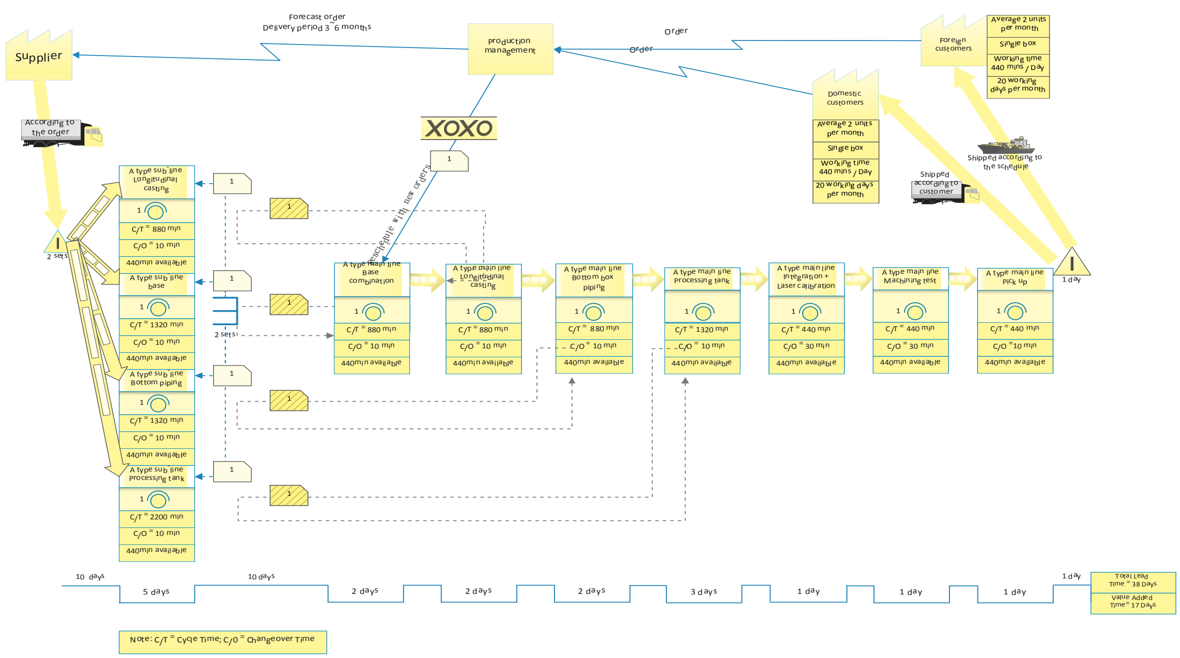

Figure 3. Future VSM of the case

4. Conclusion

Machine tool industry is a very traditional yet very important industry. To be competitive, lean manufacturing is common practices in this industry. However, the workforce arrangement is a very difficult problem for the practitioners. This work proposes the combination of VSM and IP to assist a machine tool company to assign appropriate workforce to the appropriate process in order to smoothly implement the lean production. We illstarte how to formulate IP in details in order to find the optimal workforce assignment model. The results of a case study show that the proposed method is feasible in practical applications. Future works include to integrate the current model with the ERP system and to calculate the potential wastes reduced using future VSM.

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Biographies

JrJung Lyu is a professor in the Department of Industrial and Information Management at National Cheng Kung University since 1989. He obtained a PhD degree in industrial engineering from the University of Iowa, USA. Dr. Lyu has participated in many projects, public services, and reviewing committees since 1989. He is the founder of CQI (Center for Quality & Innovation) at National Cheng Kung University and serving as the president of e-Business Management Society (EBMS) and many public services. Dr. Lyu has published over a hundred journal papers, several textbooks (including e-Business strategy, global quality management, healthcare quality management, etc.), and earned the Personal Award of the National Quality Award, Taiwan, in 2002. He is a fellow of CSQ and currently appointed as the Regional Director for ASQ, USA. His current research interests include strategy for innovative services, big data applications, biz model of new industries, genetic diagnostics applications, etc.

Ching-Hsiang Tung is a graduate student in the Department of Industrial and Information Management at National Cheng Kung University. He is a manager in a machine tool company located at Tainan, Taiwan.

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