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

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SUMMARY

目前工具機業大多導入精實生產，用來改善製程降低生產成本，但導入精實生產後仍有人員調度問題需要配合，否則製程無法暢流，因為工具機產業的問題點在各製程需要的技能不同且多能工養成不易，在多筆不同製程的機型訂單下，即便已經繪製出未來價值流程圖，如何調配人力去支援未來價值流程圖能順暢運行仍是一大問題。

Currently, most of the companies in the Machine Tool Industry adopt the method of the Lean Factory to improve the manufacturing capability and process and decrease the manufacturing cost. On the other hand, the manufacturing capability & process will not execute smoothly without bearing a proper adjustment to workforce assignment although the Lean Factory is applied. The primary issue is that one of each manufacturing process does require various and specific techniques and also it is not an easy job to cultivate a technician with the expertise in multiple techniques. Although they have done the Future Value Stream Mapping (FSM) under the condition of the purchase orders released for the numbers of model with the requirement of various manufacturing capability & process, it is still a big issue of how to make the appropriate workforce assignment to be supportive to the Future Value Stream Mapping (FSM)

本研究提出一套有系統的方法，解決少量多樣工具機廠的人員排班問題。首先由各別單機生產的未來價值流圖設計開始，利用精實七大準則設計理想未來價值流圖找出關鍵流程，將製程重新配置區分主線和副線生產，搭配超級市場讓交期只受到主線生 產影響。設計未來圖的另一重點在考量人員指派，所以重新規劃各製程時，同時要定義各人員在組裝該製程所需的單位時間，當多筆不同機型的訂單下，可利用整數規劃找出最佳化人員排班，讓各機型訂單順利依據各自的未來價值流圖暢流。

This research brought you a systematic method to resolve the issue of workforce assignment when having multiple models bearing small quantity respectively. The method starts with the design of Future Value Stream Mapping (FSM) which is usually made by the individual machine. To apply the Lean seven principles to design of Future Value Stream Mapping (FSM) and try to find the key process, and to relocate and categorize the manufacturing process as the main line and sub-line along with supermarket which enables the lead-time will be affected while the mainline makes it. The other key point design of Future Value Stream Mapping (FSM) is the consideration of workforce assignment. When re-design one of each manufacturing process, it needs to define the person's time spent for the accomplishment of one particular manufacturing process. Once the several PO released with requirements of various models, To apply the integer programming (IP) can find the optimal workforce assignment which enables one of each PO bearing various models moving smoothly based on its FSM

個案情境為四種機型的五筆訂單，透過此本研究所提出之方法，在不增加人力的情況下，總完工時間由 28.03 天縮短為 12.5 天，研究結果顯示此方法於實務應用具可行性。The scenario of the case is designed based on four models in five

Purchase Orders, and the makespan decreases from 28.03 days down to 12 days without adding any additional workforce. The implementation of the proposed method is very favorable, and the result of the research indicates the feasibility to be applied to the real world

Keywords: 精實、價值流圖、整數規劃、人員指派

INTRODUCTION

工具機產業具有少量多樣的訂單特性，採接單式生產，且工具機重量重、體積大無法落實物的流動，一般由多人接續製程在原地將工具機組裝完成，這些製程需要各種技術如鏟花、高機密校調、雷射校正等需要長時間學習的技能，新進人員只能由鈑金件組裝及油箱組裝開始學起，因此人員技能落差大，造成新手和熟手組裝時間差異大。工具機製造廠在面對多筆不同製程的機型訂單時，即便各機型已設計出各自的未來理想價值流圖，但卻需要適當的人力去支援，否則無法落實製程暢流。因此本研究考慮人員技能進行人員指派，在不需增聘人員情況下，完成訂單並縮短總完工時間。

The machine tool industry bears the characteristic of many part numbers in small quantity demand, and it will not be produced until in receipt of the PO. The machine tool normally is with heavy weight, large volume and it is difficult to move and flow in the production line. In general, the way the machine tool is built at the place where it locates and the technicians take the turn to finish their job. One of each process does require different kinds of techniques; for instance Scarping, high precision adjustment, laser calibration…and so on. All of this technique and skills takes very long time to learn and practice before the learner is familiar with it. Therefore the novice can only start their job by doing sheet metal assembly and oil tank assembly, so the huge gap of the technique happens among the experienced and

inexperienced workers which differentiate the time they need to finish the assignment/assembly. When the machine tool manufacturing company face the multiple PO requires different techniques applying to different models, they still need the sufficient supportive man force although the FSM for one of each part number is done or the manufacturing flow is not going to be smooth but limp instead. Therefore the research considers the different technique the worker bears when the decision of workforce assignment is made. The accomplishment of the PO with no any additional workforce, but the job was done early.

MATERIALS AND METHOD

現況價值流圖的繪製過程幫助經營者了解產線真實樣貌，而未來理想價值流圖是改善的藍圖。Rother&Shook (2003) 提出七大準則繪製未來理想價值流圖。The process of building VSM helps the company runner to get to know the actual condition of the production line. The FSM is the blueprints for the improvement. Rother&Shook (2003)submit the seven principles for making FSM. Wang et al. (2014) 解決病人手術房的安排問題，就是先繪製現況價值流圖，才發現過去依據病理來區分手術房將因開刀時間的變異太大，導致手術房醫護人員加班時間過長，改依據預估手術時間做手術房分類，重新設計未來價值流圖，再透過整數規劃做手術室最佳安排，最終降低了手術房醫護人員加班費用。

Wang et al. (2014) find the solution to the issue of the arrangement to the operating room. Initially, he started with making VSM and realized that they used to categorize the operating room by the pathology. This arrangement enlarges the deviation of time they need and leads to the extension of the overtime for the medical staff. Therefore

已註解 [JL1]:

they tried to change it to the time a surgery needs and re-design them and then apply integer programming to optimize the operating room and finally decrease the expense of overtime for the medical staff.

本研究針對工具機製造業，使用七大準則繪製未來價值流圖，並採用整數規劃解決人員指派問題，由製程資料收集做起，先繪製現況價值流圖，再利用七大準則繪製未來理想價值流圖，最後透過整數規劃指派人員讓未來價值流圖能順利運作。

The research is specifically for the machine tool industry and uses the seven principles to build the FSM and also use the integer programming as the solution to the people assignment and to collect the information of manufacturing capability&process to build the VSM and to use the seven principles to build the FSM. Finally to use integer programing to assign the people to the operation of FSM smoothly.

整數規劃的模型如圖 1 所示，共O筆訂單，J個製程，I個員工，定義P_{ij}為員工i做製程j所需單位時間，定義變數、限制式以及目標式，求解X_{ij}、S_j、f_j可得到最佳化的排班表

The model of integer programming is illustrated in drawing ONE as shown,

圖 1 工作製程和工作週期時間關係圖

The drawing ONE the relation between working capability/process and working period

一般變數: a general variable

$i \in I$:共有I個員工。I employee in total

$j \in J$:共有J個製程。J manufacturing capability&process

$k \in \{1, \dots, K\}$：製程時間定義。The definition of time for manufacturing capability&process

$P_{ij} \in \{1, \dots, K\}$：員工$i$做製程$j$所需的製程時間，當無法製作時給定相對極大值。The time the employee i needs for proceeding the manufacturing capability & process of j, please give a relative maximum value when then process ithe s not applicable

$t \in \{0,1, \dots, T\}$:工作週期範圍定義。The definition of working period and coverage

$o \in O$:共有O筆訂單。Total numbers of Purchase Order as o

$E_o \in J$, $\forall o \in O$:每筆訂單完成的最終製程。The accomplishment of the last manufacturing capability & process for one of each PO

$F_o \in \{1, \dots, T\}$, $\forall o \in O$:每筆訂單完成的時間點。The time to the accomplishment of one of each PO

$h \in \{0,1\}$：當P_{ij}大於或等於某設定製程時間k,則為 0 否則為 1。It is 0 when P_{ij}>or= the default time of k for a manufacturing capability & process or 1

M：為了建立此排班模型數學式而定義的絕對極大值。The definition of the absolute maximum for the establishment of the specific scheduled mathematic model

決策變數: decision variable

$X_{ij} \in \{0,1\}$:當員工i做製程 j的工作時為 1，否則為 0。 It is 1 when the employee i to proceed the wor withk of manufacturing capability & process j or 0

$Z_{ij}^{t} \in \{0,1\}$:當員工i在第t個時間點當下，開始執行製程j的工作為 1，否則為 0。It is 1 when the employee i at the time of t and start proceeding the job of the manufacturing the ng process j or 0

$y_{ij}^{t} \in \{0,1\}$:當員工i在第t個時間點後的單位時間內執行製程j的工作為 1。 It is 1 after the employee i at the t th moment of time within a certain period of time and start proceeding the job of the manufacturing process j

$S_j \in \{0,1, \dots, T\}$:製程$j$的起始時間點$t$。The ignition time point t for the manufacturing process of j

$f_j \in \{1, \ldots, T\}$：製程 j 的完成時間點 t。The termination time point t for the manufacturing process of j

限制式: restriction

1. 每個製程都必須剛好指派 1 位人員去執行，數學式表達如式 2.1。
   One assigned person is to execute the specific manufacturing process shown in a mathematic formula of 2.1
2. 每個被執行的製程，在排班週期內都必須剛好被啟動執行一次，如式 2.2 所示。
   One of the each executed manufacturing process must be activated and executed once within scheduled period shown in 2.2.
3. 同一個人員在同一個時間點內只能執行一個以內的製程工作，如式 2.3 所示。
   The same person within a time moment can execute only one manufacturing process job shown in 2.3
4. 每道製程的工作時間是由指派人員的工作能力決定，如式 2.4 所示。
   The working hours for one of the manufacturing process is decided based on the assigned people's working capability shown in 2.4
5. 每道製程開始後都必須由相同的指派人員獨立完成，該員在此製程工作時間就是 P_{ij}，定義 j 製程在第 t 個單位時間點開始執行後 (被觸發後)，其後的第 P_{ij} 個單位時間內必定由同一人 i 來執行，如式 2.5.1 至 2.5.4 所示。
   Once the specific manufacturing process starts , it must be accomplished independently by the same assigned person, the P_{ij} is the time he starts the work in this manufacturing process, the definition for the execution to manufacturing process of j at the t th moment of time, (once it is activated), at the P_{ij} th moment of time later on must be executed by the same person of i shown from 2.5.1 to 2.5.4
6. 每道製程的開始時間就是該製程起始製作時間 (Z_{ij}^{t}的t)，如式 2.6 所示。

The time the specific manufacturing process begins is also the moment to start such a manufacturing process (Z_{ij}^{t}'s t) shown in 2.6

7. 每道製程的完成時間是該製程開始時間加上該加工時間，如式 2.7 所示

   The time to accomplish one of each manufacturing process is the time to begin such a process plus the time spent in the process shown in 2.7

8. 將O筆訂單內的各製程 j 先後順序做定義，如式 2.8 所示。

   To define one of each process j in 0 purchase order chronologically shown in 2.8

9. O筆訂單的完成時間正好為製程$E_1, E_2, \ldots, E_O$完成時間，數學式表達如式 2.9。

   the time to accomplish 0 purchase order is also the time of the accomplishment of one of each manufacturing process $E_1, E_2, \ldots, E_O$ shown in 2.9

RESULTS AND DISCUSSION

個案以廠內四種機型的五筆訂單生產為情境，由於工具機採用接單式生產，五筆訂單的簽約時間點不同，提早簽約的訂單自然有部分製程已完成。個案中的四種機型依序為 A 系列中型機、A 系列大型機、B 系列中型機、B 系列大型機，首先依據研究步驟收集各製程資料，並繪製出四種機型的現況價值流圖，圖 2 為 A 系列中型機的現況價值流圖。再透過七大準則繪製出四種機型的未來理想價值流圖，圖 3 為 A 系列中型機的未來理想價值流圖。The case is designed based on the scenario of four-part numbers of model in five purchase orders. The production generally will not begin without in receipt of purchase order. The time to sign-up the PO may vary and the early sign-up PO bears certain part of PO has been done, The four models in the case in sequence are medium size of series A, the large size of the series A, medium size of the series B, large size of series B. Initially to the collect the information based on the research steps for one of each manufacturing process and also make the VSM for all four models. The drawing 2 is the VSM for the medium size of series A. In addition, to

make the FSM based the AlsoA

圖 2 A 系列中型機的現況價值流圖

Drawing two the VSM for the medium size of series A

最後將數據帶入整數規劃模型求解最佳化人員指派，讓五筆訂單的未來理想價值流圖能順利運作，結果顯示，最佳化人員指派下，人員稼動率由 41.4%提升至 91.6%，總完成時間亦由 28.03 天縮短到 12.5 天， Finally to input all the numbers and data into the integer programming model and look for the optimal workforce assignment and expect the smooth operation of the FSM for the five purchase orders. The result shows that under the arrangement of optimal workforce assignment, the utilization rate moves from 41.4% up to 91.6% and the total day consumption shorten from 28.03 down to 12.5 days.

圖 3 A 系列中型機的未來價值流圖

Drawing three the FSM for the medium size of series B

5 條主線 20 個副線獨立製程 five main production lines twenty sublines and independent manufacturing process

表 1 個案情境改善前後各指標數據表

Chart 1 the indications of befroe&after the improvement in the case of scenario

指標 index	改善前 before improvement	改善後 after improvement
1.完成時間 time to finish	28.03 天 28.3 days	12.5 天 12.5 days
2.總人工時(含副線) total manual working hours	116.05 天 116.05 days	114.5 天 114 days

3.聘僱人力 the numbers of people hired	10	10
4.人員稼動率 the utilization rate for the people	41.4%	91.6%

CONCLUSION

利用精實七大準則去改善工具機的製程，區分主線和副線生產，由未來價值流圖縮短產品所需總完工時間，由主線製程時間來決定交期，當多個不同機型的未來價值流圖同步運行下，主線人員的指派問題為決定交期的關鍵，因為工具機產業不易培養多能工，必須將適當的人員指定到合適的製程才能落實多線未來價值流圖能暢流。本研究使用整數規劃建立人員最佳化指派模型，解決精實生產應用在工具機製程時，各站製程時間和人力調度無法配合的問題，由個案結果發現，本研究所提出之方法具實務可行性，可提供中小企業在有限人力資源下，逐步落實精實生產的方法。

To adopt the lean seven principles to improve the manufacturing process in the machine tool industry and to categorize the main line and the sub line. Also to use FSM to shorten the required days to accomplish the production and to use the time consumption in the main line to decide the delivery day. When the FSM for numbers of the model run simultaneously, the persons who are assigned to work in the mainline becomes a critical point, because it is hard to cultivate employees with multiple techniques in the machine tool industry, the right persons have to be assigned correctly to carry out the function of multiple lines of FSM running smoothly. The research uses the integer programing to build up the model of yielding the optimal workforce assignment and resolving the issue of having trouble to work accordingly among all the manufacturing processes and the allocation of the

workforce. The result of the research is very favorable with good feasibility and potential which may help the small to medium size of business to work on the lean production within the constraint of the workforce