A Mathematical Model for Converting Conveyor Assembly Line to Cellular Manufacturing

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Abstract. This paper proposes a mathematical model for converting conveyor assembly line to cellular manufacturing in complex production environments. Complex production environments refer to the situations with multi-products, variant demand, different batch sizes and the worker abilities varying with work stations and products respectively. The model proposed in this paper aims to determine (1) how many cells should be formatted; (2) how many workers should be assigned in each cell; (3) and how many workers should be rested in shortened conveyor line when a conveyor assembly line should be converted, in order to optimize system performances which are defined as the total throughput time and total labor power. We refer the model to a new production system. Such model can be used as an evaluation tool in the cases of (i) when a company wants to change its production system (usually a belt conveyor line) to a new one (including cell manufacturing); (ii) when a company wants to evaluate the performance of its converted system. Simulation experiments based on the data collected from the previous documents are used to estimate the marginal impact that each factor change has had on the estimated performance improvement resulting from the conversion.

Keywords: Line-cell Conversion, Cellular Manufacturing, Conveyor Assembly Line, Mathematical model

1. INTRODUCTION

Cellular manufacturing (CM) is a manufacturing system in which one (or multiple) worker carries out all of the operations of a job, usually in a U-shaped layout. Since it seems to be able to improve system performance in a changing environment, many Japanese companies have introduced CM into their factories to convert existent conveyor assembly line (CAL). An early document about such line-cell conversion was reported by Tsuru (1998), which is based on a questionnaire of 13 factories and one consulting company. These anonymous
factories converged in electronic and automobile industries. The main standpoint of the document claimed that CM can be recognized as a form of the knowledge of Toyota Production System which has been historically transferred to other industries. In recent years, after many Japanese companies shifted their production organizations to China, those manufacturers left behind in Japan have been changing their production ways remarkably. Several manufacturing methods have been developed for strengthening their competitive power of the domestic companies. In addition, instead conveyor mass production, only the products what suited the needs of customers (the kinds of products are changing dynamically) should be manufactured flexibly when they were needed (the production quantities are also variables). For example, Tanaka (2005) reported that there are seven manufacturing methods have been used to correspond so-called new manufacturing in RICOH UNITECHNO Inc., which is a middle scale Japanese company to manufacture facsimiles/copy machines/printers. Those methods are as follows: (1) One worker-One machine method (the product will be assembled by only one worker, he should do all of the assembly operations); (2) Two workers-One machine method (there are too operational works to assemble for a larger machine that can not complete by one worker, in such case two workers should be assigned to do this assembly operation); (3) Cart pulling method (instead conveyor line a cart is used as transport tool, which is pulled among several workers to complete the assembly operations); (4) Relay method (the form of assembly line is existed but the workers assigned in the line do not only those operations for themselves but also the operations not assigned for them, by their operation ability); (5) Conveyor assembly line (traditional assembly method is also remained for those large lot size products); (6) One worker CM (only one worker does all of the assembly operations of products usually in a U-shaped layout. The difference with method (1) is that the worker in the CM can do all of assembly operations of several products, that means he has a higher operation ability); (7) Division CM (several workers are assigned in one cell, they may do the assembly operations using the methods of (3), (4) or (6)). Those methods and their combinations are used to correspond flexibly different kinds (over 400 kinds of products) and different quantities (70% of products are under 100 units/month) of products, and successful performances were gained. It should be pointed that all of these innovations in Japan industries are based on the reflection of mass conveyor manufacturing and are for searching more effective production systems. Converting old conveyor assembly line to new manufacturing systems are not the goal but only the ways and means to increase the productivity of companies. A tremendous achievement of such conversion is brought from CANON Inc., a famous Japanese electronic company. Takahashi, Tamiya and Tahoku (2003) reported that by introducing CM into their factories in CANON, since 1995 there are over 20,000 meters of belt conveyor have been withdrawn and 720,000 square meters of working space from 54 related factories were emptied. The total cost rate was decreased from 62% to 50% during past eight years. Since then converting CAL to Japanese manufacturers is coming into fashion. Yin, Kaku and Murase (2006) pointed out the economic background of converting CAL to CM in Japan based on a survey of last Japanese literature. Summarily, Japanese manufacturers were faced with a decreased market demands and increased product variations. To survive in such an extremely tough business environment, the traditional high-volume conveyor assembly lines were no longer fulfilled. Speedy adjustments were needed to handle transitions in product models and demands. A company’s competitiveness was becoming dependent on whether or not it can respond to these transitions. In such an environment, there was a trend in Japanese industries toward converting conveyor assembly lines to more flexible manufacturing cells.

Basically, the term of CM is not a new concept. Over the previous decade, a series of research articles have investigated CM systems and compared the performance of traditional function layout and CM systems. For example, Wemmerlöv and Hyer (1989), Wemmerlöv and Johnson (1997), Johnson (2005) claimed that CM represents a major technological innovation to many manufacturing systems traditionally based on functional or assembly specialization. As a result, many manufacturing organizations with traditional function layout manufacturing systems have either already adopted CM or are considering their adoption. Sakazume (2005) investigated a survey of Japanese literature that included total 107 documents (12 academics, 18 technical reports and 77 newspaper articles). Through comparing their advantages and disadvantages, he tried to explain that the so-called American Cellular Manufacturing (from traditional function layout to cells) and Japanese Cell Manufacturing (from belt conveyor line to cells) are completely different in term of implementation changes and mechanisms, even through there are some similarities in term of cell features and implementation. Johnson (2005) used a previous theory to explain why the assembly cells are expected to outperform the current assembly line. He investigated simulation models to estimate the marginal impact that the operational factor change had on the estimated performance improvement resulting from the conversion. Kaku, Murase and Yin (2008) proposed a theoretical model of the conversion involved human factors. Because the performance improvement resulting from the conversion is dependent on those operating factors that can improve the system performance and overcome any task time increases caused by the loss of worker specialization, the cross-training of workers should be considered to be a key issue in the conversion. They investigated a theoretical model to analyze the cross-training of workers quantitatively by using human memory ability and to suggest that infor-