A Simulation-based Performance Comparison between Multi-Model Assembly Lines and Assembly Cells in a Just-In-Time Environment

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Abstract: In many manufacturing plants assembly lines(AL) are converted to assembly cells(AC) for satisfying the increasing market demand for shorter product delivery lead times, customization, and just-in-time(JIT) manufacturing in particular. Previous research is focused to compare two kinds of systems with some goals, such as average batch flow time and utilization rates. This research compares a multi-model assembly line (MMAL) and AC with the usage rate of all parts fed into the assembly system as constant as possible in a (JIT) environment, which is called the level-scheduling problem. Firstly, the level scheduling models in each manufacturing system are proposed for computing the performance values. Then, simulation experiments are conducted to compare the performance of MMAL and AC configurations. Operating environments vary by the ratio of product types (models) to product batches. The results indicate that AC is better than MMAL with the larger ratio. The conclusions highlight guidelines for practicing managers on the most appropriate system under a given set of operating conditions.

Key Words: Assembly Cells, Multi-model Assembly Lines, Level Scheduling, Just-In-Time, Mean Usage Parts

1 INTRODUCTION

As consumption patterns become increasingly sophisticated, manufacturers must strive to improve their competitiveness by offering higher quality and at competitive costs and providing broader mix of products. An alternative production system called assembly cells production system is an optional approach for many leading manufacturers. Since mid-1990s, many manufacturers have shifted the belt conveyor lines to work-cell based assembly systems to cope with increasing demand variation. Manufacturing cells are gaining in popularity as a way to achieve these goals which have been shown to improve manufacturing performance, such as throughput time, work-in-process inventory, finished goods inventory, product quality, and response time to customer orders in some product assembly environments [1].

Previous research has discussed the trends and conditions for successful implementation of assembly cells [2], and has compared assembly cells with traditional assembly line manufacturing systems [3-4]. In contrast, research on the comparison between a multi-model assembly line and assembly cells in just-in-time environments is relatively sparse.

Benefits of successful JIT production systems implementations are well-documented, such as less inventory, shorter lead times, improved responsiveness, and etc. The application of JIT concept has been facilitated by leveling the usage rates of all parts in the assembly line systems [5]. However, the research about this performance of assembly cells systems is relatively sparse.

This study adds to the sparse literature in this area by the mean part usage performance comparison between MMAL and AC. The conclusions highlight guidelines for practicing managers on the most appropriate system under the JIT manufacturing environment.

The remainder of this paper is divided into the following sections: Section 2 provides a literature review, section 3 describes the formulation of the problem, section 4 provides the numerical simulation experiments and results, and the last section presents the conclusions.

2 LITERATURE REVIEW

Assembly lines are a special flow-line production system which is very typical in the industrial production high quantity standardized commodities [6-7]. However, nowadays the requirements for production systems have changed dramatically. Short product delivery lead times, shorter product life cycles, and increasing demand for customization have reduced the viability of holding finished goods inventory as a way to meet these requirements. These demands require that systems can quickly manufacture, assemble and deliver small batches of customized products in a cost-effective manner. To enable such a highly diversified product portfolio without jeopardizing the benefits of an efficient flow-production, some alternative production systems, such as multi-model assembly lines and assembly cells, are developed in last decades.

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In a multi-model assembly line, several (similar) products are manufactured. Because of significant differences in the production processes, rearrangements of the line equipment are required when product changes occur. Consequently, the products are assembled in separate batches in order to minimize set-up inefficiencies. When set-up costs are reduced by enlarging batch sizes, inventory costs are increased. This trade-off leads to the problem of determining economic lot sizes and production cycles of all products. Simultaneously, the product batches have to be scheduled on the line. Hence, a combined lot sizing and scheduling problems has to be considered [8-9].

The concept of assembly cells was formed [10]. The first definition is that a small organizational unit which completes all assemblies in a continuous flow and provides with all the facilities it needs to do so. In addition, the problem about multi-objective design of team oriented assembly systems (assembly cells) based on previous researches was also addressed [11].

In practice, a number of companies in European and Japan have implemented assembly cells production system, such as Phillips, Volvo, Canon, and Sony [10, 12]. These instances highlighted the advantages of such assembly cellular layouts over traditional assembly line.

Some researches began to compare both systems and identify factors influencing performance through the simulation experiments. Sengupta (2004) compared two different cellular systems with an unpaced, mixed-model assembly line [4]. Mean flow time of end-item products as a primary comparison measure was used. The results indicated that specialized workers with assembly lines are preferable under low variance, low setup scenarios. Cellular systems are preferable when team working is efficient and under scenarios with higher variances and setup times. Johnson (2005) examined the effects on a planned conversion from a multi-model assembly line to a set of parallel assembly cells in a real plant [3]. Simulation models based on data collected from the plant were then used to estimate the marginal impact. Two comparison measures are average cycle time and average batch flow time respectively. Despite of the overwhelming performance improvements projected to occur from the use of assembly cells in that plant, the results did not mean that assembly cells should be used in all situations. Canel (2005) compared a focused cellular manufacturing (FCM) environment with traditional cellular manufacturing (CM) with three performance criteria including average end-item completion times (AEICT), average work-in-process inventory (AWIP), and average component flow time (ACFT). The results indicated that The FCM schema experiences shorter assembly waiting time since all components of an end-item are processed together in a single cell [1]. Kaku (2009) defined a line-cell conversion problem and constructed a mathematical model to describe it. The total throughput time and total labor power were used to compare both systems [13].

However, the comparison with just-in-time objectives between multi-model assembly and assembly cells isn't yet discussed. This new study adds to the sparse literature in this area by comparing smoothen capacity utilization of material between a multi-model assembly line and assembly cells with JIT-philosophy. The results will help manufacturers to implement this new production system.

3 DETAILED PROBLEM DESCRIPTION

In this section two mathematical models are developed for level scheduling in a multi-model assembly line system and an assembly cells system, respectively. Throughout this paper the following assumptions with regard to the delivery of parts are introduced:

(a) Multiple product batches are included in a production plan. The type of all products is the same in a batch. The product types in different batches are possibly different. Each batch size is possibly different.

(b) There are several parallel identical cells in the assembly cell manufacturing system. Each worker has been cross-trained for being able to finish all assembly tasks on every product. Each batch is just allowed to be processed in a cell.

(c) The assembly line production system is a multi-model assembly line which is synchronous, and the buffers are not considered.

3.1 Notations

The following terms are used in the level scheduling model in two manufacturing systems:

● Indices

i : Index set of products. $(i = 1,2,...,I)$.

j : Index set of parts. $(j = 1,2,...,J)$

k : Index set of product batches. $(k = 1,2,...,K)$.

m : Index set of cells. $(m = 1,2,...,M)$

● Parameters

d_k : Size of product batch k.

a_{ki} : A 0-1 binary variable where $a_{ki} = 1$, if product i is included in batch k ; otherwise 0.

b_{ji} : Quantity of part j assembled for product i.

● Decision variables

$X_{kmt} = 1$, if batch k is assembled in cycle t in the cell m ; otherwise is 0.

$Y_{kt} = 1$, if batch k is assembled in cycle t on the assembly line; otherwise is 0.

3.2 Problem formulation

The mathematical program model as an extension of the traditional output rate variation(ORV) problem, which can be described as follows: Consider a set K of batches (models) each of which having a demand d_k for copies of batch k to be produced during a specific period (e.g. one day or shift), which is further divided into T production cycles with $\sum_k d_k = T$. The production coefficients b_{ji} specify the number of units of parts j required for the assembly of one unit of product i. The matrix of coefficients $B = (b_{ji})$ is usually referred to as bill of material.

3.2.1 Level scheduling of multi-model assembly lines

By means of the total demand for part j required by all copies of all batches k throughout the planning horizon, the target demand rates per production cycle r_j are calculated as follows:

$$r_j = \frac{\sum_{k=1}^{K}\sum_{i=1}^{I} b_{ji} a_{ki} d_k}{T} \quad (1)$$

The produced quantities of all batches up to cycle t directly determine the cumulative demand S_{jt} for all parts j of the respective partial schedule:

$$s_{jt} = \sum_{t'=1}^{t}\sum_{k=1}^{K}\sum_{i=1}^{I} a_{ki} b_{ji} Y_{kt'}$$

(2)

This problem can be modeled as follows:

$$\text{Minimize } Z_1 = \sum_{t=1}^{T} \sqrt{\sum_{j=1}^{J} (t \cdot r_j - s_{jt})^2}$$

(3)

$$\sum_{k=1}^{K} Y_{kt} = 1 \quad \forall t = 1,2,...T$$

(4)

$$\sum_{t=1}^{T} Y_{kt} = d_k \quad \forall k = 1,2,...K$$

(5)

$$0 \le Y_{kt} - Y_{k(t-1)} \le 1 \quad \forall k = 1,2,...,K; t = 2,...,T \quad (6)$$

Objective function (3) minimizes the square root of the squared deviation of all actual parts demands from the equally distributed target demands accumulated over all cycles t. Constraints (4) force exactly one unit of a single batch in each cycle t to be produced, whereas constraints (5) ensure production quantities of batch k are equal to the required quantities. Constraints (6) ensure that cumulative production quantities increase monotonically throughput the planning horizon.

3.2.2 Level scheduling of multi-model assembly cells

Consider a set k of batches (models) to be produced in the cell m during a specific period (e.g. one day or shift), which is further divided into TC_m production cycles with $\sum_{k=1}^{K}\sum_{t=1}^{T} X_{kmt} = TC_m$. By means of the total demand for part j required by all copies of all batches k in the cell m throughout the planning horizon, the target demand rates per production cycle rc_{jm} in the cell m are calculated as follows:

$$rc_{jm} = \frac{\sum_{t=1}^{TC_m}\sum_{k=1}^{K}\sum_{i=1}^{I} b_{ji} a_{kj} X_{kmt}}{TC_m} \quad (7)$$

The produced quantities of all batches up to cycle t directly determine the cumulative demand SC_{jmt} in the cell m for all parts j of the respective partial schedule:

$$sc_{jmt} = \sum_{t'=1}^{t}\sum_{k=1}^{K}\sum_{i=1}^{I} a_{ki} b_{ji} X_{kmt'} \quad (8)$$

This problem in the cells can be modeled as follows:

$$\text{Minimize } Z_2 = \sum_{m=1}^{M}\sum_{t=1}^{TC_m} \sqrt{\sum_{j=1}^{J} (t \cdot rc_{jm} - s_{jmt})^2} \quad (9)$$

$$\sum_{k=1}^{K} X_{kmt} = 1 \quad \forall t = 1,2,...TC_m; \forall m = 1,2,...M \quad (10)$$

$$\sum_{m=1}^{M}\sum_{t=1}^{TC_m} X_{kmt} = d_k \quad \forall k = 1,2,...K \quad (11)$$

$$0 \le X_{kmt} - X_{km(t-1)} \le 1$$
$$\forall m = 1,2,...,M; t = 2,...,TC_m; k = 1,2,..,K \quad (12)$$

Objective function (9) minimizes the cumulative square root of the squared deviation of all actual parts demands from the equally distributed target demands in all cells accumulated over all cycles. Constraints (10) force exactly one unit of a single batch in each cycle t in the cell m to be produced, whereas constraints (11) ensure production quantities of batch k are equal to the required quantities. Constraints (12) ensure that cumulative production quantities increase monotonically throughput the planning horizon in each cell.

4 Computational study

For a given number of batches and cells, the objective functions are not linear but bounded. Toyota Motor Company's goal chasing algorithm I is used for simulation. The purpose of this paper is to compare the just-in-time performances of AC and MMAL under complex production environments. We do numerical experiments to simulate the effects of each of factors influenced on the performance of production system based on the model proposed above.

For comparison of the performance between AC and AL, the percentage changes are defined as below:

$$\%\ \textit{Difference} = \frac{Z_1(\delta_L^*) - Z_2(\delta_C^*)}{Z_1(\delta_L^*)} \times 100$$

Where δ_L^* is the optimal sequence for MMAL system, δ_C^* is the optimal sequence for AC system, and Z_1 and Z_2 are the objective function values of the parts usage goals, respectively.

The number of cells is 4. For simplicity, each set of assembly part at a station will be different and only one part type. The number of station is fixed at 8 units. Hence, the number of part type is also 8. The number of product type is 8. The total demand of parts is 200 units. The number of parts in each station is generated according to normal distribution $\mu = 10$ and $\sigma = 1$. The generating seed of each product type is different. The product type of batches is generated by orderly circulation. The number of runs needed would be 8. There are 10 replications per simulation run in order to achieve batch independence. Different production plans and results are listed in Table1, Table2 and figure1, where the performance values are averaged.

Table 1 Mean part usage for assembly line and assembly cells with fixed number of types

Simulation No	*Number of Batches*	*Number of types(models)*	*Types distribution*	*MMAL* (Z_1)	*AC* (Z_2)	*%Difference*
1	8	8	8/8=1	74	15.134	79.5%
2	10	8	8/10=0.8	49	10.23	79.1%
3	20	8	8/20=0.4	25	6.82	72.7%
4	50	8	8/50=0.16	8	5.725	28.4%

able 2 Mean part usage for assembly line and assembly cells with fixed number of batches

Simulation No	*Number of Batches*	*Number of types(models)*	*Types distribution*	*MMAL* (Z_1)	*AC* (Z_2)	*%Difference*
5	25	25	25/25=1	37	15.99	56.8%
6	25	20	20/25=0.8	28	12.36	55.9%
7	25	10	10/25=0.4	22	12.052	45.2%
8	25	4	4/25=0.16	16	10.235	36.0%

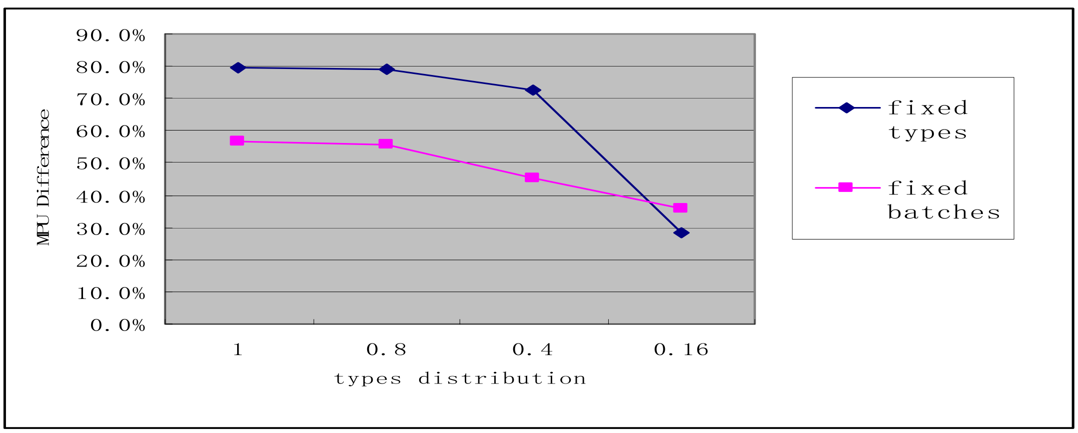

Figure 1 Difference of mean part usage over different type distributions

From Table 1 and Table 2, we can conclude the following:

- When the total demand is fixed, the mean parts usage decreases as batch size decreases in both assembly systems (Table1).
- When the batch size is fixed, the mean parts usage increases as product types increases in both systems, but the increasing range in AC is bigger than that in MMAL (Table2).
- Comparing the values of solving results reveals that results obtained from assembly cells are better than those of assembly lines under the multi-product scenarios (Figure 1).

In summary, for the companies who have had belt conveyor assembly line to manufacture their products, when the production environment is changing to more product types, level scheduling in the assembly cells system will present more flexibility to absorb the fluctuations of parts brought out from different product types.

5 CONCLUSIONS

An assembly cells manufacturing system is a kind of production system which is comparably suitable to higher variety, lower volume product demand, and the application of JIT concept. The most important contribution of this study is that two level scheduling models for multi-model assembly line and assembly cells in the batch production are proposed. In addition, the simulation-based performance comparison between both systems is done with Toyota Motor Company's goal chasing algorithm I.

There are still several research works to be investigated in the future. The optimal calculating algorithms should be developed for solving practical size problems. Because the problem is NP hard, Meta algorithms (e.g., GA) also should be developed to overcome the limit of optimization methods. In addition, the comparison in a real time environment between mixed-model assembly lines and assembly cells should be developed to present their uncertainty capability.

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