An Investigation of Production Line with a Bottleneck Operation under Different Manufacturing Strategies

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Abstract

Bottleneck resources are the major contributor to a limitation of the throughput of the whole production processes. In order to select the appropriate manufacturing system to fit a particular operation line, it is essential to carry out extensive investigation and comparison on the performance of each strategy. This paper intends to apply four main different manufacturing strategies, namely, push, pull, OPT and hybrid between push and pull strategies to a production line with a bottleneck operation. A comparative simulation study is carried out in order to suggest the appropriate manufacturing strategy and recommend important decision variables which may influence the performance of the production line. Results from the study reveals an interesting outcome, giving the best alternative for the production line with a bottleneck operation.

1. Introduction

Production optimisation is the main concern in any operation line since it seeks to achieve satisfactory production capacity under limited resources. To survive the environment where customers require prompt deliveries, a company needs sufficient flexibility to react immediately to changes in demand. To minimise the throughput time, it is necessary to find the core factor which impedes the production line. Bottleneck resource is often the contributor to such tardiness. In order to improve the production performance, the whole production process must be carefully studied and bottleneck resource must be identified. Several manufacturing strategies have been introduced to improve the efficiency of the production line. Each system has its own method of approach as well as advantages and disadvantages over one another. The question now lays within the matter of whether one manufacturing strategy is more effective and suitable to a certain situation than the others.

2. Bottleneck analysis

Bottleneck is defined as a point in the manufacturing process that holds down the amount of product that a factory can produce [1]. It causes the inability of a system to respond to sudden changes in the demand as a result of capacity restrictions. Even though undesirable, with our limited financial budget, the bottleneck may be difficult to avoid. Thus, alleviation such problem requires not only an explicit understanding of the entire process, but also a powerful production control system. Interest in bottleneck scheduling is a result of the development and aggressive marketing of a proprietary production scheduling system known as Optimised Production Technology (OPT) [2]. The OPT approach focuses on identifying bottlenecks in a manufacturing process and intensively scheduling these bottleneck resource to improve shop performance. Under the nine principles of OPT [3], better use of limited capacity is achieved by finite scheduling of bottleneck operations and the use of increased processing batch size through those bottleneck resources.

Just-in-time and pull strategy is another alternative that can be used to solve bottleneck problems. In essence, JIT organises all operations so they occur just at the time they are needed [4]. This means that if materials are needed for production, they are not bought some time in advance and kept in stock, but are delivered directly to the production process just as they are needed. The result is that stocks of materials including those in front of bottleneck resources can be greatly reduced.

Olhager and Ostlund [5] have studied the integration of pull-push system as part of a manufacturing strategy. The bottleneck resource is used as the integration and customer order point (COP). Results from their case study illustrate a success integration through the reduction of lead time. A push principle is applied to the focused machine and succeeding production stages and incoming parts are pulled. However, from their findings, there is no comparison with other strategies and further attention is also recommended.

Thus, in order for a production line to be fully effective, the whole system should be thoroughly studied so as to identify the bottleneck resource. Then, appropriate manufacturing strategy should be implemented. However, the decision of selecting the right strategy requires extensive investigation of the performance of each strategy. Advantages and drawbacks of the strategies should be put into consideration and the comparison should be evaluated on the same basis.

3. General model pattern

Owing to the complexity of the problem studied, simulation is used as the problem-solving methodology in this study. Simulation has the capability in modelling a process in such a way that the model mimics the response of the actual system that takes place over time. Advantages and drawbacks of using simulation can be seen from Law and Kelton [6]. Due to the existence of various manufacturing strategies, four main groups of strategy can be distinguished in this study, namely, push, pull, OPT and integrated or hybrid push-pull strategies. Characteristics of these four main manufacturing strategies can be described as follows.

3.1 Push system

This is the simplest system, which may be expected to be the most vulnerable system to the outcomes of the bottleneck operation. When parts or products arrive in the system, they enter machines in sequential order, i.e.

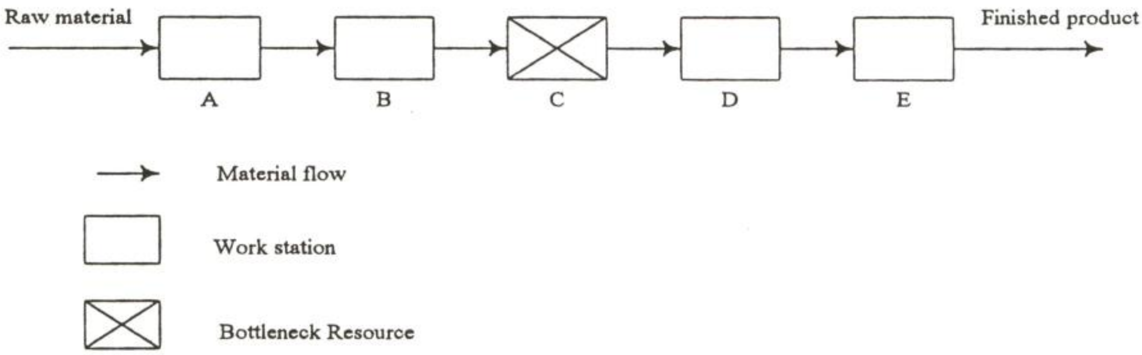

Fig. 1 Push system.

from machine A to E. The illustration of the push system is shown in Fig. 1.

3.2 Pull system

In the pull model, the system operates under a *"pull"* production strategy whereby work is only performed at a workstation when there is a downstream request for the work. Work is initiated at the last workstation (machine E) by the arrival of demand from customers (see Fig. 2). When such request arrives, machine E issues a request to the previous machine D and from D to C and so on. Number of kanbans being stocked in each workstation as means of reducing production delays from starvation are set from the machine utilisation of the bottleneck operation. From preliminary simulation runs and calculations, minimum number of kanbans to avoid starvation is 3 for the high shop utilisation situation and 2 for the low shop utilisation situation while the size of kanban containers is set at 5 items.

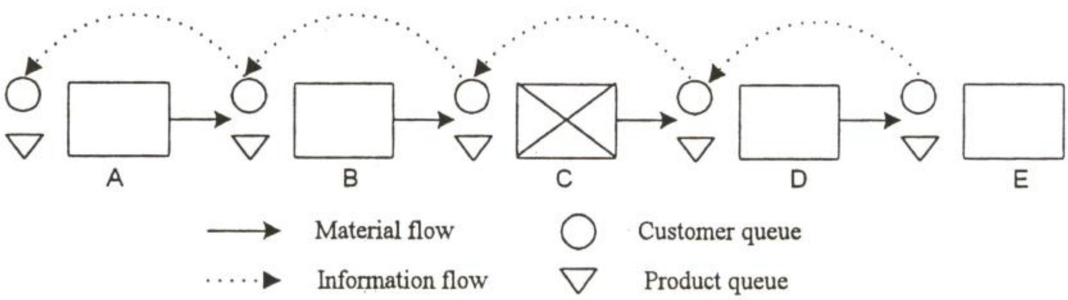

Fig. 2 Pull system.

3.3 System with OPT concept

Since backward scheduling is not considered in this study (due-date is not considered), only partial OPT strategy can be implemented. Strategic buffer is placed in front of the bottleneck resource (machine C) in order to prevent the machine from starvation and thus maximise the machine utilisation. To minimise the set up time at the bottleneck resource, the products which are released from the machine prior to machine C are bound to combine with another group of products of the same product type, which are waiting in the buffer queue, before being operated by machine C. The illustration of a partial OPT system is shown in Fig. 3. To determine the efficiency of the OPT system, the model is therefore divided into two separate models having two levels of the combination of batch sizes operating through the bottleneck, namely, OPT1 and OPT2. In OPT1, the new processing batch size of products waiting to be operated by the bottleneck resource is twice as large as the original batch size. In OPT2, however, the new batch size is 3 times larger than the original batch size.

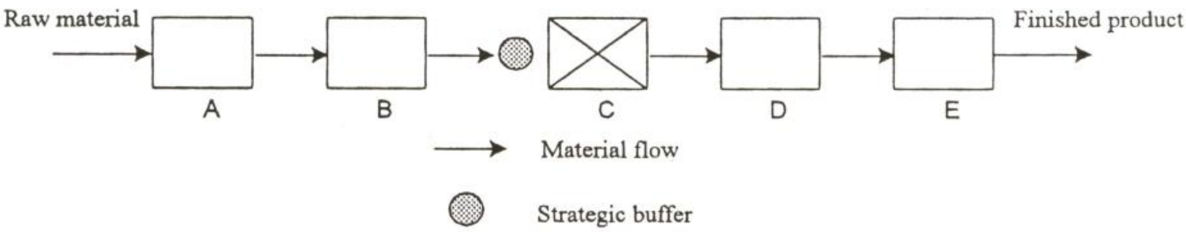

Fig. 3 OPT concept.

3.4 Integrated push-pull system

The integrated push-pull model combines the concept of push and pull systems together. By applying the integrated system concept from Olhager and Ostund [5] who consider the bottleneck resource as an integrated point, there are, in fact, two possible ways of implementing the integrated push-pull concept into this production line. Considering the bottleneck operation, the first way is to apply the push policy to the first two workstations and pull policy to the remaining three workstations (Fig. 4). Another possible way, which is the opposite to the first, is to carry out the pull policy to the first two workstations and then followed by the push policy to the other workstations (Fig. 5). The push-pull strategy considers the customer order point (COP) at the last workstation due to the pull system operating later. When an order arrives, it will try to match with the same parts in machine E's kanban queue and, at the same time, activate the release of raw material to the first workstation. If required parts are available, a signal can be sent to the upstream workstation asking for the replenishment of the parts just taken. The process of the pull strategy is operated up to the bottleneck operation. The pull-push strategy, on the other hand, considers the station just before the bottleneck operation as the customer order point. Thus, the bottleneck and succeeding stages are operating under the push strategy.

4. Experimental plan

All models are developed using SIMAN simulation language [7]. Regardless of the manufacturing strategies implemented, they are based on the same operation line involving five workstations and four different product types arriving with equal probability. To create the bottleneck operation, each product type has different sequence routings in which all product types attend machine C

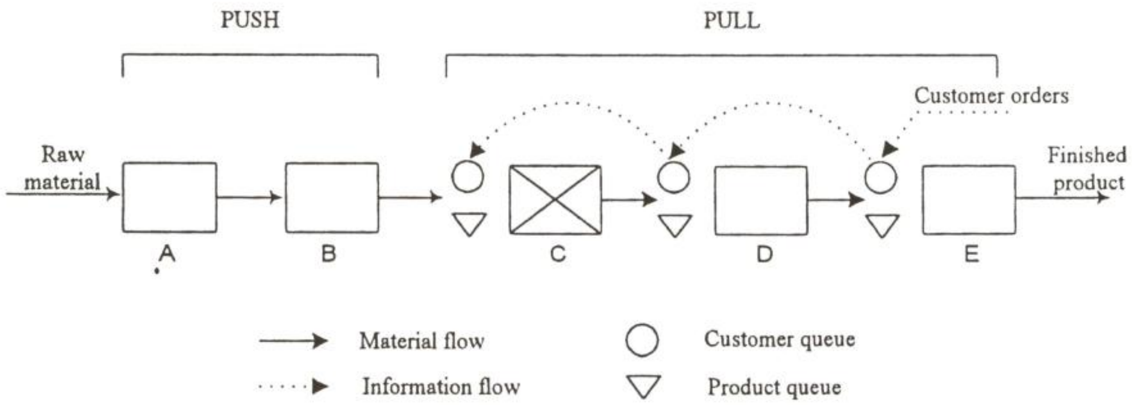

Fig. 4 Push-Pull system.

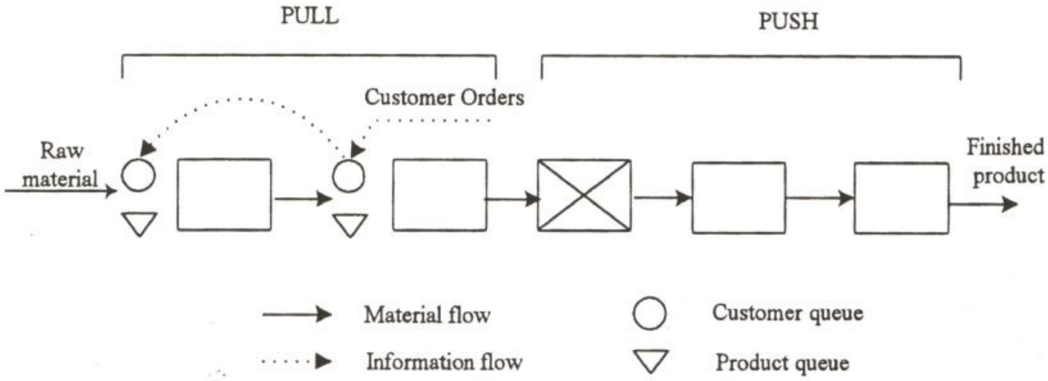

Fig. 5 Pull-Push system.

(the bottleneck operation in this case). Under a make-to-order type production, an order (batch of 5 equally set to the size of kanban containers to avoid bias towards the pull system) arrives in the system with a mean of 35 and 60 minutes exponentially distributed. The mean interarrival time of every 35 minutes indicates high shop utilisation situation (average shop utilisation higher than 65%) and 60 minutes indicates low shop utilisation (average shop utilisation lower than 45%). There will be a set up if the succeeding part is not the same as the previous part operated. In the base case, the operation time of machines follows triangular distribution with the minimum value of 4, mode of 5 and maximum value of 6 minutes.

Simulate this model for a replication length of 150,000 minutes of 10 replications (which yields the width of mean flow time for all policies within 5% of their means under 95% confidence level) and record statistics on average process waiting time at bottleneck, total process waiting time of the production line, average job flow time and number of finished jobs. Controlled variables used during simulation runs for experimenting the severity of the bottleneck are the order interarrival time (exponential 35 and 60 minutes), the ratio between machine operation time and set-up time (1:0, 1:0.5, 1:1.0 and 1:1.5) and the ratio between the production time of the non-bottleneck resource and that of the bottleneck resource (1:1, 1:1.5 and 1.2).

5. Results and discussion

The results from four performance measures obtained from the different strategies are now compared. These four performance measures are:

- Average flow time: to measure average amount of time that a system can respond to a customer order.

- Number of completed jobs: to measure number of finished jobs under the controlled timing period.

- Average process waiting time at the bottleneck operation (machine C): to measure average amount of time that parts spend waiting for operation at the bottleneck.

- Total process waiting time: to measure total amount of time that parts spend waiting for operations (just in case that more than one bottleneck is created).

Analysis of Variance (ANOVA) is used to analyse the significant difference among these results under 95% confidence level. The overall results reveal that the ratio of set-up time, the ratio of machine operation time and their interaction have significant effect to all performance measures of the production line studied. Tables 1-4 summarise the comparative results from all strategies according to the combination of the controlled variables. The left-hand-most number in the ranking column is the best policy with the minimum time and the right-hand-most number is the worst policy, consuming the most time. In general, the results are divided into two main classes, which are the low shop utilisation class where the severity of bottleneck is not so critical and the high shop utilisation class where the severity of bottleneck is quite critical.

Table 1 Average flow time

Low shop utilisation			High shop utilisation		
Policy	Significance	Ranking*	Policy	Significance	Ranking*
1:0.0-1:1.0**	✓	2,5,1,6,3,4	1:0.0-1:1.0**	✓	2,5,1,6,3,4
1:1.5	✓	2,5,1,6,3,4	1:1.5	✓	2,5,1,6,3,4
1:2.0	✓	5,2,1,6,3,4	1:2.0	✓	2,1,6,3,4,5
1:0.5-1:1.0	✓	5,2,1,6,3,4	1:0.5-1:1.0	✓	2,5,1,6,3,4
1:1.5	✓	2,5,1,6,3,4	1:1.5	✓	2,5,4,1,3,6
1:2.0	✓	2,5,1,6,3,4	1:2.0	✓	4,2,5,3,1,6
1:1.0-1:1.0	✓	5,2,1,6,3,4	1:1.0-1:1.0	✓	2,5,1,6,3,4
1:1.5	✓	5,2,1,6,3,4	1:1.5	✓	4,3,1,6,5,2
1:2.0	✓	2,5,1,6,3,4	1:2.0	✓	4,3,5,2,1,6
1:1.5-1:1.0	✓	5,2,1,6,3,4	1:1.5-1:1.0	✓	4,2,5,1,3,6
1:1.5	✓	5,2,1,6,3,4	1:1.5	✓	4,3,2,6,5,1
1:2.0	✓	5,2,1,6,3,4	1:2.0	✓	4,3,2,5,1,6

* 1 = push, 2 = pull, 3 = OPT1, 4 = OPT2, 5 = push-pull and 6 = pull-push

** ratio between machine operation time and set-up time (1:0, 1:0.5, 1:1.0 and 1:1.5) - ratio between the production time of the non-bottleneck resource and that of the bottleneck resource (1:1, 1:1.5 and 1:2).

Table 2 Average process waiting time at bottleneck (machine C)

Low shop utilisation		
Policy	Significance	Ranking*
1:0.0-1:1.0	✓	6,1,5,2,3,4
1:1.5	✓	6,1,5,2,3,4
1:2.0	✓	5,2,1,6,3,4
1:0.5-1:1.0	✓	6,1,5,2,3,4
1:1.5	✓	6,1,5,2,3,4
1:2.0	✓	5,2,6,1,3,4
1:1.0-1:1.0	✓	6,1,5,2,3,4
1:1.5	✓	6,1,5,2,3,4
1:2.0	✓	5,2,3,6,1,4
1:1.5-1:1.0	✓	6,1,5,2,3,4
1:1.5	✓	1,6,2,5,3,4
1:2.0	✓	5,2,3,4,6,1

High shop utilisation		
Policy	Significance	Ranking*
1:0.0-1:1.0	✓	6,1,5,2,3,4
1:1.5	✓	5,2,1,6,3,4
1:2.0	✓	5,2,1,6,3,4
1:0.5-1:1.0	✓	6,5,2,3,1,4
1:1.5	✓	2,5,4,3,6,1
1:2.0	✓	2,5,4,3,1,6
1:1.0-1:1.0	✓	5,2,6,4,3,1
1:1.5	✓	5,2,4,3,1,6
1:2.0	✓	5,2,6,4,3,1
1:1.5-1:1.0	✓	5,2,4,3,6,1
1:1.5	✓	2,5,4,3,1,6
1:2.0	✓	2,5,4,3,6,1

* 1 = push, 2 = pull, 3 = OPT1, 4 = OPT2, 5 = push-pull and 6 = pull-push

Table 3 Total process waiting time

Low shop utilisation		
Policy	Significance	Ranking*
1:0.0-1:1.0	✓	1,5,2,3,6,4
1:1.5	✓	1,6,5,2,3,4
1:2.0	✓	2,5,1,6,3,4
1:0.5-1:1.0	✓	1,6,3,5,2,4
1:1.5	✓	1,6,5,2,3,4
1:2.0	✓	2,1,5,6,3,4
1:1.0-1:1.0	✓	1,6,3,5,2,4
1:1.5	✓	1,6,3,5,2,4
1:2.0	✓	2,5,3,1,6,4
1:1.5-1:1.0	✓	1,6,3,5,2,4
1:1.5	✓	1,6,3,5,2,4
1:2.0	✓	2,5,3,4,6,1

High shop utilisation		
Policy	Significance	Ranking*
1:0.0-1:1.0	✓	5,2,1,6,3,4
1:1.5	✓	5,2,1,6,3,4
1:2.0	✓	5,2,1,3,6,4
1:0.5-1:1.0	✓	5,2,3,6,4,1
1:1.5	✓	5,2,4,3,1,6
1:2.0	✓	2,5,3,1,6,4
1:1.0-1:1.0	✓	5,2,3,4,1,6
1:1.5	✓	2,5,4,6,1,3
1:2.0	✓	2,5,4,3,6,1
1:1.5-1:1.0	✓	5,3,2,6,4,1
1:1.5	✓	5,2,4,6,3,1
1:2.0	✓	2,5,3,6,4,1

* 1 = push, 2 = pull, 3 = OPT1, 4 = OPT2, 5 = push-pull and 6 = pull-push

Table 4 Number of finished jobs**

Low shop utilisation		
Policy	Significance	Ranking*
low-1:0.0-1:1.0	✗	–
1:1.5	✓	5,3,1,2,6,4
1:2.0	✓	5,2,3,1,6,4
1:0.5-1:1.0	✗	–
1:1.5	✓	2,5,1,6,3,4
1:2.0	✓	2,5,1,6,3,4
1:1.0-1:1.0	✗	–
1:1.5	✓	5,2,1,6,3,4
1:2.0	✓	5,2,6,1,3,4
1:1.5-1:1.0	✗	–
1:1.5	✓	5,2,1,3,6,4
1:2.0	✓	5,2,3,1,6,4

High shop utilisation		
Policy	Significance	Ranking*
high-1:0.0-1:1.0	✗	–
1:1.5	✓	5,2,3,6,1,4
1:2.0	✓	5,3,2,1,6,4
1:0.5-1:1.0	✗	–
1:1.5	✓	4,3,5,1,6,2
1:2.0	✓	4,3,5,1,6,2
1:1.0-1:1.0	✗	–
1:1.5	✓	4,3,6,1,5,2
1:2.0	✓	4,3,5,6,1,2
1:1.5-1:1.0	✗	–
1:1.5	✓	5,4,1,6,3,2
1:2.0	✓	4,3,5,1,6,2

* 1 = push, 2 = pull, 3 = OPT1, 4 = OPT2, 5 = push-pull and 6 = pull-push

** The strategies are ranked from the maximum number of jobs done to the minimum

According to the results, it can be easily seen that for the **low shop utilisation situation,** the pull system and the push-pull system show the lowest mean flow time and most number of finished jobs. This is due to the kanban containers that the pull system keeps between stations, especially at the downstream stations where the customer order point takes place. Thus, the customers do not have to wait for all the machines to operate on the ordered products. Rather, they only wait for the workstations after the customer order point to process on the products and then the process is said to be completed.

On the other hand, it is not surprising that the pull-push system and the simple push present a lowest process waiting time, both its total and at the bottleneck except when the bottleneck is severe (2 times the non-bottleneck operating time). This may be due to the fact that the flow of production of the push and pull-push (bottleneck operation operates under the push policy) is continuous and smooth with the presence of small bottleneck problem. Both OPT policies (OPT1 and OPT2) which are expected to tackle bottleneck problems have disappointing results for all performance measures. With the implementation of the OPT concept, products form a larger batch size prior to entering the bottleneck operation. When the shop utilisation is low and the bottleneck problem is not so significant, instead of being able to be operated by the bottleneck resource right away, forming a bigger batch causes not only longer processing waiting time but also longer job flow time. This explains why OPT concept is not so well-applicable in operation line with a small bottleneck problem.

However, under the **high shop utilisation** when the problem of bottleneck has become more severe, with the low set-up time ratio, the pull and the push-pull systems (the bottleneck operates under the pull policy) present good results for all performance measures (low job mean flow time, high number of finished jobs and low process waiting time). This may be due to the fact that is stated above in which under the pull system, the bottleneck operation can only be operating when there is a signal from downstream stations. This automatically smoothens the production line by not over-producing work more than necessary and passing on to the bottleneck operation. Thus, it decreases the bottleneck severity and alleviates the long queue awaits in front of the bottleneck resource which can be evident by the low process waiting time at machine C.

But when the shop utilisation is high and the set-up ratio is also high, this operation line with OPT principle turns out to give the lowest mean flow time and OPT2 (with a bigger processing batch) slightly outperforms OPT1. Naturally, when the time spent on setting-up the machine is longer, combining batches of the same product type together can save this set-up time and, eventually, minimise the flow time of the production line. Thus, a reduction in time wasted during the setting up of machine in this case can offset forming time due to the bigger processing batch and have large impact on the overall average flow time of the production line. Finally, as expected, when the problem of bottleneck operation becomes more severe, the worst performance can be seen from the simple push system where works pile up in front of the bottleneck resource.

6. Conclusions

Bottleneck has proved to be the core factor which restricts the performance of the production line. To improve the production line performance, the bottleneck must be identified and the suitable strategy must be implemented. The comparison between the results of different manufacturing strategies in this paper reveals an interesting outcome. One manufacturing strategy may yield good results on one performance measure, but not on the others. This greatly depends on the severity of the bottleneck resource and how busy the production line is. In general, if the shop is not so busy (the severity of bottleneck is not so high), there is no major drawback in operating under the simple push system regarding the bottleneck problem. Otherwise, having the bottleneck operation operating under the pull system has proved to improve overall shop performances. Moreover, the significant effect from operating under OPT system can only be seen when both the utilisation of the shop and the set-up ratio are high. Otherwise, the performance of the shop with OPT generally yields poor results. Thus, the decision of selecting the suitable manufacturing strategy will largely depend on the condition of its bottleneck and the characteristic of shop and its set-up function. The study is also extended to include more controlled variables on the bottleneck resource and different kinds of justification method for quantifying the production line performances under various conditions.

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