

# A Comparative Study of Production Control Systems through Simulation

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*Abstract:* - The purpose of this paper is to simulate pull, push and hybrid production control systems for a single line, multi-stage and continuous production process, which is aluminium casting, in order to compare their performances where the current production control system is push system. The paper also provides an approach in constructing hybrid system by using TSP in minimizing total setup time to obtain optimal sequence of orders.

*Key-Words:* - Production control systems, Pull system, Push system, Hybrid system, Simulation

## 1 Introduction

One of the most important issues for managers of manufacturing companies to decide on is what production control system would be the most appropriate for their companies. The choice is a matter of research and investigation but choosing the right system is a very important competitive advantage for the manufacturing companies.

Production systems are used to control the movement of product through the manufacturing process. A push system is defined by make to stock and a pull system is defined by make to order [1]. Materials resource planning is the best and most classical example to push systems, which uses past information to forecast the customer demands. Much of the discussion in the literature focuses the relative merits of push (e.g., MRP) and pull (e.g., Kanban) systems [2]. In the case of a pull system the best example is Kanban approach. Although the just in time method is gaining popularity, the MRP philosophy is still quite compelling, as it not only incorporates the relationship between end items and components, but also uses forecasts of future demand over a reasonable planning horizon. However, the two philosophies are not necessarily contradictory. Many manufacturing systems incorporate a hybrid of the two [3]. The relationship between MRP/JIT and push/pull strategies, major controversies, and related literature for their comparison and integration are examined in detail by [4].

In the literature one can find studies in which simulation is used as a tool to evaluate and compare the performances of push and pull systems [5] [6] [7]. A hybrid push/pull production control algorithm is developed and tested for use in a multi-stage, multi-line,

assembly-type repetitive manufacturing environment via simulation by [8].

The purpose of this study is to compare the performances of push, pull, and hybrid production control systems for a single line, multi-stage and continuous process using simulation as a tool. The study is inspired by a production scheduling problem in a large aluminium rolling and processing factory in Istanbul. The production process is aluminium casting and the current production control system is a push system.

## 2 Production Process

The production process takes place on a casting line and continuous production is required to avoid reheating a furnace after it cools down since it is a long and costly process. The first operation is the casting operation whereby ingots or slabs of pure aluminium are melted in a furnace. Then, additive elements such as magnesium, vanadium, etc. are added to the furnace in specific amounts, which determine the alloy of the aluminium. The melted metal in the furnace flows through a shaper and a rolling mill (Figure 1).

After the casting operation, to obtain the desired width and thickness, the metal is fed in coil form through a series of cold rolling mills, which successively reduce the metal thickness and recoil it after each rolling pass, getting it ready for the next until the required thickness is obtained. Annealing may be required between passes, depending on the final temper required. This is followed by surface processing and cutting operations which are called secondary operations. According to customer specifications the coils are rolled to the desired properties through these secondary operations.

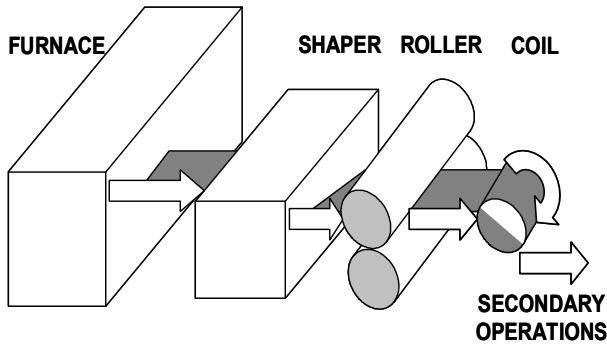


Fig. 1: Aluminium casting line

Final products can be used in the manufacturing of aircraft, satellites, space laboratory structures, tankers and freight wagons, buses, truck bodies, tankers, radiators, traffic signs and lighting columns, chemical process plants, chemical carriers, food handling and processing equipment, packaging, cans, bottle caps, wrapping, packs, and containers.

The products ordered by the customers may have various properties. These properties are width, thickness, and alloy. The important factors that need to be considered are listed below:

**Width:** If two consecutively scheduled jobs have different widths, then there will be a setup time after the first job. For two consecutive jobs, the setup time when the width of the second order is narrower than the first order is shorter than the setup time when the first order is narrower than the second order. This is because both shaper and roller must be changed to process a wider job.

**Thickness:** The orders may require different casting thicknesses. However, the change in thickness can be handled in a very short amount of time and minimally impacts setup in casting scheduling.

**Alloy:** If there is an alloy change between two consecutive orders, then a setup is required. Most of the time, no significant setup is required to process a more composite alloy after a purer alloy (i.e., some additive elements are added to the furnace and then production continues). However, in the reverse case, i.e., if a purer alloy is to be cast after a composite alloy, the furnace must be cleaned thoroughly (i.e., hot cleaning must be done), and this process usually takes significantly longer than the previous case.

**Last Job of the Previous Schedule:** Since the production is continuous, the current month's schedule should take into account properties of the last job of the previous schedule as the initial condition of width, thickness and alloy for minimizing total setup time.

### 3 Simulation Models

This comparative study of production control systems consists of three simulation models. First one is the simulation of the current system which is a push system. Second one is the simulation model of the pull system. The third one is the hybrid system which starts with a push system applied to the casting line and continues with a pull system applied to the secondary operations where the roller is the boundary between push and pull. The approach used in constructing hybrid model is that production orders for casting operation are obtained by applying MRP method with TSP optimization then the production goes on with Kanban signal for secondary operations.

The production control systems are modelled using ARENA simulation software which is a SIMAN-based simulation language. Bestfit distribution fitting software is used to find the probability distributions to be used in the modules of the simulation models. The following assumptions are made:

- The system is a single line, multi stage and continuous production system.
- Setup characteristics of the server modules are similar; they all follow the same distribution.
- Transportation time is negligible.
- Processing on all workstation is carried out without defects, a perfect quality conformance is assumed along the system.
- Each order being manufactured follows the same process routine.
- Production is assumed to be continuous, without any maintenance or failure, but the setup times are included into the probability distributions for times.

#### 3.1 Push System Model

Push system is the current production control system in the company. There is a master schedule of the production and this schedule is built with the MRP method. Orders are forecasted and the material requirements are planned according to these forecasts. The information flow has the same direction with the material flow.

For push model probability distribution of arrival time of the orders is included in the arrive module. The probability distributions of casting and secondary operations' processing times are included in the involved modules. These probability distributions are obtained from the original production orders data of the manufacturing system.

### 3.2 Pull System Model

Schedule is being built according to customer demand in the pull system. The information flow has the opposite direction with the material flow. Production is of make to order type and hence inventory level is affected by the changes in customer demands.

For pull model probability distribution of arrival time of the orders, which are obtained from the real customer demand data, is included in the arrive module. The module of secondary operations pulls the materials from the casting line module and casting operation module pulls the materials from the arrive module. Signal module is used to pull the materials from the preceding operation. Create, Signal and Dispose modules are used to create the first signal after the first signal is created the model itself creates the following signals, which release the material being hold in the wait module.

### 3.3 Hybrid System Model

The simulation model of the hybrid system consists of two phases. During the first phase the orders are being forecasted and these forecasts are turned into production plans with MRP method after that this master plan is revised with applying Travelling Salesman Problem (TSP) method to find out the production plan with minimum setup times and then metal is being cast according to this revised plan. Then these melted and cast-metal half-products are stored for the secondary operations. After that these half products turn into finished products through customer demand so this second phase is a pull system. Therefore, the whole model can be called a hybrid system. The production control system is built as an appropriate mixture of the push and pull. There is a boundary in this model, which separates the production system into two parts as push for casting and pull for secondary operations. This kind of a control strategy is so called hybrid. First part of the production is scheduled according to the forecasts, and the outputs of this first part are pulled through the secondary operations according to the customer demand. In the push part of the model, information flow has the same direction with material flow while in the pull part, they are opposite.

For hybrid model probability distribution of arrival time of the orders is included in the arrive module. Secondary operations pull the materials from the wait module and the production is being pushed through this wait module. The wait module is the boundary between the two parts; push oriented part and pull oriented part. Signal module is used to pull the materials from the preceding operation. Create, Signal and Dispose modules are used to create the first signal and after the first signal is

created the model itself creates the following signals, which release the material being hold in the wait module.

### 3.4 Travelling Salesman Problem (TSP) Approach

In the hybrid production control model TSP method was used to minimize setup times to obtain a better schedule. Probably the most famous routing problem is the travelling salesman problem, which can be described as follows: A travelling salesman is required to call at each town in his district before returning home. The salesman would like to schedule his visits so as to travel as little as possible. Thus, the salesman encounters the problem of finding a route that minimizes the total distance (or time or cost) needed to visit all the towns in the district [9]. The cities are considered to be the orders and the distances between the cities are considered to be the setup times between the orders. So the route acquired from the optimal solution of TSP is also the optimum sequence of the orders with the minimum total setup time.

Although the TSP is so simple to characterize, it is very difficult to solve. The TSP belongs to the class of NP-hard problems. Thus it is unlikely that any efficient algorithm will be developed to solve it. Because of its simplicity, however, the TSP has been one of the most studied problems in this class [9]. The following is the integer programming formulation of TSP:

$N$ : number of cities

for  $i \neq j$ ,  $c_{ij}$  = distance from city  $i$  to city  $j$

$c_{ii} = M$  (a very high distance compared to real distances)

$x_{ij}$  is identified as 1 or 0 according to the conditions mentioned:

$x_{ij} = 1$ , TSP solution offers to go from city  $i$  to city  $j$

$x_{ij} = 0$ , otherwise

TSP Formulation:

$$\text{Min } \sum_i \sum_j c_{ij} x_{ij} \quad (1)$$

$$\text{As } \sum_i x_{ij} = 1 \text{ for every } j \quad (2)$$

$$\sum_j x_{ij} = 1 \text{ for every } i \quad (3)$$

$$u_i - u_j + N x_{ij} \leq N - 1 \text{ for every } i \neq j; i=2,3,\dots,N; j=2,3,\dots,N \quad (4)$$

Every  $x_{ij} = 0$  or 1, Every  $u_i \geq 0$

The objective function is defined to minimize total setup time (1). The constraint group (2) makes the salesman to visit every city just once. The constraint group (3) makes the salesman leave every city just once. The constraint group (4) provides that any group of  $x_{ij}$ , which does not complete the tour, is not a possible solution and any group of  $x_{ij}$ , which completes the tour, is a possible solution [10].

In this study Lingo software is used to solve the TSP applied to the hybrid system model. This software finds the optimal solution for TSP by using branch & bound method with integer programming model.

#### 4. Performance Measures

The performance comparison of the models is made using the following performance measures:

- **Total Output:** Total system output is measured as the average of 100 total runs which has the run length of 436320 minutes each.
- **Average Number in Queue:** It is defined for all processing modules and measured as the average number of units waiting for each process.
- **Utilization:** It is defined as the busyness percentage and gives opinion about idle time.

#### 5. Model Validation

The current production system was a push oriented system and after building the simulation model it was run. The results were compared to the production data of the current system and the model was validated. It was observed that from run length to the number of products manufactured, there is conformance between the model and the system in use (Table 1).

Table 1: Push oriented model and current system in use

	Push System Model	Current System in Use
Total run length (min)	436320	436320
Total output (units)	58	60

#### 6. Results

The results of the runs from simulation models are used to compare performances of push, pull and hybrid production control systems.

The results on Table 2 represent the comparison of three strategies according to the performance measures. The pull system seems to have the best performance according to the total output.

Table 2: Performance measures for each model

	Push	Pull	Hybrid
Total Output	58	61	59
Avg. # in queue	0.61	0	1.68
Busyness (%)	82.26	100	81.60

Figure 2 is the graphic for comparing the total outputs of the. As mentioned above pull seems to show the best performance. Also there are other parameters to be reviewed and next one is average number of entities in casting queue (Figure 3). As a property of the pull system the queues before the processing modules are eliminated so the value of the average number of entities in casting queue of pull model is zero. And also it seems that applying hybrid strategy to this production system causes an increase in the number of entities waiting for operation at the point of boundary (work in process). But still total output value of the hybrid model is better than the push model.

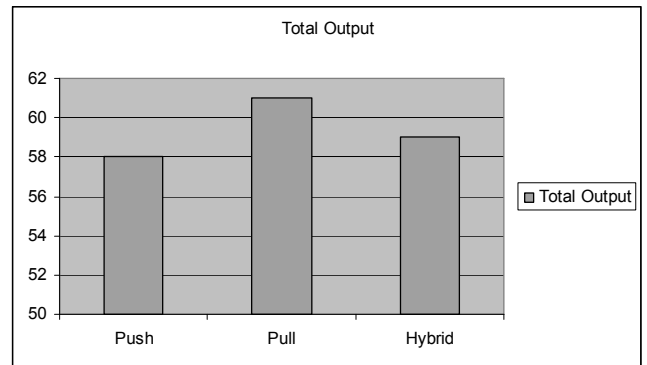


Fig. 2: Total output

Last graphic to be discussed is the busyness percentage of casting module. Again as a characteristic of the pull system idle time seems to be eliminated (Figure 4).

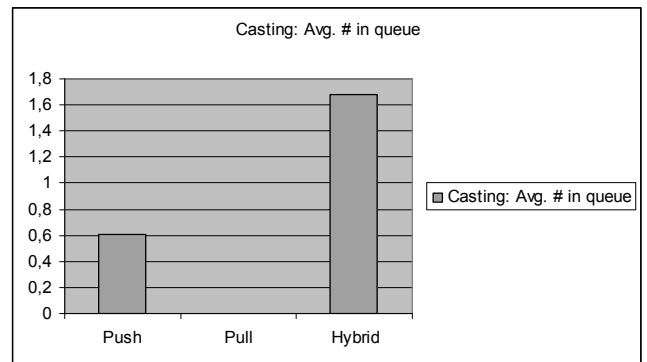


Fig. 3: Average number of entities in queue

These last two parameters show that the principle characteristics of pull system are observed on the model. So it can be said that the applications are valid, effective and successful. When these parameters are compared it is obvious that pull model seems to outperform the other models.

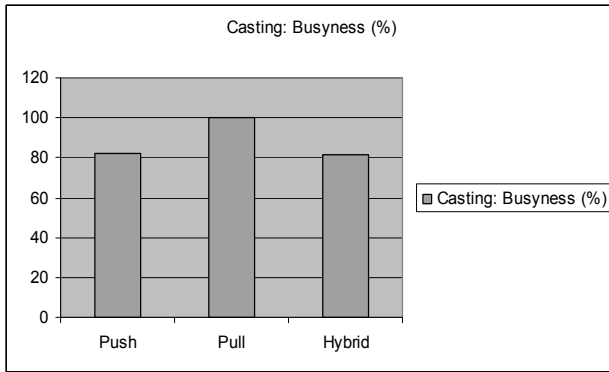


Fig. 4: Busyness percentage of casting line

These last two parameters show that the principle characteristics of pull system are observed on the model. So it can be said that the applications are valid, effective and successful. When these parameters are compared it is obvious that pull model seems to outperform the other models.

### 6.1 Analysis Of Variance (ANOVA) Study

To find out the significant differences of the models an ANOVA study was performed. Since in the ANOVA output (Figure 5) p-value is less ( $p\text{-value}=0$ ) than the level of significance ( $\alpha=0.05$ ) it is concluded that there are significant differences between average total outputs of models in advantage of pull model. Also Tukey's multiple comparisons procedure was used to indicate pairs which are significantly different and shows that pull is better than the others. The important parts and values of the figure are highlighted with bold and italic characters (Figure 5).

Analysis of Variance for Total Ou					
Source	DF	SS	MS	F	P
Model	2	1109,5	554,7	37,83	0,000
Error	297	4354,9	14,7		
Total	299	5464,4			

Individual 95% CIs For Mean Based on Pooled StDev					
Level	N	Mean	StDev	CI	
1	100	57,950	3,409	(-1,727, 117,627)	
2	100	61,780	4,426	(52,928, 70,632)	
3	100	57,490	3,575	(-1,727, 117,627)	

Pooled StDev = 3,829      57,6      59,2      60,8      62,4

Tukey's pairwise comparisons

Family error rate = 0,0500  
Individual error rate = 0,0199  
Critical value = 3,31

Intervals for (column level mean) - (row level mean)

	1	2
2	<b>-5,097</b>	<b>-2,563</b>
3	-0,807	3,023
	1,727	5,557

Fig. 5: ANOVA and Tukey's multiple comparison results

## 8. Conclusion

Production control systems are one of the most important issues for managers to decide. The choice between different systems is a matter of research and investigation. But choosing the most appropriate system is a very important competitive advantage for the manufacturing companies. Here, in this study, using simulation the most appropriate production control system was searched among push, pull and hybrid systems for a multi-stage single-line continuous production system. Arena simulation software was chosen as the simulation tool and BestFit distribution fitter software was chosen for the statistics studies such as determining the probability distribution of the data. Results of the three systems were compared for the performance measures through graphs. The performance measures are total output, average number in queue and utilization. It was clear that the pull system was the best and push system was the worst choice as a production control system. But before a manufacturing organization can enjoy the benefits of pull, it must be aware of the fact that the lean manufacturing philosophy must be accepted and this may require it to change or modify its operating and management procedures, even it may have to make adjustments for its plant layout. Therefore, may be it is better for a manufacturing organization to adopt hybrid production control system for avoiding vital changes required by pull system. As this study indicates that hybrid system outperforms push system by using both MRP and kanban and also the TSP method for minimizing total setup time, this may cause less suffer for the manufacturing organization.

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