Modelling a Batch Production System through Tecnomatix: A Case Study

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Abstract: *In present business environment it has become imperative for the manufacturing firms to adapt themselves to the ever changing needs of the customers. This article presents a case wherein considerable increase in throughput was required in a manufacturing plant with a specific focus on the modelling of the typical batch type production system.The study focuses on suggesting feasible alternatives to decrease the cycle time and consequently increase the throughput of a batch production system in a sheet metal parts manufacturing firm. In this study simulation is used as the main tool to experiment on the system with various feasible alternatives. Siemens Tecnomatix has been used as the prime software in this study.*

Keywords: *Cycle time reduction, Tecnomatix, Theory of Constraints.*

I. INTRODUCTION

Delivering the desired level of performance in minimum time has become a key objective of every competitive organization. In context of manufacturing this situation has led to very little flexibility in terms of production schedules, production rate, delivery schedules, quality and other such avenues associated with manufacturing systems. Cycle time in the context of manufacturing can be defined as the total time spent by the part/product in the manufacturing system or the time between the exits of two consecutive parts or it can also be called as the time part spends as work in process (Hopp and Spearman, 2001). Throughput may be defined as the production rate or the number of components produced in a specific period of time as below.

$$\text{Throughput} = \frac{1}{\text{cycle time}}$$

The throughput rate is governed by the most laden workstation, while the other stations undergo idle times (Anuar and Bukchin, 2006). For an efficient production operation, all stations should be loaded with equal amount of work. Several aspects of manufacturing make it complicated to assign equal work assignments to all workstations. Generally most operations are supposed to be done in a particular sequence. Also the capacity of the equipment and the efficiency of the people on the assembly line differ. So, it becomes difficult to improve the production rate and reduce the cycle time. Various techniques are available for this purpose but none of them guarantees the optimum solution but the best of the considered arrangements is expected to be found.

II. LITERATURE REVIEW

There are various techniques available for the reduction of cycle time, but which one to apply depends upon the existing system and adaptability of the system to the change i.e. how flexible the system is?

Several methods to reduce the cycle time are as under:-

- Assembly line balancing,
- Plant layout optimization,
- Minimization of material handling,
- Work study,
- Simulation and modelling.

The assembly line balancing problem comprises of effective distribution of complete work regarding manufacturing of a product amongst all the work stations (Scholl and Vob, 1996). Narasimhan et al., (2010) suggested that there are various approaches to assembly line balancing which include heuristics, mathematical modelling, operations research based techniques such as linear programming and dynamic programming and exact procedures such as branch and bound method etc. However heuristics do not assure an optimal solution but a nearly optimal solution is expected to be achieved. Bidanda et al., (2004) discussed the basic heuristics which involve the ranking of tasks according to a particular criterion and then redistributing the workload to balance the assembly line.

Perera and Liyanage (1999) described computer simulation as a rigidly established support tool for decision making in the manufacturing world. They found collection of data, generation of model and experimentation as the pillars of simulation and if these three factors are of bad quality then there will be certain inhibition to good results. Sokolowsky and Banks (2010) found that when processes to be analysed become more convoluted and intricate and as more factors have to be included, then simulation becomes more important with its analysis of real processes. These processes cannot be covered by mathematical processes or optimization processes or they may be done only by exploiting a large number of resources. The aim of simulation is to come on objective decisions by lively analysis, to empower managers to securely sketch plan, in the end, to reduce cost (Sokolowsky and banks 2010). Smith (2003) conducted a survey on the use of simulation as a tool for the operation and design of manufacturing systems, his study also covered the development of simulation software for manufacturing systems. He found that out of total literature he considered 49% of the papers were from the manufacturing systems design category, 41% of the research papers belonged to the manufacturing systems operation category and 9% papers were from the simulation software development area.

Law and McComas (1999) describe the basics of simulation of manufacturing systems. In their work they have explicitly defined the benefits of simulation for manufacturing systems as throughput examination, planning of control strategy, work in process analysis, requirement of workers and machinery, adaptability and flexibility of a system to change, inventory issues and planning of production related activities. In their work they have also explained the importance and role of statistical considerations and randomness in the development of a simulation model.

Theory of constraints was given by Eli Goldratt during mid 1980s. The concept of theory constraints is summarized below as interpreted and described by (Rahman, 1998).

Every system is supposed to have at least one constraint. The presence of constraints depicts chances of betterment. According to Goldratt as described by (Rahman, 1998) while dealing with constraints, managers generally have to take three decisions:

- what is supposed to be changed?
- what it should be changed to?
- what should be the right methodology?

Tersine and Hummingbird (1995) detailed about the importance of theory of constraints in manufacturing. They discussed about reducing lead time through theory of constraints. Chaudhary and Mukhopadhyay (2003) discussed about the application of theory of constraints to integrated poultry industry. They found that theory of constraints solved the problem of throughput increment without any major investment. They suggested the development of web based information technology system and changes in sales policy and sales decision criteria.

Mabin and Balderstone (2003) examined the results obtained from the application of theory of constraints in the past literature. They found that theory of constraints have been applied to a number of areas in past twenty years. They found that the organizations which applied theory of constraints in the past have reported sizeable improvements in important performance parameters such as lead time, throughput, revenue etc.

III. CASE COMPANY

The case (sheet metal parts manufacturing firm) company manufactures various sheet metal parts such as ironing board, chassis support, fuel tanks etc. The problem addressed in this study is of ironing board manufacturing process.

The problem before the company was that the customer for whom the ironing board was being manufactured was asking continuously to increase the supply, but company due to the limited resource capacity and limited personnel was unable to meet out that demand of the customer. Therefore, there arose a possibility of slipping the orders from company to any other similar company, due to this it became essential for the company to somehow manage to increase its capacity and fulfil the demand of the customer. The current production system produces nearly 900 (as discussed by the company officials) parts per day. The customer wanted company to supply 200 to 300 more pieces per day. Following points will be capable enough to present the problem in a more lucid manner:-

1. Being a batch production system, right batch size was supposed to be determined.
2. Increase in throughput was desired.
3. Control over expense was a major concern while increasing the throughput.
4. The improvements needed to be made to increase the production should not hinder in the processes of other assembly lines.

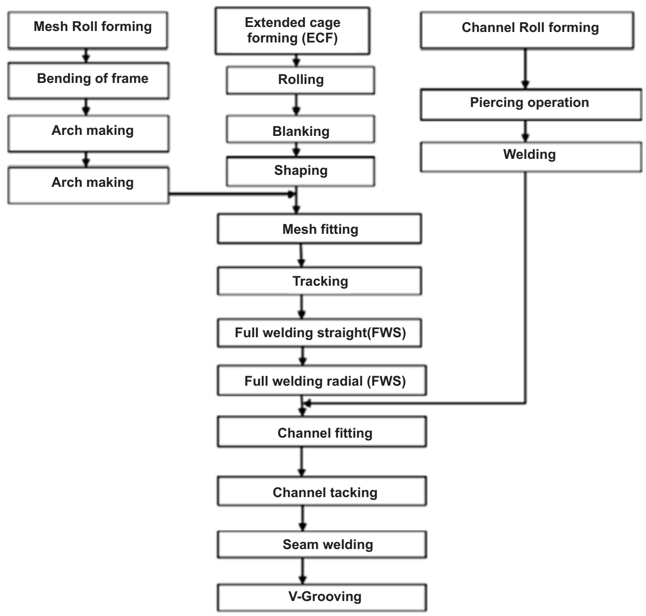

Fig. 1: Precedence diagram for the ironing board manufacturing process

5. The planning should be such that the investments required to increase the throughput should have a low pay-back period.

The figure (Fig. 1) the precedence diagram of the manufacturing operations involved in the process of ironing board manufacturing.

IV. METHODOLOGY

The methodology to address the above problem is shown below in 7 steps :

1) Analysis of assembly process.
2) Identification of feasible alternatives.
3) Building a simulation model.
4) Experimentation on the simulation model.
5) Analysis of results.
6) Results

A. Analysis of the Assembly Line

This is the first step towards the objective. This includes the analysis of the assembly line in terms of number of operations, types of operations, current sequencing of operations, current production rate etc.

B. Identification of Feasible Alternatives for Cycle Time Reduction

This step involves the identification of various alternatives which can be looked for and their selection on the basis of feasibility and cost effectiveness. These alternatives need to undergo the experimentation part so that their feasibility and reliability can be judged. Firstly, since the travel time or the time in taking one part from one workstation to the other was long and there was large distance between machines as the machines were located in their respective sections, so it was thought to optimize the plant layout or the machine layout. But in doing so disturbance to other assembly lines could be created. Moreover, this requires a fair amount time to setup and install different machines to a new place and production needs to be stopped, so this alternative could make the company lose their production targets and could result in lost sales. Hence, this alternative was rejected.

Secondly, the processing times for different workstations were very much uneven and had a lot of difference between them. So assembly line balancing was considered as an alternative which could reduce the cycle time and increase the throughput. But assembly line balancing was not feasible with this assembly line. The main alternatives which are considered in this study are:

- Assembly line balancing.
- Theory of constraints.
- Change in design of the product.

i) Assembly Line Balancing

The assembly line balancing approach for the reduction of cycle time was also seen as an alternative in this study, as shown in figure 1. The precedence diagram was referred for generation of the feasibility matrix (Bidanda et al., 2004).

After the precedence diagram was known the next step was to construct the feasibility matrix. In constructing the flexibility matrix following are the basic rules involved:

a) The number of rows (i) and columns (j) of the matrix correspond to the number of task elements in the assembly problem.

b) If task i must precede task j, '1' is entered at the intersection of row i and column j otherwise, '0' is entered at this intersection.

c) The upper right half of the matrix is then used to calculate the F-ratio by the following formula:

$$F = \frac{2h}{k\,(k - 1)}$$

The F ratio in this case came out to be 0.3, which means there is only 30% probability for this line to get balanced. So, this alternative was not further considered for the reduction of cycle time.

ii) Theory of Constraints

The theory of constraints tells about finding the bottleneck in the process and exploiting the bottleneck to make the best out of the system. Initially in this process we found that the whole system is suffering from one or two big bottleneck processes. The first bottleneck operation was extended cage forming operation which had the highest processing time of 51 seconds which was hindering in other operations' productivity. If, somehow this is improved or removed the second big bottleneck was full welding straight (FWS) operation which had a mean cycle time of 46.04 seconds.

iii) Change in Design of the Product

In the study of the process it was analysed that three continuous welding operations i.e. tacking, full welding straight and full welding radial were contributing to only one purpose which was to fix the mesh in the frame of the ironing board top. So, it was thought that if something could be done in order to fix the mesh in the frame and these processes could be eliminated as they were consuming too much of time, then there can be certain benefits to the organization.

C. Building a Simulation Model

This step includes the construction of a simulation model. Building the simulation model requires the probability distribution of various processing times taken on different work stations. It also requires the data regarding availability and MTTR. Then using simulation software such as TECNOMATIX in which the simulation model will be built.

D. Experimentation on the Model

This step includes the experimentation part on the already built simulation model. Experimentation process is necessary to evaluate and analyse the results after selection of alternatives. Simulation also gives the real time analysis of the assembly line which serves as the authenticating factor for the validation of results.

E. Analysis of Results

After experimentation results of the experiment needs to be analysed which will give an insight about how far have the selected alternatives been able to meet the desired goal?

F. Conclusion

Finally on the basis of the results the work has to be included in order to give a final word to what all has been done.

V. SIMULATION WORK

As mentioned earlier the main objectives of the simulation study were:

1. Being a batch production system, right batch size was supposed to be determined.
2. Increase in throughput was desired.
3. Control over expense was a major concern while increasing the throughput.
4. The improvements needed to be made to increase the production should not hinder in the processes of other assembly lines.
5. The planning should be such that the investments required to increase the throughput should have a low pay-back period.

For the above objectives various alternatives were explored as discussed in the previous section, but the most basic need was to build a simulation model on which experimentation could be done.

- **Collection of Data**

Collection of data was the first step that was taken in the process. Data was collected by observing the work being done in the case company. Data regarding following activities was taken into consideration:

- Processing times + loading and unloading times
- Availability of machines
- Time taken to take the parts from one workstation to other. Processing times & loading and unloading times

The readings of processing times and loading and unloading times were taken considering both the times as a single unit because in some processes it was difficult to separate the tasks of loading and unloading from processing, for example in the process of Extended Cage Forming the coils of steel sheet automatically unrolls and the mesh is formed. In this process it is difficult to separate the two. Moreover, the total time spent by a part on a workstation is the sum of both the times therefore loading, unloading and processing times have been taken as a single unit. The observations of processing and loading and unloading times for a single part as well as batch sizes of 10, 20, 30, 40 and 50. The observations of times of only two segments of assembly line were made as the time for the third segment is very less as compared to the other two therefore simulation study of only first two segments was required in order to increase the throughput.

- **Availability of Machines**

Data regarding the availability of machines was gathered from the company and it was found that there are no considerable failures in the past one year but there are some small hindrances due to which an operation has to be stopped during work. This stoppage is periodic and cannot be avoided hence it has been counted as reduction in availability of machine. There are two such workstations namely-

A. MIG welding

In MIG welding it was found that after every 18 pieces, electrode was changed and time consumed was observed 20 times and mean was taken to represent the time taken to change the electrode, table below shows the sample. The mean came out to be 18.73 seconds. According to our data 24.03 is the mean time taken by a job on MIG welding station, so 18 pieces would take 432.6 seconds. Now, after every 432.6 seconds there will be a lapse of 18.73 seconds.

$$availability = \frac{total\ operation\ time - total\ down\ time}{total\ operation\ time}$$

If taken for one day it comes out to be –

$$availability = \frac{52776 - \dfrac{52776 * 18.3}{432.6}}{52776} = 0.956$$

B. Blanking

Blanking is another operation that faces such unavoidable hindrance to production. In this case the stoppage is due to the accumulation of removed material on the bed of the press due to the press' action. After every 12 pieces the operator needs to clean the bed so as that the press can function properly. Twenty readings were taken as to find out the mean time taken by operator to clean the bed. The mean came out to be 23.885. It takes 39.66 seconds to process one piece in the blanking process so 12 pieces would take 475.92 seconds. So after every 475.92 seconds there would be a lapse of 23.885 seconds. Total operation time for one day is 52776 seconds. So availability can be given as under–

$$availability = \frac{total\ operation\ time - total\ down\ time}{total\ operation\ time}$$

If taken for one day it comes out to be –

$$availability = \frac{52776 - \dfrac{52776 * 23.885}{475.92}}{52776} = 0.956$$

The availability as calculated comes out to be 94.98% and 95.6%. The availability calculation is necessary in order to achieve the good amount of similarity with the real production system. Since it is one of the most vital points while simulating the production system it has been taken care of in the study.

C. Travel Time

Travel time is the time taken in taking the part from one workstation to the other. Since the parts are carried manually in trolleys therefore there is not constant or fixed travel time between any two workstations. So, it becomes necessary to incorporate travel time in the model to get authentic results.

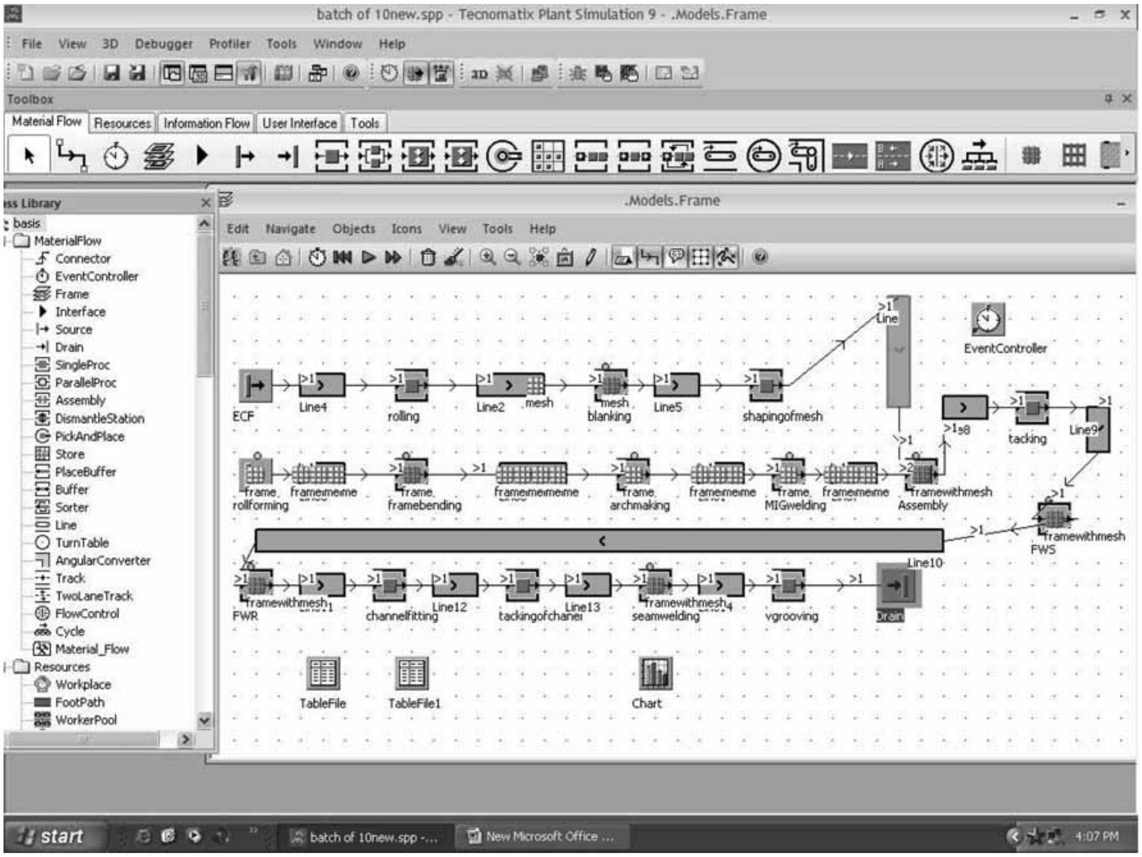

Fig. 2: Basic model

Here various readings have been taken and then mean travel time is considered for generating the basic model.

D. Generation of Basic Model

Initially a basic simulation model (Figure 2) was created with the inbuilt entities available in SIEMENS TECNOMATIX 9.0 software. Following are the basic entities used in the model.

i) Source

In the starting a source was created which initiates the production or it can also be called as the first member of the assembly line. So the two segments of the assembly line considered in the simulation study have extended cage forming (ECF) and Roll forming as the sources respectively.

ii) Line

After the source a line was introduced into the model which serves as a transportation medium for the parts from one workstation to the other. This entity is the most important entity pertaining to the transportation and material handling of the model. It has some of the most vital data and setting options for required work. Line has the settings regarding time taken, length and speed to control the rate of flow.

iii) Connector

After creating the line a connector was used to connect the source and the line. Connector is necessary to allow the material movement as it establishes a link between two entities.

iv) Event controller

Event controller is a watch which controls the timings of the different events taking place inside a model. It can be made to run faster or slower as per the requirements. It is generally used during a simulation run.

v) Models for different cases and important parameters in the models

Since the company had a batch production system and it did not have a fixed batch size so the batch size which gives maximum throughput was found out first. Company could accommodate a maximum batch size of 50 and as told by the officials of the firm batch size should be in the multiples of 10 for the ease of their painting and packing. So, batch sizes of 10, 20, 30, 40, and 50 were selected for analysis.

Firstly the processing time belonging to different workstations was entered in the software. In Tecnomatix 9.0 the processing times can either be constant or can have a probability distribution. There are a number of probability distributions available in Tecnomatix 9.0 such as normal, log normal, weibull, beta, gamma etc. Probability distributions obtained for our data were either normal or log normal. In normal and log normal, five values are required to be entered namely:

- Probability distribution
- Random number stream
- Mean
- Standard deviation
- Upper bound
- Lower bound

Table 1, shows the above parameters for various operations. All the above listed fields were computed as stated above. So the respective values were entered for all the workstations for different batch sizes.

Probability distributions of the collected data were found out by using STATFIT software. It gives a rank wise list of the distributions which can be fit to the given data. The distribution with the highest rank is supposed to be the best fit for that particular data. It applies K-S test and Anderson Darling test to estimate the fit. The snapshot on the right side (Fig. 3) is of the STATFIT software to show how it gives the distributions. In the above shown manner the probability distributions of all the data samples were estimated and the basic descriptive were also computed. Only operations with probabilistic processing times are considered.

In the context of manufacturing simulation the results found out by long term runs of the models or steady state condition results are more reliable. This is because if there is no warm-up period then the model will every time start from initial stage or point zero, it will not start with a normal working point, therefore this will deviate the results. Hence, a warm-up period was chosen here also. Here in this context, since it is a batch manufacturing system and we have models for five different batch sizes, the assembly line will come into flow or its normal working state when one part (batch) will come out as finished batch i.e. after the exit of first batch from the system, the system will come into steady state. Moreover for every batch size there will be a different warm-up time because the time taken by one batch to exit the system is different for different batch sizes. Therefore a common warm-up period was selected as 12 hours. The Fig. 3 shows the curve fitting exercise done in statfit software to find out the best suited distribution for the data samples.

Table 1: Typical probability distributions and statistical data for batch of size 10

	Arch making	MIG welding	Blanking	Shaping	Channel fitting	Channel tacking	Mesh fitting	FWS	FWR	Seam welding
Probability distribution	Normal	Log normal	Log normal	Log normal	Log normal	Normal	Log normal	Log normal	Normal	Log normal
Mean	371	240	396	169	181	268	412	469	300	169
Standard deviation	54.3	45.3	77.6	28.7	33.4	21.3	60.4	40.6	47.4	35.8
Sample Lower bound	288.4	159.1	290.7	119	119.9	233.3	229.4	348.7	226.8	123.9
Sample	521.9	337.2	560.9	219	249.7	310.2	572.1	566.3	401.1	389.4

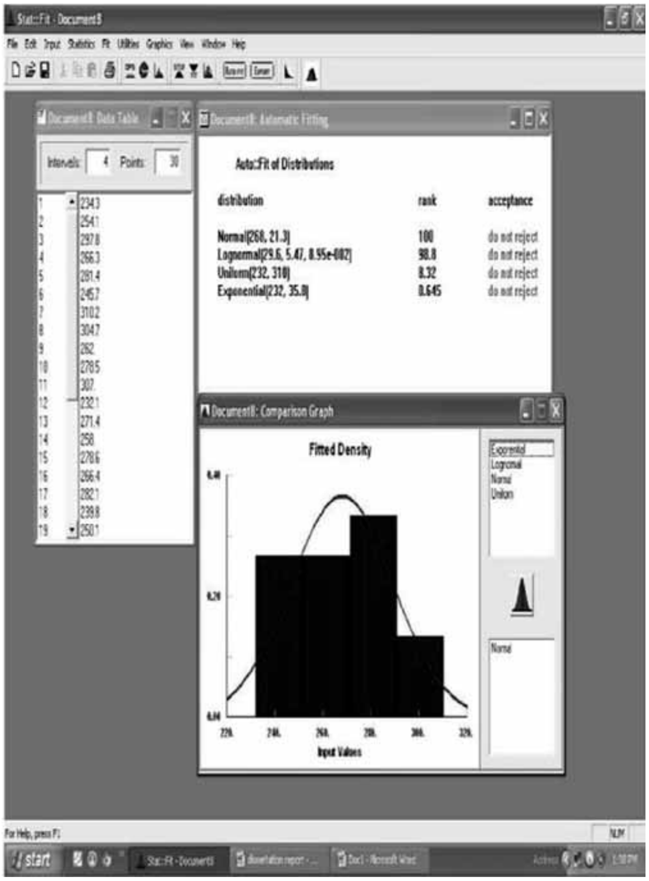

Fig. 3: Curve fitting and probability distribution in STATFIT

E. Finding the Appropriate Batch Size through Simulation Run

In finding the appropriate batch size the generated models were supposed to be run and on the basis of highest throughput, the most appropriate model was to be selected.

F. Simulation Run

The simulation runs were done using the following seed values some initial default seed values. SIEMENS TECNOMATIX 9.0 uses a multiplicative linear congruential generator to generate the random numbers and the random numbers are generated using seed values. Every random number stream has two seed values, the random number generator generates a value between 0 and 1 from each seed and then merges them to generate the final random number. Therefore different random numbers can give different results, so seed values were changed in order to get the more reliable results. Table 2 shows the initial seed values.

Table 2: Initial seed Values

Random number stream	Seed value 1	Seed value 2
1	0	1
2	1	1
4	3	1
5	4	1
7	6	1
9	8	1
10	9	1
11	10	1
12	11	1
13	12	1

Table 3: Results of Simulation Run

Batch size	Batch of 10	Batch of 20	Batch of 30	Batch of 40	Batch of 50
Throughput (parts/hour)	70.75	70.6	71.7	66	69

After the warm-up period all the models were run for 10 hours. Further, the results of the simulation run for all the batch sizes are discussed and it is checked that which batch size gives the maximum throughput. Table 3, shows the results for different models.

G. Experimentation

After selecting the most appropriate batch size **(Batch size 30 with highest throughput)** it was necessary to experiment with the model so as to increase the throughput of the manufacturing system which is the main objective of this study. During experimentation with different alternatives the simulation models were run for long time till the results became stable. Figure 4 shows the results of the experimentation with reference to various alternatives considered during the study. Theory of constraints scenario 2 can be considered as the best alternative as it is giving the highest throughput or highest reduction in cycle time.

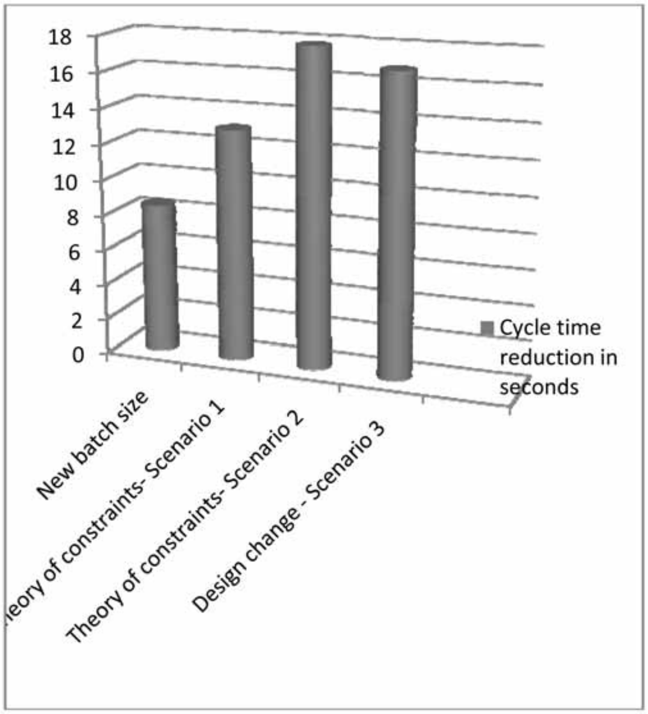

Fig. 4: Results of Experiments

VI. ACKNOWLEDGEMENT

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