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Optimization In A Casing Manufacturing Industry Using Simulation Study

Jayachitra R[1], Siddhaarth D R[2]

[1]*PG Student, PSG College of Technology, Coimbatore*
[2]*Associate Professor, PSG College of Technology, Coimbatore*

Abstract: This project describes how Simulation can be applied to optimize a job shop scheduling problem (JSSP) at a precision aerospace components manufacturing company. The product selected for the simulation study is casing. As 8 different casings are manufactured in a single casing manufacturing line, the demand requirements are not met. To identify the bottleneck operations, the existing manufacturing process is simulated using Arena simulation software. The model is simulated for various batch sizes and Scheduling rules and the performance parameters like total casing output, average work in process, average utilization and average flow time were determined. Design of experiments and Interaction plot is used to determine the optimum batch size and scheduling rule. The results showed that for maximum casing output and Resource utilization, the optimum batch size is 5 and optimum scheduling rule is Shortest processing time (SPT) priority rule. To minimize the Average WIP and flow time, the optimum batch size is 2 and optimum scheduling rule is Shortest processing time (SPT) priority rule.

Keywords: Arena, Scheduling

1. INTRODUCTION

Simulation modeling and analysis is the process of creating and experimenting with a computerized mathematical model of a physical system. A system is a collection of interacting components that receives input and provides output for some purpose. Some manufacturing systems simulation includes machining operations, assembly operations and warehousing. Machining operation simulations are the processes involving manually or computer numerically controlled factory equipment for machining, turning, bending, cutting, welding, and fabricating. Assembly operations can cover any type of assembly line or manufacturing operation that requires the assembly of multiple components into a single piece of work. Warehousing simulations have involved the manual or automated storage and retrieval of raw materials or finished goods.

Production sequencing rules are also called as dispatching rules. These are a kind of priority rules that are applied to assign a job to a machine. When a machine gets idle and there are jobs waiting. The dispatching rule assigns a priority to each job and the job with the highest priority is sent to be processed. The main dispatching rules can be defined as

- First In First Out (FIFO) Priority is given to the first piece that is input, which must be the first to be output. It can be taken as an arrival order into the machine in the factory. This rule seeks to minimize the time of staying on the machine or in the factory.

- Last In First Out (LIFO) Priority is given to the last piece that is input, which is the first to be output. Due to the fact of it being adverse and negative with regards to reliability and quickness to deliver and for not having a sequencing based on quality, flexibility or cost, this rule is used hardly ever.
- Shortest Processing Time (SPT) Priority is given to the shortest total processing time. It is classified in an ascending time order. Its use is aimed at reducing the size of the queues and the increasing of the flow.
- Longest Processing Time (LPT) Priority is given to the longest total processing time. It is conversely to the SPT rule. Its utilization focus on reducing the changes of machines.

PROBLEM STATEMENT

The industry manufactures compressor parts that are to be exported. The part selected for the study is casing. In casings there are 8 different type of casings manufactured in a single manufacturing line. Each casing has its separate sequence of operations to be carried out with varying processing times for each operation. The resources available for the casing manufacturing are Initial inspection station, IP turn station, NDT inspection station, Vertical turret lathe, 5 Axis and 3 Axis milling machines, grinding machine, heat treatment are, painting, fitting and final inspection area. As all 8 casings are manufactured in a single manufacturing line, there are some bottleneck operations due to which demand requirements are not met.

OBJECTIVES

The objectives of the study are, To model and simulate the existing casing manufacturing process and to find the optimum batch size & scheduling rule for improving casing manufacturing process using Design of experiments

2. METHODOLOGY

Initially the industry and the problem is identified. Then the literature related to the problem are studied, followed by data collection for the various processes involved like the sequence of operation for each casing, processing time on each resources and the number of resources available like number of 5 Axis milling machines etc. Then an initial Arena Simulation model for the existing process is built. The Model is studied for Bottleneck operations. To improve the casing manufacturing process, the Batch size and scheduling rules are varied in the Simulation Model. The model is simulated for Batch size of 2, 5, 10 casings and the different Scheduling rules like FIFO, SPT, LPT. The process parameters like Average flow time, Average WIP, Average Resource Utilization and the total Product output for various combination of Batch size and Scheduling rule are tabulated. Now 2 factor, 3 level Taguchi Design of Experiments is carried out to identify the optimum Batch size and Scheduling rule for the casing manufacturing process.

DATA COLLECTION

Resources Available

In the casing manufacturing line there are several resources available like inspection station, Vertical turret lathe (VTL) station, IP turn station , Metal spray Station, NDT inspection, Final inspection station, Painting , fitting station and heat treatment area etc. The IP Turn station has 5 machines, 5 Axis and 3 Axis milling machine have 3 and 2 machines respectively. The metal spray station has 2 resources available, whereas all other process have one resource each.

Table 1. Resources Available

Description	**No of Resources**
IP Turn Station	5
5 Axis Milling	3
3 Axis Milling	2
Metal Spray Station	2
Heat treatment area	1
Painting	1
Grinding Machine	1
VTL Station	1
NDT Inspection Station	1
Fitting	1

Casing Sequence

Each casing has a different operation sequence in the casing manufacturing process. The processing time spent on each of the resources vary between casings..

SIMULATION AND ANALYSIS

Simulation Input Parameters

The resources available are given by creating Sets in Arena Simulation software. As all 8 casings are manufactured in a single casing manufacturing line, the model cannot be built by directly connecting the process module and as the sequence, processing time for each casing vary, a Sequence is created in the Arena to imitate the sequence followed by the casing. Figure shows the sequence s1 for casing 001CA, the processing time is also entered in the sequence as it varies from casing to casing. Steps indicate the process sequence for casing 001CA. In similar manner the inputs are given for the remaining 7 casings.

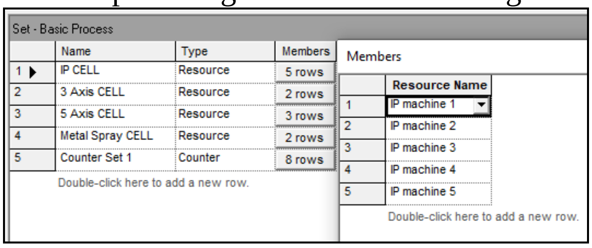

Fig. 1 Resource Available

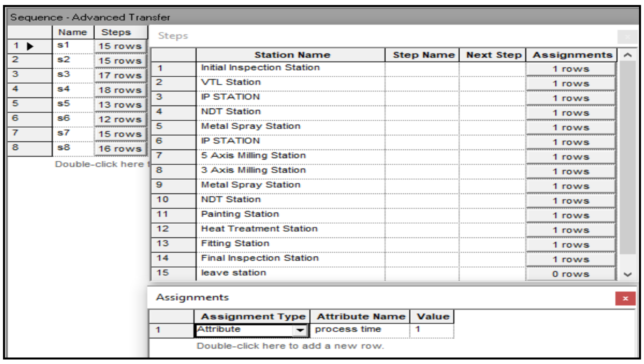

Fig. 2 Casing Sequence input in Arena

Existing Simulation Model

The parts are created in create module. The decide module splits the parts created in 8 way based on the demand rate. Then the parts are assigned to different casing sequence in assign module. Then each part is batched separately, then the casing enters the manufacturing line according to the sequence. Another assign module named arrival rate is used to record the time casing enters the manufacturing line. The probabilities of assigning a casing to its sequence is based on the demand requirements of the casing. The processing time for various processes are given by creating a attribute process time, which can be used to enter processing time for different casing. The station module from Advanced Transfer helps to route the casing according to the sequence. The route module after each process is used to connect the previous process to the next process based on the sequence of the casings. A leave station which is used to dispose the processed casings out of the manufacturing system. There are two record modules to record the flow time and to record the number of different type of casing manufactured. In the existing casing manufacturing process, the parts are not batched and the FIFO dispatching rule is followed, that is the job that is available first for processing will be processed first. In order to simulate the existing model the batch size is given as one and the dispatch priority rule by default in Arena is FIFO.

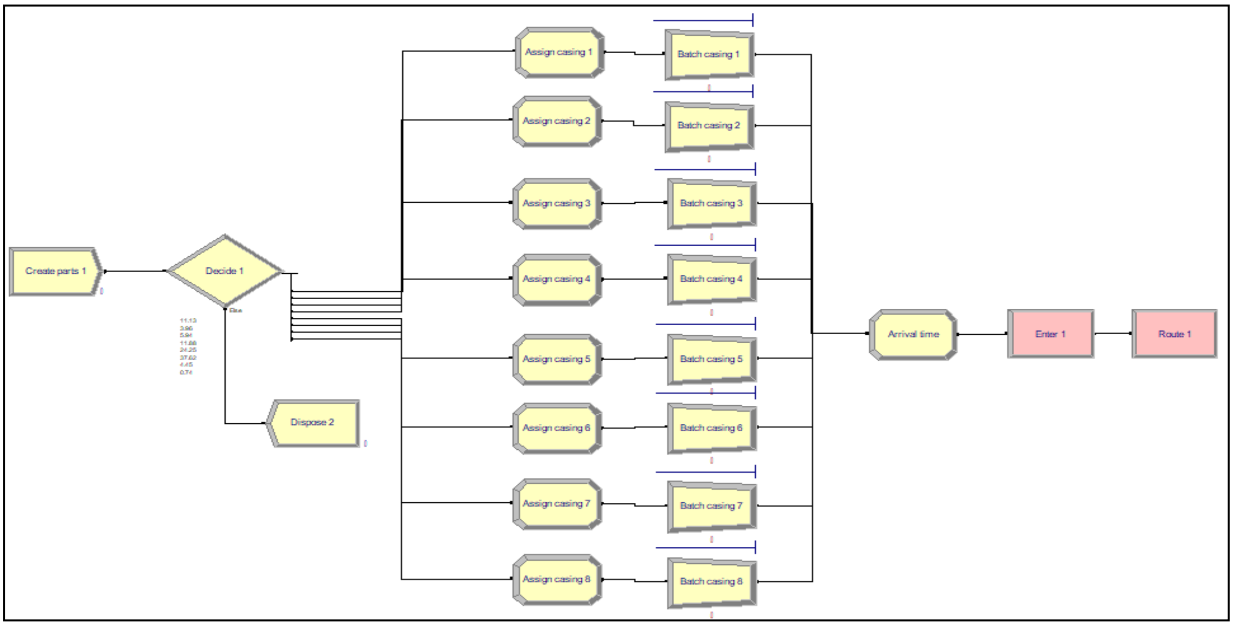

Fig. 3 Arena Model

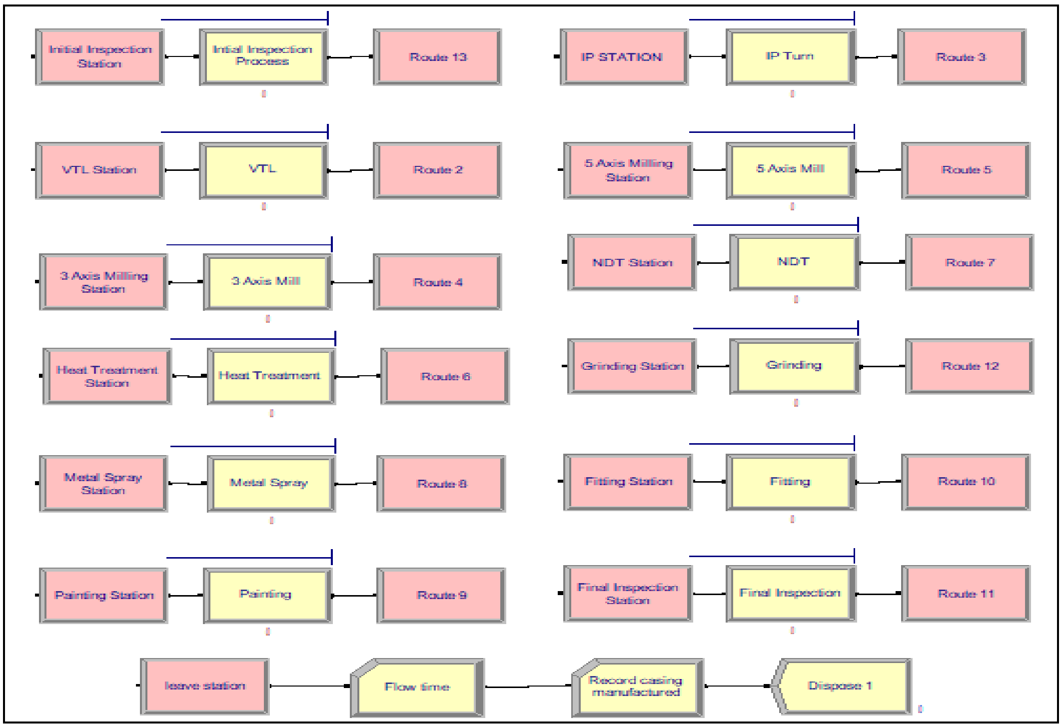

Fig. 4 Casing Manufacturing line

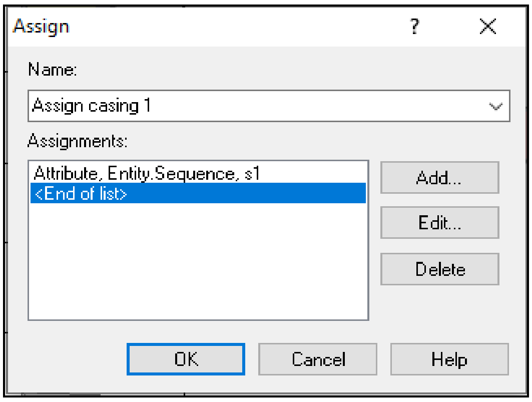

Fig. 5 Assign Module for existing model

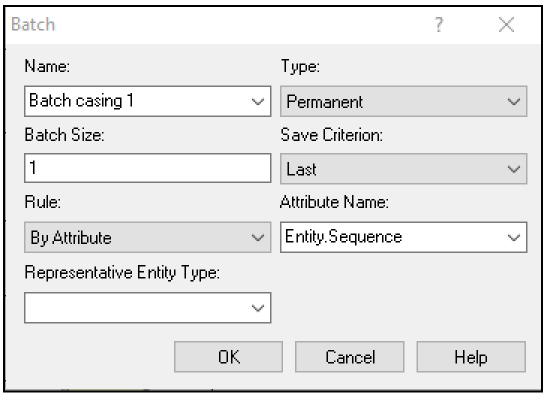

Fig. 6 Batch Module for existing model

Results For Existing Model

Table 2. Average number of parts waiting

Machine Queue	Number of parts waiting (nos.)
3 Axis Mill Queue	0
5 Axis Mill Queue	0
Final Inspection Queue	1
Fitting Queue	1
Grinding Queue	0
Heat Treatment Queue	0
Initial Inspection Queue	56
IP Turn Queue	0
Metal Spray Queue	139
NDT Queue	0
Painting Queue	0
VTL Queue	2000

Table 3. Resource utilization

When the simulation model is run for 1 month and the industry works for all the 3 shifts. The total number of casing manufactured are 523 and the average flow time is 368 hours. The average WIP is 4420 parts.

Machine	Machine Utilization (%)
3 Axis Mill 1	30.36
3 Axis Mill 2	26.96
5 Axis Mill 1	54.17
5 Axis Mill 2	51.85
5 Axis Mill 3	56.7
Final Inspection Process	42.04
Fitting Process	52.07
Grinding Machine	18.94
Heat Treatment Furnace	20.83
Initial Inspection	8
IP machine 1	72
IP machine 2	73.83
IP machine 3	73.99
IP machine 4	73.34
IP machine 5	72.56
Metal spray 1	99.38
Metal spray 2	99.33
NDT Inspection	70.84
Painting Process	9.07
VTL machine	100

Model Creation Using Doe

In order to improve the casing manufacturing process the batch size and scheduling rule can be varied. The batch size can be varied as 2,5,10 casings. The first in first out (FIFO),

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shortest processing time (SPT) and the longest processing time (LPT) rule are selected. The batch size of the model can be varied. To enter the various scheduling rule an Attribute SPT_Priority was created, which will be assigned the total processing time value of that particular casing in the Assign module along with assigning of sequence to the casing.

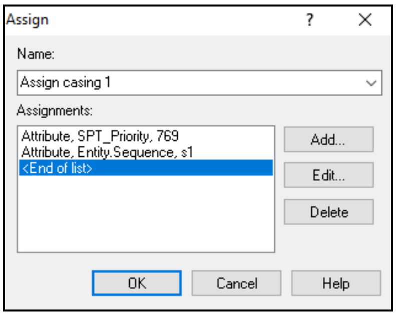

Fig. 7 Assign Module for DOE model

Results For Doe Model

The average flow time, WIP, utilization and the total casing output are tabulated. The machine utilization and the number of casing in queue output for each combination of batch size and scheduling.

Table 4. Results for DOE Model

Batch size	Scheduling rule	Total output (nos.)	Avg. WIP (nos.)	Avg. Utilization (%)	Avg. Flow time (hours)
2	FCFS	495	3000	51	379
2	LPT	130	3500	60	361
2	SPT	591	2694	50	304
5	FCFS	496	1411	42	336
5	LPT	495	1764	42	421
5	SPT	456	1284	39	270
10	FCFS	246	669	20	167
10	LPT	246	838	20	212
10	SPT	246	626	20	155

3. RESULTS AND DISCUSSION

Doe For Total Casing Output

The optimum batch size is 5 and scheduling rule is SPT.

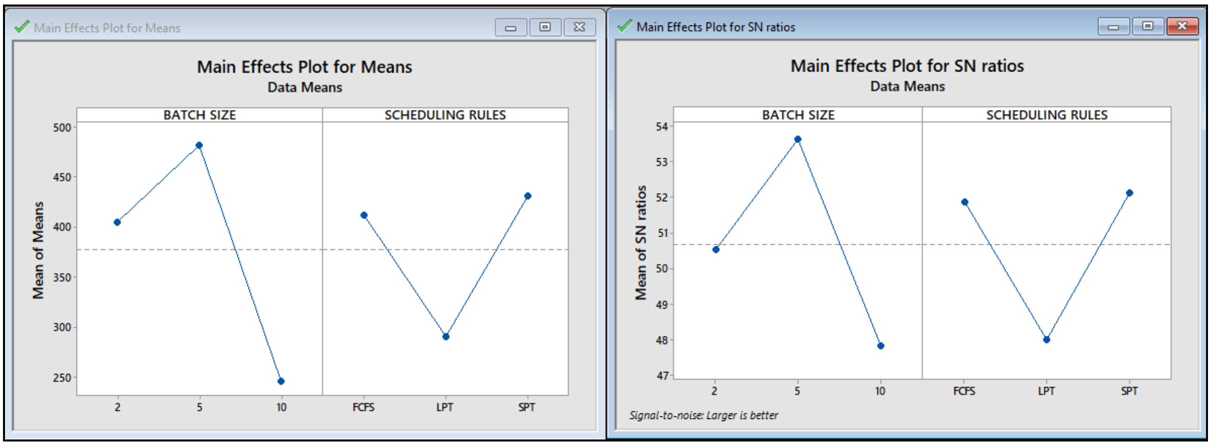

Fig. 8 DOE for Total Casing Output

Doe For Average Work In Process

The optimum batch size selected is 10 and scheduling rule is SPT. As the WIP is minimum for batch size of 10 and LPT priority rule. For a batch size 10 the demand of 404 casings per month is not met. Therefore, an alternative batch size and scheduling rule is to be selected

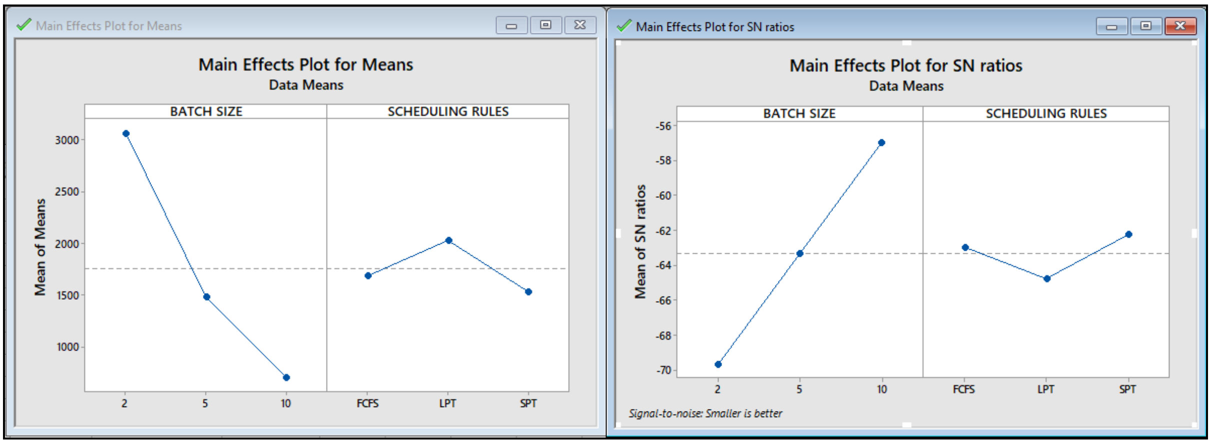

Fig. 9 DOE for WIP

Doe For Average Machine Utilization

The optimum batch size is 2 and the preferred scheduling rule is LPT. For this batch size and scheduling rule the casing output is 130, demand is not met.

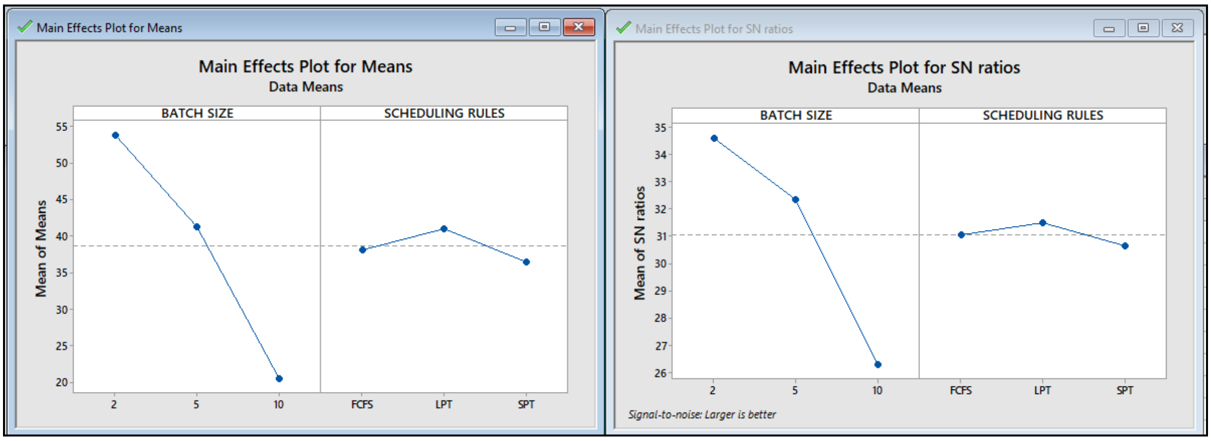

Fig. 10 DOE for Average Utilization

DOE For Average Flow Time

The optimum batch size is 10 and preferred scheduling rule is SPT. Using a batch size 10 the demand requirement for the casings will not be met.

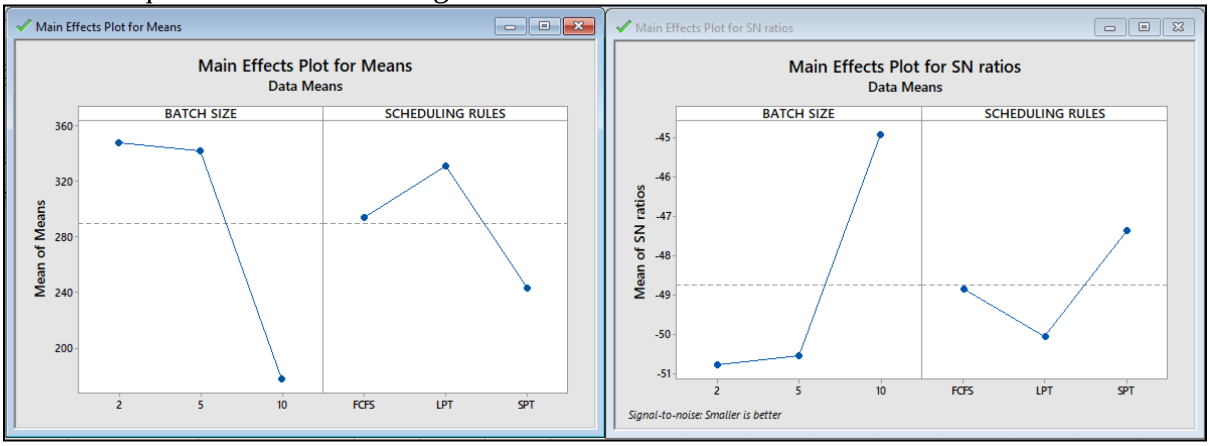

Fig. 11 DOE for Average flow time

Interaction Plot

To verify the DOE results, interaction plot is plotted. If the lines are non-parallel in the interaction plot then there is a relation between batch size and scheduling rule. From the results of design of experiments it can be inferred that, optimum batch size and optimum scheduling rule cannot be obtained. So in order to reduce WIP, Flow time and increase machine utilization alternative parameters is to be found.

Interaction Plot For Total Casing Output

For batch size 2 and scheduling rule SPT the mean is highest. If the batch size 5 is selected, then LPT scheduling rule has highest mean.

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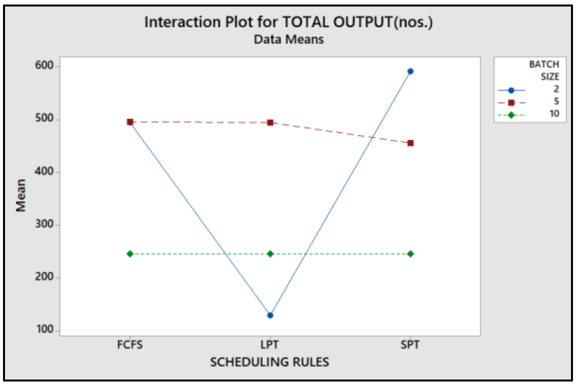

Fig. 12 Interaction Plot for Total casing output

Interaction Plot For Average Wip

For batch size of 10 and SPT scheduling rule the mean is lowest. But batch size 10 cannot be selected as the total casing output is less than the demand requirement. So the next lowest mean value is obtained by batch size 5 and SPT scheduling rule.

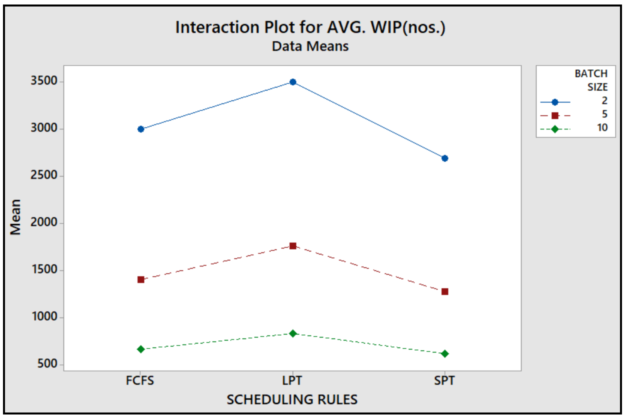

Fig. 13 Interaction Plot for Average WIP

Interaction Plot For Average Utilization

For batch size 2 and LPT scheduling rule the mean is maximum. Similar to WIP, this cannot be selected as total output is only 130, which is less than the demand requirement. Therefore, the next highest mean is obtained when batch size is 2 with FCFS or SPT scheduling rule.

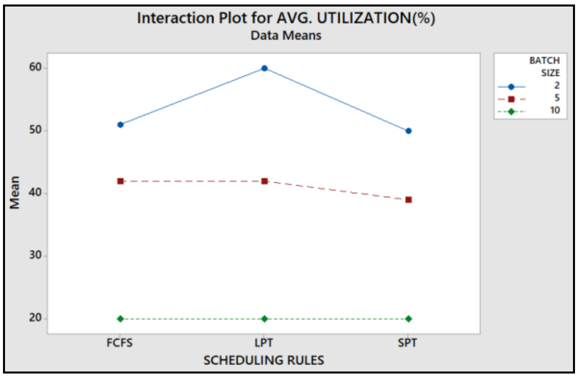

Fig. 14 Interaction Plot for Average utilization

Interaction Plot For Average Flow Time

For batch size 10 and SPT scheduling rule the Flow time has lowest mean. For batch size 10, demand will not be met. Therefore, next lowest mean is obtained by batch size 5 and SPT.

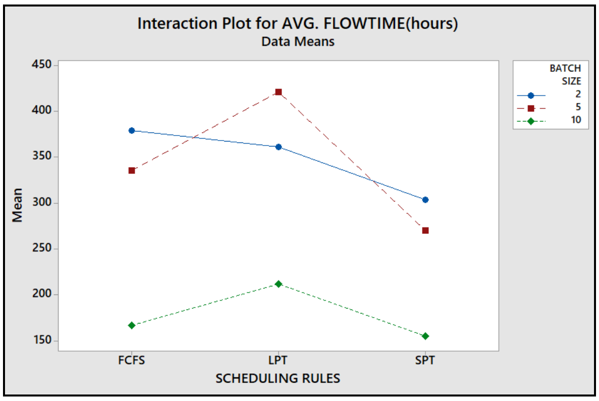

Fig. 15 Interaction Plot for Average flow time

4. CONCLUSIONS

Conclusions From Doe

For lower WIP and Flow time, a batch size of 10 and SPT scheduling rule can be selected, but when the batch size is 10, for all the scheduling rules the demand requirements are not met. Similarly to maximize the machine utilization according to the DOE results, batch size 2 and LPT scheduling rule should be selected. But the total casing output for the mentioned batch size of 2 and LPT rule is only 130 casing, which does not meet the demand requirements. Therefore, the optimum batch size is 5 and scheduling rule is SPT according to total casing output parameter.

Table 5. Optimum batch size and scheduling rule from DOE results

Performance parameter	Optimum Batch size	Optimum scheduling rule
Total output	5	SPT
Average WIP	10	SPT
Average Utilization	2	LPT
Average Flow time	10	SPT

Conclusions From Interaction Plot

As batch size 10 cannot be selected due to insufficient casing output. To minimize the work in process the next best solution is batch size 5 and SPT scheduling, which gives the next lowest mean.

Table 6. Optimum batch size and scheduling rule from Interaction plot

Performance parameter	Optimum Batch size	Optimum scheduling rule
Total output	2	SPT
Average WIP	5	SPT
Average Utilization	2	FCFS or SPT
Average Flow time	5	SPT

The optimum scheduling rule is Shortest processing time (SPT) rule. To obtain maximum output and resource utilization the batch size should be 2. To obtain minimum WIP and flow time batch size should be 5.

Simulation Results For Optimum Parameters

From the interaction plot results, the optimum parameters for maximum total output and utilization is from scenario 1, with batch size of 2 and SPT scheduling rule. The optimum parameters for minimum WIP and flow time is from scenario 2, with batch size of 5 and SPT scheduling rule.

Results For Scenario 1 & 2

The optimum parameters for maximum total output and utilization is from scenario 1, with batch size of 2 and SPT scheduling rule. Batch size of 5 and scheduling rule selected is SPT for maximum total casing output and resource utilization. The queue for VTL station is highest with 149, followed by metal spray station with 38 casing. The fitting station has 7 casings in its queue. In other stations there are no parts waiting. The optimum parameters for minimum WIP and flow time is from scenario 2, with batch size of 5 and SPT scheduling rule. The VTL station has 832 casings waiting in its queue. The metal spray station has 49 casings waiting to be processed. There are 3 casings on an average in the initial inspection queue. In all the other stations there are no casings waiting in the queue.

Table 7. Average numbers waiting

Machine Queue	**Average Numbers waiting (nos.)**	
	Scenario 1	**Scenario 2**
3 Axis Mill Queue	0	0
5 Axis Mill Queue	0	0
Final Inspection Queue	0	0
Fitting Queue	7	0
Grinding Queue	0	0
Heat Treatment Queue	2	0
Initial Inspection Process Queue	0	3
IP Turn Queue	1	0
Metal Spray Queue	38	49
NDT Queue	2	0
Painting Queue	0	0
VTL Queue	149	832

Table 8. Resource Utilization

Machine	**Machine Utilization (%)**	
	Scenario 1	**Scenario 2**
3 Axis Mill 1	22.81	12.88
3 Axis Mill 2	19.84	14.31
5 Axis Mill 1	41.11	68.59
5 Axis Mill 2	40.88	67.76
5 Axis Mill 3	41.9	67.78
Final Inspection Process	21.81	7.43
Fitting Process	24.69	8.84
Grinding Machine	15.94	9.81
Heat Treatment Furnace	21.25	9.7
Initial Inspection	1.56	3.99
IP machine 1	51.32	74.9
IP machine 2	52.68	74.2
IP machine 3	51.27	74.17
IP machine 4	52.45	73.83
IP machine 5	52.13	74.1
Metal spray 1	79.38	92.68
Metal spray 2	79.65	92.65
NDT Inspection	49.51	67.73
Painting Process	9.72	5.04
VTL machine	63.17	99.99

CONCLUSIONS FOR OPTIMUM PARAMETERS

In both the scenarios the utilization of 3 axis milling machine was less than 20%. As there are 2 machines, one of them can be made inactive to increase the station utilization. The metal spray has utilization of 70% in scenario 1 and 92% in scenario 2. So, an additional machine can be added to reduce load on the machine.

In scenario 1 the VTL machine had lower utilization and queue length as compared to scenario 2. IP turn station has a utilization of 52% in scenario 1 and 74% in scenario 2. The IP turn station has 5 machines, one of them can be made inactive without affecting the manufacturing line. Similarly 5 Axis milling station has a utilization of 41% in scenario 1 and 67% in scenario 2. As there are 3 5 Axis milling machine, one of them can be made inactive without affecting the casing manufacturing line. One machine each from 3 Axis milling station, 5 Axis milling station and IP Turn station is made inactive and simulated.

Table 9. Results for suggested model

Batch size	Scheduling rule	Total output (nos.)	Avg. WIP (nos.)	Avg. Utilization (%)	Avg. Flow time (hours)
2	SPT	402	1761	47	347
5	SPT	314	793	36	289

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