



Simulation modeling, Performance evaluation and Optimization of a Flexible Manufacturing Cell

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Abstract: In recent time of global competition, Flexible Manufacturing Cell (FMC) has emerged as important technology to meet customers' continuously varying demands effectively. Its successful implementation results in improvement of capital utilization, quick throughput, increased flexibility along with integrity and automation. However, the adoption of a FMC involves a substantial investment and a high degree of uncertainty for the organization. Therefore it is necessary to evaluate and optimize the FMC performance prior to making costly investment of the system. This paper provides an attempt to evaluate and optimize the performance of a FMC consisting of four workstations and light load automated guided vehicles (AGVs) based on simulation modeling and optimization approach. Criteria considered for performance measures are system throughput, average resource utilization and AGV utilization. Arena software is used for simulation modeling.

Keywords: FMC; simulation; performance evaluation; optimization; Arena

I. Introduction

A flexible manufacturing system (FMS) is a highly automated group technology machine cell consisting of a group of processing workstations (usually CNC machine tools), interconnected by an automated material handling and storage system, and controlled by a distributed computer system. [1]

Flexibility signifies a manufacturing system's ability to adjust to customers' preferences.

Flexible Manufacturing Cell (FMC) consists moderate number of components than FMS. FMC consists of components like flexible machines and automated material handling system. While FMS includes flexible machines, automated material handling system along with other components such as automated storage and retrieval system, co-ordinate measuring machines, non-processing stations etc.

The optimization of simulation model deals with the study in which the analyst would like to find possible sets of model specifications which are input parameters which lead to optimal performance.

This paper presents the simulation and optimization study of a Flexible Manufacturing Cell using different tools such as Arena simulation software and Minitab software.

II. Literature Review

Smith [2] showed an evidence of references for using simulation in flexible manufacturing system design. A GPSS/H model was presented by Schriber [3] for analyzing hypothetical flexible manufacturing system. In Jovanovic's [4] work, bottleneck model and extended bottleneck model are used for quantitative analysis of flexible manufacturing system. Insup Um and others [5] prepared simulation design and analyzed the flexible manufacturing system consisting AGVs. Yusuf Tansel and others [6] presented a simulation model based case study of a flexible manufacturing system considering a multi-response simulation optimization using TOPSIS based Taguchi approach. B Santosh Kumar and others [7] modeled and analyzed flexible manufacturing system using FlexSim software. Sanjibkumar and others [8] presented detailed review of flexible manufacturing system based on modeling and simulation approaches. Literature study reveals that creating simulation model of the complex system is easier and effective in computer simulation softwares rather than mathematical model.

III. Problem Definition

A hypothetical manufacturing system which consists of four workstations producing four part types with different operation is considered here. Each workstation consists of one machine except the third workstation which consists two machines. All parts enter in the system at the load station and exit from the unload station. Part arriving probabilities are: Part1 - 27%, Part 2 - 36%, Part 3 - 25% and Part 4 - 12%. The conventional system has manual material handling system. Eight number of workers are used for manual material handling. Processing time of each operation on each machine is given in the below table 1.

Table 1 Processing time of each operation on each machine (min.)

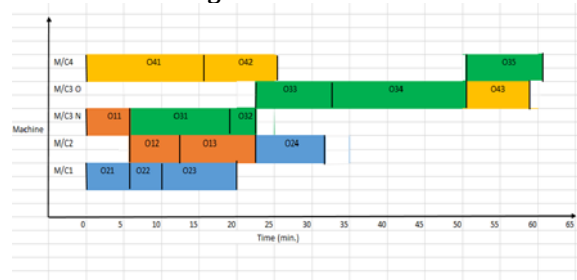
Part/Machine	Operation	Processing time (min.)				
		M/C1	M/C2	M/C3 New	M/C3 Old	M/C4
P1 (n1=3)	O ₁₁	9	8	6	8	7
	O ₁₂	9	7	8	10	10
	O ₁₃	12	10	11	12	14
P2 (n2=4)	O ₂₁	6	7	9	10	7
	O ₂₂	4	6	8	10	6
	O ₂₃	10	11	12	14	11
P3 (n3=5)	O ₃₁	14	14	12	15	13
	O ₃₂	6	5	5	8	9
	O ₃₃	13	11	11	10	15
P4 (n4=3)	O ₄₁	18	18	20	22	16
	O ₄₂	15	12	11	12	10
	O ₄₃	9	10	8	7	9

For this conventional manufacturing system, system throughput per year is in the range of 8000-9500. Avg. resource utilization is 0.41. The average transfer time for the part 1, part 2, part 3 and part 4 are 38.8 min., 27 min., 26.4 min. and 35.8 min. respectively. These performance values are conceded in the Arena simulation software. The layout of the system is similar with the layout of [9] and FMC also follows the same layout. Before installation of expensive FMC for this system, it is necessary to evaluate the performance of the system and optimize it so that better decisions to improve the system performance of future FMC can be taken.

IV. SIMULATION MODELING AND PERFORMANCE EVALUATION OF FMC

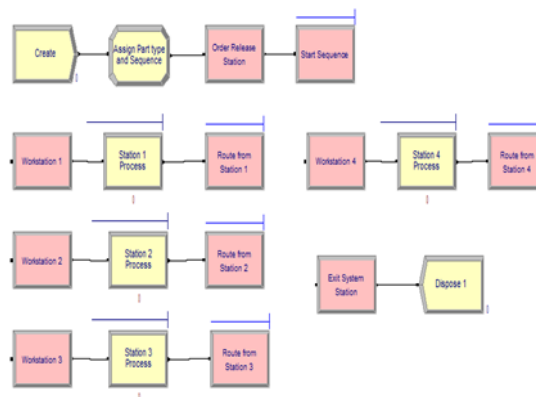
Shortest Processing Rule (SPT) is simple, fast and generally superior in terms of minimizing make span and maximizing throughput for system like FMC. Operation sequence is obtained using this rule. Gantt chart, as shown in the below fig. describes clearly, sequencing and scheduling of various operations on different machines.

Figure 1 Gantt chart



Arena is an easy-to-use, powerful modeling and simulation software tool that allows the user to construct a simulation model and run experiments on the model. Simulation model of FMC developed in the Arena simulation software is shown below:

Figure 2 Simulation Model of FMC Prepared by Arena



Some decision variables which affect the FMC performance is selected as shown below:

Table 2 Decision Variables

Factors	Levels		
	1	2	3
Selection rule	SD	CD	PO
No. of AGVs	2	3	4
Speed of AGVs (ft./min)	40	55	70
Inter-arrival time (min.)	10	15	20

SD rule selects available AGV nearest to the requesting station. CD rule selects the first available AGV unit beginning with the successor of the last unit selected. PO rule selects available AGV unit that has the lowest unit number.

For the FMC performance evaluation, taguchi's standard orthogonal array experimental design is used.

Table 3 Experimental Design and Performance values of FMC

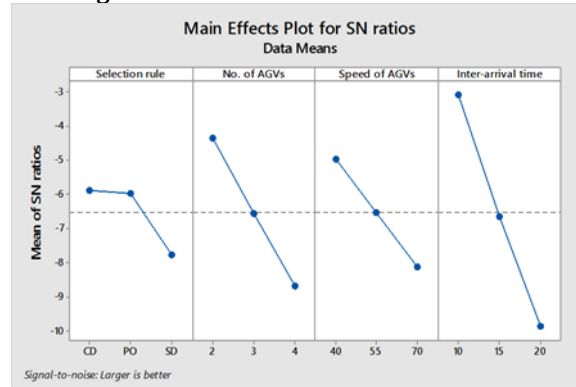
Exp.	Selection rule	No. of AGVs	Speed of AGVs	Inter-arrival time	System Throughput	Avg. Resources Utilization	AGV Utilization
1	SD	2	40	10	32187	0.68	0.89
2	SD	2	55	15	21200	0.45	0.46
3	SD	2	70	20	16228	0.34	0.27
4	SD	3	40	15	21488	0.46	0.36
5	SD	3	55	20	16021	0.34	0.19
6	SD	3	70	10	31825	0.68	0.35
7	SD	4	40	20	16205	0.35	0.17
8	SD	4	55	10	32130	0.68	0.30
9	SD	4	70	15	21499	0.46	0.15
10	CD	2	40	10	32381	0.69	0.90
11	CD	2	55	15	21351	0.45	0.50
12	CD	2	70	20	16083	0.34	0.31
13	CD	3	40	15	21282	0.45	0.44
14	CD	3	55	20	16029	0.34	0.25
15	CD	3	70	10	32023	0.68	0.43
16	CD	4	40	20	16033	0.34	0.25
17	CD	4	55	10	32283	0.68	0.39
18	CD	4	70	15	21404	0.45	0.21
19	PO	2	40	10	31799	0.67	0.89
20	PO	2	55	15	21547	0.46	0.51
21	PO	2	70	20	16107	0.34	0.31
22	PO	3	40	15	21460	0.46	0.45
23	PO	3	55	20	15974	0.34	0.25
24	PO	3	70	10	32253	0.69	0.43
25	PO	4	40	20	16078	0.35	0.25
26	PO	4	55	10	32146	0.68	0.39
27	PO	4	70	15	21453	0.45	0.21

This experimental design's experiments data along with other data such as processing time and processing sequence are used as input given to simulation model. Running the simulation model give the values of system throughput, resource utilization and AGV utilization as shown in the above table 3.

V. Optimization

Taguchi philosophy is widely used in engineering optimization processes. Taguchi analysis can be carried out easily in the Minitab software. Minitab calculates response tables and generates main effects and interaction plots for signal-to-noise ratios (S/N ratios, which provide a measure of robustness) vs. the control factors. Here largest S/N ratio is -0.45 for experiment 10. So factors settings for this experiment would give optimum FMC performance. Also, smallest value of S/N ratio is -12.15 which indicates that experiment 9 would give lowest value of responses. Minitab provide main effects plot for SN ratios which is called as Optimization plot also. From the optimization plot it is clear that to maximize the FMC performance inter-arrival time should be exponentially distributed to 10 min. Optimum number of AGVs obtained is two. Two AGVs will be enough for the considered FMC to perform at its best level. Also, optimization plot gives the detail about optimum speed of AGVs and Selection rule of AGVs. Optimization plot is shown in the below figure 3.

Figure 3 Main Effects Plot for SN ratios



VI. Results and Discussion

Response table for signal to noise ratio is obtained using Minitab. Delta value for selection rule, no. of AGVs, speed of AGVs and inter-arrival time is 1.345, 4.007, 2.401 and 5.872 respectively. From the response table, it can be said that FMC performance is highly influenced by Inter-arrival time and number of AGVs. Also, followed by inter-arrival time and no. of AGVs, Speed of AGVs and Selection rule affect FMC performance. Thus, analyzing taguchi design using Minitab gives optimum levels of factors. Using these values of factors, FMC performance is maximized which is shown below:

Table 4 Optimum FMC Performance

Performance measure	Value
System throughput	32381
Avg. Resource utilization	0.69
AGV utilization	0.90

Below table depicts improvement in the FMC performance compare to the conventional manufacturing system (CMS) performance:

Table 5 Improvement in the FMC Performance

Criteria	CMS	FMC	Improvement
System throughput	9279	32,381	248.97 %
Avg. Resource Utilization	0.41	0.69	68.29 %
Avg. Transfer time (min.)			
Part 1	38.8	9.7	75 %
Part 2	27	6.8	74.81 %
Part 3	26.4	6.6	75 %
Part 4	35.8	9	74.86 %

VII. Conclusions

This study extends the current state-of-the-art in the simulation and optimization of flexible manufacturing systems. From this work, it can be stated that FMC performance is highly influenced by inter-arrival time and number of AGVs. Also, followed by inter-arrival time and no. of AGVs, speed of AGVs and selection rule affect the FMC performance. So before implementing an expensive FMC, decision variables should be identified and optimized to improve the system performance. It can be concluded that for the system which is not yet existing, computer simulation is an effective and useful decision making tool for analyzing the system. Moreover, it can be concluded that designing advanced manufacturing systems such as FMC involves the simultaneous consideration of various decision variables and various performance measures. If the system like FMC has to be implemented, it is better to analyze and optimize its performance using tools like simulation and optimization so that better decisions for improving the proposed system performance can be taken.

VIII. Future Scope

This work is limited to a Flexible Manufacturing Cell which is one of types of Flexible Manufacturing System. For future research, the simulation methods of analysis can be expanded for other Flexible Manufacturing System design parameters such as different layouts, sequencing and scheduling rules, material handling system and machines specifications etc. Various components of Flexible Manufacturing System such as automated storage and retrieval, co-ordinate measuring machines, non-processing stations etc. can be also considered in the

simulation study. System performance measures such as cost, system utilization, make span, availability, reliability etc. can be considered for the performance evaluation. Different simulation tools and softwares can be used for the simulation study.

References

- [1] Groover, M. P., (2008), Automation, Production Systems and Computer Integrated Manufacturing, Edition:3, Pearson Education. pp.463.
- [2] Smith, J., (2003), "Survey of the use of simulation for manufacturing system design and operation", Journal of manufacturing systems, Vol. 22, No. 2, pp.157-171.
- [3] Schriber, T.J., (1985), "A GPSS/H model for a hypothetical flexible manufacturing system." Annals of Operations Research, Vol.3, pp.171-188.
- [4] Jovanovic, S., (2015), "Flexible manufacturing systems and quantitative analysis of flexible manufacturing systems", International Journal of Computer Applications, Vol.132, No.1, pp.6-14.
- [5] Um I., Cheon H., Lee Hongchul, (2009), "The simulation design and analysis of a flexible manufacturing system with automatic guided vehicle", Journal of Manufacturing Systems, Vol.28, pp.115-122.
- [6] Ic, Dengiz O., Dengiz B., Cizmeci, (2014), "TOPSIS based taguchi method for multi-response simulation optimization of flexible manufacturing system", Proceedings of the 2014 Winter Simulation Conference, pp.2147-2155
- [7] B. Santhosh Kumar, V. Mahesh, B. Satish Kumar, (2015), "Modeling and analysis of flexible manufacturing system with FlexSim", International Journal of Computational Engineering Research, Vol.5, No.10, pp.1-6.
- [8] Saren S., Tiberiu V., (2016), "Review of Flexible Manufacturing System based on Modeling and Simulation", Annals of the university of Oradea, No.2, pp.113-118.
- [9] Kelton, W.D., Sadowski, R.P & Swets N.B., (2010), Simulation with Arena, 5th Edition, McGraw-Hill, pp.268.
- [10] Getting started with Arena, (2014), Allen Bradley, Rockwell automation.
- [11] Phadke, M. S. (1989), Quality engineering using robust design, Prentice-Hall, ISBN: 0-13-745167-9.
- [12] Shivanand, H. K., Benal, M. M. & Koti, V., (2006), Flexible Manufacturing System, New Delhi, New Age International (P) Ltd.
- [13] P. Rama Murthy, (2007), Operation Research, 2nd Edition, New Age Publications.