A Simulation Study to Evaluate the Performance of FMS Using Operations Flexibility

Huzefa Mashhood and Prof. Mohammed Ali
Department of Mechanical Engineering
Aligarh Muslim University
Aligarh, UP 202002, INDIA
huzefa.mashhood@gmail.com, mohdali234@rediffmail.com

Abstract

The advancement of modern technology, specifically speaking Industry 3.0 and 4.0 has brought enormous amount of changes to the manufacturing sector. It has resulted in a very high automation of existing manufacturing sectors. Flexible Manufacturing Systems (FMS) have become the backbone of the modern industries due to this technological advancement. However, the complexity of the FMS requires a system to be developed to analyze and design complex manufacturing systems. This paper attempts to find a solution to this problem. Simulation is a powerful tool that is used to study and analyze the system performance. Numerous works has been done by various researchers considering various types of flexibilities. The main aim of this study is to develop a demonstrative model of Flexible Manufacturing System (FMS) using ARENA simulation software and to study the effect of operations flexibility on the performance of FMS. One of the reasons to select the operations flexibility for the study is due to very limited work done for this flexibility type. Based on the selected configurations, the conceptual and simulation models and their respective animations have been developed by ARENA Software. To verify the simulation results, multi-criteria decision making techniques viz. Grey Relational analysis (GRA) is used.

Keywords
Flexible Manufacturing Systems, Simulation, Operations Flexibility, Grey Relational analysis

1. Introduction
FMS is defined as a highly automated machine cell, which consists of a group of workstations interconnected by an automated material handling (AGVs, Robots, conveyors etc.) and storage system (AS/RS etc), and all of these integrated workstations are controlled by a computer system. A FMS layout is capable of processing a large variety of different part styles simultaneously at different workstations. The use of robots, AGVs in the manufacturing industries or a given FMS layout provides a variety of benefits ranging from high volume of productivity to high utilization. The production of each part or product requires a different combination of operations or manufacturing nodes (sequencing or operations flexibility). The FMS provide better flexibility, productivity, efficiency and adaptability which is lacking in traditional manufacturing systems. The simulations are performed for designing a model of a real life system and conducting the required experiments with this model instead of running the actual system. In this paper we are studying the effect of operations flexibility on the performance of the FMS. Operations flexibility can simply be defined as possibility of performing an operation on more than one machine. In other words the operations flexibility refers to producing same part or some part feature by varying the operations. Some researchers have referred operations flexibility while some have referred the sequencing flexibility in the research papers.

Our initial motivation is based on to explore the effect of operations flexibility on the performance of FMS. Since the parts are made at various operational conditions, FMS will take care of the variation in operational conditions to give the desired output. Despite recent interest in flexible manufacturing, more work is to be done in the domain of operations flexibility. This consists of determining the effect of manufacturing flexibility in order to improve performance measure such as average system output, average machine utilization and the average queue time of FMS. The proposed models of FMS will help decision makers to take appropriate decision regarding the choice of various manufacturing for FMS.

1.1 Objectives

From the perspective of our study, the literature review is used to identify a number of research gaps in the field of FMS and simulation and modeling which is basically our domain of work. Using these research gaps, we summarize the basic objectives of our study as follows.
(i) To develop a demonstrative model of Flexible Manufacturing System (FMS) using ARENA simulation software.
(ii) To study the effect of operations flexibility on the performance of FMS.
(iii)To perform multi-criteria performance measure with the help of Grey Relational Analysis (GRA)

2. Literature Review

Once we are done with the introduction and the initial idea of this research study, we perform a rigorous literature review of the past researches done in his field. Literature review basically acts as the foundation regarding the work. By studying the relevant publications, critically analyzing them and looking for the areas of improvements, we find the research gaps and propose the research objectives of the study. Apart from this there are certain parameters such as number of machines, part types, variation in buffer sizes etc which can be either selected by performing the experiments by developing a FMS environment or by rigorously performing a literature review and analyzing the parameters selected by the previous researchers.

Before 1990s there were eight types of flexibility discussed in the literature machine, routing, production, operation, expansion, product, process and volume. Later, there was addition of three more types of flexibility viz. material handling, market and program flexibility by *Sethi and Sethi (1990)* which he discussed in a survey study of Flexible manufacturing system. A framework has been provided to be used for analyzing the implementation of flexibility by *Oke (2005)* and a case study has been done for four different UK manufacturing plants in four major industrial sectors: electronics (Plant1), process (Plant2), household (Plant3) and general goods and food (Plant 4). For improving the performance of flexible manufacturing system, a case study has been done by *Singholi (2010)*. The study is based on the mathematical models illustrated in literature to estimate possible performance parameters like make span time , maximum production rate, and overall utilization of system. Finally, an effort is also made to present the improved design for existing FMS**.** The different merits, demerits, types of FMS system and various applications of FMS have been discussed in detail by *Kaushal (2016)* and some other aspect of FMS have also been overviewed and have reached to conclusion that in order to achieve higher productivity & high quality product at low cost as per market demand, the FMS is an efficient and effective tool. The effect of different flexibility parameters/measures on the performance of FMS is studied by *Raj (2016).* The analysis of the performance of a FMS has been done by *Mahmood (2017)* by using the manufacturing process modeling and simulation. The modeling has been done to know how the current system is working and to evaluate the proposed changes in the process before making the actual decisions.

Simulation analysis of different dispatching rules for an automated material handling system has been done by *Lin (2001).*The results showed that the different dispatching rules have a significant impact on various FMS parameters viz. average waiting time, transport time, throughput and vehicle utilization. The paper developed by *Anglani (2002)* presents a new procedure to develop flexible manufacturing system (FMS) simulation models, based on the ARENA simulation language**.** The manufacturing flexibility has been selected as a competitive tool by *Chan (2007)* for the simulation study done for analyzing purpose. This paper has discussed the impact of variations in physical and operating parameters of an FMS**.** The paper by *Hussein (2010)* presents a simulation analysis and optimization of a bakery production line using ARENA simulation software, done to optimize the processes on line and for energy consumption of the production devices. The performance of the FMS is evaluated by *Joseph (2011)* using various measures related to flow time and tardiness of parts. Further, the effects of sequencing flexibility, routing flexibility, and scheduling decision rules on the performance of FMS are discussed. An analytical model has been developed simulation modeling of automatic production lines with intermediate buffers by *Heshmat (2013)* to clarify the problems in real production lines. Apart from this, a case study is also done that provides analysis for a real cement production line taken as a case study has been done by *Heshmat (2013).* Analysis and Simulation of a Factory Layout has been done by *John (2013)* using ARENA. The simulation study has been undertaken to find out the efficiencies of the different machines in the industry and to find out the most efficient arrangement of machines in the machine shop. The existing layouts of crankshaft manufacturing unit are simulated by *Faisal (2015)* by using the ARENA simulation software. An introductory chapter on the topic of Simulation and Modeling has been written by *Abu-Taieh (2019)* emphasizing on the importance of simulation and modeling in academics. According to one of his reference, he has stated that in the 4 years (2014–2017), 43,188 scientific research papers were published in the abovementioned topic.

The above literature review works as a guideline for our study in the simulation and modeling area. Analysis and Optimization on similar lines can be done for a Flexible manufacturing system using ARENA simulation software and the effect of operations flexibility on the performance of system can be studied.

3. Methodology

In this study a framework has been developed to provide a model for improving the performance of a FMS. For this a rigorous literature review is done to determine the design parameters and the performance measures. In design parameters first we select the types of flexibility to be studied. We have selected operations flexibility for the study due to the limited amount of work done in this field and due to high possibility of improving the performance of FMS using this flexibility. Next we select the operating parameters namely the buffer size (based on past researches it's selected as infinite), simulation run time (24 hour run with three shifts of 8 hour each), and replication parameter (taken as 25, to minimize the possibility of errors in the simulation results). The number of machines and the number of part types has been taken as 6. This is also selected by performing the literature review of the past researches in this area. The sequencing rules are used while performing the study of the operations flexibility. For sequencing rules, we have undertaken four sequencing rules- First In First Out (FIFO), Last In First Out (LIFO), Shortest Processing Time (SPT) & Longest Processing Time (LPT) rules. Till here we are done with the flexibility type and the operating parameters to be used for the study. Finally we select the three performance measures namely average system output, average machine utilization and the queue time. We have selected a manufacturing system having six machines with each machine having a respective input and output system for the movement of parts. This movement can take place with the help of pallet changer, robots, AGVs etc. There are six part types that enter the FMS from one end and with the help of AGVs, the parts travel to the machine 1, machine 2 and so on. Finally the parts leave the system from the same end by the unload station. Each machine has a buffer system just before it with an assumed capacity of infinite parts.

4. Development of Simulation Model & Data Collection

In our research, we have used computer simulation due to the complexity in the operation problem solving and mathematical analysis for FMS. Also from literature, we have seen that most researchers have used simulation to analyze the performance of FMS. In an experiment, one or more variables are manipulated and its/their effects on other variables are measured, in other words, the testing is done in a controlled environment. The simulation model of FMS has been developed in the ARENA simulation package. The ARENA package was selected for modeling as it provides a good graphical interface and also the animation utilities. This helps in modeling and its verification.

Before development of simulation model for the study of operations flexibility, following assumptions are taken into account:
(i) Parts are created by assuming an exponentially distributed.
(ii) One unit of raw material (arriving part) is used to produce one unit of finished product.
(iii) Operation time for each product is considered randomly.
(iv) Each machine can process only one operation at a time.
(v) Each part-type, once entered in the system, must be processed to completion, without any order cancellation.
(vi) It is assumed that each machine is doing only one operation for a given part. This reduces no. of possibilities to 6! ie 720 possibilities.
(vii) It is assumed that each part much enter machine 5 and machine 6 at the end and in this order only. By doing this that is fixing the machines for last two operations, the possibilities further reduces to 4! i.e. 24 possibilities.
(viii) Finally assuming machine 4 can be used only when part has been processed on machine 3 and vice versa is not possible (machine 3 can be assumed as drilling machine and machine 4 as boring machine). This finally reduces possibilities to *12 sequences* (figure 1).
(ix) Breakdown &maintenance activities for both machines &vehicles are neglected.

The figure 1 shows the conceptual framework for operation flexibility. It's observed that twelve sequences can be modeled for the given set of operations on the six machines by taking the above assumptions into consideration.

The figure 2 shows the ARENA model that has been developed for studying the effect of the operations flexibility on the performance of the FMS. For this part of study we have considered the operations flexibility without any routing (that is routing flexibility, RF = 0). We have taken certain assumptions to reduce 6^6 sequences (6 machines and 6 operations, with one operation on each machine) to 12 sequences which has been explained. For our study we have used create module, assign module, process module, decide module, dispose module etc. The arrival per unit type is 1 and maximum arrival of a part type is assumed to be infinite. We have fixed the time of simulation run (24 hours) and varied the number of parts. The route module is used for defining the sequence of operations for each machine and the station module is used to define the various stations. Finally, while considering the system output we use a 95% acceptance limit (2 sigma limit). That is out of 100 parts, 5 parts are rejected after inspection and 95 parts are accepted after inspection.

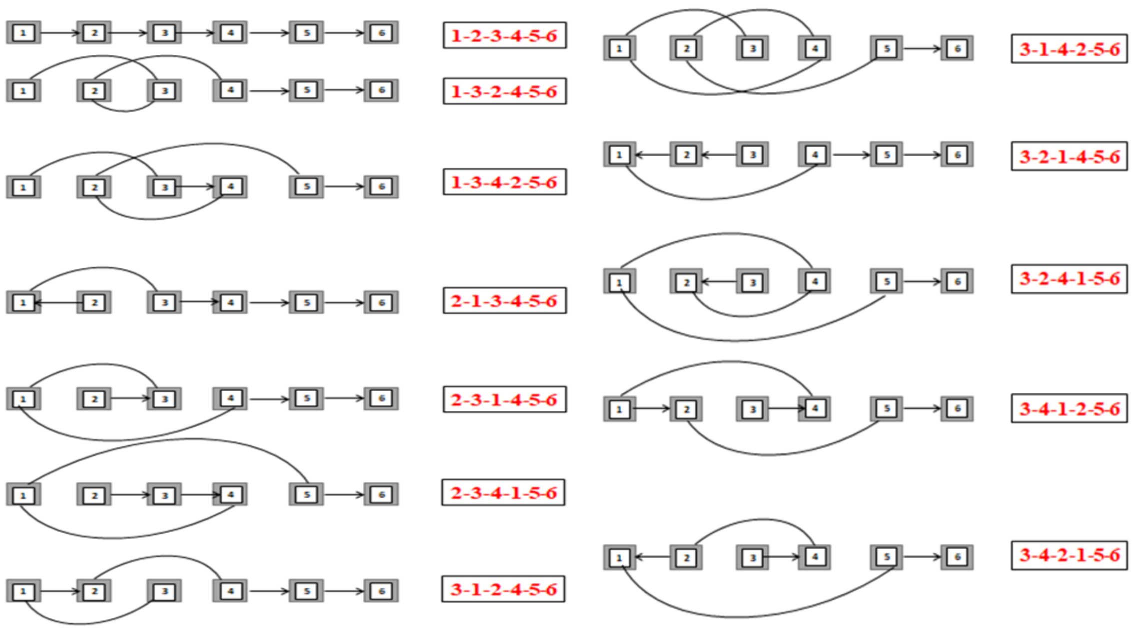

Figure 1. Twelve sequence to be modeled for the study of operation flexibility

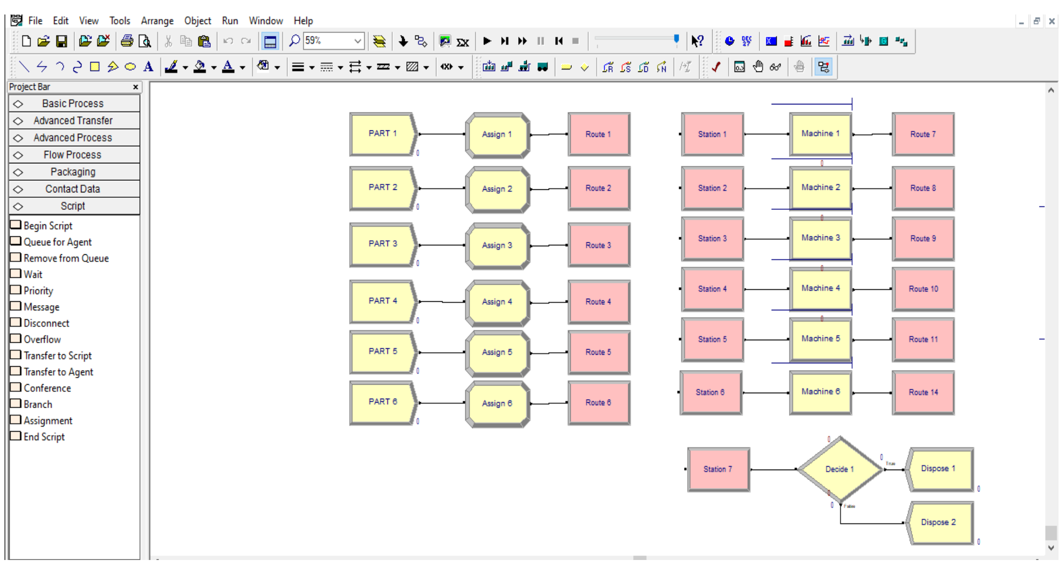

Figure 2. ARENA simulation model for studying the effect of operations flexibility

Once the model is developed, an important step is to verify and validate the simulation model. For the *verification* of our models we have used the basic verification method which allows only a single entity to enter the system and the movement of that entity is followed to be sure that the model logic and data are correct. Additionally we use the Step button found on the Standard toolbar to control the model execution and check the step by step movement of the entity through the system. This is done by setting the Max Arrivals field in the Create module to 1. To observe the movement of the different part types, we replace it with that part type which we want to observe. This allows us to check each of the part sequences. To *validate* a simulation model, we should compare the results from your model to the results from the real system. If the system does not yet exist, like in our case we have considered a hypothetical model; such a comparison may be a difficult task. In that case, the best method to validate the system is to make a subsequent animation with the logic model on ARENA software. The animations are developed on the ARENA simulation software itself and its working is verified by using the verification methods as discussed earlier in this section.

5. Results and Discussion

In the following section, we study the effect of sequencing rules on the performance of FMS. The performance measures considered are number of parts out of system, Average System Utilization and Average Queue time. For this study we consider the 12 sequences as discussed earlier. The following sequences rules are used in this study:

i. First In First Out (FIFO)
ii. Last In First Out (LIFO)
iii. Shortest Processing Time (SPT)
iv. Longest Processing Time (LPT)

Finally, before proceeding further we also have to keep in mind the nature of the three performance measures for optimizing the system. The first two works on ‘Higher the better’ and queue time works on ‘Lower the Better’. Although, the higher machine utilization implies larger queue time due to machine being in use for larger time, which results in larger queue formation. But, generally the queue time must be as small as possible to avoid wastage of time. The amount of time taken by the different part types (6 part types) for various operations (6 operations) on respective machines has been provided in the Table 1. For our study the operation times have been randomly generated (by using the normal distribution).

Table 1. Operations time on each machine for various part types selected for the study

Parts type	**Operations**					
	O1	**O2**	**O3**	**O4**	**O5**	**O6**
P1	M1(3)	M2(5)	M3(7)	M4(6)	M5(3)	M6(5)
P2	M1(4)	M2(3)	M3(3)	M4(7)	M5(3)	M6(4)
P3	M1(3)	M2(4)	M3(3)	M4(3)	M5(2)	M6(6)
P4	M1(4)	M2(4)	M3(6)	M4(3)	M5(7)	M6(3)
P5	M1(3)	M2(3)	M3(6)	M4(7)	M5(6)	M6(4)
P6	M1(5)	M2(6)	M3(6)	M4(4)	M5(2)	M6(4)

5.1 Simulation Results

The table 2 shows the effect of four sequencing rule and operations flexibility on the performance measures viz. Number of parts out of the system, average system utilization and average queue time. For observing the effect of sequencing rules and Operation Flexibility on performance of FMS, first we developed a model for the sequence 1-2-3-4-5-6 and run the model for a 24 hour run with 3 shifts of 8 hour each. The value of replication parameter is taken as 25. After this we tabulate the results of performance measures. After this we change the sequence one by one to the remaining 11 sequences. The sequences are changed by ‘sequence option’ in the ‘advanced transfer panel’. Same procedures repeated by varying the sequencing rules. Final results are shown in Table 2.

Table 2. Effect of sequencing rule on performance measures

S.No.	Sequence	Performance measures											
		No. of parts out				Avg System Utilization (%)				Avg Queue time (min)			
		FIFO	LIFO	SPT	LPT	FIFO	LIFO	SPT	LPT	FIFO	LIFO	SPT	LPT
1	***1-2-3-4-5-6***	143	145	145	142	43.10	43.93	44.10	43.48	4.01	4.15	3.10	7.01
2	***1-3-2-4-5-6***	146	148	146	144	44.24	45.26	44.28	44.18	4.21	4.31	3.14	6.28
3	***1-3-4-2-5-6***	146	142	145	145	44.19	43.17	43.47	44.39	4.26	3.94	3.08	6.61
4	***2-1-3-4-5-6***	146	142	146	143	44.05	43.08	44.10	43.22	4.16	4.06	2.99	6.25
5	***2-3-1-4-5-6***	143	146	146	142	43.28	44.23	44.24	42.88	4.11	4.25	3.12	6.56
6	***2-3-4-1-5-6***	145	144	143	142	44.08	43.65	43.34	42.76	4.44	4.24	3.11	6.33
7	***3-1-2-4-5-6***	145	145	146	141	43.67	43.87	44.00	42.72	4.06	4.13	2.93	6.87
8	***3-1-4-2-5-6***	145	143	147	141	43.84	43.19	44.87	42.84	4.21	3.99	3.10	6.58
9	***3-2-1-4-5-6***	145	145	148	146	43.75	43.68	44.93	45.02	4.09	4.14	3.10	6.80
10	***3-2-4-1-5-6***	147	143	146	142	44.48	43.09	44.21	43.04	4.49	4.05	3.11	6.62
11	***3-4-1-2-5-6***	146	146	146	140	44.04	44.37	44.76	42.47	4.21	4.22	3.05	6.02
12	***3-4-2-1-5-6***	143	143	142	142	43.43	43.08	42.73	43.62	4.05	4.04	2.74	6.90

From the above table following observations about the effect of sequencing rules on the performance measures can be made:

i. It is observed that, For FIFO rule, the number of parts coming out of the system varies from 143 to 147 parts. The sequence 3-2-4-1-5-6 results in maximum output while the 1st, 5th and 10th sequences result in minimum output. For LIFO rule, the number of parts coming out of the system varies from 142 to 148 parts. The sequence 1-3-2-4-5-6 results in maximum output while the 3rd and 4th sequences result in minimum output. For SPT rule, the number of parts coming out of the system varies from 142 to 148 parts. The sequence 3-2-1-4-5-6 results in maximum output while the 12thsequence results in minimum output. Finally, for LPT rule, number of parts coming out of the system varies from 140 to 146 parts. The sequence 3-2-1-4-5-6 results in maximum output while the 11thsequence results in minimum output.

ii. Next, it is observed that for FIFO rule, the average machine utilization of the system varies from 43.10% to 44.48%. The sequence 3-2-4-1-5-6 results in maximum average machine utilization while the first sequence results in minimum average machine utilization. For LIFO rule, average machine utilization of the system varies from 43.08% to 45.26%. The sequence 1-3-2-4-5-6 results in maximum average machine utilization. For SPT rule, the average machine utilization of the system varies from 42.73% to 44.93%. The sequence 3-2-1-4-5-6 results in maximum average machine utilization. Finally, for LPT rule, average machine utilization of the system varies from 42.72% to 45.02%. The sequence 3-2-1-4-5-6 results in maximum average machine utilization.

iii. Finally, For FIFO rule, it is observed that the average queue time of the system varies from 4.01 min to 4.49 min. The sequence 3-2-4-1-5-6 results in maximum average queue time while the first sequence results in minimum average queue time. For LIFO rule, average queue time of the system varies from 3.94 min to 4.31 min. The sequence 1-3-2-4-5-6 results in maximum average queue time while the third sequence results in minimum average queue time. For SPT rule, average queue time of the system varies from 2.74 min to 3.14 min. The sequence 1-3-2-4-5-6 results in maximum average queue time while the last sequence results in minimum average queue time. Finally for LPT rule, average queue time of the system varies from 6.02 min to 7.01 min. The sequence 1-2-3-4-5-6 results in maximum average queue time while the 11th sequence results in minimum average queue time.

5.2 Comparison of sequencing rule

The effect of the individual sequencing rules on the performance measures have been discussed in the above sections. For each of the rule, we have reached to a selection of an optimum sequence resulting in the maximum system output and the average system utilization. Table 3 shows the comparison of average of performance measures for different sequencing rules. For each sequencing rules the optimum sequence is different, so they can be compared just by comparing the performance measures of the optimum sequence. To overcome this issue, what we have done is that we have taken the average of 12 sequences to get a single value for the performance measures. By doing this the sequencing rules become comparable. The Table 3 shows the average values of performance measures for different sequencing rules.

Table 3. Comparison of average of performance measures for different sequencing rules

S.No.	Sequencing Rule	Performance measures		
		No. of parts out	Average System Utilization (%)	Average Queue time (min)
1	FIFO	145	43.85	4.19
2	LIFO	144	43.72	4.13
3	SPT	146	44.09	3.05
4	LPT	143	43.39	6.57

From the above table it can be concluded that the maximum system output is 146 parts, maximum average system utilization is 44.09% and the minimum queue time is 3.05 min. SPT as the sequencing rule. This rule is followed by FIFO, LIFO and LPT respectively. Figure 3 shows the variation in number of parts out of system with changing sequencing rules.

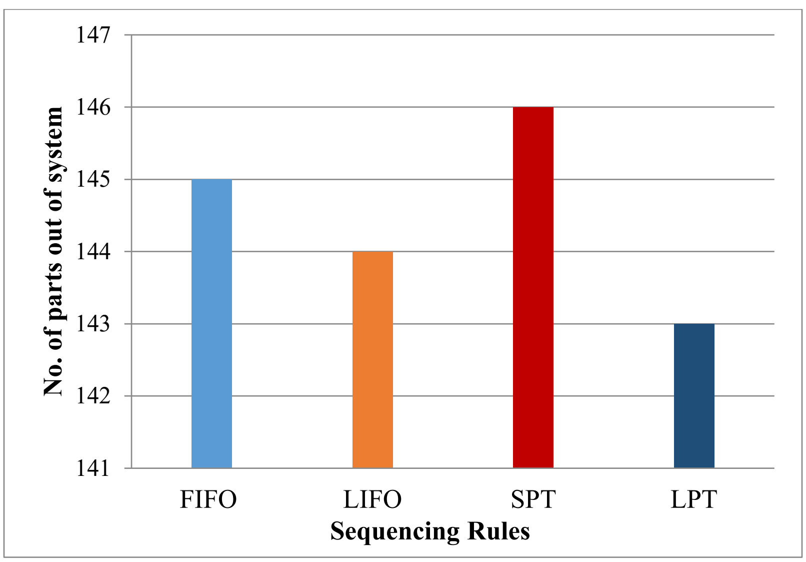

Figure 3. Variation in number of parts out of system with changing sequencing rules

5.3 Grey relational analysis to study the effect of sequencing rules on performance of FMS

For the verification of the simulation results and the selection of the optimum sequence & sequencing rule, the Multi Criteria Decision Making (MCDM) technique is used. The MCDM technique is a decision making tool that is used for the evaluation of the problems involving multiple alternatives and performance measures. It is used to find the optimum alternative with regard to different objectives. The grey relational analysis is used for the optimization of multiple performance characteristics or performance measures which are converted into optimization of a single grey relational grade. This makes the comparison of various sequences easier. Based on the work done on the grey relational analysis, the steps used in the GRA for this study can be defined as follows: *(Sarucan 2011, Goyal 2012, Chang 2013, Wang 2013, Jain 2015, Ertugrul 2016, Ahmad 2021)*

I. Data collection
II. Calculation of the Normalized values.
III. Deviation sequences
IV. Calculation of the grey relational coefficients
V. Calculating of the grey relational grade
VI. Ranking the various sequences

Based on the above steps of the procedure the effect of sequencing rule on the FMS performance is verified by Grey Relational Analysis (GRA). For this analysis part, we already have the results table for each sequencing rule. Now for each rule, first of all we develop the normalized values table, then the deviation sequences will be calculated by using the normalized values, next by using the deviation sequences the grey relational coefficients are calculated and tabulated. Now by using the values of the grey relational coefficients the grey relational grades are calculated. As we have assumed the equal weights for the three performance measures, it can be calculated by simply taking the average of the grey relational coefficients. Next, the rankings are assigned to all the sequences by giving first rank to the one with highest grey relational grade value and so on. Finally the optimum sequence is selected.

Applying GRA technique on the results of Table 2, the normalized value, grey relational coefficients and grey relational grades are calculated for the twelve sequences discussed earlier. Once we have the simulation results we calculate the normalized values as shown in Table 4. Now, using the GRA formulae with normalized values and the deviation sequences, we calculate the grey relational coefficients and tabulate the coefficients in Table 5. Finally, by taking the average of grey relational coefficients for various performance measures, the Grey relational grades are calculated and the grade values are ranked for the sequences in descending order and all these results are shown in Table 6. The ranked 1 sequence is marked as the optimum sequence.

Table 4. Normalized values of performance measures for different sequencing rules

Normalized values											
FIFO Rule			**LIFO Rule**			**SPT Rule**			**LPT Rule**		
No. of parts out	**Avg. System Utilization (%)**	**Avg. Queue time (min)**	**No. of parts out**	**Avg. System Utilization (%)**	**Avg. Queue time (min)**	**No. of parts out**	**Avg. System Utilization (%)**	**Avg. Queue time (min)**	**No. of parts out**	**Avg. System Utilization (%)**	**Avg. Queue time (min)**
0.00	0.00	1.00	0.50	0.39	0.43	0.50	0.62	0.10	0.33	0.40	0.00
0.75	0.83	0.57	1.00	1.00	0.00	0.67	0.70	0.00	0.67	0.67	0.73
0.75	0.79	0.48	0.00	0.04	1.00	0.50	0.34	0.15	0.83	0.75	0.40
0.75	0.69	0.68	0.00	0.00	0.66	0.67	0.62	0.38	0.50	0.29	0.76
0.00	0.13	0.79	0.67	0.53	0.16	0.67	0.69	0.04	0.33	0.16	0.45
0.50	0.71	0.09	0.33	0.26	0.17	0.17	0.28	0.07	0.33	0.11	0.69
0.50	0.41	0.89	0.50	0.36	0.48	0.67	0.58	0.53	0.17	0.10	0.14
0.50	0.53	0.58	0.17	0.05	0.86	0.83	0.97	0.10	0.17	0.14	0.43
0.50	0.47	0.83	0.50	0.28	0.46	1.00	1.00	0.09	1.00	1.00	0.21
1.00	1.00	0.00	0.17	0.01	0.70	0.67	0.67	0.07	0.33	0.22	0.39
0.75	0.68	0.58	0.67	0.59	0.24	0.67	0.92	0.23	0.00	0.00	1.00
0.00	0.24	0.92	0.17	0.00	0.73	0.00	0.00	1.00	0.33	0.45	0.11

Table 5. Grey relational coefficients of performance measures for different sequencing rules

Grey Relational coefficient											
FIFO Rule			LIFO Rule			SPT Rule			LPT Rule		
No. of parts out	Avg. System Utilization (%)	Avg. Queue time (min)	No. of parts out	Avg. System Utilization (%)	Avg. Queue time (min)	No. of parts out	Avg. System Utilization (%)	Avg. Queue time (min)	No. of parts out	Avg. System Utilization (%)	Avg. Queue time (min)
0.33	0.33	1.00	0.50	0.45	0.47	0.50	0.57	0.36	0.43	0.45	0.33
0.67	0.74	0.54	1.00	1.00	0.33	0.60	0.63	0.33	0.60	0.60	0.65
0.67	0.70	0.49	0.33	0.34	1.00	0.50	0.43	0.37	0.75	0.67	0.46
0.67	0.61	0.61	0.33	0.33	0.60	0.60	0.57	0.44	0.50	0.41	0.68
0.33	0.37	0.70	0.60	0.51	0.37	0.60	0.61	0.34	0.43	0.37	0.48
0.50	0.63	0.35	0.43	0.40	0.38	0.38	0.41	0.35	0.43	0.36	0.61
0.50	0.46	0.82	0.50	0.44	0.49	0.60	0.54	0.51	0.38	0.36	0.37
0.50	0.52	0.54	0.38	0.35	0.79	0.75	0.95	0.36	0.38	0.37	0.47
0.50	0.49	0.74	0.50	0.41	0.48	1.00	1.00	0.35	1.00	1.00	0.39
1.00	1.00	0.33	0.38	0.33	0.62	0.60	0.60	0.35	0.43	0.39	0.45
0.67	0.61	0.54	0.60	0.55	0.40	0.60	0.87	0.39	0.33	0.33	1.00
0.33	0.40	0.86	0.38	0.33	0.65	0.33	0.33	1.00	0.43	0.48	0.36

Table 6. Grey relational grades and ranks for different sequencing rules

Grey Relational Grade				Rank			
FIFO	LIFO	SPT	LPT	FIFO	LIFO	SPT	LPT
0.56	0.47	0.48	0.40	8	7	10	10
0.65	0.78	0.52	0.62	2	1	7	3
0.62	0.56	0.43	0.63	4	2	11	2
0.63	0.42	0.54	0.53	3	11	6	5
0.47	0.50	0.52	0.43	12	5	8	7
0.50	0.40	0.38	0.47	11	12	12	6
0.60	0.48	0.55	0.37	6	6	5	12
0.52	0.50	0.68	0.40	10	4	2	11
0.58	0.46	0.78	0.80	7	8	1	1
0.78	0.44	0.52	0.42	1	10	9	8
0.61	0.52	0.62	0.56	5	3	3	4
0.53	0.45	0.56	0.42	9	9	4	9

Based on the grey relational analysis highlighted sequences comes out to be the optimum sequence for the four rules respectively. The same sequences had been selected as the optimum sequence while performing the simulation study and studying its results. So, this analysis results in the verification of that selection. Finally it can be concluded that our selection was correct and it’s further verified by GRA. So, to get optimum performance output the highlighted sequences must be selected.

The same procedure is applied to Table 3 also to verify that SPT is the best sequencing rule. Based on the grey relational analysis, SPT comes out to be the optimum sequencing rule. The same sequencing rule had been selected as the optimum sequencing rule while performing the simulation study and studying its results. So, this analysis also results in the verification that SPT is best rule followed by FIFO, LIFO and LPT respectively.

6. Conclusion

This work provides a framework based on simulation experiments which can be applied to a FMS for improving its performance by optimizing certain design parameters. This has been done by developing a dynamic, deterministic and discrete type of the simulation models using ARENA simulation software to study the effect of operation flexibility on the performance of FMS. From the series of experiments conducted with four sequencing rules viz. FIFO, LIFO, SPT & LPT and operation flexibility it was found that SPT rule comes out to be the best rule followed by the FIFO rule. The sequence '3-2-1-4-5-6' in combination with the SPT sequencing rule gives the optimum performance for FMS. This selection of optimum sequence and the sequencing rule was verified by performing a MCDM analysis i.e. Grey Relational Analysis (GRA). The GR analysis results were found to be in accordance with the simulation results and it verified the selection of optimum sequence and sequencing rule.

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Biography

Huzefa Mashhood graduated from the Z.H. College of Engineering & Technology, Aligarh Muslim University, Aligarh (INDIA) with a B.Tech in Mechanical Engineering (2019) and did M.Tech in Industrial and Production Engineering (2021).

Mohammed Ali took his Mechanical Engineering in 1991 and Master in Industrial Engineering in 1995 from Aligarh Muslim University, Aligarh, U.P. Subsequently he did Ph.D. from IIT-Delhi, in 2007, in the domain of CIM systems under the supervision of Late Professor Subhash Wadhwa. At present he is working as Professor in Department of Mechanical Engineering, A.M.U. Aligarh. He has publications in journals such as International Journal of Production Reserach, Global Journal of Flexible Systems Management, International Journal of Industrial and System Engineering, International Journal of industrial Engineering, Studies in Informatics and Control Journal etc. He has also number of publications in International and National Conference proceedings. Two patents is published in Official Journal of the Patent, New Delhi. His interest includes Flexible Systems, Simulation, CIMS etc. He has also reviewed papers for renowned journals.