Comparison of using dispatching mechanisms in mutli-cell and random flexible manufacturing system

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This paper presents a comparative study to evaluate the dispatching mechanisms for multi-Cell Flexible Manufacturing Systems (MCFMS) and Random Flexible Manufacturing Systems (RFMS). The proposed model is based on a number of assumptions. It comprised computer-controlled machine tools, storage buffer areas, receiving area, and a load and an unload stations. The model also included robots and pallets. Parts enter and leave the FMS at load/unload stations and are transferred between machine centers by Automated Guided Vehicles (AGVs). Twelve different polices were considered to evaluate the impact of the system design parameters. A simulation run was made for each policy where the design parameters were systematically changed. The obtained results were analyzed under a number of performance criteria. The results show that the overall performance of MCFMS is better than RFMS.

إن مستوى أداء المنظومات الصناعية المرنة يعتمد بشكل كبير على قواعد الدفع المستخدمة وكذلك التركيب الهيكلي للنظام ذاته. في هذا البحث تم استعراض دراسة مقارنة لنظم التصنيع المرنة العشوائية ونظم التصنيع ذات الخلايا المتعددة من حيث مستوى الأداء المبنى على تأثير قواعد الدفع المستخدمة في عملية الإنتاج. تم استخدام عدد أثني عشر قاعدة دفع للمنتجات في داخل منظومتي التصنيع المستخدمتين في الدراسة ولقد أظهرت النتائج أن هناك تحسن ملحوظ في مستوى أداء المنظومة ذات الخلايا المتعددة عن المنظومة عشوائية الهيكلية.

Keywords: Dispatching rules, Flexible-manufacturing systems, FMS scheduling, Performance measure

1. Introduction

FMS is defined as "a manufacturing system that consists of automatically re-programmable machines, automated tool deliveries and changes, automated material handling and transport, and coordinated shop floor control". A flexible manufacturing cell is a type of flexible manufacturing that consists of a group of single FMSs sharing one common material-handling device, where as Multi-Cell Flexible Manufacturing Systems (MCFMS) there is a type of FMS which consists of a number of FMCs, and possibly a number of single flexible machine, all connected by an automated material handling systems, if necessary. A fundamental property of such a system is the processing flexibility where it is defined in two levels: the cell level and the system level. At the cell level, processing flexibility relates to the ability to perform the same operation on various machines. At the system level, processing flexibility is the system's capability to process the same part type in various cells. However, firms adopt cellular manufacturing systems to achieve, in less-repetitive environments many of the benefits associated with mass production. Some of the benefits ascribed to cellular manufacturing include reduced set up times; lower work-in-process levels, faster throughput times, improved product quality, and reduced material handling. Although the above are the most advantages of cellular manufacturing systems, researches have not found cellular manufacturing of a superior to the functional layout in all instances. Many researchers [1,2] had focused their field on attempting to identify those environments in which cellular manufacturing systems are superior. A learning-based methodology for dynamic scheduling that explores flexibility and handles uncertainties in distributed manufacturing system is developed by Chiu and Yih [3]. An extended dispatching rule approach, which applies different dispatching rule combinations in the mechanisms, and a search algorithm to find an appropriate dispatching rule combination has been advised by Ishii and Muraki [4]. Two models for evaluating some operation control rules in scheduling functional and cellular FMS and in the presence of work center interruptions are introduced by Shouman et al. [5,6]. In these models, a combined routing, planned, unplanned interruption ratios and different dispatching mechanisms are considered. Dispatching rules for FMSs under the condition that the part types and their quantities are dynamically changed over some specified stages or periods of the entire scheduled horizon are studied by Abouali and Shouman [7].

The aim of this paper is to study the effect of FMS layouts on dispatching mechanisms. It describes a comparative study for evaluating dispatching mechanisms of two flexible manufacturing system layouts MFMC and RFMS. The MFMC model consists of two independent flexible manufacturing cells. Some of the part types can be processed in the two cells, generally with different processing times, while others can be processed only in one of the cells. Each cell consists of several computer-controlled machines, capable of performing a wide range of operations. An operation can, typically, be processed by more than one machine. Machines are equipped with means (automatic tool changers, communication network, etc.) for the processing of different parts with relatively short change over activities. Each machine is served by a local Work-In-Process (WIP) buffer. Parts can be handled from each buffer to any machine, and from the machines back to WIP buffer, or out of the cell by AGV. A computer controlled handling device transfers workpieces between machines and buffers, one at a time. In the case of RFMS, the machines used in MFMCs are distributed as a random FM layout. Each machine has a local buffer and the system facilities are connected by AGV as a material handling system. Both the flow of parts and transfer networks are designed to be in agreement with multi-cell and random flexible manufacturing systems.

2. Model assumption

The multi-cell flexible manufacturing model presented in this paper is based on a model proposed by Atmani et al. [2]. In this work, the proposed models were developed based on the following major assumptions:

1. The system processes a variety of part types out of a large but finite and known population. Each cell can process a known subset of part types from the system part type's population. In a specific time the machine cells and the entire system are ready to process part of types from only a finite set.
2. The material handling between cells is performed by the AGV and handling times are considered negligible relative to operation times. It is assumed that the cells are technologically well designed. Handling devices will not constitute a major constraint.
3. Completion of part typically requires several operations. It is possible to perform the operations in several sequences. Operation time is dependent only on the machine and is independent of the sequence.
4. The secondary facilities such as tool magazines, pallets, controller's memories, and etc. do not constitute constraints. This assumption reflects the current state of technology where means like automated tool delivery, tool management system, large memory file servers etc. are in use.
5. The dispatching rules control parts flow with the proposed system with the objective of optimizing the performance index.
6. The distribution of interruptions of machines is deterministic.
7. In addition to the major assumptions, the following assumptions were also considered:

- The part moving time has no effect on lead-time and parts size transporters.
- Limiting the total service time of each machine station to the capacity of that place prevents system congestion and each operation can be processed by one machine only at a time.
- Data for alternative routes, processing times, and arrival rates, due dates, transporter

speed, resources, set-up and tear down times are deterministic.

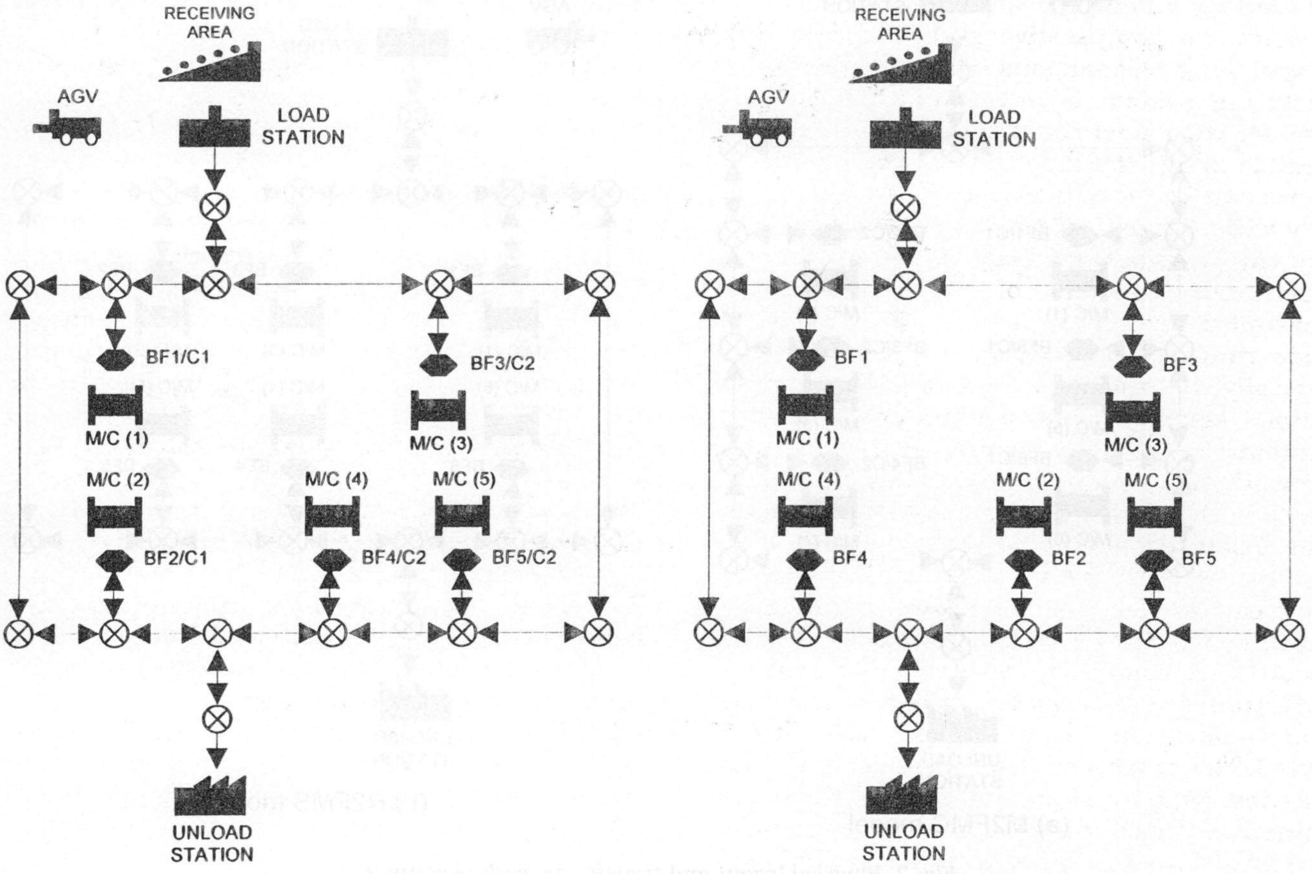
3. Description of model experiments

Two independent sets of experiments were conducted for each model. Experiments referenced as M1FMC, M2FMC for MFMC model and as R1FMS, R2FMS for RFMS model. These four experiments were conducted on two main machine setups: setup1 and setup2. Experiments M1FMC and R1FMS were conducted on setup1 while experiments M2FMC and R2FMS were conducted on setup 2.

3.1. Physical layout

Setup1: consists of five computer-controlled machine tools (M/C1, M/C2, M/C3, M/C4 and M/C5) each of which has a storage buffer (BF1, BF2, BF3, BF4 and BF5). Setup1 has a receiving area, and a load and an unload stations. Parts enter and leave the FMS at load/unload stations and are transferred between machine centers by the aids of AGV. Two models were considered on setup1, M1FMC and R1FMS. M1FMC model consists of two cells (cell 1 and cell 2). Cell 1 consists of M/C1 and M/C2. Cell 2 consists of M/C3, M/C4 and M/C5. Each machine has a local storage buffer. Fig. 1-a and 2-b exhibits the physical layout of M1FMC and R1FMS models, respectively,

Setup2: consists of six computer-controlled machine tools (M/C1, M/C2, M/C3, M/C4 M/C5 and M/C6) each of which has a storage buffer (BF1, BF2, BF3, BF4 BF5 and BF6). Setup2 has a receiving area, and a load and an unload stations. Parts enter and leave the FMS at load/unload stations and are transferred between machine centers by the aids of AGV. Two models were considered on



(a) M1FMC model

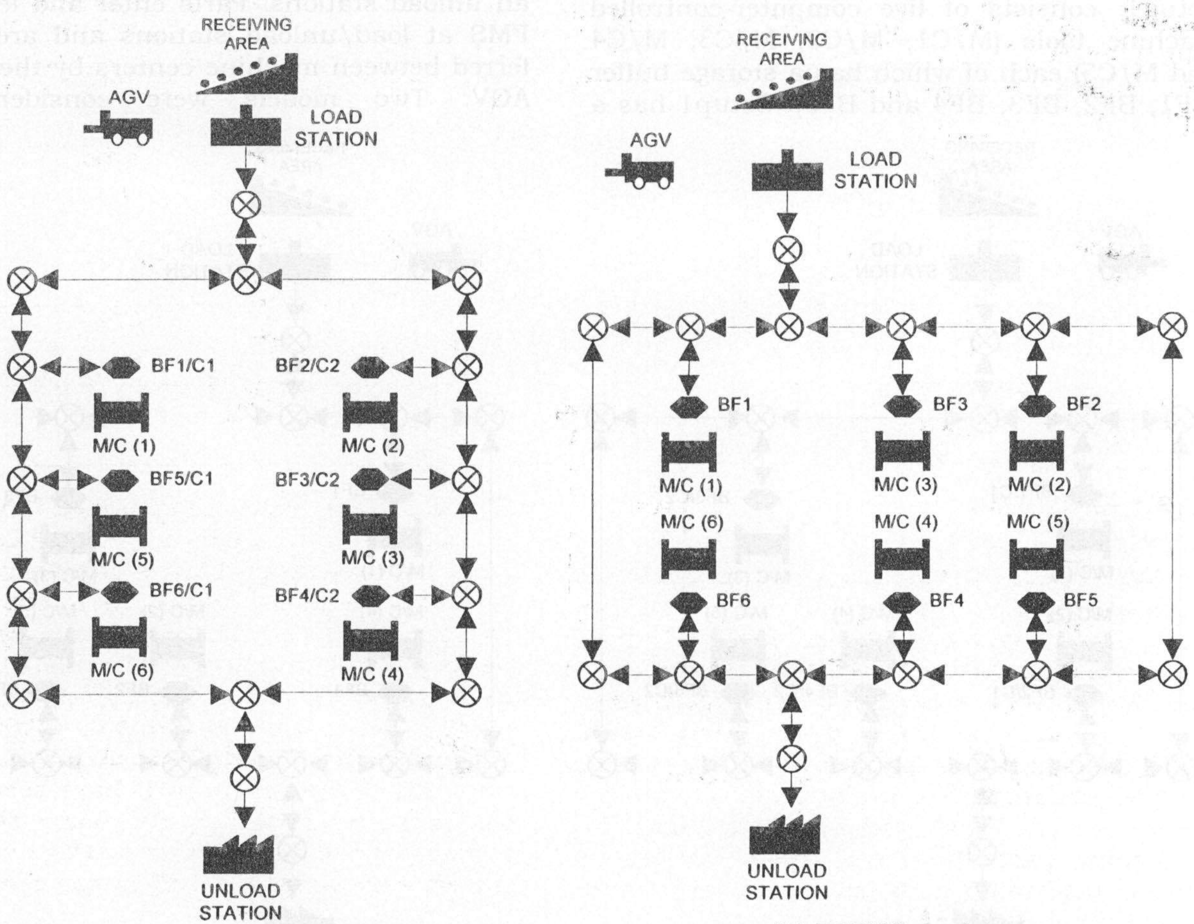
(b) R1FMS model

Fig. 1. Physical layout and transfer network of setup 1.

setup2, M2FMC and R2FMS. M2FMC model consists of two cells (cell 1 and cell 2). Cell 1 consists of M/C1, M/C5, and M/C6 while cell 2 consists M/C2, M/C3, and M/C4. Each machine has a local buffer. Fig. 2-a and 2-b exhibits the physical layout of M2FMC and R2FMS models, respectively.

3.2. Part data

Four distinct part types are to be processed within the models. Each part type requires several operations, routes and process plans. Table 1 presents the possible routes through the system for each part type and the unit processing time of each operation as well as the due dates of the M1FMC and R1FMS models. Table 2 presents the possible routes through the system for each part type and the unit processing time of each operation as well as the due dates of the M2FMC and R2FMS models. The operating characteristics for the AGV, receiving area capacity storage, and local buffer capacity are held unchanged for each considered setup.



(a) M2FMC model

(b) R2FMS model

Fig. 2. Physical layout and transfer network of setup 2.

Table 1
Data of part types of M1FMC and R1FMS models

Part type	Cell #	Machine #	Operation required and processing time				Due date (minutes)
			OP1	Time	OP2	Time	
P1	1	1			OPB11	5.9	5200
		2	OPA1	3	OPB1	6	
P2	1	1	OPA2	9			4500
		2			OPB2	3.5	
P3	2	3	OPA31	8			5500
		4	OPA3	7	OPB31	5	
		5			OPB3	5.5	
P4	2	3	OPA4	7			5400
		4			OPB4	8.7	
		5	OPA41	6			

Table 2
Data of part types of M2FMC and R2FMS models

Part type	Cell #	Machine #	Operation required and processing time						Due date (minutes)
			OP1	Time	OP2	Time	OP3	Time	
P1	2	2	OPA12	7.5	OPB1	2.4			3600
		3	OPA1	3.2					
		4			OPB12	7.3			
P2	1	1	OPA2	4.3					5200
		5	OPA22	6.8	OPB21	2.2			
		6	OPA23	6.3					
	2	2			OPB22	3.5			
		3	OPA21	5.2	OPB2	2.7			
		4			OPB23	8.2			
P3	1	1	OPA3	2.5					3700
		5			OPB3	2.5			
		6					OPC3	3.5	
P4	2	2							5300
		3	OPA43	6.8	OPB43	4.2			
		4	OPA4	5.8	OPB4	3.7			

3.3. Available resources

Five types of resources are included in both setups, four robots (ROB 1, ROB 2, Robload, Robunload) and pallets. ROB 1 is used for the setup and teardown of parts on M/C1 and M/C2. ROB 2 is used for setup and teardown of parts on M/C3, M/C4, and M/C5. Robload is used for loading parts into pallets in load situation with uniform distribution for setup of (1, 1.5). Robunload is used for unloading parts from the pallets in unload station with uniform distribution for teardown of (0.5, 1).

4. Model implementation

The designed transferred networks connecting the subsystems of material handling under consideration are exhibited in fig. 1 and 2. Based on the operation sequence on the work-stations for part types and the classification of operations/each work station, the process plans for the two setups have been designed and constructed. The complete data information for these models, as well as the process plans are addressed in SIMFACTORY II.5 and verified through its verification procedure. Many simulation runs have been carried out for each dispatching rule/each case, till it reaches stable state or the average values for the most stable station will be considered.

4.1. Measuring performance criteria

Simulation output provides the scalar of the simulator with a performance measure, which quantifies the performance of the simulated model. A few important equivalences in performance measures are applied in this work: throughput rate, product make span, mean flow time (MFT), mean tardiness (MT), sum of Mean Flow Time and Mean Tardiness, and number of Tardy Jobs (TJ). These measuring performance criteria are considered for the evaluation of dispatching mechanisms for each model configuration in order to determine the dispatching rule that will perform the best. In the case, when throughput and product make span are insignificant parameters for evaluation; MFT, MT, sum of both, and number of tardy jobs will be considered. MFT and MT are estimated as in eqs. (1) and (2):

$$\text{Mean flow time} = \Sigma\,(C_i - R_i)/n, \qquad (1)$$

$$\text{Mean tardiness} = \Sigma \max\,(0, L_i)\ /\ NT. \qquad (2)$$

Where C_i is the completion time of part i, R_i is the time of entry, D_i is the due date of part i, NT is the number of tardy jobs, L_i is the lateness of part i ($C_i - R_i - D_i$), and n is number of completed parts.

4.2. Simulation tool

Simulation software tools are classified into three different levels (system, application and structural) (8). Also, many aspects are considered as essential and desirable features in the selection of simulation software product. Those that are pertinent to manufacturing environment, are: input flexibility, modeling conciseness, macro-capability, material handling modules, standard statistics generation, data analysis, animation, interactive model debugging, and micro/mainframe compatibility. According to the considered groups of criteria, SIMFACTORY II.5 has an advanced position based on a simulation software survey provided by Law and Haider [9]. In this software no programming is required, model construction and data input are simplified through the menu-driven interface. In addition, there are no arbitrary limits to the number and type of items that the model can include. Animated pictures of a factory can be obtained at work during simulation and not after the action is over. For evaluation of the present work, twelve dispatching rules are considered; Random, By turn, Low usage, High usage, Closest, Farthest, Shortest idle, Longest idle, Fewest parts, Most parts, Oldest parts and Newest parts.

4.3. Pattern of arrivals

The pattern of arrivals for M1FMC and R1FMS is considered a repeating pattern, while it is scheduled for M2FMC and R2FMS. Following are the specifications of the pattern of arrivals:

- M1FMC and R1FMS:

First arrival: Constant (100) for p1, p2, p3, and p4
ATBA: Nor. (5, 1.2, 1) for p1
Exp. (8, 1) for p2
Exp. (4, 1) for p3
Poi (6, 1) for p4
Quantity: Constant (5) for p1, p2, p3, and p4.

- M2FMC and R2FMS:

First arrival: Constant (100) for p1, p2, p3, and p4
Quantity: p1 = 100, p2 = 150, p3 = 130, p4 = 175

4.4. Interruptions

Two types of interruptions, planned and unplanned are considered. Planned interruptions are passive in nature, while unplanned interruptions have priority over any current operation. The basis of the interruption tells whether to measure the times in terms of elapsed time or operating time. Elapsed time refers to the simulation clock, while operating time refers to the amount of time spent operating. The mean Time Between Interruption (MTBI) distributions is interrupted as a number of operations, which occur at the station between interruptions. The Mean Time To Repair (MTTR) distribution is still interrupted as elapsed simulation times since no operations occur while the station is down. The interval flags are start-to-start and end-to-start. These tell how to apply the mean time between interruptions. In this aspect, the main characteristics of the interruptions under consideration of the current models are exhibited in table 3.

5. Simulation results

Twelve different policies were simulated to estimate the impact of the system design parameters for the comparative study. The design parameters were systematically changed for each policy and the simulation run has been made for each policy. Many simulation runs have been performed for each dispatching rule till the results became stable and then recorded for both setup models.

5.1. M1FMC and R1FMS

The model has been simulated using twelve replications each of 480 minutes length and 100 minutes as a warm-up length for each dispatching rule. The throughput, products make span, and trace messages have been recorded. Table 4 shows both the throughput and product make span for each dispatching mechanism. From the obtained data and considering the performance measuring criteria, it is clear that experiment M1FMC2, which corresponds to rule 2, has the best performance for M1FMC while experiment R1FMS1, which corresponds to rule 1, has the best for R1FMS. Table 5 presents throughput, makespan in addition to MFT, MT, MFT + MT for the simulation tests of the best dispatching rules obtained for both models. The average resources and machines utilization of models are exhibited in figs. 3 and 4.

Table 3
Distributions for machines interruptions of the two setups

Setup type	Setup one					Setup two	
M/C # Distribution	M/C1	M/C2	M/C3	M/C4	M/C5	M/C3	M/C5
MTBI	Con (60)	Con (75)	Nor (15,5,1)	Con (100)	Exp (50)	Con (75)	Con (90)
MTTR	Uni (10,12,1)	Uni (10,15,1)	Nor (2, 10,1)	Uni (10,18)	Exp (20)	Uni (10,15)	Uni (10,12)

Table 4
Simulation experiments data of throughput and make span of the M1FMC and R1FMS models

Rule	Simulation file reference	M1FMC		Simulation file reference	R1FMS	
		Throughput	Make span		Throughput	Make span
1	M1FMC1	44.59	40.7575	R1FMS1	45.33	42.5175
2	M1FMC2	46.00	44.5175	R1FMS2	45.07	45.1150
3	M1FMC3	43.16	48.0950	R1FMS3	41.25	51.6625
4	M1FMC4	45.25	44.4950	R1FMS4	44.09	41.9025
5	M1FMC5	45.25	44.4950	R1FMS5	44.09	41.9025
6	M1FMC6	45.41	43.8250	R1FMS6	44.67	42.3825
7	M1FMC7	43.57	47.0075	R1FMS7	42.41	46.4500
8	M1FMC8	44.41	46.1875	R1FMS8	43.76	43.3400
9	M1FMC9	44.41	46.1875	R1FMS9	43.84	43.3125
10	M1FMC10	45.41	42.3500	R1FMS10	44.58	42.0675
11	M1FMC11	43.83	47.1250	R1FMS11	42.08	47.3350
12	M1FMC12	45.25	44.4950	R1FMS12	44.09	41.9025

Table 5
Measuring performance criteria of simulation tests of the M1FMC and R1FMS models

Best rules	Throughput	Make span	MFT	MT	MFT+MT	TJ
M1FMC2	46.00	44.5175	2837.3439	183.004410	3020.348310	32.0
R1FMS1	45.33	42.5175	2829.1116	192.132740	3021.244340	21.0

5.2. M2FMC and R2FMS

The model has been simulated using twelve replications each of 480 minutes length and 100 minutes as a warm-up length for each dispatching rule. The throughput, products make span, and trace messages have been recorded. Table 6 shows average data the two observed streams of both the throughput and product make span for each dispatching mechanism. From the obtained data and considering the performance measuring criteria, it is clear that experiments M2FMC1 and R2FMS1, which correspond to rule 1, have the best performance for both models. Table 7 presents throughput, makespan in addition to MFT, MT, MFT + MT for the simulation tests of the best dispatching rule obtained for both models. The average resources and machines utilization is exhibited in figs. 5 and 6.

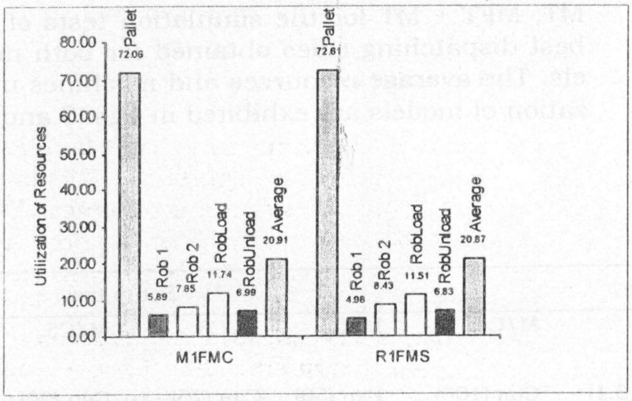


Fig. 3. Resources utilization.

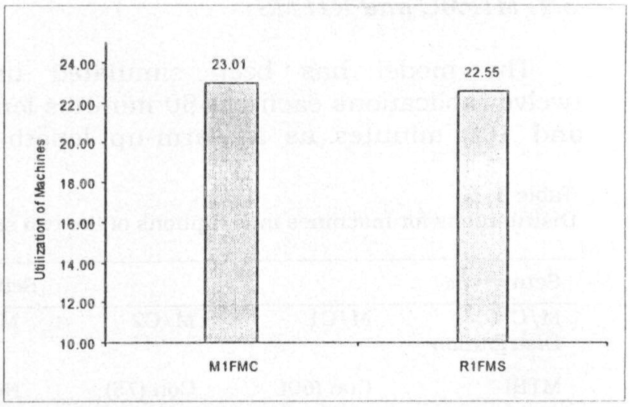


Fig. 4. Machines utilization.

Table 6
Simulation experiments data (average) of throughput and make span of the M2FMC and R2FMS models

Rule	Simulation file reference	M2FMC		Simulation file reference	R2FMS	
		Throughput	Make span		Throughput	Make span
1	M2FMC1	46.240	7.7287	R2FMS1	46.240	8.9113
2	M2FMC2	43.365	15.1162	R2FMS2	43.450	15.0925
3	M2FMC3	46.240	10.9137	R2FMS3	46.240	12.0800
4	M2FMC4	46.240	8.9925	R2FMS4	46.240	9.2762
5	M2FMC5	46.240	8.9925	R2FMS5	46.240	9.2762
6	M2FMC6	46.240	8.5800	R2FMS6	46.240	8.7012
7	M2FMC7	43.615	14.1762	R2FMS7	43.620	14.1575
8	M2FMC8	46.240	8.9037	R2FMS8	46.240	9.3962
9	M2FMC9	46.240	8.9037	R2FMS9	46.240	9.3962
10	M2FMC10	46.240	8.4650	R2FMS10	46.240	8.7175
11	M2FMC11	46.240	11.2387	R2FMS11	44.535	13.2137
12	M2FMC12	46.240	8.9925	R2FMS12	46.240	9.2762

Table 7
Measuring performance criteria of simulation tests (average) of the M2FMC and R2FMS models

Best rules	Throughput	Make span	MFT	MT	MFT+MT	TJ
M2FMC1	46.240	7.72870	2659.1625	55.298790	2714.461290	18.5
R2FMS1	46.240	8.91125	2713.5465	96.638525	2810.185025	37.0

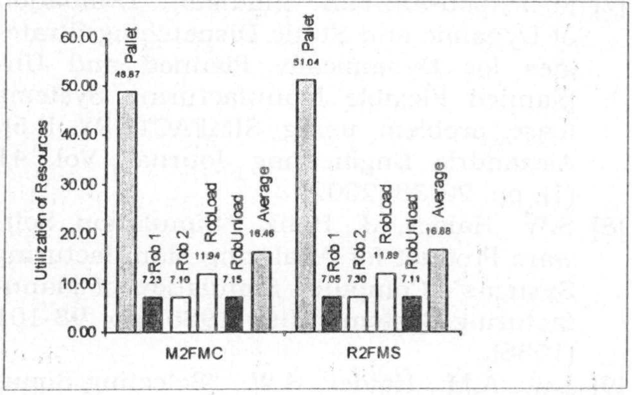


Fig. 5. Resources utilization.

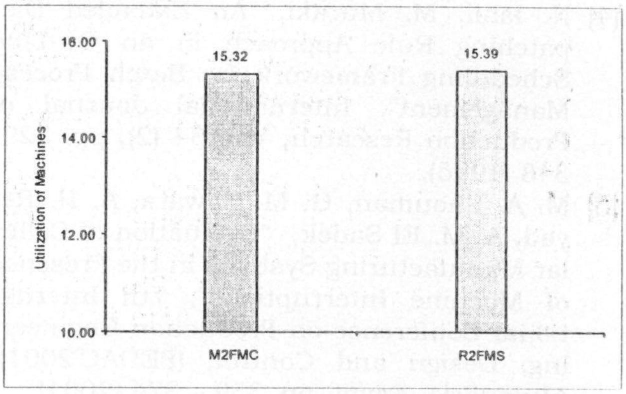


Fig. 6. Machines utilization.

6. Concluding remarks

The obtained simulation results in this paper lead to the following concluding remarks:

- Rule 1 is the best schedule for M2FMC, R2FMS and R1FMS while Rule 2 is the best schedule for M1FMC.
- The throughput of cellular layout is greater than the random layout for all dispatching rules except the first one.
- Production make span is always better for M2FMC model than R2FMS model for most considered dispatching rules, while vise versa for M1FMC and R1FMS models.
- The average resource and machines utilization are better for R2FMS than M2FMC for all considered dispatching rules, while vise versa for M1FMC and R1FMS models.
- Considering MFT, ML, MFT+ML, and number of tardy jobs as measuring performance criteria, cellular layouts are better in their performance than random layouts for all the considered dispatching rules.
- The level of inventory buffers for cellular layout is better than random layout for some dispatching rules and vise is versa for the other.

Cellular layout is not always superior to any functional or random FMS. This finding is supported in the current study where resources and machine utilizations were better for random FMSs than cellular FMSs. However, the system features, characteristics and dispatching rules play an important role in its performance. Also, it is not recommended to design the FMS in cell structure as long as the part types can not be grouped in part families and be of high degree of repeatability. This is a crucial key element for system economics. No specific dispatching rule can be considered as the best rule than others. The best dispatching rule depends on the system configuration, the number of part types, and the production mix. No significant influence has been recognized due to the interruptions except that the level of inventory buffer for random FM layouts where they are better than cellular FM layouts for some dispatching rules. This remark requires more attention and investigation to study the influence on the performance separately. However, this point might offer some insights and encourage further study in this field.

References

[1] Y. Arzi, "On-line Scheduling in a Multi-Cell Flexible Manufacturing System", International Journal of Production Research, Vol. 33 (12), pp. 3283-3300 (1995).

[2] A. Atmani, R.S. Lashkari, R.J. and Caron, A Mathematical Programming Approach to Joint Cell Formation and Operation Allocation in Cellular Manufacturing", International Journal of Production Research, Vol. 33, pp. 1-15 (1995).

[3] C. Chiu, Y. Yih, "A Learning-Based Methodology for Dynamic Scheduling in Distributed Manufacturing Systems", International Journal of Production Research, Vol. 33 (11) (1995).

[4] N. Ishii, M. Muraki, "An Extended Dispatching Rule Approach in an On-Line Scheduling Framework for Batch Process Management", International Journal of Production Research, Vol. 34 (2), pp. 329-348 (1996).

[5] M. A. Shouman, G. M. Nawara, A. H. Reyad, A. M. El Sadek, "Evaluation of Cellular Manufacturing Systems in the Presence of Machine Interruptions", 7th International Conference on Production Engineering, Design and Control, (PEDAC'2001), Alexandria, Egypt, pp. 359 – 374 (2001).

[6] M. Shouman, G. M. Nawara, A. H. Reyad, and A. M. El Sadek, "Evaluation of Some Operational Control Rules in Scheduling Flexible Manufacturing System", 7th International Conference on Production Engineering, Design and Control, (PEDAC'2001), Alexandria, Egypt, pp. 471 – 484 (2001).

[7] M.G Abou-Ali, M.A. Shouman, "Evaluation of Dynamic and Static Dispatching Strategies for Dynamically Planned and Unplanned Flexible Manufacturing Systems (case problem using SIMFACTORY II.5), Alexandria Engineering Journal, Vol. 41 (1), pp. 29-38 (2002).

[8] S.W. Haider, J. Bank, "Simulation Software Product for Analyzing Manufacturing Systems", Computer Simulation of Manufacturing Systems, July 1986, pp. 98-101 (1986).

[9] Law, A.M., Haider, S.W., "Selecting Simulation Software for Manufacturing Applications: Practical Guidelines and Software Survey", Industrial Engineering, Vol. 34, pp. 33-46 (1995).

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