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Research paper

Simulation of the machine loading decision in flexible manufacturing cell based on FlexSim environment

H.T.Nguyen[1], Q.N.Tran[2] ,A.P. Rifai[3] ,H.N.Huynh[4] ,Siti Zawiah Md Dawal[5]

[1,2]Ho Chi Minh City University of Food Industry (HUFI), Tan Phu, Ho Chi Minh City 700000, Vietnam
[3]School of Integrated Design Engineering, Keio University, Yokohama 223-8522, Japan
[4]Ho Chi Minh city University of Technology, 268 Ly Thuong Kiet, Dist.10, Ho Chi Minh city 700000, Vietnam
[5]Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, MALAYSIA

Abstract

This paper presents a simulation study to understand the behavior of flexible manufacturing cell (FMC) based on the optimal machine loading decision obtained from analytical approach. The machine loading model considered the allocation of machine and operation of each part in its batch in manufacturing environment. The simulation experiment is utilized to evaluate the effects of the most suitable combination of machines and operations in FMC, in relation to the system unbalance, makespan and total flow time based on two experimental scenarios, with 4 machines and 5 part types/8 part types. Results highlighted the competitive performance of obtained optimal loading solution and confirmed the reasonableness of the designed cell. Moreover, the comparison of performance indicators also confirmed that the FlexSim is a helpful and powerful tool to validate the optimal solutions from analytical approach. Finally, the machine loading decision of FMC is effective to be applied in real system at the manufacturing small and medium enterprises (SMEs).

Keywords: *FMC; FlexSim; simulation; machine loading; machine assignment.*

1. Introduction

The growing trend of the production enterprises is to satisfy the customer needs by reducing the batch quantities and increasing the variety of product and shrinking the product life cycle. In particular, the characteristics of flexibility, efficiency and quality were considered as the vital criteria in improving the manufacturing systems with the aims of reducing the production lead time. Moreover, the flexibility is able to adapt to the dynamic manufacturing environment and improve the productivity as well as the cost and service to maintain the market share [1, 2].
The flexible manufacturing system (FMS) is an automated manufacturing system obtained the flexibility of job shop while remaining the efficiency of the flow shop in producing many part types with different small-to-medium size batches. The duality of efficiency and flexibility causes the management of FMS to become more difficult and reflected in planning as well as scheduling [3]. In the other words, this system is an attempt to preserve the efficiency of mass production while maintaining the flexibility of traditional production process [4]. The structure of FMS comprises at least four programmed and multifunctional machines (usually from 5 to 25 machines) interconnected together mechanically by an automatic material handling system and controlled electronically by a communication network [5]. The benefit of FMS/FMC is the high machine utilization, fewer machine and reduction in the floor space, ability of responding to changeability, easiness for re-configurability and agility, reduced inventory requirements, lower labor productivity, opportunity for automated production [6].
One of the systems responding flexibly is FMS, present a powerful innovation for production environment [3]. Since FMSs are expensive, so its management to obtain the efficiency with less investment risk become extremely important [7, 8]. The FMC is considered as the basic component in accordance with development strategies in SMEs and is the survival of the modern manufacturing industry. In recent years, FMC is concerned for the implementation in the developing countries due to the flexibility and high efficiency up to 90%. However, the implementation and re-planning of FMC in SMEs play the important role and should be addressed in order to increase the CNC machines and cutting tools utilization [9].
The flexibility of FMC determines the total performance of system by operational decisions that are classified into two types. Those are the pre-decision and post-decisions. The pre-release decisions related to the planning issues, considering the re-arrangement of machining parts and cutting tools before starting the machining process. Post-release decision is known as the scheduling problem of FMS, solving the sequencing of part types when operating the system. Among the pre-decisions, the machine loading issue is one of the most crucial production planning issues because of its strong influence on the productivity of FMC [10].
The objective of loading is problem dependent. The system unbalance has been popular in FMC, which attempt to allocate the total processing times to each CNC machine as equal as possible. This objective makes all machines in system complete the desired operations more or less at the same time. So, minimization of system unbalance (balancing the workload) is very important to the machine loading decision in producing new batch of part types [11]. Minimization of transportation time as well as minimization of the number of part type movements will make the workload unbalanced with the larger queue closed to the most heavily used machines.
Simulation is a potential tool to analyze the general systems. It is widely used to design and evaluate operation of manufacturing system. The successful application of simulation in solving

numerous real world problems has proved that it has been an extremely useful tool to handle various issues in the manufacturing field [12, 13]. Simulation involves the development of computer models to describe a system and observe the behavior and predict the operational performance of underlying system [13]. It is used to verify the mathematical model through a computer model to predict the unknown outcomes. The validation of the model means that the simulation is run for some cases and compared the obtained solution with real data. The accurate prediction of simulation will validate the mathematical model. Simulation has been successful adopted in numerous studies related to manufacturing system design and operation which leaded to an increased interest in this research topic. In summary, simulation techniques proved to be very effective in solving dynamic problems and required a large number of running simulation iterations to evaluate the operating state of the system. Therefore, it is timely to employ powerful simulation model to observe the behavior of FMC focus on machine loading decision for small and medium enterprise.

2. Literature review

Simulation is the imitation of the system through experimental work with a model describing the real system. It involves performing activities such as the definition, design and modeling, experimental definition, collect and analyze data, interpret results from experiments [14, 15]. Simulation can help observe the behavior of the system predicted that we could gain information about the system, train personnel to operate without disrupting the real system because the real system experiments are uneconomic and impossible [16].
The simulation model is a collection of the objects representing an actual system with full detail information to show the system behavior. The objects in the models consist of the fixed and mobile resources connected together in the systems. In particular, the objects of fixed resources are the backbone of the simulation models because they are used to define the product flow [15]. The simulation models has been often used to evaluate the systems when the system is being designed or investigate the operation of system, evaluate the performance, avoid the stochastic events such as machine breakdown, tool or lack of supplied materials and electricity. Its application is important to develop the manufacturing systems. For instance, numerous studies applied the simulation for scheduling problems [17-20], storage location problems [21, 22], allocation [23-25], sequence [26, 27], and determination of buffer sizes [28]. Besides, for FMS loading problem, Tripathi, Tiwari and Chan [29] developed the multi-agent-based method for selecting the parts and allocating the task in FMS based on the processing costs, transporting costs and time. In general, most of studies applied the simulation methods to find the solutions quickly and to validate the mathematical model of FMS through the performance index. Kaban et al. [30] used simulation to evaluate 44 dispatching rules in job-shop scheduling problem and realized that simulation is a powerful tool for testing the efficiency of various scheduling policies. Discrete event simulation is a widely used technique to analyze and understand a general production system and support the decision-making in the manufacturing. As a computationally expensive tool, the increase in computer power and memory has further increased the use of discrete event simulation in recent years [12]. Several recent successful applications of discrete-event simulation to handle the practical problem were presented in [31-34].
To obtain the purpose mentioned above, we proposed a simulation model based on FlexSim software to simulate the FMC with the aim of aiding the organizations to have the best information and knowledge on the resources when the description of the relationship of the components in the systems is very difficult on the mathematics. The practical model is built based on the objects and interfaces in FlexSim simulation environment. Development of the model comprises five basic steps, which consists of developing a layout, connecting the objects, detailing the objects, running the models, and review the output. All above things showed that FlexSim is a powerful tool to achieve the greater knowledge and deeper insight about the complex and uncertain systems. When – and only when-the relationship of the elements in the systems are clearly understood can the systems be improved [35]. The procedure of simulation is described in Fig. 1. The objectives of simulation model is (1) To verify the results obtained from analytical approach in selecting the most suitable combination of machines and operations for processing in FMC; (2) To evaluate the capacity of machine utilization.
The simulation model is applied in the scope of the FMC of SME manufacturing environment where many part types are produced on the suitable CNC machine tools and transported among the machines by the conveyor system. The validation is done by comparing the results of the simulation study with those of the analytical approach. In FMC simulation, if the system has normally not yet been built, so this is impossible. But the system is already in existence, the problem of validation does not usually arise. The only thing that we can do is to ensure the validity of the data supplied from the proposed process plan. Therefore, simulation model is used to estimate the performance's indicators of system unbalance, makespan and total flow time.

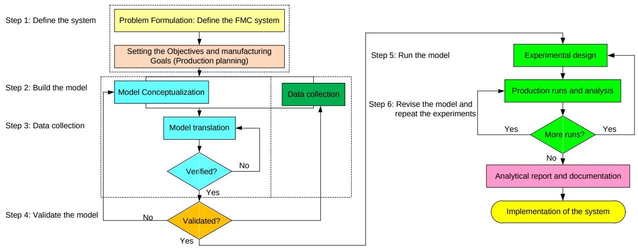


Figure 1: The steps of simulation procedure (adapted from [16, 36]).

3.Process Plan of FMC

The aim of simulation model is to observe the most suitable best allocation of operations into machines to satisfy the manufacturing goals through FMC simulation process in FlexSim environment. These objective functions are considered for this system as minimization of system unbalance, makespan and total flow time. In the Fig. 2, the FMC consists of four CNC machines connected together by the conveyor system. Each CNC machine has a buffer for the part storage. The conveyor transports the parts from the loading/unloading station into the buffers of CNC machines. Besides, it can transport the parts among CNC machines for continuous machining operations. The machines receive the parts from the buffer and do operations of machining process as planned and scheduled. Since the part is completed, it will be picked up and transported to the loading/unloading station for unloading by conveyor. The finished parts can be stored in an automatic storage and retrieval system (AS/RS). All equipment in the system operate together simultaneously to produce the part types according to the customer's demand.

The structure of FMC is shown as in Fig. 2. The conveyor system is served to transport the part types according to the requirements of different processing. Many part types have different desired batch sizes and chosen for machining process in FMC to complete the customers' demand. The buffers are used to store the parts at each machine. The workpecies are started at loading station, and the completed parts are moved to unloading station for storage. The part types' selection and loading is considered as a tactical planning problem in manufacturing system.

A production plan includes the indices of part types, operations and machines corresponding to the operations of all parts. Therefore, each operation is processed on the corresponding machines. A machining part consists of more operations, and each operation can be produced on more CNC machines.

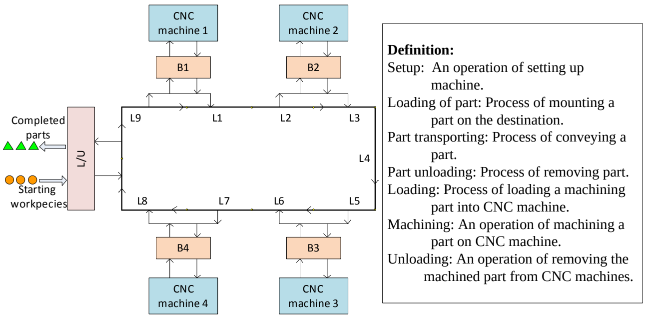


Figure 2: Flexible Manufacturing Cell (FMC).

The purpose of simulation model is to observe the behavior and performance of FMC with the best combination of machines and operations to obtain the minimization of system unbalance, makespan and total flow time. The process plan of FMC with numerous alternatives in assigning machines was extracted from [37]. Table 1 presents the potential solutions obtained from analytical solution. These solutions show the most combination of CNC machines and the machining operations with satisfying three objectives of minimum system unbalance, makespan and total flow time.

Table 1: The potential solution for the machine loading (SU=819, MK=353, TFT=9448).

Batch No	Part Type in batch	Operation 1	Operation 2	Operation 3
1	1, 2, 3, 4, 5, 6	2	1	4
2	1, 3, 4, 5, 6, 7, 8, 9	3	3	0
	2	4	3	0
3	1, 2, 3, 4, 5, 6, 7, 8	4	0	0
4	1, 2, 3, 4, 5, 6, 8, 9, 10	2	3	2
	7, 11, 12	3	3	2
5	1, 2, …, 16	1	0	0

The process plan consists of 8 part types in Table 2. The batch size for each part type is 8, 9, 13, 16, 9, 10, 12 and 13, respectively. The parameters of processing time and traveling are explained as in case study 1. In this process plan, the number of optional operation is large, so the production process becomes more flexible. It means that the opportunity for combining the machines and operations is considerable.

Table 2 shows the best solution for selecting the most appropriate combination of machines and operations in FMC as a case study 2 [37]. These solutions gained for the most combination of 4 CNC machines and 8 part types with different batch sizes and satisfy three objectives of minimum system unbalance, makespan and total flow time. The most suitable combination of machines and operation of each part of part type with different batch size is described. The optional operations of part type are assigned to obtain the optimal objectives of system unbalance, makespan, and total flow time.

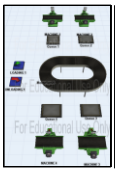
Table 2: The most suitable solution for case study 2.

Part type	Batch size	Part Type in batch	O1	O2	O3
1	8	1,2,…,8	3	0	0
2	9	1, 3, 4, 5, 7, 9	4	4	2
		2, 6, 8	1	4	2
3	13	1,2,3,4,5,6,7	1	3	0
		8	4	3	0
		9, 10, 11, 12, 13	1	3	0
4	6	1, 2, 3, 4, 5, 6	3	4	0
5	9	1	2	2	0
		2, 3, 4, 5, 6, 7, 8, 9	3	2	0
6	10	1, 2, 3, 4, 6, 7, 8, 9	4	2	2
		5, 10	4	3	2
7	12	1, 3, 4, 5, 6, 8, 11, 12	3	3	4
		2, 7, 9, 10	3	2	4
8	13	1, 2, 6, 7, 8, 9, 10, 11, 12, 13	1	2	1
		3, 4	2	2	1
		5	2	1	1
System Unbalance: 1793; Makespan: 978; Total Flow Time: 50828					

The simulation model allows observe the behavior and evaluate the system's performance in terms of the system unbalance, makespan and total flow time. The purpose of simulation process is to prove that the newly design FMC has potential applicability in manufacturing SMEs. The sequence of this research procedure starts with the construction of simulation model of FMC; then, the results and discussion are carried out based on experiment of simulation runs.

4.Simulation implementation in FlexSim

Each part called item types in simulation model, is connected with a particular name and label to be distinguished for simulation purposes.The FMC is modeled based on the fixed resources (source, conveyor, machine, queue, sink, etc.) and mobile resources (task executors such as transports, operator, etc.) in FlexSim simulation environment. The fixed resources comprise of four CNC machines, which are described as MACHINE1, MACHCINE2, MACHINE3 and MACHINE4 for processing various part types with required batch sizes. The machined parts are called flowitems in FlexSim, which are entities that flow through a model. The fixed resources (CNC machines) will send and received the flowitems. The conveyor is used to transport the parts between the objects (source, machine, sink, etc.) in FMC. The part types are moved from source to machines for processing and from machine to sink for storage. Fig. 3 shows the designed cell and lists the equipment used to establish the FMC in FlexSim environment.



Objects	Resource name	Description	Capacity
Fixed resources	MC1	CNC machine 1	1
	MC2	CNC machine 2	1
	MC3	CNC machine 3	1
	MC4	CNC machine 4	1
	Conveyor	Transporting parts	1

Figure 3: Simulation model of FMC in FlexSim.

The simulation model of FMC is implemented in FlexSim with objects presented the components of system as a source, conveyor, mergesoft, processors, and sink.

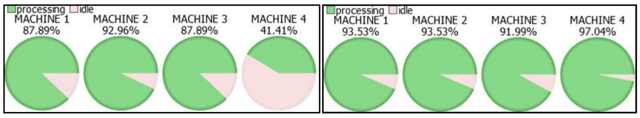
The performance indicators used to measure the similarity between the simulation model and analytical approach are the system unbalance, makespan and total flow time when the total part types are completed all operations and stored by the queue.

The inputs of simulation process are summarized as follows: First, the processing time of each operation of each part type in each CNC machine. Second, the sequence and routing of part enter in the FMC to produce many various operations of part types in the different CNC machines with the pre-determine batch sizes as required by customer's demand. The path of part in the cell is correctly suitable for operations' assignment into machines which is suggested. The output is comparison of the performance's indicators (system unbalance, makespan and total flow time) between two models of simulation and numerical study based on two case studies. Figure 4 presents the FMC model with machine assignment and allocation of processing time for each operation.

Figure 4: FMC with the inputs of machine sequence and processing time.

5. Results and discussion

The processing time, traveling time and operations for each machine determined to produce the part type are assigned. The statics of the state of CNC machines in FMC is described as the pie charts in Fig. 5. For case study 1 as described in Fig. 5(a), it shows that the 12.11 % of the total simulation time, the CNC machine MC1 was idle, and 87.89 % of the time the machine MC1 was busy. Similarly, other machines such as MC2, MC3 and MC4 also had the percentage of the busy time were 92.96 %, 87.89 % and 41.41 %, respectively. This last metric is also known as the machine utilization. In particular, machine MC2 had the highest utilization rate in FMC. Machines MC3 and MC1 had the balance rate of utilization. The optional operations of part types 2 and 4 (case study 1) are common assigned to machines 2 and 3.

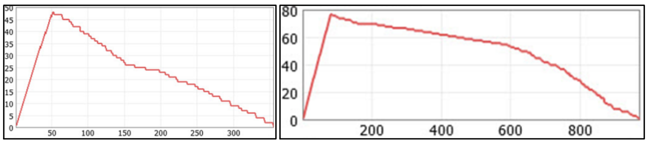


(a): Case study (b): Case study 2

Figure 5: The statistics of the state of CNC machines in simulation model.

Fig. 5(b) shows the utilization rate of each machine in FMC in case study 2. This case has 8 part types with large batch sizes. There are many optional operations of part types need to be considered. So the utilization of machine becomes more flexible and easier to get the trade-off among each machine. Most of machines in FMC obtained the very high utilization rate, and machine MC4 has the highest rate of 97.04 % of busy time.

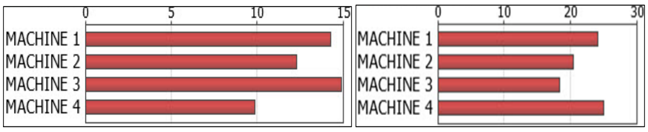
Fig. 6 shows the work in progress (WIP) vs time in the FMC in simulation process. It describes the WIP will reduce when the running time of simulation increase. The WIP will be zero when the running time obtains the values of the makespan 355.01 min (Fig. 6(a) for case study 1) and 978 min (Fig. 6(b) for case study 2), and FMC completes the machining process to obtain the desired batch sizes.



(a): Case study 1 (b): Case study 2

Figure 6: Work In Progress (WIP) vs Time.

Fig. 7 shows the average staytime for each machine when to complete the simulation process of FMC (Fig. 7(a) for case study 1 and Fig. 7(b) for case study 2).



(a): Case study 1 (b): Case study 2

Figure 7: Average Staytime of each machine.

The simulation run time to complete all the batch sizes of case study 1 for 5 part types (51 items) is 355.01 min and case study 2 for 8 part types (81 items) is 978 min. Trace Gantt of FlexSim provides the values of makespan and total flow time to compare with the analytical solution. Table 3 shows the comparison of system unbalance, makespan and total flow time from analytical and simulation experiments. We realized that the result of analytical approach is quite similar to results of FlexSim simulation. It means that FlexSim simulation of FMS is powerful tool to validate the proposed model, and results of simulation study are competitive and potential to explore the most appropriate process planning.

In conclusion, simulation is used to evaluate the designed FMC in terms of productivity to produce the various part types with the corresponding batch sizes from customers' demand. From the results of the comparison between the two models of simulation and analytical method, it's easy to realize that the proposed FMC model is able to complete the process planning and achieve batch size as required. Simulation model also shows the status of each CNC machine to improve the machine's utilization and evaluate the total performance of FMC.

Table 3: The comparison of performance indices of FMC (min)

	Case study 1			Case study 2		
Performance index	Simulation	Plan	Error	Simulation	Plan	Error
System unbalance	818.936	819	0.06 %	1739.36	1793	3%
Makespan	355.01	353	0.57 %	973.01	978	0.5 %
Total flow time	9532.6	9448	0.89 %	50560.01	50858	0.6 %

6. Conclusions

This work presented a detailed development of a simulation model of proposed FMC to validate and verify the accuracy of a process plan which is available based on previous computational results. The objective is to determine the behavior of a FMC in manufacturing environment with the most suitable allocation of machines and operations. Moreover, the model can be employed to verify and validate the feasible solutions from an optimization model. Based on the simulation results, it is easy to realize that the proposed model of FMC is effective and practical to develop the real applications at the SMEs.

The newly design FMC system consists of four CNC machines, conveyor systems and robots are connected together and controlled by a computer workstation. Although the proposed model of FMC assumed a hypothetical manufacturing scenario, it is easily modified to adapt to a real environment by changing suitably a number of machines and adjusting the distributions of the part type arrival likelihood and processing time based on the predetermined process plan.

The simulations are carried out based on two case studies of 5-part types and 8 part types with various desired batch sizes from customer's demand. The experiment and simulation of the newly design FMC is implemented for the most appropriate process plan predetermined by the computational method. The simulation results of performance indicators such as system unbalance, makespan and total flow time have confirmed the reasonableness of the designed cell. Besides, the results have also confirmed the capacity of finely complete the part types with different batch sizes, and proposed model is potential to implement in practice at manufacturing SMEs of the local as well as the developing countries. It can help SMEs reduce the manufacturing cost and train the personnel to improve the operational skills for real system.

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