



## Real-time Scheduling of a Flexible Manufacturing System using a Two-phase Machine Learning Algorithm

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### A B S T R A C T

The static and analytic scheduling approach is very difficult to follow and is not always applicable in real-time. Most of the scheduling algorithms are designed to be established in offline environment. However, we are challenged with three characteristics in real cases: First, problem data of jobs are not known in advance. Second, most of the shop's parameters tend to be stochastic. Third, thousands of jobs should be scheduled in a long planning horizon. In this work we designed an expert model for achieving better performance of real-time scheduling tasks in a flexible manufacturing system (FMS). The proposed expert model is comprised of two sets of modules, namely FMS simulator and decision (control) modules. Information is translated from the first set of modules to the second in two phases. First, a feed-forward neural network as a supervised machine learning mechanism is set to capture the queueing attributes of the shop and train in initialization and pre-run mode. Second, system states (in real run) are interpreted to the control module which is comprised of interconnected online learning activation function and a feed-forward neural net, and finally the best strategy is selected. Therefore, an interactive discrete-event simulation model with control module is implemented in order to evaluate different scenarios and reduce the computational time and complexity. Eventually, the presented procedure is benchmarked through simulation modeling of a triple-stage-triple-machine flexible flow shop with some embedded stochastic concept. Results support our proposed methodology and follow our overall argument.

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## 1. INTRODUCTION

In many flexible manufacturing systems (FMS), it is necessary to set up a set of competent techniques in the processing of jobs in order to keep up the pace of change in customer needs. Many of the systems used in our modern society ought to be such configured that they provide correct and on-time response to these changes. In case of schedulable real-time systems, the goal is to meet the deadline of every task by ensuring that each task can complete execution by its specified deadline. This deadline is adopted from environmental constraints imposed by the application of system in real-time [1]. Moreover, we are faced with three important attributes of the tasks scheduling in real-time: shortage of tasks information in advance, stochasticity of the shop's parameters, and long-term planning horizon.

However, many researchers unanimously have concluded that there exists no certain rule, say sequencing rule, which is universally better than others. The most famous and simple rules are: shortest processing time (SPT), longest processing time (LPT), earliest due date (EDD) and first in queue (FIQ). The popular rules like SPT fail at light load levels and generous due date allowances [2] and as the complexity of problem increases, simple rules and respectively statically utilization of these rules don't perform well with respect to dedicated objective function. One acceptable solution is to dynamically alternating these rules upon receiving undesirable signals from system and according to the system's conditions such as shop congestion [3]. Many researchers (See for example [4-6]) have suggested that dynamically alternating the sequencing policies can be highly effective.

More flexible approaches are required for a FMS scheduling. In fact, most FMS scheduling problems are NP-Hard [7-9]. Due to the environmental constraints,

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acquisition of knowledge can be very useful for tasks scheduling in real time. In such cases, the scheduling parameters have to be tuned very quickly so that the system will be able to continue to produce optimum performance quickly corresponding to the system state changes [10].

In this study, we used a feed-forward neural network in the control module suggesting that parts of the information, acquired from initialization mode, remains unchanged and the rest are updated through an online transfer function in real-time simulation, which enables the system to learn efficiently in online mode in the context of discrete-event system.

## 2. RELATED WORKS: A COMPARATIVE STUDY

According to Maccarthy and Liu [7], three types of approaches can be used for FMS scheduling in real-time: (1) Heuristics, priority rules and simulation, (2) Mathematical programming and (3) Artificial intelligence (AI) techniques. In the literature, various methods can be recognized according to these three approaches. These methods include composite priority rules, decomposition methods [11, 12], single-pass and multi-pass methods [13, 14], real time dispatching and dynamic selection of priority rules [4, 8], adaptive scheduling [14], discrete-event (stochastic) simulation [4, 5, 15, 16], neighborhood search [9] and machine learning techniques [3, 11, 17].

A substantial number of priority rules (simple and composite) has been reported in the literature. Performance of some rules is better than others in particular cases; however, yet no rule has become known that universally outperforms the others. For example, rules such as weighted shortest processing time (WSPT), earliest modified operation due-date (EMODD), combination of critical ratio and shortest processing time (CR+SPT) and processing time plus work in queue of its next operation (PT+WINQ) have been reported to produce better performance in response to due-date embedded objective functions or reversely, they fail in other measures [16]. An advantage in applying simple or composite priority rules directly underlies in ease of implementation. However, many researchers have used these rules in conjunction with other dynamic methods.

One of the useful heuristics for scheduling tasks in a FMS, particularly in presence of uncertainty, is decomposition -partial sequencing- method. This technique consists of subdividing the original problem into equally sized and more manageable sub-problems which are optimized and then the best combination is taken as solution to the problem in hand [18]. Different forms of Decomposition methods exist in the literature:

time-based, job-based and machine-based (for more information see [11]). In this study, a time-based decomposition approach is deployed to generate training samples.

Supported by object-oriented programming, queueing structure and capability of analysis the stochastic procedures, discrete-event simulation modeling basically regarded as a last resort (if analytical methods fail) in the performance evaluation of a system. As an instance, Barrett and Barman [3] and Jeong and Kim [6] put forth a simulation model for scrutinizing the effects of candidate dispatching rules, Nakasuka and Yoshida [19] and Li and Lin [9] used simulation as a knowledge acquisition tool, Kuo, et al. [8] and Vinod and Sridharan [20] also took advantage of simulation for testing different production scenarios and strategies. Since optimization of the parameters of decision module in an online control system is time-consuming [19], an interactive discrete-event simulation model with control module is implemented in order to evaluate different scenarios and reduce the computational time and complexity.

There exist two basic techniques, namely reactive (dynamic) and robust approach, for dealing with uncertainties and stochastic nature of a shop in real-time according to the literature. Despite of time-based decomposition method in which the planning horizon are decomposed into equal or unequal periods, reactive approach by selecting priority rules may well be suited to the shop in real-time case. In contrast, it would be unfavorable to the manager to expect an undesirable event (triggering) and then react to it. Furthermore, one might establish the measuring of robustness [11]. According to this, the probabilities of particular event can be estimated and the system will react with respect to the probability of the corresponding event in advance. There are also other efficient techniques for dealing with complex circumstance in the literature, e.g. single-pass and multi-pass methods. Single-pass period technique combines single priority rule and schedule generation procedures to construct a particular algorithm. Lova and Tormos [10] suggest that this combination is central to constructing a feasible schedule. In contrast, one might deploy a multi-pass approach when there are multiple buffers between stages. This method is the mixture of randomly sampling method and multi-priority rules method in the steady-state planning horizon.

In order to better address a dynamic scheduling during the planning horizon in real-time, not only a quickly-reacting procedure to the changes is required, but it should be possible for its parameters to be modified in response to the system state changes [10]. Machine learning approach can be utilized such that decision module parameters are updated according to system state during the planning horizon. To

complement human knowledge of scheduling tasks or development of rule selection without human intervention [21], Machine learning is basically taken to fully reflect the real-time information of production scheduling based on knowledge gaining from system behavior. Three types of technique exist with respect to machine learning concept: case-based reasoning, neural network and trigger-based learning. Priore, et al. [3] conducted a comparison between these algorithms and Mouelhi-Chibani and Pierreval [22] used the second class (a multi-layer perceptron) to select priority rules in a FMS. A drawback might be in adjusting networks total weights in online mode. Consequently, in this study, we used a neural network with a different topology in the control module suggesting that parts of information acquired from initialization mode, remains unchanged and the rest are updated through transfer function in the real-time simulation, which enables the system to learn efficiently in online mode.

The rest of this study is organized as follows: First, an overview of machine learning mechanism is given in section three. Next section formulates the problem by the neural network and discrete-event simulation configuration. In section (5), the propose model is validated and the results are analyzed. Finally, section (6) concludes section (5) through a summary and recommendation for future research.

### 3. OVERVIEW OF MACHINE LEARNING: NEURAL NETWORK APPROACH

System components tend to have specific connections together. However the connection may vary from a simple cause and effect to a dynamic full-ecological connection. It is also required that some system parameters be estimated through these connections.

To attain the aforementioned goals, in this study a novel framework of discrete-event simulation and neural network through iteratively learning characteristics of queues in a FMS is proposed. In real time simulation, a linear transfer function allows the inputs of offline network to be adapted and learned from changes in the system. This process requires substantial amount of experimental work of collecting practical data for training neural network, of an appropriate learning structure. It is a demanding task to develop a sustainable algorithm for any instance with a reasonable and acceptable solution in real time. In the first step of design, machine learning mechanism is the sheer amalgamated structure of human intuition and machine computational capability [23]. This will chronologically develop a procedure that can adapt itself to the new changes in the system conditions.

There are two types of learning methods. The employed procedure can be either “supervised” or

“unsupervised”. In supervised learning or machine learning mechanism, the learning mechanism takes only a set of input data and known responses to the inputs, and seeks to construct an estimator model that generates reasonable prediction to new data. Nevertheless, in unsupervised learning, the system learns of itself by adapting to the structural features in provided input patterns. Therefore, the framework of input and output learning vector should be such interconnected that taken training policy is able to reach maximum estimation accuracy. Therefore, if we reassess the machine learning idea with the FMS concept, it can be elicited that if a set of jobs in the  $i$ th queue experiencing the state  $S$  which contributed to performance measure  $P$ , then the system can learn from state  $S$ , if the state  $S$  improves the performance measure  $P$ .

A popular form of constructing a supervised learning mechanism can be established through a neural network. A neural network is comprised of a number of interconnected neurons. The synapse (connection) between neurons has weights, which depicts the strength level of these connections. The philosophy behind the vast utilization of neural networks is that incentivized by their non-parametric properties of any linear and non-linear functions and they are capable of fast-learning when appropriate parameters are chosen.

A number of machine learning methods have been studied with regard to their applicability to scheduling. These techniques shall be categorized into four major groups: The first mechanism is referred to as rote learning. In this mode, even though the system saves old decisions that gave good results, it has no means of generalizing them and user should be very careful in implementing them in a complex environment in which the chances of observing the same state is very low. This form of learning is only useful when the number of possible scheduling instances is limited [11, 17].

Case Based Reasoning (CBR) is another machine learning paradigm being considered for application to scheduling problems. CBR seeks to exploit experience gained from past similar cases. The larger scheduling problem requires the identification of salient features of past schedules, generalization, and a mechanism for determining which stored case best matches and is useful in the problem context. CBR can be applied to multi-objective scheduling problems as well [3, 20].

The third class of learning mechanisms are the induction type. A very common form of an induction type is a neural network. This mechanism is applicable in three steps: (1) data collection, where a trace of decisions and corresponding system states is obtained from the simulated system; (2) data analysis, where the traces are examined to determine the scheduling rules used; and (3) rule evaluation, where the performance of these obtained rules is compared against the expert's performance [16,19,22]. The fourth class of learning

mechanisms are classifier systems. The classifier system learns rules which were found to perform better than the application of any of the single heuristics alone. A chromosome (or string) in such algorithm representing a list of rules (e.g., priority rules) that are to be used in the successive steps (or iterations) of an algorithmic framework designed to generate schedules for the problem at hand [11,22].

#### 4. PROPOSED STRATEGY

**4. 1. Problem Formulation** The topology of proposed neural net model is illustrated in Figure 1. In the first step, the states of queues are preprocessed through a linear transfer function, which can make the online learning possible, and fed as inputs to the network. Furthermore, consideration of time component cannot be neglected. For example, if the steady state period in the time horizon of shop simulation is  $T$ , then it is required that period  $T$  is decomposed into equal units of  $T/n$  with  $n$  training sets for network configuration. In this study, it is supposed that system can uniformly experience stochastic changes during the steady state period. This procedure can also be applied for both deterministic and nondeterministic flexible flowshop scheduling where all jobs ought to undergo waiting in buffers sequentially. Two phases are prescribed in the presented network. The first phase includes a linear transfer function so that corresponding weights ought to be updated in the real run. The philosophy behind choosing a linear transfer function in the first step is that it is easy to be learned and second all essential parameters can be included directly without any sophistication. The second phase consists of a multi-layer perceptron network which should be trained in initialization mode. Therefore, its weights are static during the simulation run. By letting  $S_{ij}$  state  $j$  corresponding to queue  $i$  and  $PR_i$  selected rule for queue  $i$ , it is assumed that  $PR_i$ s are set as input vector by randomly sampling in pre-run mode (offline input) and responses gaining from simulation run are set as target vector in that mode (offline target or online input). Once the network is trained offline, the triggering signal generated from real-time simulation run induces the network and by feeding the states of queues as an online attribute vector at specific moment the appropriate priority rule will be selected. Let  $M$  number of system state,  $H$  number of hidden layer neurons and  $N$  number of candidate priority rules, then, in order to mathematically illustrate the offline network and online transfer function, the two following expressions can be written:

$$\text{Estimated\_}PR_i = F_i^{(2)} \left\{ \sum_h^H [F_h^{(1)} (\sum_j^M S'_{ij} w_{jh}) + \alpha_h] w'_{hi} \right\} + \beta_i \quad (1)$$

$$S'_j = F^{(3)}(S_{1j}, S_{2j}, \dots, S_{Nj}, \lambda_{1j}, \lambda_{2j}, \dots, \lambda_{Nj}, \delta) = \lambda_{1j} S_{1j} + \lambda_{2j} S_{2j} + \dots + \lambda_{Nj} S_{Nj} + \delta \quad (2)$$

where  $w_{jh}$  is the strength level of connection between  $j$ th element of  $S'_j$  and  $h$ th neuron of hidden layer,  $F_h^{(1)}$ ,  $\alpha_h$ ,  $F_i^{(2)}$  and  $\beta_i$  are activation function and threshold component associated with  $h$ th and  $i$ th neuron, respectively,  $w'_{hi}$  the weight symbolizing the connection between  $h$ th neuron of hidden layer and corresponding  $i$ th neuron of priority rules vector and  $S'_j$  the output of linear online transfer function.  $\lambda_{ij}$  is the strength weight corresponding to state  $S_{ij}$  and  $\delta$  the threshold value of linear transfer function  $F^{(3)}$ .

Expression (1) should be minimized through backpropagation technique. To put it precisely, errors generated from objective function are backpropagated to the neurons of each layer by the negative gradients. In this study, in order to approach a fast training speed for both minimization of expression (1) in offline mode and updating the weights of expression (2) in online mode, a well-known levenberg-marquardt algorithm is used. The philosophy behind utilization of this algorithm is its design characteristic owing to the fact that there is no need to compute the hessian matrix; consequently, it can compute the gradient quickly. (For more information about this technique, see [25])

**4. 2. Model Development** By acquiring the training sets from discrete-event simulation with replication and uniformly sampling the simulation results in the time horizon, the network is trained offline. The parameters of online transfer function are updated with respect to defined performance criteria. The neural network implemented in this study is three-layer feedforward consisting of one input layer, one hidden and one output layer. For the reason that there exist large number of training samples, number of neurons associated with hidden layer is chosen slightly larger, say 15, for keeping away underfitting problem. Also, overfitting problem is considered to avoid misleading results of training condition. A tangent hyperbolic transfer function is used in conjunction with initialization net.

In this study, some basic queueing characteristics which can affect the process of rule selection are employed. In complex problems, an attribute extraction step is required for later use of knowledge acquisition process (for example see [10,14]). However, for better generalization of results, some basic queueing characteristics which can affect the process of rule selection are employed. The states associated with particular queue are provided by simulation model with corresponding initial inputs and then are fed to the network as a target in the offline training phase. The states are given in Table 1.

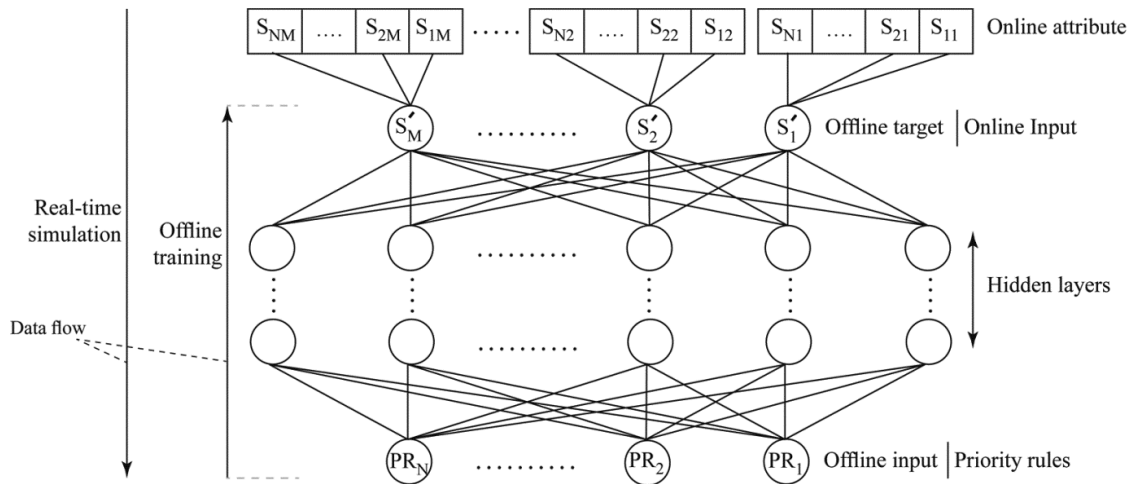


Figure 1. Offline and online training framework of Neural Network

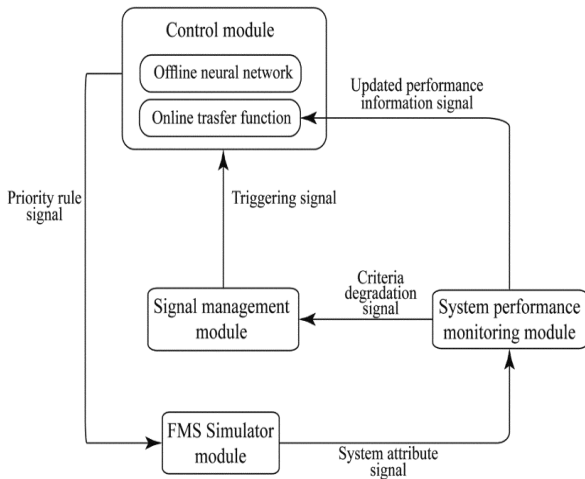


Figure 2. General overview of proposed strategy (in real-time run)

TABLE 1. Online attributes of queueing states

State	Description
$S_{i1}$	Length of the $i$ th queue
$S_{i2}$	Maximum processing time of jobs in the $i$ th queue
$S_{i3}$	Average waiting time of jobs in the $i$ th queue
$S_{i4}$	Number of jobs of which corresponding processing times are smaller than one-third of mean total jobs processing time in the $i$ th queue
$S_{i5}$	Number of jobs of which corresponding processing times are greater than one-third and smaller than two-third of mean total jobs processing time in the $i$ th queue
$S_{i6}$	Number of jobs of which corresponding processing times are greater than two-third of mean total jobs processing time in the $i$ th queue

Before configuring the network, data collected from each state are normalized to have the same effect when processing through activation function. During the offline training, a set of equal-length intervals  $[\#PR1\#(t_1, t_2), \#PR2\#(t_2, t_3), \dots, \#PRn\#(t_n, t_{n+1})]$  is used for offline input and later in selection of priority rules in online mode. For example, if the network yields a constant  $a/3$  and intervals are  $[\#SPT\#(0, a), \#LPT\#(a, 2a)]$ , we use SPT as selected priority rule.

Performance criterion monitors FMS simulator for any disturbance, if an event degrades the performance, then a signal is sent to both triggering module and for online transfer function to updates its weights. Later, control module sends a best suited signal corresponding to priority rule module for rule selection. This procedure is outlined in Figure 2.

The simulation model is constructed in a modular way, of which each perform a particular role. There are three types of module deployed in this model: (1) Signal generation module, (2) Signal management module and (3) physical modules. The role of the first class of modules is generating signal for simulating breakdowns, reworks, etc. The second class interprets the signal in order to acquire desired signal like control module or triggering module and the third class are physical entities such as jobs.

Steps of the Algorithm:

- 1) Simulate and run the shop model.
- 2) Collect inputs and outputs for training offline network.
- 3) Set coefficients of online transfer function to be unit.
- 4) Re-run the simulated model which is connected to the network (real time).
- 5) Upon receiving a signal implying that the previously selected rule fails in satisfying performance criteria, the

network alternates the existing rule and then updates the online transfer function weights.

- 6) Repeat step 5 until running the simulation model stops.

### 5. EXPERIMENTAL STUDY

#### 5.1. The Proposed FMS Model

The basic model is based on computer simulation study proposed by Barrett and Barman [24] and further employed in other pertinent articles (see for example [19, 22]). However, some stochasticity is embodied to measure the reliability of the proposed methodology. Thus, a specific hybrid flow shop model called ‘triple-stations-triple-machines’ are put forth for study in the representation of a FMS in real-time. The presented model is comprised of three stations and each station has three machines which can do parallelly the same operations. Each job upon arrival to the work center goes to the first free machine. If all machines are loaded, the job waits in a queue until a machine becomes free. Transportation time from work center 1 to work center 2 assumes to be 0.3 units with a constant speed. Machines require 0.5 time units for changing tools periodically upon servicing 50 jobs, and it is supposed that absent machine operators can be replaced without disrupting production. Inspection time after jobs processing on work center 2 is negligible, however it assumes that 10% of the completed jobs requires rework; with rework time of 0.1 unit at work center 2 and also waiting jobs for rework have the highest priority among other jobs in queue. A time-based (independent of processed jobs) repair operation needed for machines breakdown in work center 3 on the supposition that occurrence of machines failure follows an exponential distribution with 1/50 of the mean and duration of the breakdown is uniformly distributed over the interval (10,100). This component is the only one amongst virtual and physical components, which imposes stochasticity on the system. Furthermore, Arrival and processing times of each job in any work center are not deterministic, exponentially distributed with mean of 1.0 time units and preemption is not

allowed. Due to the randomly generation of arrival times, it is also assumed that arrival times of jobs are uncorrelated with each other and are known in advance. The proposed FMS model for study is illustrated in Figure 3.

In order to evaluate objective function, say mean tardiness, due date parameter should be imposed on jobs completion times. Thus, with the lack of adequate exogenous due dates from customer, it is considered that system generate its due dates itself, namely controllable due dates, by total work content (TWK) method [25]. According to this, the due-date of each job is equal to the sum of the job arrival time and due-date allowance factor – the amount of time that the job will spend in the system- multiplied by the total processing time. Then, due dates could be established as follows:

$$\text{shop loading} \propto \beta \times \left( \sum_{i=1}^n ep_i \right) , \tag{3}$$

where  $DD_i$  is the due date of job  $I$ ,  $Ar_i$  the arrival time of job  $I$ ,  $k$  the due-date allowance factor and  $p_{ij}$  the processing time of job  $I$  on machine  $j$ .

It is also suggested that random generation of jobs arrival and processing times in each work center ought to be circumscribed and such manipulated that it can simulate the shop congestion condition [26]. Due to the stochastic nature of the model, obtaining the exact formula for shop load determination is somewhat difficult. Therefore, the relationship between arrival, processing time of jobs and loads to the work center can be written as following:

$$DD_i = Ar_i + k \sum_j p_{ij} , \tag{4}$$

where  $\beta$  is the mean arrival rate of jobs,  $n$  the number of work centers,  $ep_i$  the mean expected processing time of jobs at work center  $i$ . Accordingly, the above expression suggests that if the load of the shop is constant, then increasing the mean rate of jobs arrival will reduce the mean processing time of jobs, and vice versa. In this study, 91 percent (heavily load) for shop loading has been chosen.

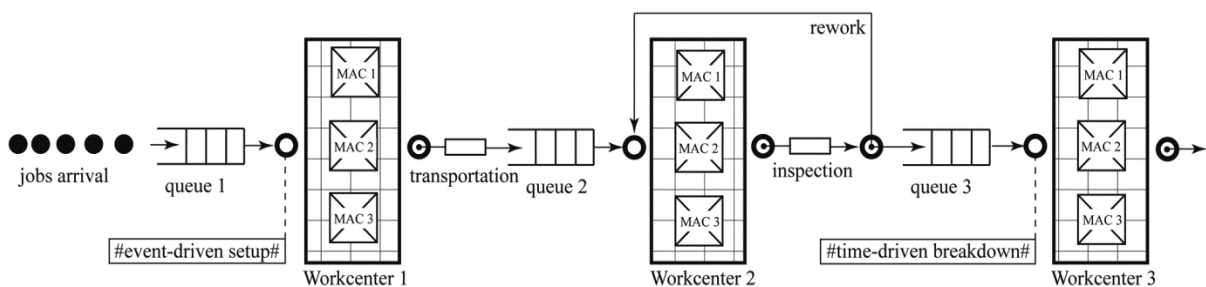


Figure 3. Proposed FMS model

## 5. 2. Validation, Evaluation and Analysis of the Results

In order to justify the performance of proposed methodology, a simulation model of previously mentioned configuration with neural network is developed and conducted. In this study, for the sake of ease in analysis of responses, four basic priority rules are deployed: SPT, LPT, EDD and FIFO. For statistics generation, a run length of 30000 hour is selected. The entire procedure (from neural network configuration to real-time simulation of the shop model) is programmed and simulated by Matlab & Simulink software package.

In this study, a multi-level verification [16] is implemented to ensure the correct configuration of simulated model and programming logic. For this purpose, five steps are performed: (1) Program debugging, (2) checking the consistency of internal logic, (3) plausibility checking through running model under different configuration of exogenous parameters (initial seeds), (4) steady state analysis and (5) schedulability test. A robust generalization of a simulated model substantially depends on steady state analysis. It is assumed that steady state period corresponding to run time  $h$  takes a fraction of  $h$  for which plotted moving average performance measure indicates a reasonably smaller variation. Due to the presence of randomnesses like breakdown, to some extent a pure steady phase could be elusive (semi-steady-state period). Figure 4 provides a summary plot of mean flowtime and mean tardiness moving average in the increments of simulation run length.

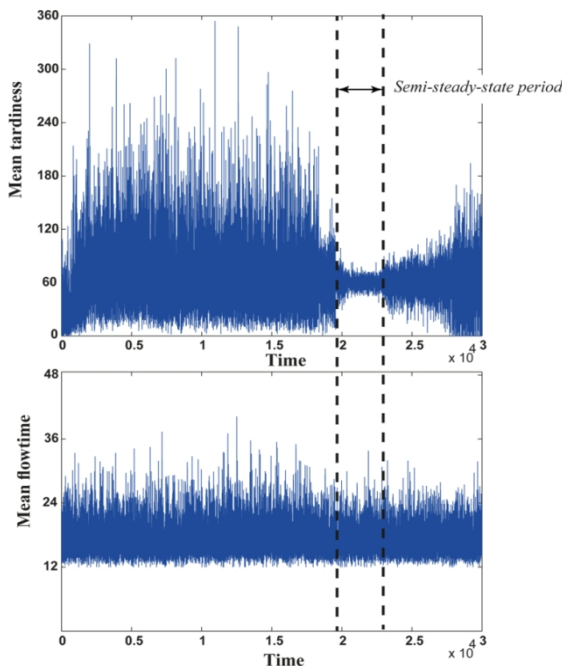


Figure 4. Steady state analysis of mean flowtime and mean tardiness

Also, a schedulability test is employed to validate that a given task can satisfy its specified deadlines when scheduled according to a specific scheduling algorithm [1]. For example, in case of violent stochastic occurrence, even a best-known algorithm corresponding to a specific benchmark could yield a result which is far from predictions. Therefore, system is tested under different priority rules before reaching the steady state to ensure that tasks are schedulable.

Table 2 summarizes the pertinent results of 64 combination of PR1/PR2/PR3 plus proposed strategy. For each combination 20 replications have been conducted. Note that PR1/PR2/PR3 represents the rules selected for respectively first, second and third queues. It is obvious that among all tested combinations EDD/SPT/SPT has shown better performance with respect to mean tardiness. Given the mean flowtime, SPT/FIFO/SPT gets the best score in comparison with other combinations. LPT/LPT/LPT exhibits the poorest result among other combinations in terms of both objective functions. The evidence suggests that (according to Table 2) the proposed strategy outperforms EDD/SPT/SPT and SPT/FIFO/SPT combinations in both measures. Figure 5 illustrates the overall density of priority rule selection in the planning horizon. It can be concluded that priority rules like LPT and FIFO are rarely chosen by control module, due to the degradation of performance criteria with respect to objective functions. Also, proposed simulation metamodel with control system are illustrated in Figure A.1.

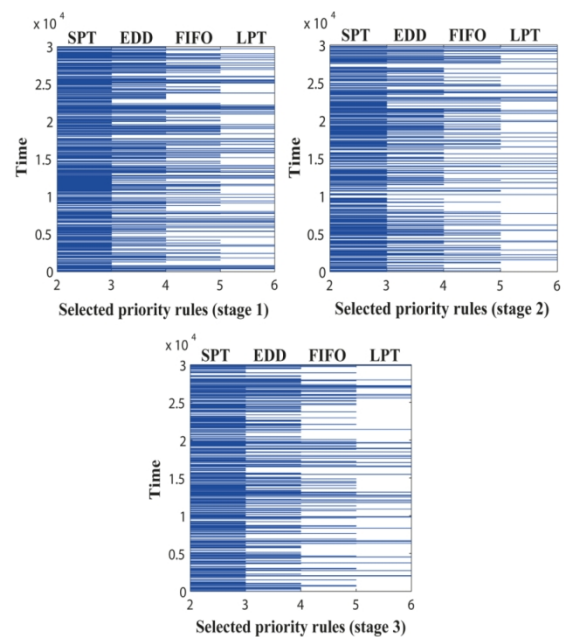


Figure 5. Selected priority rules upon a triggering signal at stage 1, 2 and 3

**TABLE 2.** Mean tardiness and mean flow time for priority rules and proposed strategy

PR	Mean tardiness	Mean flowtime	PR	Mean tardiness	Mean flowtime
SPT/SPT/SPT	63.12	22.43	EDD/SPT/LPT	109.34	31.61
SPT/SPT/LPT	94.09	25.66	EDD/SPT/EDD	70.32	29.02
SPT/SPT/EDD	81.67	23.12	EDD/SPT/FIFO	80.93	25.82
SPT/SPT/FIFO	83.52	32.76	EDD/LPT/SPT	123.16	26.65
SPT/LPT/SPT	115.36	31.89	EDD/LPT/LPT	194.07	26.64
SPT/LPT/LPT	188.23	33.38	EDD/LPT/EDD	138.22	32.71
SPT/LPT/EDD	101.30	27.33	EDD/LPT/FIFO	154.19	25.32
SPT/LPT/FIFO	107.68	26.12	EDD/EDD/SPT	75.53	29.91
SPT/EDD/SPT	78.12	24.66	EDD/EDD/LPT	118.33	33.26
SPT/EDD/LPT	83.39	30.50	EDD/EDD/EDD	84.10	30.83
SPT/EDD/EDD	75.98	29.97	EDD/EDD/FIFO	122.05	24.11
SPT/EDD/FIFO	78.55	27.42	EDD/FIFO/SPT	148.39	24.01
SPT/FIFO/SPT	109.85	20.26	EDD/FIFO/LPT	160.90	32.80
SPT/FIFO/LPT	154.19	24.76	EDD/FIFO/EDD	121.96	31.96
SPT/FIFO/EDD	95.66	26.32	EDD/FIFO/FIFO	130.51	25.76
SPT/FIFO/FIFO	115.03	23.02	FIFO/SPT/SPT	87.18	24.25
LPT/SPT/SPT	97.27	28.55	FIFO/SPT/LPT	159.63	26.53
LPT/SPT/LPT	175.94	34.08	FIFO/SPT/EDD	93.57	31.17
LPT/SPT/EDD	85.32	27.53	FIFO/SPT/FIFO	114.46	23.56
LPT/SPT/FIFO	133.26	28.05	FIFO/LPT/SPT	172.05	22.84
LPT/LPT/SPT	168.56	29.72	FIFO/LPT/LPT	214.82	34.00
LPT/LPT/LPT	231.08	35.62	FIFO/LPT/EDD	159.88	33.32
LPT/LPT/EDD	203.88	29.75	FIFO/LPT/FIFO	177.19	28.71
LPT/LPT/FIFO	174.85	32.65	FIFO/EDD/SPT	127.41	26.12
LPT/EDD/SPT	125.34	30.99	FIFO/EDD/LPT	139.11	31.20
LPT/EDD/LPT	166.15	32.41	FIFO/EDD/EDD	95.28	29.19
LPT/EDD/EDD	136.08	32.61	FIFO/EDD/FIFO	119.33	26.65
LPT/EDD/FIFO	153.77	30.70	FIFO/FIFO/SPT	117.78	23.06
LPT/FIFO/SPT	121.57	29.74	FIFO/FIFO/LPT	171.32	30.72
LPT/FIFO/LPT	171.20	33.13	FIFO/FIFO/EDD	140.40	27.36
LPT/FIFO/EDD	137.91	28.16	FIFO/FIFO/FIFO	162.03	24.58
LPT/FIFO/FIFO	148.32	27.85	Proposed Model	59.21	20.13
EDD/SPT/SPT	62.34	22.25			

## 6. CONCLUSION

In this study, we presented a two-phase framework of a supervised machine learning approach. A discrete-event simulation in conjunction with proposed control module was implemented to study dynamic characteristics of a

FMS and then a best-suited strategy was repeatedly chosen according to the system attributes. This procedure has been done in deploying a two-phase learning neural net. First phase in real time plays the role of online learning and second including a multi-layer network can store the information from



initialization mode. Furthermore, there are two points in configuration of such expert model that we should refer to them:

1. Careful choice of system attributes should be taken into account. Developed model could be very sensitive or oblivious to considered states and yields misleading results.
2. There is no guarantee that that dynamically selection of priority rules will have better performance compared with static counterparts.

Though, we address the future work direction in the first step of design, defining more appropriate system architecture. We suggest that other machine learning architecture to be tested and developed in interaction with more complex FMS scheduling contexts, such as flexible job shop.

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## APPENDIX:

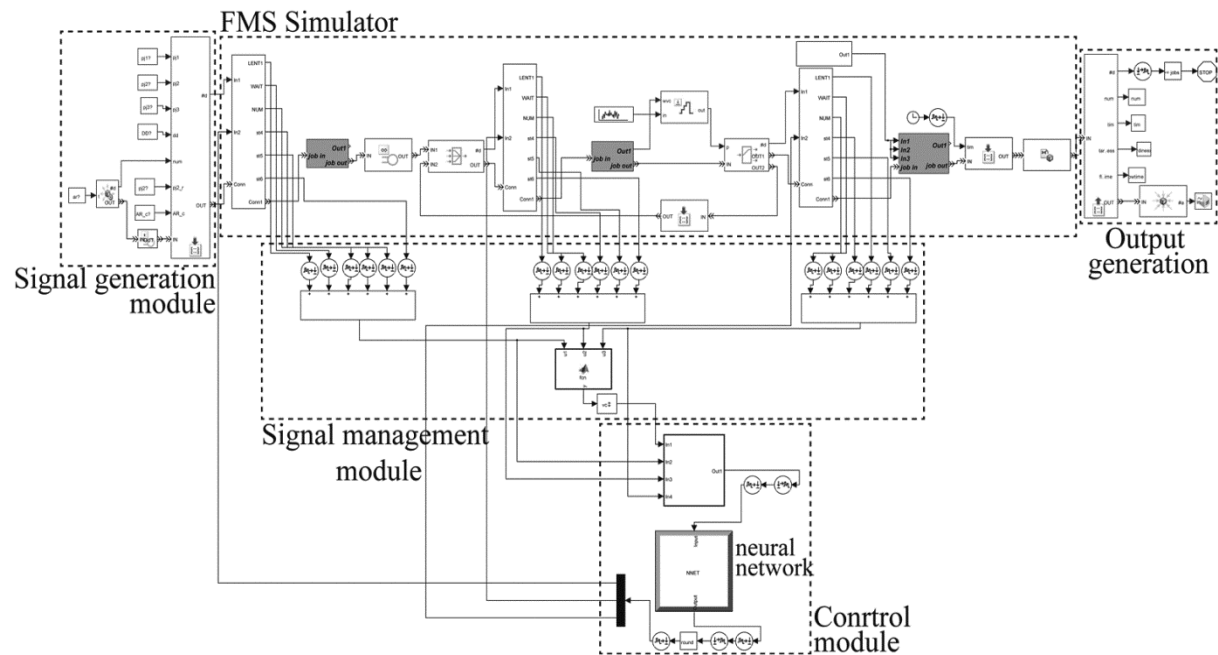


Figure A.1. Simulation model with control module in Simulink

## Real-time Scheduling of a Flexible Manufacturing System using a Two-phase Machine Learning Algorithm

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در شرایط واقعی، رویکردهای تحلیلی موجود در مباحث تئوری توالی عملیات اجرا شدنی نیست. بسیاری از الگوریتم‌های موجود کارایی خود را در محیط‌های پویا از دست می‌دهند. علی‌رغم این مشکل، سه شاخصه اصلی در شرایط واقعی، چالش برانگیز است: اولاً، داده‌های کارها در ابتدای برنامه‌ریزی در دسترس نیست؛ ثانیاً، پارامترهای کنترلی کارگاه، احتمالی است؛ ثالثاً، در یک افق برنامه‌ریزی، هزاران کار بایستی زمان‌بندی شوند. در این بررسی، سیستم خبره‌ای در محیط سیستم تولیدی منعطف طراحی شده است تا با عملکردی کارا زمان‌بندی کارها را در شرایط واقعی انجام دهد. این مدل خبره شامل دو مجموعه از ماژول (پودمان)‌های کلی است: شبیه‌ساز کارگاه و تصمیم‌گیرنده (کنترلر). داده‌ها و اطلاعات از مجموعه‌ی اول به مجموعه‌ی دوم در دو فاز تفسیر می‌شوند. ابتدا یک شبکه‌ی عصبی پس‌خوراند به عنوان مکانیزم یادگیری ماشینی نظارتی، شاخصه‌های صف سیستم را از کارگاه گرفته و قبل از اجرای مدل به وزن‌ها و پارامترهای خود مقادیردهی اولیه می‌کند. سپس، حالات سیستم (در اجرای اصلی) به جزء کنترلی که خود شامل تابع فعال‌سازی آن‌لاین و شبکه‌ی عصبی است، ترجمه شده و بهترین استراتژی انتخاب می‌شود. همچنین، به منظور ارزیابی سناریوهای مختلف و کاهش زمان محاسباتی، مدلی مبنی بر مفهوم شبیه‌سازی گسسته-پیشامد در تعامل با جزء کنترلی به کار گرفته شده است. دو تابع هدف میانگین حداکثر تأخیر کارها و میانگین مدت زمان جریان کارها در سیستم در ارزیابی مثال معروف سه ایستگاهی با پارامترهای احتمالی در نظر گرفته شده است. نتایج و شواهد نشان دهنده‌ی سازگاری ادعای مطرح شده و کارایی مدل است.

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