Performance Improvement of the Flexible Manufacturing System (FMS) with a Proper Dispatching Rules Planning

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Abstract

Avoiding low performance, dispatching rules which commonly applied in determining job execution sequences should be well planned. Several dispatching rules are set in a comparison to establish a compact production schedule on an FMS using a model simulation, such as First Come First Served (FCFS), Shortest Processing Time (SPT), Longest Processing Time (LPT), Earliest Due Date (EDD) and a proposal to consider the wasted time caused in waiting execution on a same machine at a same time. The model of FMS environment, so as production sequences on each dispatching rules, is built on software. The completion time and tardiness of each product are analyzed and compared to gain a proper dispatching rule in giving the best performance. The proper dispatching rules will reduce the completion time without violating the due dates. The result shows that the proper dispatching rule is a combination between EDD and the proposal considering the wasted waiting time considering minimum due dates attributed by each product execution.

Keywords
Completion time, dispatching rule, due date, Flexible manufacturing system, model simulation

I. Introduction

Product variants and their relation to consumer demand are classic challenges faced by manufacturing industries. FMS is applied to cope with this matter.

FMS is defined by El-Sayed et al. as an integrated, computer-controlled configuration of material handling devices and numerically controlled machines that can simultaneously process a variety of part types. This enables FMS to be developed into an integrated system which capable to produce a wide variety of products in large quantities efficiently.

Improving the performance of FMS, Chan, et al. introduced a variety of dispatching rules as means to control the material handling system. Some of the rules are then demonstrated by Reddy, et al. in form of simulation models. The result verifies the fact that within the three dispatching rules (First Come First Served, Longest Processing Time and Shortest Processing Time), there will be differences in throughput time, and machine utilization rate and the percentage of Automated Guided Vehicle (AGV). Analysis and simulation to dispatch rules has also been carried out on fresh fruit canning industry in Thailand by Parthanadee, et al. The given due dates must be considered carefully since there is extreme uncertainty, both in terms of quantity and quality. The system can eventually complete the work order in a shorter completion time without violating the given due dates.

This research is also done to pursue the contribution to the methods development in improving the performance of FMS through a selection of a proper dispatching rule. This study will compare the use of four standard dispatching rules, namely; First Come First Served (FCFS), Shortest Processing Time (SPT), Longest Processing Time (LPT), earliest due date (EDD), and proposes a simple heuristic method in sorting out the waiting time with no or minimum tardiness to the due dates.

The model will be created in a software, and then simulated according to each dispatching rule scenarios respectively, so that the completion time and tardiness of each product which recorded in the simulation result can be analyzed and then compared in order to select the proper dispatching rule which provides the best performance.

II. Literature Review

Flexible Manufacturing System defined by Shivanand et al. is an arrangement of several machines, which is connected to a transport system. The transporter in the transport system carries the work piece to the machines in a pallet or other container so that the register between the machines and the work pieces are known accurately, quickly and automatically. Both machines and transport system are controlled by a computer control system. FMS is quite flexible for its ability to process a wide variety of products on a same machine and the quantity of production can be adjusted to respond a changing market demand.

Dispatching rule is the priority of all jobs to be processed in a machine / work station. The priority scheme determined by using any attribute of each job, any attributes of each machine / work stations, and as well as the ongoing time. When a machine / work station finished processing the previous work piece, dispatching rule would determine the order of the next job from the rest of the work that has not been executed. Research on the dispatching rules has been counducted for decades, and a wide variety of dispatching rules has been established and studied in the literature. According to Pinedo, after a lot of researches, there are wide varieties of dispatching rules that have been created and studied, however, dispatching rules can be classified into several groups. The classifying process is done according to their orientation in determining priorities when carrying out the work.

Table 1: Dispatching rules

DISPATCHING RULES		DATA	OBJECTIVES
First come First Served	FCFS	r_j	min $Z = r_j$
Longest Processing Time	LPT	p_j	max $Z = P_j$
Shortest Processing Time	SPT	p_j	min $Z = P_j$
Earliest Due Date	EDD	d_j	min $Z = d_j$

Table 1 shows some examples of dispatching rules used in this study. There are also other dispatching rules which are not mentioned in the table. In this overall study, we will be discussing the dispatching rules listed on the table, namely FCFS, LPT, SPT, and EDD.

i = Process which the work piece through in.
j = Type of the work piece.
r_j = The order of work arrival.
p_j = The order of the time required to complete the entire process for each work piece.

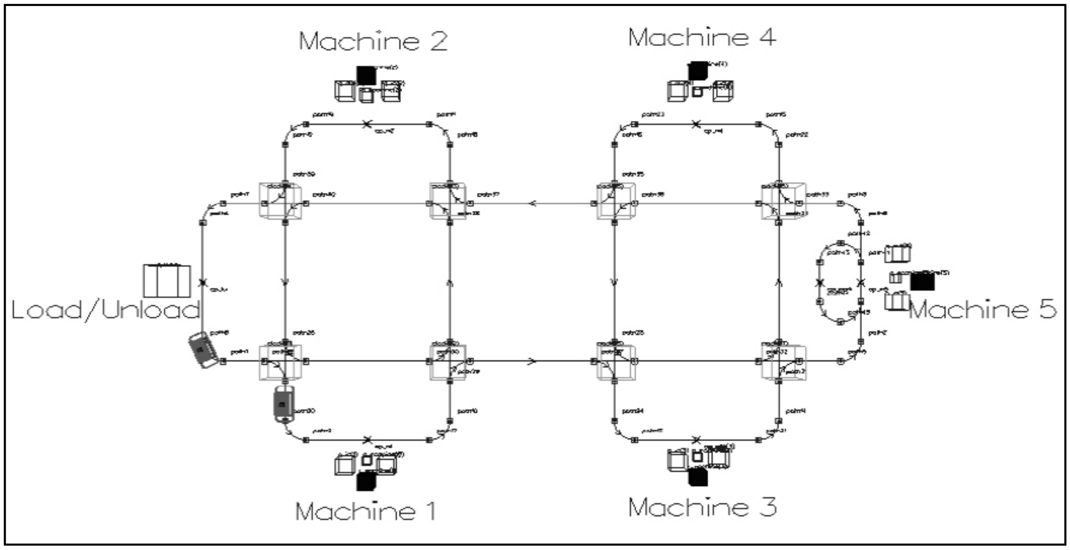
$$p_j = \sum_{i=1}^{m} \sum_{j=1}^{n} (s_{ij} + t_{ij}) \quad (1)$$

s_{ij} = The time required for the process on each work station.
t_{ij} = The time required to perform transportation to the next work station.
d_j = The given due dates that must be obeyed in completing each work piece.

In relation to model simulation, Bangsow stated that simulation technology is an important tool in the design, implementation, and operation phase of a complex system. Existing trends such as the advancement of the complexity and variety of products, the demand for higher quality with the demands of the suppression costs, demands for flexibility, shorter product life cycles, reduction of the lot size number, and increasing competitive pressures, will force the planning cycles to be carried out faster. Thus, the simulation is used to fill the gap where simple methods are no longer able to answer these demands with satisfactory results.

III. Research Methodology and Operation of the Model

Model simulations performed in this research is a soul of Research Methodology. A software named Tecnomatix Plant Simulation is used. The parameters used in this simulation is taken from a journal written by Reddy et al. in 2011, with a layout that can be seen in Figure 1. As written in the journal, the configuration of FMS models in this study are as follows: There are five machines / work stations that are arranged as described in Figure 1, one of which is a combined loading and unloading station (Load / Unload) as upstream and downstream traveling in simulations, there are ten types of work pieces to be processed in the system, and two AGVs are used to perform the material handling system.



(Source Reddy et al., 2011)

Figure 1: Layout of the model simulation

Operations of the model simulated by Reddy et al. are as follows:

- A machine / work station can only work on one job at a time.
- The work piece is processed in the system as ordered, and the order of the process of the work piece at each machine / work station can be seen in Table 2.
- The work piece to be processed in the system must be done to complete once entered, the cancellation of order was never carried out.
- The time required for each machine / work station in completing the process is different according to the work piece to be done, as shown in Table 3.
- There is no inspection process in the system, so there will be no re-work and reject.
- Machines / work stations are assumed not having a buffer.
- Machines / work stations requires no setup time.
- Machines / work stations and AGVs have never experienced a breakdown.
- Each AGV moves on 40 meters per minute, and is assumed to have no acceleration and inertia, so that the time required to travel a distance of AGV in each machine / work station and Loading / Unloading station is like which can be seen in Table 4.
- Each AGV is only able to carry one piece of the work piece at a time.
- Time required to perform the loading and unloading of each are 30 seconds to load the work piece into the AGV, and also 30 seconds to move the work piece from the AGV.
- Each AGV will wait for each process on each machine / work station until the process is completed, before proceeding to the next stage of the process.

Table 2: The sequence of each work piece order

Work piece	Process 1	Process 2	Process 3	Process 4	Process 5
Product A	Machine 2	Machine 1	Machine 5	Machine 4	Machine 3
Product B	Machine 1	Machine 4	Machine 5	Machine 3	Machine 2
Product C	Machine 4	Machine 5	Machine 2	Machine 3	Machine 1
Product D	Machine 2	Machine 1	Machine 5	Machine 3	Machine 4
Product E	Machine 1	Machine 4	Machine 3	Machine 2	Machine 5
Product F	Machine 2	Machine 3	Machine 5	Machine 1	Machine 4
Product G	Machine 4	Machine 5	Machine 2	Machine 3	Machine 1
Product H	Machine 3	Machine 1	Machine 2	Machine 4	Machine 5
Product I	Machine 4	Machine 2	Machine 5	Machine 1	Machine 3
Product J	Machine 5	Machine 4	Machine 3	Machine 2	Machine 1

(Source Reddy et al., 2011; edited)

Table 3: The time required for the process on each work station

Work piece	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5
Product A	53	21	34	55	95
Product B	21	71	26	52	16
Product C	12	42	31	39	98
Product D	55	77	66	77	79
Product E	83	19	64	34	37
Product F	92	54	43	62	79
Product G	93	87	87	69	77
Product H	60	41	38	24	83
Product I	44	49	98	17	25
Product J	96	75	43	79	77

Unit: Minute(s).

(Source Reddy et al., 2011; edited)

Table 4: The time required to perform material handling system to the next work station

	L/U	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5
L/U	0	2.5	4.5	4.5	6.5	5.5
Machine 1	4.5	0	3.5	3.5	5.5	4.5
Machine 2	2.5	3.5	0	5.5	7.5	6.5
Machine 3	6.5	7.5	5.5	0	3.5	2.5
Machine 4	4.5	5.5	3.5	3.5	0	4.5
Machine 5	5.5	6.5	4.5	4.5	2.5	0

Unit: Minute(s).

(Source Reddy et al., 2011; edited)

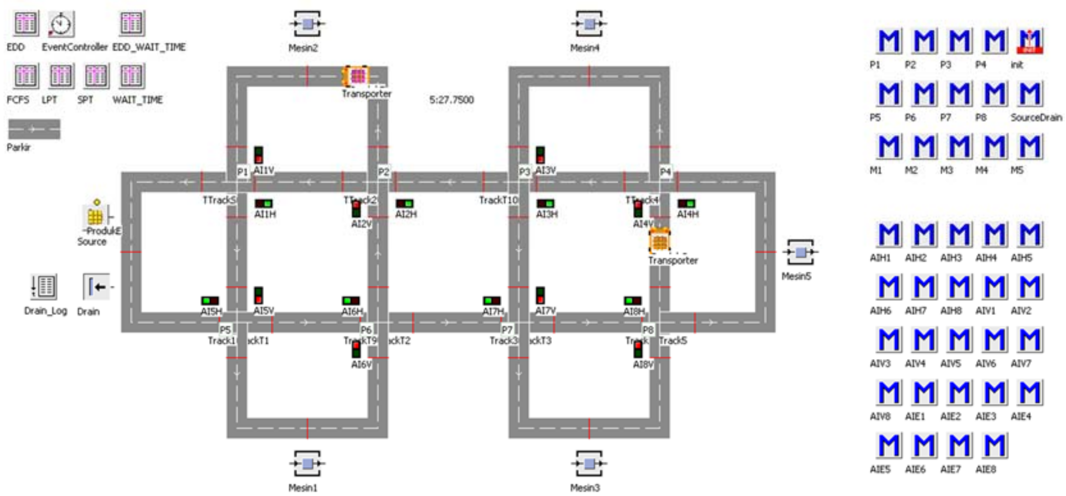


Figure 2: Display of model simulation

The display of the model simulations performed in this study are shown in Figure 2. Once the model simulations are successfully created, the simulation results must be validated before used as a tool in research. Validation of the model simulations carried out with the intention of ensuring the simulation has been run in accordance with the specifications given. It is expected that the simulation results can provide an accurate and reliable timing refference. The model simulations in this study has been validated by comparing the result of the simulation with the specifications that have been described previously. The validation performed are:

- Examination of the processes' sequence which each type of work piece goes through, and the results are in accordance with Table 2.
- Examination of the time required to perform each process on each type of work piece, including the loading / unloading process, and the results are in accordance with Table 3.
- Examination of the time spent to travel by AGV to each machine / work station and unloading station, and the results are in accordance with Table 4.

After the simulation model validated properly, execution order of the work piece in the system is taken into consideration. This research will use four basic dispatching rules in determining execution order of the work piece in the system; FCFS, SPT, LPT, EDD and a new sorting which considers the wait time which are created when a work piece has to be done on a machine that is still busy working on the other work piece. The sequence of the work piece order created through standard dispatching rules as found in Table 1, and will result in the order as listed in Table 5.

Table 5: Processing work pieces due to some dispatching rules

FCFS		LPT		SPT		EDD	
Work piece	Order of work arrival	Work piece	Time Accumulation (minutes)	Work piece	Time Accumulation (minutes)	Work piece	Due Dates (hours)
Product A	1	Product G	447	Product B	212	Product F	16
Product B	2	Product J	396	Product C	256	Product C	17
Product C	3	Product D	380	Product E	267	Product G	18
Product D	4	Product F	360	Product I	267	Product I	19
Product E	5	Product A	284	Product H	280	Product A	30
Product F	6	Product H	280	Product A	284	Product H	31
Product G	7	Product E	267	Product F	360	Product E	32
Product H	8	Product I	267	Product D	380	Product B	33
Product I	9	Product C	256	Product J	396	Product J	34
Product J	10	Product B	212	Product G	447	Product D	35

At certain moments, the work piece process must be postponed as the next machine / work station is still working on the other work piece.

While wait their turn to be processed, the work piece and AGV will be adding no value to the process that should be taken by the work piece, while the completion time will still continue growing. This causes a longer time required to complete the work piece. The wait time method will try to determine the execution order of the work piece with respect to the combination of each pair of work piece so that the waiting time can be minimized. Wait time can be determined through a mathematical equation;

$$W = \sum_{k=1}^{o} C - \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o} S_{ijk} - \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o} T_{ijk} \tag{2}$$

i = Process which the work piece through in.
j = Type of the work piece.
k = The number of AGV used.
C = Completion time required to complete each work piece combination.
S_{ijk} = The time required for the process at each work station.
T_{ijk} = The time required to perform transportation to the next work station.

Through this equation, the wait times obtained by each combination are listed as shown in Table 6. By doing simple heuristic iterations, the combination of the shortest wait time as shown by Table 7 can be obtained.

Table 6: Wait time of each combination of two work pieces

AGV1 \ AGV2	Product A	Product B	Product C	Product D	Product E	Product F	Product G	Product H	Product I	Product J
Product A		6228	9168	11605.5	7908	13225.5	9865.5	9025.5	3648	6805.5
Product B	6145.5		4968	10165.5	5845.5	8965.5	14185.5	4165.5	3385.5	11125.5
Product C	9085.5	4885.5		7885.5	745.5	10885.5	19645.5	1525.5	9025.5	9850.5
Product D	17125.5	10083	7968		6948	12505.5	10450.5	9108	17148	1045.5
Product E	7825.5	8245.5	663	6865.5		5665.5	10885.5	9205.5	3745.5	7825.5
Product F	10428	8883	10968	8065.5	5583		5305.5	4803	15205.5	2245.5
Product G	9783	14103	12925.5	10368	10803	5223		10023	20448	12453
Product H	9108	4083	1443	9025.5	9288	4885.5	10105.5		783	7045.5
Product I	3565.5	3303	11088	17230.5	3828	15288	14125.5	865.5		18910.5
Product J	6723	11043	9768	963	7743	2163	12370.4	6963	18888	

Unit: Second(s).

Table 7: Order of Combination with the shortest wait time created

Combination	AGV 1	AGV 2	Wait time
1	Product E	Product C	663
2	Product H	Product I	783
3	Product J	Product D	963
4	Product G	Product F	5223
5	Product A	Product B	6228

Unit: Second(s).

Therefore, the sequence of the work piece order by considering the wait time is created as follows; Product E → Product C → Product H → Product I → Product J → Product D → Product G → Product F → Product A → Product B.

IV. Results and Analysis

Through the simulation model, it is known that the overall completion time result of each dispatching rule is as shown in Table 8.

Table 8: Completion time

	Day(s)	Hour(s)	Minute(s)	Second(s)
FCFS	1	7	51	39
LPT	1	4	26	1.5
SPT	1	6	16	20.25
EDD	1	5	49	50.25
Wait time	1	3	35	5.25

Although Table 8 has shown that the shortest completion time is achieved when the work order was sorted by the shortest created wait time, a fast completion time is not enough to provide a good solution. Each work piece still have given due dates of which that must also be considered. The given due dates must be followed to avoid penalty cost or quality problems that might be emerged if the completion of each product exceeds the given deadline (tardiness) as shown by Table 9.

Table 9: Due date violations

	FCFS	LPT	SPT	EDD	WAIT TIME	Due Dates
Product A	5.00	18.32	13.98	16.89	27.58	30
Product B	3.55	28.43	4.59	23.50	26.13	33
Product C	8.41	27.08	4.28	5.73	4.28	17
Product D	11.87	13.58	21.57	29.83	15.28	35
Product E	12.86	22.81	8.73	21.49	4.45	32
Product F	17.95	15.15	20.29	6.66	22.07	16
Product G	21.22	8.75	30.27	15.25	22.73	18
Product H	25.26	19.82	15.20	19.92	8.95	31
Product I	25.67	24.74	9.25	12.15	8.90	19
Product J	31.86	7.20	28.72	28.17	15.50	34
Tardiness	11.84	15.82	16.56	0.00	10.80	

Unit: Hour(s).

By looking at the result's performance of each dispatching rule used against the due dates, it can be seen that it is possible to complete the entire process without any tardiness by using the EDD dispatching rule, while another dispatching rule, though it has a faster completion time, results in 10-17 hours tardiness that could potentially lead to the penalty cost, or quality problem.

In order to improve the performance of the completion time without violating the given due dates, this research can be done by combining two dispatching rules to obtain a better solution such as combining the EDD dispatching rule with the wait time consideration.

In addition to considering the wait time that is created between work piece combinations, the minimum given due dates owned by each work piece on the combination can also be considered to shorten the completion without violating the given due dates. The order of each combination according to minimum deadline is as shown in Table 10.

Table 10: Order of Combination with the shortest wait time created and minimum due dates

Combinations	AGV 1	AGV 2	Wait time	Due Dates for AGV 1	Due Dates for AGV 2	Minimum Due Dates
4	Product G	Product F	1.45	18	16	16
1	Product E	Product C	0.18	32	17	17
2	Product H	Product I	0.22	31	19	19
5	Product A	Product B	1.73	30	33	30
3	Product J	Product D	0.27	34	35	34

Unit: Hour(s).

Therefore, the sequence of the work piece order by considering the due dates and the wait time is created as follows; Product G → Product F → Product E → Product C→ Product H → Product I → Product A → Product B → Product J → Product D.

The results occurred when the sequence was simulated through the model simulation will lead into 2 hours and 3.6 minutes faster completion time when compared to the use of single EDD dispatching rule, yet not violating the due dates, thus providing a better solution. Completion time of each work piece and the comparison with the given due dates are shown in Table 11.

Table 11: Table Comparison of EDD and EDD + Wait Time

	EDD	EDD+Wait Time	Due Dates
Product A	16.89	21.03	30
Product B	23.50	21.43	33
Product C	5.73	11.72	17
Product D	29.83	27.77	35
Product E	21.49	11.85	32
Product F	6.66	6.80	16
Product G	15.25	7.45	18
Product H	19.92	16.38	31
Product I	12.15	16.30	19
Product J	28.17	27.63	34
Tardiness	0.00	0.00	
Completion Time	29.83	27.77	

Unit: Hour(s).

Therefore, this method is the best to improve the performance of the FMS completion time without violating the due dates solution amongst other methods presented in this study. Results and comparative performance analysis of each dispatching rule used in this study regarding to completion time and the due dates violation are shown in Figure 3.

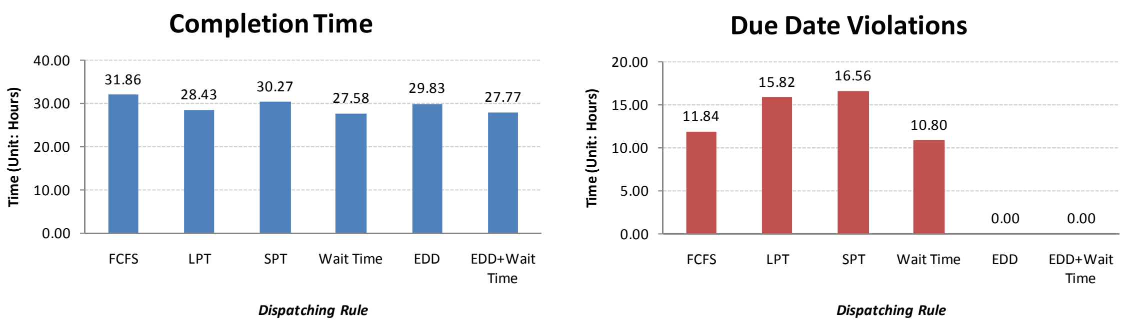


Figure 3: Performance of each dispatching rule

V. Conclusions

Based on the analysis and data processing from the results of model simulation, it can be concluded that:

- From the comparison of the four dispatching rules and Wait Time, the obtained results that FCFS has a completion time of 31.86 hours, LPT has a completion time of 28.43 hours, SPT has a completion time of 30.27 hours, EDD has a completion time of 29.83 hours, and Wait Time has acompletion time of 27.58 hours. Therefore, the sequence made with a consideration to Wait Time has the shortest completion time of 27.58 hours.
- Regarding the due dates of each work piece in this study, obtained results that FCFS has a number of due date violations by 11.84 hours, LPT has a number of due date violations by 15.82 hours, SPT has a number of due date violations by 16.56 hours, EDD has number of due date violation at 0 hours, and Wait time has a number of due date violations for 10.8 hours. In this case, the EDD is an option that does not have a deadline violation, but the resulting EDD completion time can still be shortened by combining the consideration against a due date with the created wait time by considering the minimum due date of each pair combination of the work piece, so the completion time which is generated by the use of single EDD dispatching rule at 29.83 hours may be shortened by the use of EDD and Wait time into 27.77 hours, yet still without any violation to the due dates.

In accordance with the research objectives, the performance of FMS completion time can be improved through the selection of proper dispatching rule; In this study, EDD + Wait Time is the best solution among other simulated dispatching rule options, in delivering the performance of a fast completion time and without violating the due dates.

Future Research

This study still had a lot of shortcomings, therefore, other studies similar to the following suggestions are expected:

- Using other tools with any optimation methods. (For example, by using a meta-heuristic method like Tabu search with matlab or excel macros software tools)
- Using a different layout, routing and parameters, such as increasing the number of AGV, the use of larger number of machines, as well as the simultaneous production on a greater batches.
- Adding several aspects of the dispatching rule such as ease of the process, the cost of the work piece, and the addition of a penalty cost variations, as well as other limitations that have not been covered in this study.

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