# Selection of alternative routings in real time: DMM and modified DMM rules

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**Abstract:** The objective of this study is to test the effectiveness of the modified Dissimilarity Maximisation Method (modified DMM) for real-time Flexible Manufacturing Systems (FMSs) scheduling. The modified DMM is an improvement over the DMM. It is a plan selection method for an alternative process that was developed for routing selection in real-time FMS scheduling. A computer simulation model, which mimics a physical system, is used to evaluate the effect of DMM and modified DMM rules on the system performance. The results show that the modified DMM outperforms DMM on system throughput in a saturation case and increases the utilisation rate of machines and the material-handling system.

**Keywords:** flexible manufacturing systems; FMSs; routing; real-time FMS control; dispatching rules; simulation.

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## 1 Introduction

Nowadays, businesses are facing increased competition; pressure for higher variety of customised products, shorter lead times, higher quality, and lower cost due to competitors. Today, production and manufacturing systems such as Flexible Manufacturing Systems (FMSs) provide great flexibility. They provide various benefits such as increased resource use and productivity, reduced work in process and many more.

In such systems, allocation decisions and the scheduling of operations and plans for the process are generally taken dynamically and in the very short term, depending on the state of the production system (availability of resources, availability of system handling, the presence of bottlenecks), the characteristics of the production plan (due date of manufacturing orders) and the production targets (production rate decrease, reduced work in process).

The real-time scheduling of operations uses multiple approaches such as the management of queues by priority rules. This scheduling approach is one of the simplest and most commonly used. These priority rules arose several years ago from many research to find solutions to problems in real-time scheduling.

Among the rules and methods of scheduling in real time, we can find the Dissimilarity Maximisation Method (DMM) rule, which is a rule for selecting between alternative routings in real time in an FMS. This rule was developed by Saygin *et al.* (2001). It aims to select a routing among several other routings available for a part entering the system. This method is based on the coefficients of dissimilarity between machines.

In this work, we propose an improvement of the DMM rule in order to improve the performance of the production system. In our approach we will use the simulation to show the results obtained by the DMM and modified DMM rules.

## 2 Literature review

Scheduling problems are usually NP hard. One of the first studies on the scheduling of FMSs is the work of Nof *et al.* (1979), where they demonstrate the importance and effect of scheduling decisions on the performance of production systems.

The definition of classical and traditional scheduling shows that the production operations are sequenced before the start of production.

With real-time scheduling, there are many problems caused by the inevitable shifts in reordering due to equipment failure or lack of materials.

The factors listed above and many others make reordering necessary to avoid an increase in waiting time, an increase in work in process, a low utilisation of machinery and equipment and possibly the degradation of production system performance (Wu and Wysk, 1989; Ishii and Muraki, 1996).

Several researchers propose different methods to provide maximum flexibility in real time scheduling in order to increase the performance of systems (Saygin and Kilic, 1999; Liu and MacCarthy, 1997; Saygin and Kilic, 1996).

However, real-time scheduling has always been a desirable but elusive goal (Basnet and Mize, 1994; Shukla and Chen, 1996).

Consequently, establishing an integrated system for real-time scheduling and control that responds to changes in the state of the system is essential to improve its performance. The control and real-time scheduling of flexible production systems have been a popular research area since the early 1980s, a period in which flexible production systems were adopted by industrialised countries (Saygin *et al.*, 1995; Saygin and Kilic, 1997; Peng and Chen, 1998).

But many studies on controlling and scheduling FMS in real time do not take into account the flexibility of alternative routing (Byrne and Chutima, 1997; Kazerooni *et al.*, 1997), and most of the studies that take into account this point, handle the problem of routing selection prior to the start of production (Das and Nagendra, 1997; Cho and Wysk, 1995).

This approach is not applicable for random flexible production systems (Rachamadugu and Stecke, 1994), where we cannot anticipate the arrival or entry of parts in the system before the start of production because the routing of the parts may be different, even for parts of the same type (Rachamadugu and Stecke, 1994). Thus the control system of a random FMS is needed to effectively and efficiently use the flexibility of operations and routing in real-time handling, when random parts and unforeseen events occur (Mamalis *et al.*, 1995; Rachamadugu and Stecke, 1994).

The use of rules of allocation as a tool for decision making, ordering and scheduling of FMSs in real time, has already been covered by several studies. But the myopic nature of the rules leads to imperfect scheduling, since they do not capture relevant information at certain levels of production systems (Rachamadugu and Stecke, 1994; Gupta *et al.*, 1989). In addition to the effectiveness of rules, their assignment to the production system depends on the characteristics of production systems, conditions on the operations of treatment and the performance measurement system (Kouiss *et al.*, 1997).

The weakness of these methods in handling real-time scheduling in FMSs was the driving force behind the development of a new alternative routing method of real-time selection. This method is the DMM.

When the current authors studied the method, they noticed some weaknesses when the system is overloaded. Hence some modifications were introduced to overcome these weaknesses.

In this work we present the DMM rule, the modified DMM rule and the simulation result obtained on a generic FMS model.

## 3 The DMM rule for selecting alternative routing in real time

The rule for selecting alternative routing in real-time DMM is a method inspired by group technology. The DMM has a reciprocal function to group technology, as it tends to maximise the dissimilarity coefficients instead of the similarity coefficients.

DMM is a method of selecting between alternative process plans. It was developed by Saygin and Kilic (1999) for the selection of an alternative routing to schedule offline FMSs.

In order to reduce congestion and increase the rate of production of FMSs, the DMM will be used for FMS real-time scheduling.

This method is based on maximising the dissimilarity coefficients between alternative routings. These coefficients use types of machines that belong to each routing.

The selection of a routing among alternative routings of each type of part is performed according to the maximisation of the sum of the dissimilarity coefficients.

*Notations*

n : number of parts

q : number of routings

$D_{ij}$ : dissimilarity between routings i and j

$C_{ij}$ = 1 if routing j belongs to the routings of part i; otherwise, $C_{ij} = 0$

$X_j$ = 1 if routing j is selected; otherwise, $X_j = 0$

$S_j$ : maximum sum.

The dissimilarity coefficient (dissimilarity of machine type) between two routings i and j is defined as follows (Saygin and Kilic, 1999):

$$\mathrm{D_{ij}} = \frac{\text{Number of machine types that are not common in both routing i and j}}{\text{Total number of machine types in both routings}}. \quad (1)$$

For the selection of an alternative routing, we will maximise the total sum of dissimilarities between the routings as follows (Saygin and Kilic, 1999):

$$S_j = Max\sum_{i=1}^{q}\sum_{j=1}^{q} X_j D_{ij} \quad (2)$$

subject to:

$$\sum_{j=1}^{q} C_{ij} X_j = 1 \quad \text{for all parts } \mathrm{i} = 1,..,\mathrm{n}. \quad (3)$$

Equation (3) states that only one routing will be selected for each part.

$$\sum_{j=1}^{q} X_j = n \quad \text{for all routings } \mathrm{j} = 1,..,\mathrm{q}. \quad (4)$$

Equation (4) states that the number of selected routings will be equal to the number of parts.

## 4 Algorithm of the DMM rule

Through a description of its algorithm, in this section we present the DMM rule proposed by Saygin *et al*. (2001). We will show various steps to integrate the DMM rule as a tool for selecting alternative routings in real time.

Here we show how to apply the DMM rule in FMSs to select a routing among those available for each type of part. The parts that arrive first have the highest priority in accordance with the rule First in First out (FIFO); the other parts will wait in input or output queues of various machines or in the loading station. The algorithm of the DMM rule is as follows:

Step 1 All routes are free (available) so X(i) = 0.

Step 2 Calculation of dissimilarity coefficients $D_{ij}$ (1).

Step 3 Creation of parts.

Step 4 Condition: depending on the type of part tested, if there is at least one free routing and at least one free place in the queue of the loading station.

Step 5 If the previous condition is not verified, the part is in a queue until the condition is verified.

Step 6 If the condition of Step 4 is satisfied, then we calculate the sum:

$$S(j) = \sum_{i=1}^{q} X(i)\, D(i, j). \tag{5}$$

Step 7 Find the maximum of S(j).

Step 8 The routing j corresponding to the maximum value of S(j) found in the previous step is selected, so: X(j) = 1.

Step 9 Treatment of the part according to the selected routing j.

Step 10 At the end of the treatment, routing becomes available again, X(j) = 0.

Step 11 The part leaves the system.

*Note*: This cycle will repeat itself from Steps 3 to 11 at each part creation, until the end of the simulation time.

## 5 Modified DMM rule for selecting an alternative routing in real time

In this section we explain the modified DMM rule that we developed from the DMM rule mentioned earlier. This rule is also used in the selection of an alternative routing in real time in an FMS.

In our study of the DMM rule, we noticed that for a large creation rate of parts and for small queue sizes:

- The production system is saturated.
- The machine and the transporter utilisation rates are rather low.

These will influence the performance of the production system. To overcome these problems, we propose the modified DMM rule. In the DMM rule, after selecting a routing for a part, that routing cannot be used by another part until the first part has left the system Therefore each routing cannot contain more than one part at a time.

Our modification of this rule is intended to keep the same principle of relying on the maximisation of dissimilarity coefficients for the selection of various routings, but also by assigning several parts to a single routing.

So if all routes are selected by a part, the newly created part will choose among the routings. The piece will be delivered in the routing where the queue of the first machine of this routing contains at least one free place.

## 6 Algorithm of modified DMM rule

In this section we show the integration of the modified DMM rule in FMS for the selection of a routing among the routings available for each type of part.

The parts arriving first have a higher priority following the FIFO rule. The other parts will wait in input or output queues of various machines or in the loading station. The modified rule will use the following algorithm for the selection of an alternative routing in real time in a flexible production system.

Step 1 All routes are free (available) so X(i) = 0.

Step 2 Calculation of dissimilarity coefficients $D_{ij}$ (1).

Step 3 Creation of parts.

Step 4 Condition: depending on the type of part tested:

- If there is at least one free routing and at least one free place in the queue of the loading station.

or

- If all routes are busy and the input queue of the first machine of at least one routing contains at least one free place and this machine is not broken down.

Step 5 If the previous condition is not verified, the part is in a queue until the condition is verified.

Step 6 If the condition of Step 4 is satisfied, then we calculate the sum:

$$S(j) = \sum_{i=1}^{q} X(i)\, D(i, j). \tag{6}$$

Step 7 Test if we have found a maximum of S(j) (There are free routings).

Step 8 If the previous condition is satisfied then go to Step 10.

Step 9 If the condition of Step 7 is not satisfied, then select the routing where the input queue of its first machine contains at least one free place.

Step 10 Routing j is selected, X(j) = 1.

Step 11 Treatment of the part according to the selected routing j.

Step 12 At the end of treatment, routing becomes available again X(j) = 0.

Step 13 Part leaves the system.

*Note*: This cycle will repeat itself from Steps 3 to 13 at each part creation, until the end of the simulation time.

## 7 Simulated FMS Model

To make a comparison between the two rules DMM and modified DMM, we studied and simulated an FMS.

This system contains seven machines, one AGV and two stations: a loading station and an unloading station. Six different types of parts are treated in the system.

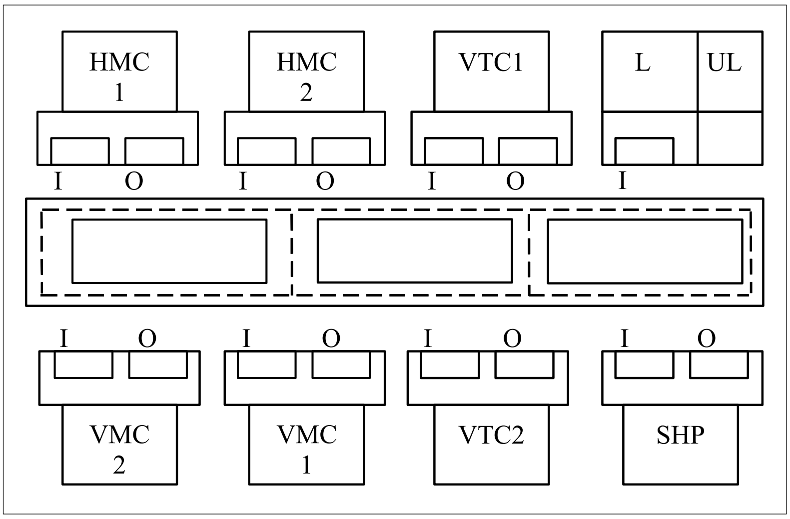
The machines and stations that compose the studied system are as follows:

- two vertical milling machines (VMC)
- two horizontal milling machines (HMC)
- two vertical turning centres (VTC)
- one shaper (SHP)
- one loading station (L)
- one unloading station (UL).

Each machine has an input queue and an output queue. The loading station also contains an input queue.

The configuration of the FMS is given in Figure 1.

**Figure 1** Configuration of the FMS model




Notes: HMC: Horizontal Machining Centre.
VMC: Vertical Machining Centre.
VTC: Vertical Turning Centre.
SHP: Shaper.
L: Loading station.
UL: Unloading station.
I: Input buffer.
O: Output buffer.
– – – – AGV routes.

The alternative routing and the processing time for each type of part are given in Table 1.

**Table 1** Alternative routings of part types

| *Part type* | *Production ratio (%)* | *Routings and processing time (min)* |
|---|---|---|
| A | 17 | L – VTC1 (30) – VMC1 (20) – UL |
| | | L – VTC1 (30) – VMC2 (20) – UL |
| | | L – VTC2 (30) – VMC1 (20) – UL |
| | | L – VTC2 (30) – VMC2 (20) – UL |
| B | 17 | L – VTC1 (20) – SHP (1) – VMC1 (15) – UL |
| | | L – VTC1 (20) – SHP (1) – VMC2 (15) – UL |
| | | L – VTC2 (20) – SHP (1) – VMC1 (15) – UL |
| | | L – VTC2 (20) – SHP (1) – VMC2 (15) – UL |
| C | 17 | L – VTC1 (40) – VMC1 (25) – UL |
| | | L – VTC1 (40) – VMC2 (25) – UL |
| | | L – VTC2 (40) – VMC1 (25) – UL |
| | | L – VTC2 (40) – VMC2 (25) – UL |
| D | 21 | L – VTC1 (40) – SHP (1) – VTC1 (20) – HMC1 (35) – UL |
| | | L – VTC1 (40) – SHP (1) – VTC1 (20) – HMC2 (35) – UL |
| | | L – VTC1 (40) – SHP (1) – VTC2 (20) – HMC1 (35) – UL |
| | | L – VTC1 (40) – SHP (1) – VTC2 (20) – HMC2 (35) – UL |
| | | L – VTC2 (40) – SHP (1) – VTC1 (20) – HMC1 (35) – UL |
| | | L – VTC2 (40) – SHP (1) – VTC1 (20) – HMC2 (35) – UL |
| | | L – VTC2 (40) – SHP (1) – VTC2 (20) – HMC1 (35) – UL |
| | | L – VTC2 (40) – SHP (1) – VTC2 (20) – HMC2 (35) – UL |
| E | 20 | L – VTC1 (25) – SHP (1) – VTC1 (35) – HMC1 (50) – UL |
| | | L – VTC1 (25) – SHP (1) – VTC1 (35) – HMC2 (50) –UL |
| | | L – VTC1 (25) – SHP (1) – VTC2 (35) – HMC1 (50) – UL |
| | | L – VTC1 (25) – SHP (1) – VTC2 (35) – HMC2 (50) – UL |
| | | L – VTC2 (25) – SHP (1) – VTC1 (35) – HMC1 (50) –UL |
| | | L – VTC2 (25) – SHP (1) – VTC1 (35) – HMC2 (50) –UL |
| | | L – VTC2 (25) – SHP (1) – VTC2 (35) – HMC1 (50) – UL |
| | | L – VTC2 (25) – SHP (1) – VTC2 (35) – HMC2 (50) – UL |
| F | 8 | L – HMC1 (40) – UL |
| | | L – HMC2 (40) – UL |

The studied operations on the flexible production system are based on the following assumptions:

- The alternative routings of each type of part are known before the start of production.
- The AGV routes depend on the selected alternative routings in real time.
- The processing, setup and machining times are known.

- The processing time of an operation is the same as on the alternative machines identified for this operation.
- Each machine can process one piece at a time.

## 8 Simulation results

In this section we present the simulation results of DMM and modified DMM and a comparison between these two methods. Two simulations were performed: with and without the breakdowns of machines.

ARENA software was used for the simulations.

### *8.1 Without the presence of a breakdown in the system*

In this paragraph we present the results of the production rate obtained by simulating the two methods.

1. Due to the large CPU time of the replication execution (30 min for one replication), we take the average of only ten replications; the replication length being 20 000 h.
2. Depending on the parts creation rate, the number of produced parts varies considerably. Therefore and in order to standardise the results, we divided the number of parts leaving the system (finished parts) by the number of parts created.

#### *8.1.1 Production rate*

Figure 2 shows that, for a significant rate of creation of the parts, the results obtained by the modified DMM method are better than those obtained by the DMM. Below the creation rate of 1 part/25 min, the production rate is practically the same for the two methods. Figure 3 shows that, for a queue length less than 8, the modified DMM gives better results than the DMM.

**Figure 2** Rate of parts leaving the system for queue size = 2 (see online version for colours)

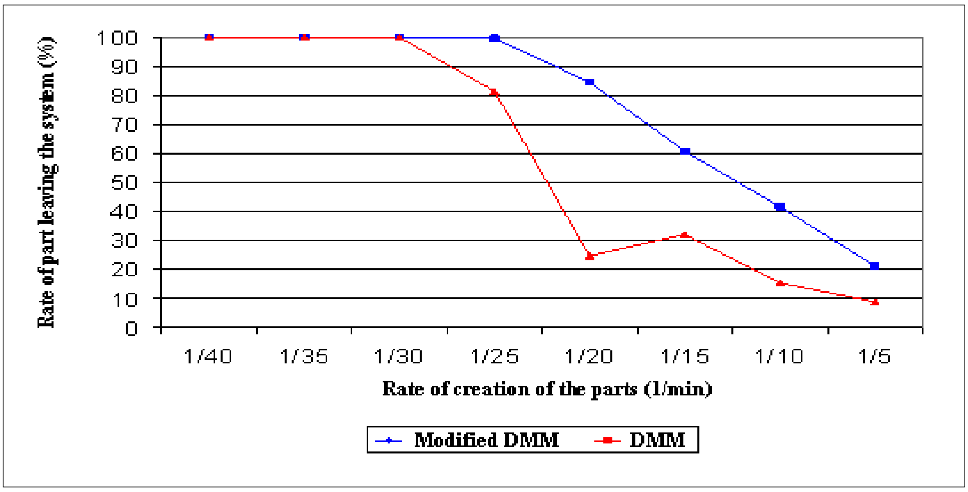
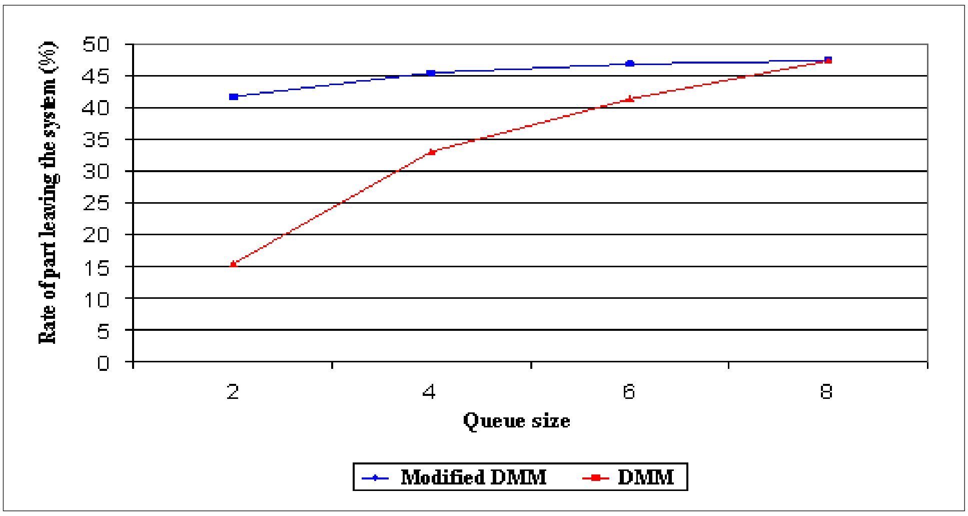


**Figure 3** Rate of parts leaving the system for the parts creation rate = 1 part/10 min (see online version for colours)




### *8.1.2 Machine utilisation rate*

The utilisation rate of the machines is a very significant criterion in the measurement of the performance of a production system. The utilisation rate for the machines VTC1 and VTC2 is more significant for the modified DMM than for the DMM for a significant rate of creation, *i.e.*, higher than 1 part/25 min (see Figure 4) and queue size less than 8 (see Figure 5).

**Figure 4** Rate of the machines VTC1 and VTC2 for queue size = 2 (see online version for colours)

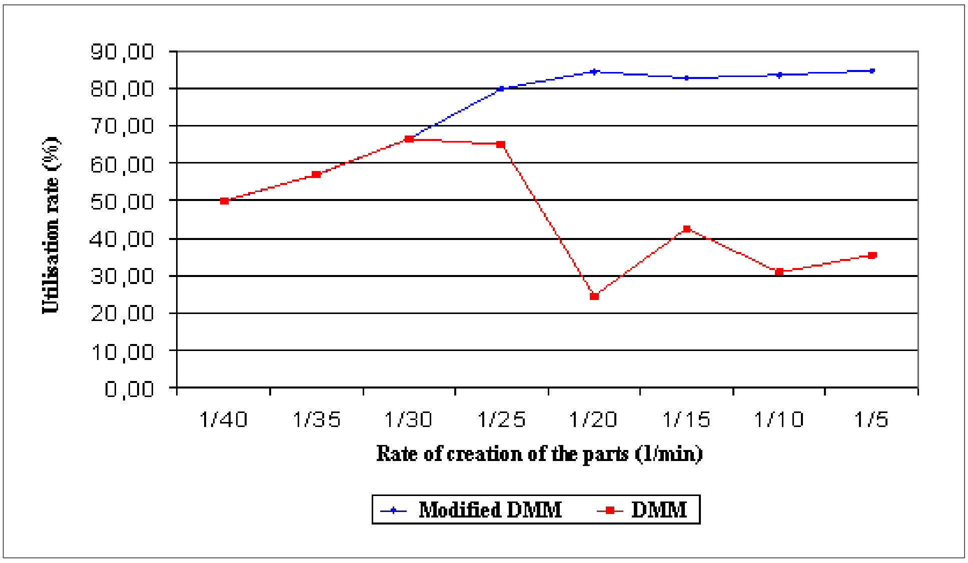
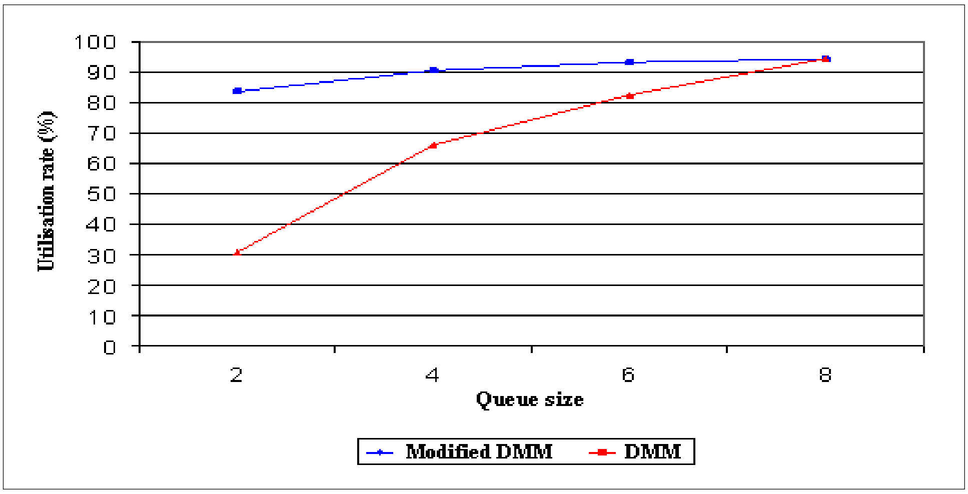


**Figure 5** Rate of the machines VTC1 and VTC2 for the parts creation rate = 1 part/10 min (see online version for colours)




### *8.1.3 Material handling utilisation rate*

Figures 6 and 7 show that, for a saturated system, the utilisation ratio of the AGV is more significant for the modified DMM rule. This is due to the high production rate and the increase in machines utilisation.

**Figure 6** Utilisation rate of AGV for queue size = 2 (see online version for colours)

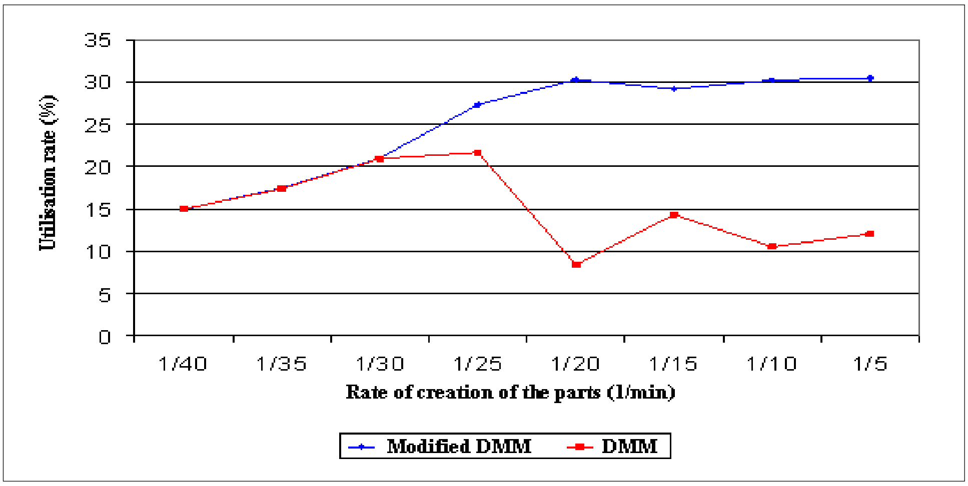
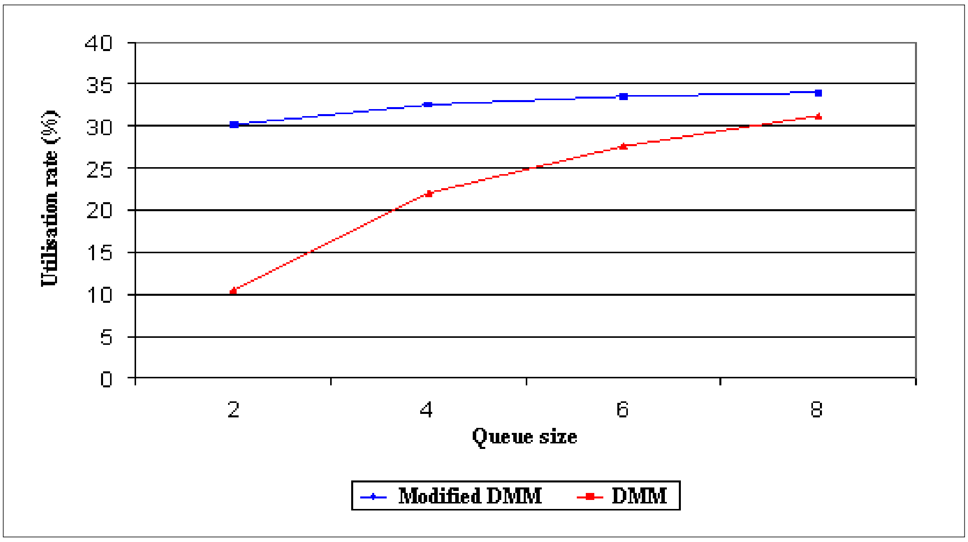


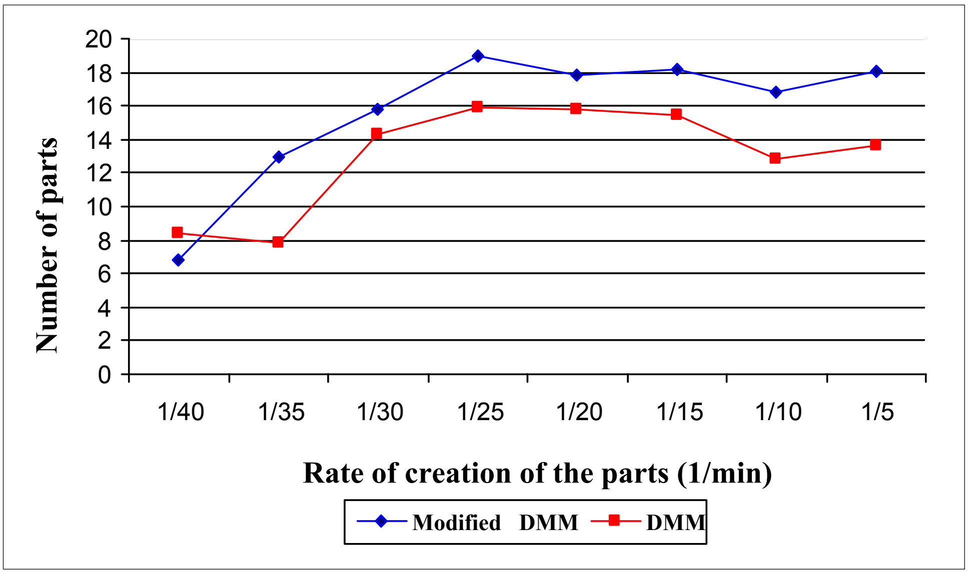
**Figure 7** Utilisation rate of AGV for parts creation rate = 1 part/10 min (see online version for colours)




### 8.1.4 *Work in process*

Figure 8 shows that, if the rate of creation of the parts is greater than 1 part/40 min, the number of parts that remain in the system of the modified DMM is higher than that in DMM. The increase in work in process for the modified DMM is due to the high number of pieces that go into the system and the high production rate.

**Figure 8** Work in process for queue size = 2 (see online version for colours)



## *8.2 With the presence of a breakdown in the system*

The results presented here are similar to those in the Section 8.1, but with occurrence of breakdowns according to the following criteria:

- occurrence of breakdown using exponential distribution with a mean value of 100 h
- maintenance time using exponential distribution with a mean value of 2 h.

The time between failures will only be considered when the resource is in its busy state.

### *8.2.1 Production rate*

The results in Figure 9 are similar to those in Figure 2 and those in Figure 10 are similar to those in Figure 3. Therefore it can be concluded that the modified DMM rule has outperformed the DMM rule even in the presence of a failure.

**Figure 9** Rate of parts leaving the system for queue size = 2 (see online version for colours)

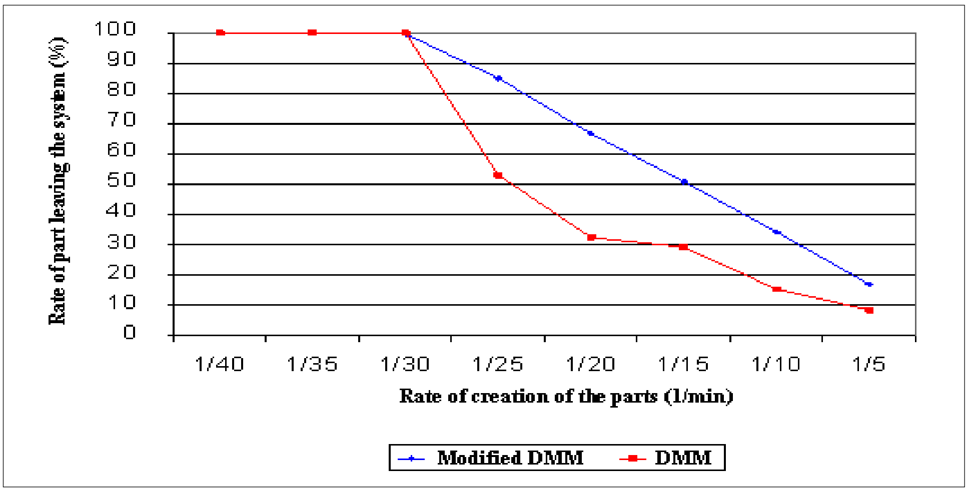
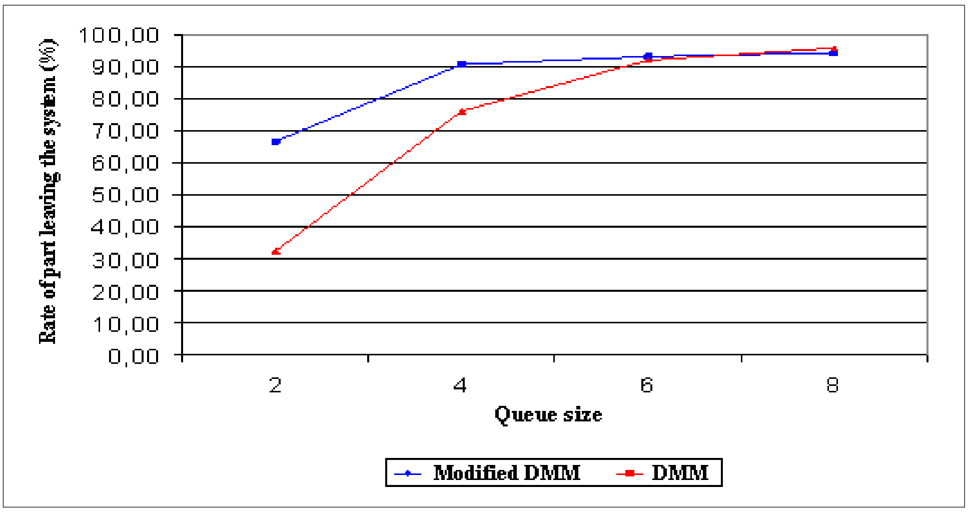



**Figure 10** Rate of parts leaving the system for the parts creation rate = 1 part/20 min (see online version for colours)



### *8.2.2 Machine utilisation rate*

Even with the introduction of failures, the utilisation rate for the machines VTC1 and VTC2 is more significant for the modified DMM than for the DMM for a significant rate of creation, *i.e.*, higher than 1 part/25 min (see Figure 11) and a queue size less than 6 (see Figure 12).

**Figure 11** Rate of the machines VTC1 and VTC2 for queue size = 2 (see online version for colours)

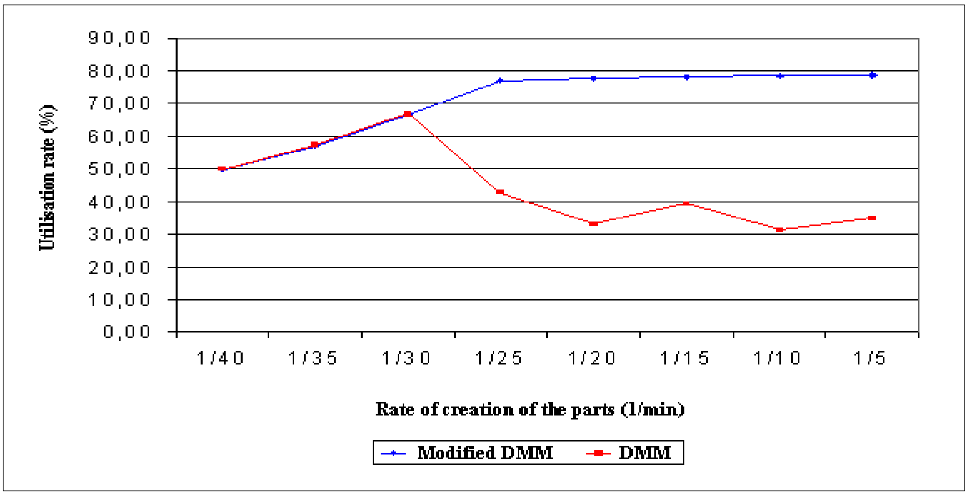
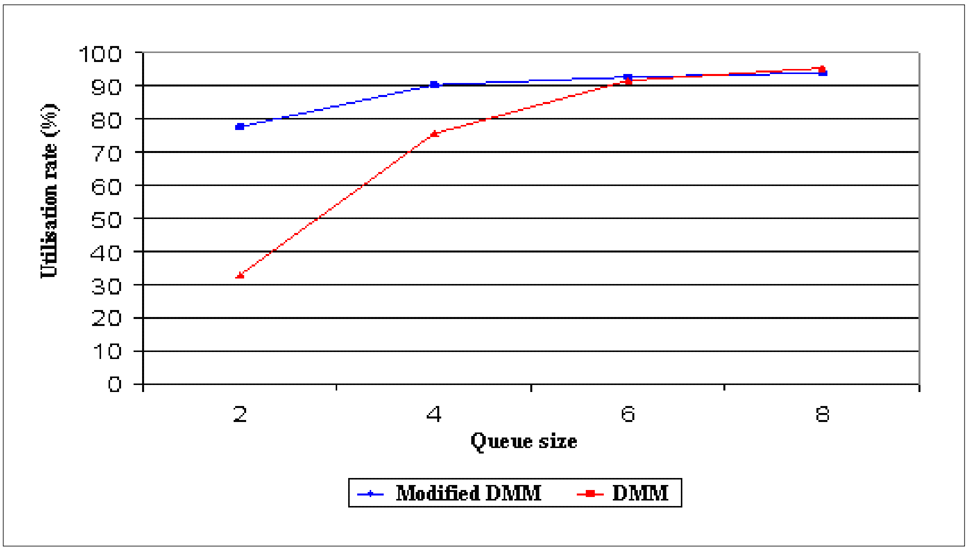



**Figure 12** Rate of the machines VTC1 and VTC2 for the parts creation rate = 1 part/20 min (see online version for colours)



### *8.2.3 Material handling utilisation rate*

In Figures 13 and 14 we can notice that the handling system is best used with the modified DMM rule for a saturated system.

**Figure 13** Utilisation rate of AGV for queue size = 2 (see online version for colours)

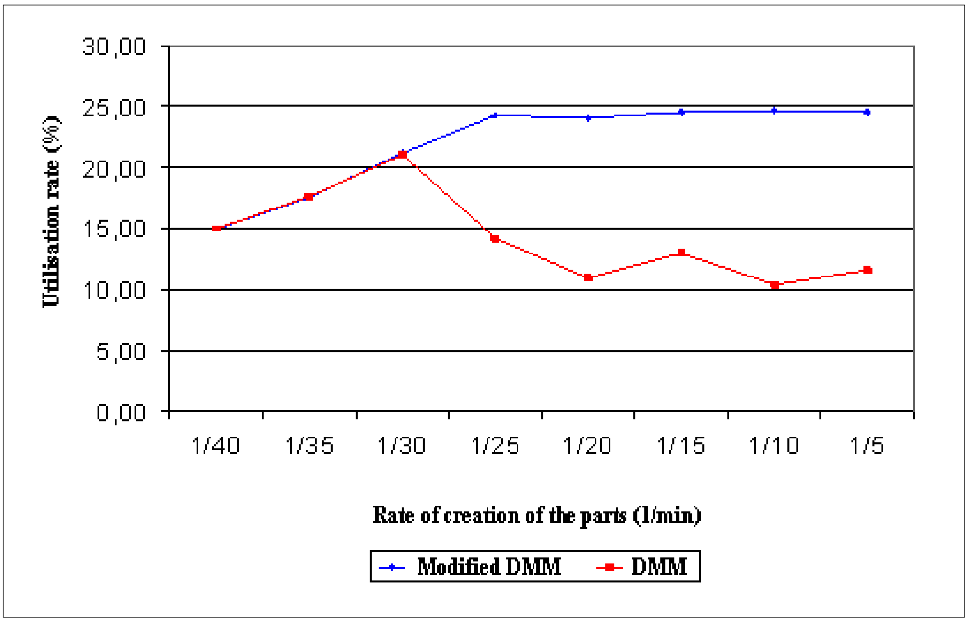
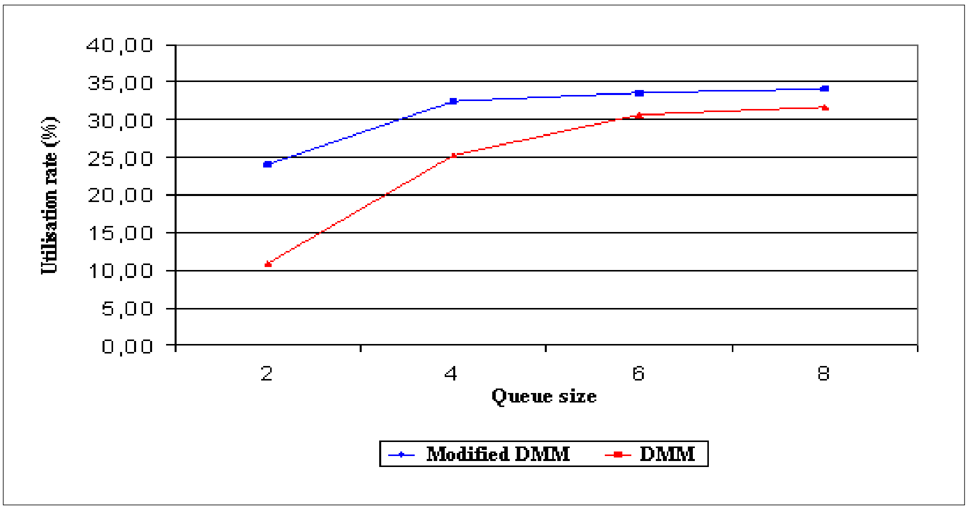


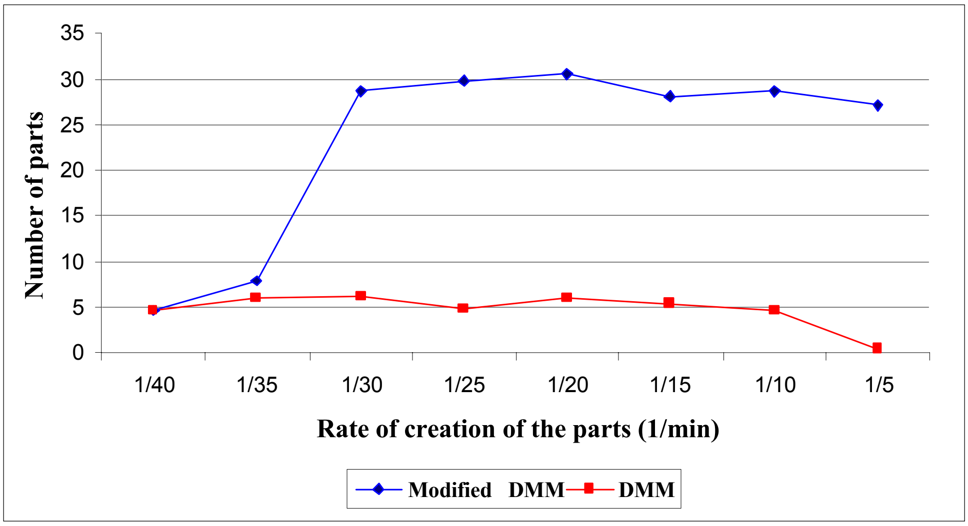

**Figure 14** Utilisation rate of AGV for the parts creation rate = 1 part/20 min (see online version for colours)



### 8.2.4 Work in process

The number of parts that remain in the system is greater for the modified DMM (Figure 15). This is due to the increased use of machines.

**Figure 15** Work in process for queue size = 2 (see online version for colours)




## 9 Conclusion

The obtained results all showed that the modified DMM provides better results than DMM for a saturated production system. For high rates of parts creation, the modified DMM clearly increased the performance of the production system, for which we record an increase in the production rate, an increase in the utilisation rate of the machines and an increase in the use of the handling system.

The introduction of a breakdown did not change the results much. The modified DMM still remains more efficient for an overloaded system.

For each rule, we notice that the simulation results without breakdowns are better than those with breakdowns, which is predictable since breakdowns lower the performance of the system.

Because of the complexity of FMSs, this method could not improve the performance concerning the cycle time and the rate of the work-in-progress of the system. This is because the number of parts which circulate in the system is higher during the use of the modified DMM.

We can conclude that the performance of the rules of priority or of the selection of routing such as the modified DMM depends on the configuration of the workshop and the operating conditions. Thus we suggest a selection of alternative routings in real time, using the modified DMM with other distpatching rules.

## References


Basnet, C. and Mize, J.H. (1994) 'Scheduling and control of flexible manufacturing systems: a critical review', *International Journal of Computer Integrated Manufacturing*, Vol. 7, No. 6, pp.340–355.

Byrne, M.D. and Chutima, P. (1997) 'Real-time operational control of an FMS with full routing flexibility', *International Journal of Production Economics*, Vol. 51, pp.109–113.

Cho, H. and Wysk, R.A. (1995) 'Intelligent workstation controller for computer-integrated manufacturing: problems and models', *Journal of Manufacturing Systems*, Vol. 14, No. 4, pp.252–263.

Das, S.K. and Nagendra, P. (1997) 'Selection of routes in a flexible manufacturing facility', *International Journal of Production Economics*, Vol. 48, pp.237–247.

Gupta, Y.P., Gupta, M.C. and Bector, C.R. (1989) 'A review of scheduling rules in flexible manufacturing systems', *International Journal of Computer Integrated Manufacturing*, Vol. 2, pp.356–377.

Ishii, N. and Muraki, M. (1996) 'A process-variability-based on-line scheduling system in multi product batch process', *Computing in Chemical Engineering*, Vol. 20, pp.217–234.

Kazerooni, A., Chan, F.T.S. and Abhary, K. (1997) 'A fuzzy integrated decision-making support system for scheduling of FMS using simulation', *Computer Integrated Manufacturing Systems*, Vol. 10, No. 1, pp.27–34.

Kouiss, K., Pierreval, H. and Mebarki, N. (1997) 'Using multi-agent architecture in FMS for dynamic scheduling', *Journal of Intelligent Manufacturing*, Vol. 8, pp.41–47.

Liu, J. and MacCarthy, B.L. (1997) 'A goal MILP model for FMS scheduling', *European Journal of Operational Research*, Vol. 100, pp.441–453.

Mamalis, A.G., Malagardis, I. and Pachos, E. (1995) 'On-line scheduling in metal removal processing using variable routing and control strategies', *Computer Integrated Manufacturing Systems*, Vol. 8, pp.35–40.

Nof, S., Barash, M. and Solberg, J. (1979) 'Operational control of item flow in versatile manufacturing system', *International Journal of Production Research*, Vol. 17, pp.479–489.

Peng, C. and Chen, F.F. (1998) 'Real-time control and scheduling of flexible manufacturing systems: a simulation based ordinal optimization approach', *International Journal of Advanced Manufacturing Technology*, Vol. 14, No. 10, pp.775–786.

Rachamadugu, R. and Stecke, K.E. (1994) 'Classification and review of FMS scheduling procedures', *Production Planning and Control*, Vol. 5, pp.2–20.

Saygin, C., Chen, F.F. and Singh, J. (2001) 'Real-time manipulation of alternative routings in flexible manufacturing systems: a simulation study', *International Journal of Advanced Manufacturing Technology*, Vol. 18, pp.755–763.

Saygin, C. and Kilic, S.E. (1996) 'Effect of flexible process plans on performance of flexible manufacturing systems', *Proceedings of 7th International DAAM Symposium*, Vienna, Austria, pp.393–394.

Saygin, C. and Kilic, S.E. (1997) 'Scheduling of flexible manufacturing system', *MicroCAD 97 Conference*, University of Miskolc, Hungary, Vol. H, pp.19–23.

Saygin, C. and Kilic, S.E. (1999) 'Integrating flexible manufacturing systems with scheduling in flexible manufacturing system', *International Journal of Advanced Manufacturing Technology*, Vol. 15, No. 4, pp.268–280.

Saygin, C., Kilic, S.E., Toth, T. and Erdelyi, F. (1995) 'On scheduling approaches of flexible manufacturing systems: gap between theory and practice', *Postprint Volume of the 3rd IFAC/IFIP/IFORS Workshop – Intelligent Manufacturing Systems 95*, Pergamon/Elsevier Science, pp.61–66.

Shukla, C.S. and Chen, F.F. (1996) 'The state of the art in intelligent real-time FMS control: a comprehensive survey', *Journal of Intelligent Manufacturing*, Vol. 7, pp.441–455.

Wu, S.Y.D. and Wysk, R.A. (1989) 'An application of discrete event simulation to on-line control and scheduling in flexible manufacturing', *International Journal of Production Research*, Vol. 27, pp.1603–1623.