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# Testing a Flexible Manufacturing System Facility Production Capacity through Discrete Event Simulation: Automotive Case Study

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***Abstract*—**In the age of automation and computation aiding manufacturing, it is clear that manufacturing systems have become more complex than ever before. Although technological advances provide the capability to gain more value with fewer resources, sometimes utilisation of the manufacturing capabilities available to organisations is difficult to achieve. Flexible manufacturing systems (FMS) provide a unique capability to manufacturing organisations where there is a need for product range diversification by providing line efficiency through production flexibility. This is very valuable in trend driven production set-ups or niche volume production requirements. Although FMS provides flexible and efficient facilities, its optimal set-up is key in achieving production performance. As many variables are interlinked due to the flexibility provided by the FMS, analytical calculations are not always sufficient to predict the FMS' performance. Simulation modelling is capable of capturing the complexity and constraints associated with FMS. This paper demonstrates how discrete event simulation (DES) can address complexity in an FMS to optimise the production line performance. A case study of an automotive FMS is presented. The DES model demonstrates different configuration options depending on prioritising objectives: utilisation and throughput. Additionally, this paper provides insight into understanding the impact of system set-up constraints on the FMS performance and demonstrates the exploration into the optimal production set-up.

***Keywords*—**Automotive, capacity performance, discrete event simulation, flexible manufacturing system.

## I. INTRODUCTION

MANUFACTURING becomes more complex than ever before due to increasing trends in product range diversification, requirements for smaller production lot sizes, and increase of shorter lead times. Automation and technological advances make manufacturing support manufacturing in achieving more capabilities in delivery and better resource utilisation.

Flexible manufacturing systems (FMS) is a computer controlled set-up that provides a dynamic and responsive production system capable to handle range of different products in production at the same time.

As customisation and product diversification is becoming standard, the automotive industry is looking for the strategies to become more adaptable in responding to customer's needs. Exploration of flexible manufacturing system set-up is one of the explored avenues.

FMS characteristics are: flexibility of production and efficient use of resources. However, FMS performance optimisation can prove difficult as, in such system, level of complexity may be very high. Analytical tools may not be able to cope with the level of complexity that need to be address to optimize the FMS set-up.

Discrete event simulation (DES) is a simulation approach that allows measurement of the interactions of the system elements with one another over time. It is an object-oriented simulation method, defined as an imitation of the operation of the real-world processes or system over time [1]. DES is considered to be successful in addressing real world problems in manufacturing sector [2]. Jahangirin et al. [3] also point out that DES is appropriate for tactical and operational level decision-making.

This paper demonstrates how DES can address complexity in an FMS and aid in the optimization of the production line performance within the automotive industry. The structure of this paper is essentially in four parts, firstly the related research literature is covered, following this, the methods for FMS simulation development and validation are discussed, next a case study of an automotive FMS is described and finally, discussion is presented and conclusions are drawn.

## II. RELATED RESEARCH

Benjafaar and Sheikhzadeh [4] highlight the need for more flexible, reconfigurable and modular factories to address the dynamic changes of the market demands, supply and legislation. Flexible Manufacturing System (FMS) is a system controlled by computer numerical control that brings together material handling system, machines and industrial robots [5] creating a highly-automated production facility [6]. Caprihan et al. [7] define FMS as a state of the art system that is able to process multiple part types through the synergy of flexibility, integration and automation. Such systems can be adaptable to change with minimal time, cost and effort in comparison to the traditional production set-ups (Upton, 1994 in [6]).

The flexibility of FMS can yield significant benefits to industry. However, achieving an optimal flexibility level can mean a variety of different things. Joseph and Sridharan [8] define flexibility as the ability of a system to respond

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effectively to changes. Flexibility itself has been characterised at many levels. In manufacturing, it is classified as machine flexibility, routing flexibility, process flexibility, operation flexibility, product flexibility, volume flexibility and expansion flexibility [9]. Basnet [10] recognises that in the FMS configuration, there can be multiple factors which set requirements for a high level of complexity. Some of the FMS operating elements that scope flexibility are: pallet availability, part routing alternatives, availability of material handling devices, availability of tools, machine capacity, and job arrivals [10]. Joseph and Sridharan [8] divide those factors into: components, capabilities, interconnections, model of operation and control.

Although the idea of FMS has been studied for decades, utilisation of its full potential can be explored in significantly greater detail through the use of simulation. Simulation modelling is more intrinsically capable of capturing complexity and constraints associated with FMS. Chan and Chan [11] reported that simulation is the most widely used tool for modelling FMS. Also, a review of simulation techniques [3] demonstrates that DES is the most widely used technique in business and manufacturing accounting for 40% of the total number of research documents reviewed.

Simulation research has considered different types of flexibility depending on the type of production and production system constraints. Vast research in scheduling for FMS has been highlighted. Simulation has been used to test real-time dispatching rules selection in FMS [10]. Scheduling problems in FMS have been recognized to be at both the selection of planning horizon and the selection of dispatching rules across the production system.

Routing flexibility has been identified by [8], [12] as a main contributor to flexibility of FMS and is described as availability of machines for part processing [13]. Ali and Wadhwa [14] use simulation to compare how different levels of routing flexibility affect the performance of manufacturing systems. It was concluded that the optimal level of flexibility is to provide one alternative machine to improve system performance. Baykasoglu and Göçken [4] looked at how performance of a job shop production set-up is affected by different degrees of flexibility. He concludes that the degree of flexibility will have different effect on various performance indicators. It was discovered to have a strong relationship with WIP levels, and supports the reduction of mean absolute performance errors in workload delivery. Djassemi [13] found out that providing flexibility in operations by a skilled workforce in cellular manufacturing system improves overall system performance. Further, [12] investigates the effect of sequencing flexibility levels, routing flexibility and part sequence rules on FMS performance.

Renna [16] proposed applying simulation for capacity reconfiguration problems in the reconfigurable manufacturing system. Sharma et al. [17] use simulation to test the effect of period delays on FMS with different routing flexibility levels. Suresh Kumar et al. [15] investigate the impact of scheduling rules and tool request decisions in FMS environment when tool sharing is applied. Tool sharing has been found to minimise the total number of tools in the system while maximising the tool utilisation but insignificant effect on performance has been reported. Use of different scheduling rules at launch of the production has been found to have significant impact on performance.

Although there are many cases of measuring routing flexibility and its effect on performance, there has been limited insight into systems that assume total flexibility in FMS. The usual strategy is to define the system constraints and set-up flexibility levels to test performance. In most cases, the higher the number of pallets, the better the results, simply because increasing the number of parts in the system can absorb the idle time of the machines [14]. In this paper, the investigation into optimal production set-up in total flexibility on machines is explored.

## III. METHODS

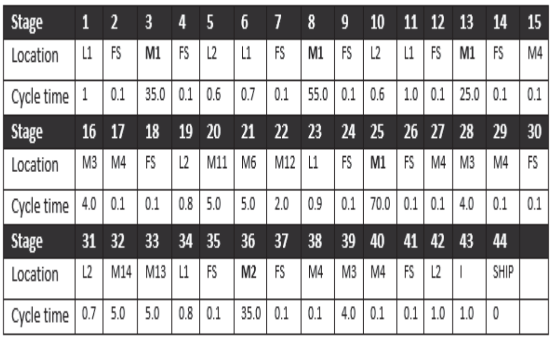
This section introduces the methodology for development of simulation to measure the system performance under a variety of conditions. The research stages were divided into model development stage, experimentation, and validation of results. This section covers the methods applied in the research stages.

Although there is no standard methodology for simulation model development, there are many guidelines reported. In [18], framework has been applied to develop a conceptual model for this simulation case. Data collection of the industrial site's operational and layout data supported the simulation scope and boundary development. Conceptual model framework has been developed to capture the experimental factors and desired responses. DES model has been built in WITNESS simulation software. A design of experiments approach has been used for the experimentation.

## IV. CASE STUDY

The automotive FMS case study is considered in this paper. In this case the FMS is a system supervised by the PLC where two types of CNC machining stations process two part variants. The parts are mounted on dedicated pallets and transported within the FMS by a stacker crane. The system has 68 internal storage spaces. The parts go through 44 steps in production. The example of part profile used in the simulation is displayed in Fig. 1. Stage and location represent the sequence and cycle times represent the time spent in locations. Out of these steps five operations happen in CNC machines (highlighted bold in the Fig. 1). The remaining operations are either automatic operations in FMS or assembly operations that happen in dedicated assembly stations outside the FMS.

The model assumes full labour availability and no transportation time outside the FMS as this has been identified as insignificant for the FMS performance. A detailed model boundary is outlined in Fig. 2 and the model layout is represented in Fig. 3.



| Stage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | L1 | FS | **M1** | FS | L2 | L1 | FS | **M1** | FS | L2 | L1 | FS | **M1** | FS | M4 |
| Cycle time | 1 | 0.1 | 35.0 | 0.1 | 0.6 | 0.7 | 0.1 | 55.0 | 0.1 | 0.6 | 1.0 | 0.1 | 25.0 | 0.1 | 0.1 |
| **Stage** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** |
| Location | M3 | M4 | FS | L2 | M11 | M6 | M12 | L1 | FS | **M1** | FS | M4 | M3 | M4 | FS |
| Cycle time | 4.0 | 0.1 | 0.1 | 0.8 | 5.0 | 5.0 | 2.0 | 0.9 | 0.1 | 70.0 | 0.1 | 0.1 | 4.0 | 0.1 | 0.1 |
| **Stage** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** | **40** | **41** | **42** | **43** | **44** | |
| Location | L2 | M14 | M13 | L1 | FS | **M2** | FS | M4 | M3 | M4 | FS | L2 | I | SHIP | |
| Cycle time | 0.7 | 5.0 | 5.0 | 0.8 | 0.1 | 35.0 | 0.1 | 0.1 | 4.0 | 0.1 | 0.1 | 1.0 | 1.0 | 0 | |

Fig. 1 Part A profile (M1, M2 – CNC machining centers, M3- Robot, M4- Wash Cell)

| Included in the model | Excluded from the model |
|---|---|
| FMS and surrounding manual operations | Labour |
| Total flexibility of FMS operation | Breakdowns |
| Two parts are machined on one pallet | Transportation of parts |
| Shift time– 24/5 | Set-up times |
| 4 type 1 machines (M1) | |
| 1 type 2 machines (M2) | |
| Manual operations dedicated to stations (no flexibility) | |
| Raw material is always available | |

Fig. 2 Boundary of FMS facility defined in conceptual model

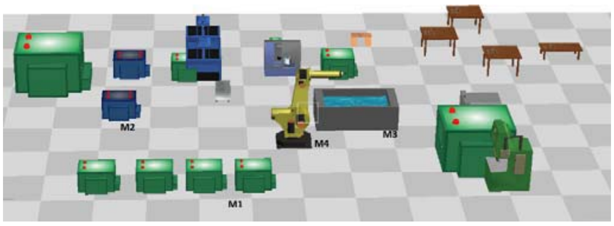


Fig. 3 Simulation model layout of the facility

## V. EXPERIMENTATION

This section describes the set-up of the simulation experiment. The summary of experimental parameters and responses is contained in Fig. 4. The three experimental parameters were selected to test how change or limiting the system capacity in different scenarios can affect the FMS performance. The sequence parameter (S1, S2) scenario refers to the change in the scheduling area. The sequence S2 has an additional three processes and the cycle time for manual operations is 75 minutes longer than S1. The aim is to investigate whether a change in part sequence will influence the system performance. The number of pallets parameter (N2, N3, N4) refers to constraining the production system while maintaining the machine capacity. The range corresponds to the range of 2 to 4 pallets. The number of machines (M3, M4) parameter refers to limiting available capacity. M4 refers to four available machines and M3 to three machines available. The summary of the experiment is located in Fig. 5.

As the scenarios focus on FMS performance, the responses selected to measure how disruption affects the throughput and machines utilisation.

Total available time – Idle time = Machine utilisation rate (1)

Average throughput is measured by the total number of parts divided by number of weeks:

Parts produced/ Number of weeks = Average throughput (2)

| Experimental Factors | Responses |
|---|---|
| Sequence of parts (S1, S2) | Machine Utilisation |
| Number of pallets (N2,N,N4) | Throughput |
| Machine breakdown (M4,M3) | |

Fig. 4 Summary of the model experimental factors and responses

| Scenario | Parameters | | |
|---|---|---|---|
| No. | Sequence (S) | Number of pallets (N) | Number of machines (M) |
| **Base Case** | 1 | 3 | 4 |
| **1** | 2 | 3 | 4 |
| **2** | 1 | 2 | 4 |
| **3** | 2 | 2 | 4 |
| **4** | 1 | 4 | 4 |
| **5** | 2 | 4 | 4 |
| **6** | 1 | 3 | 3 |
| **7** | 2 | 3 | 3 |
| **8** | 1 | 2 | 3 |
| **9** | 2 | 2 | 3 |
| **10** | 1 | 4 | 3 |
| **11** | 2 | 4 | 3 |

Fig. 5 The design of experiments set-up

As the model has no variability at this stage, it is considered as deterministic. This also meant that only one run of each scenario has been run. The experiment set-up is based on an orthogonal array per the DoE approach. A total of 12 experiments has been performed. The warm-up period has been established from time-series inspection of throughput [18]. It has been identified that after week 10 the throughput is stable and reaches the steady-state. The run time of the model is 52 weeks which was sufficient to provide consistent data. The validation of results has been carried out by using the capacity loading analysis and comparisons of variance in responses. As it was based on the company confidential data, it is not included in this paper.

## VI. RESULTS

This section covers the results of the experiment. The three parameters are discussed separately (the results are demonstrated in Figs. 6-8 and further the overall view on combined parameters performance is overviewed.

Sequence related parameters (S) indicate that extension of the manual operation processes has influenced the performance of the FMS. S1 scenarios have performed better in terms of average throughput and both types of machine utilisation. The reason for S2 scenarios not performing as well is that the manual processes set-up has created bottlenecks in the system, which caused machine starvation.

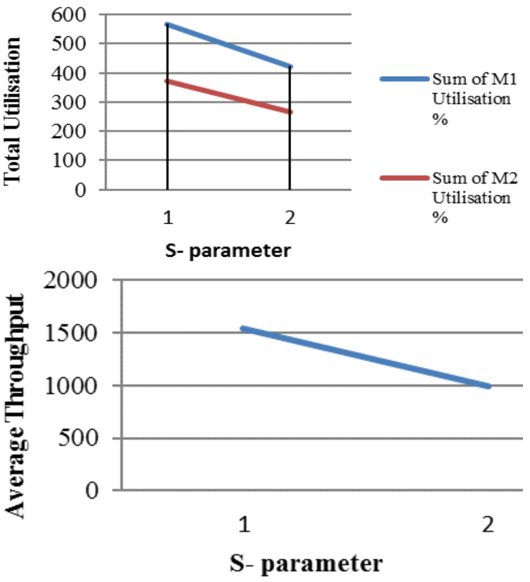


Fig. 6 S-parameter results

The number of parts parameters (N) implies that the optimal number of pallets for the system is three regardless of the machine capacity or sequence. Two pallets are not sufficient to utilise the full loading capacity of the machines, whereas four pallets create more WIP in the FMS. This contributes to bottlenecks in production.

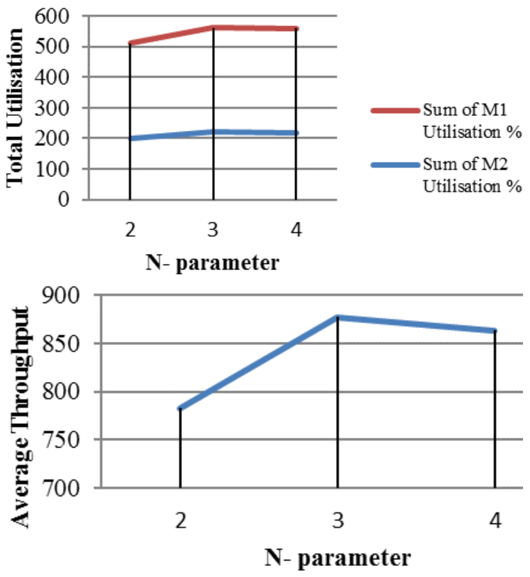


Fig. 7 N-parameter results

The results show that limiting the number of machines limits the possible throughput, which is an expected outcome. However, for M2 machine utilisation, the increase of M1 machines meant the increase of the utilisation due to higher demand of parts being processed. The average total utilisation of M1 in the scenario where the number of machines was increased, actually caused a reduction in loading and so the machines are less used than when three machines are used.

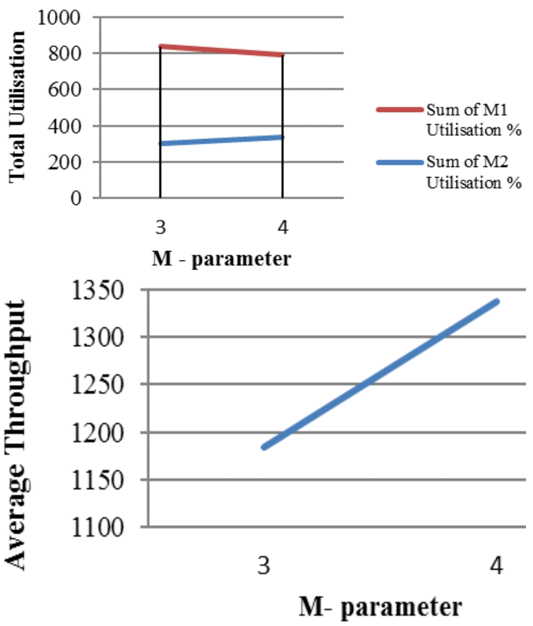


Fig. 8 M-parameters results

When combined, the results matrix suggests that the best machine utilisation for the flexible manufacturing set-up in the experiment is S1, N2, M4 both in maximising machines utilisation and throughput. The graphs 6 and 7 provide summary of the results.

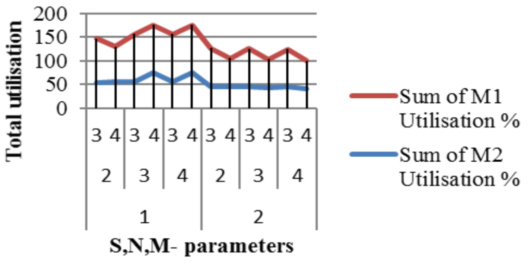


Fig. 9 Machine utilisation scenarios fo S, N, M parameters

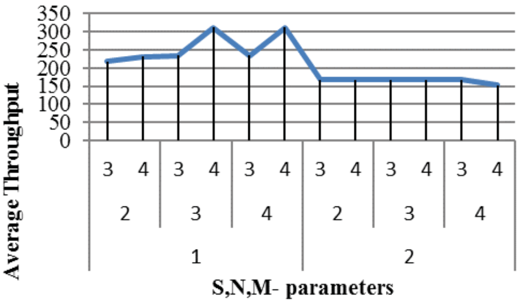


Fig. 10 Average throughput for S, N, M parameters

## VIII. CONCLUSIONS

The aim of this paper was to demonstrate how DES software can support flexible set-up in a flexible manufacturing system. The WITNESS simulation software has been used to develop a model of an actual automotive production line. Parameters of sequences change, number of pallets and number of machines have been tested to measure the impact on FMS performance. The optimal parameters have been selected based on simulation experiments. Additionally, some general conclusions can be drawn about the FMS behavior to support flexibility. The sequence of operation around the FMS has an impact on the FMS' performance as it influences the feed rate into the system. It is important to optimise the number of pallets in the system as its shortage can lead to FMS starvation and its over provision creates bottlenecks in the system affecting throughput.

This research contributes to widening an understanding in a fully flexible FMS as well as supporting decision making in the FMS set-up. Further research should focus on mix-model FMS as well as development of more sophisticated decision making tools for FMS set-up and optimisation through simulation.

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