Modeling and Performance Analysis of a Flexible Manufacturing Cell with Machine Failures

Abdulmajeed Dabwan^{1,a}, Husam Kaid^{1,b}, Abdulrahman M. Al-Ahmari^{1,c}, and Tariq Aziz^{1,d},

¹College of Engineering, Industrial Engineering Department, King Saud University, Riyadh 11421, Saudi Arabia

<u>abmj999@yahoo.com, byemenhussam@yahoo.com, caalahmari@ksu.edu.sa</u>, <u>dtariq_aziz_37@yahoo.com</u>,

Abstract

A flexible manufacturing cell (FMC) is studied in this paper under operation of machine failures and repairs in a situation of stochastic model. Three machines served by a robot for loading and unloading purposes, and a pallet handling system is used in FMC. The model is developed using ARENA software to estimate system performance measures. The simulation model validated with available exact solutions for the selected cell operations. The model utilized to analyze the FMC performance such as production rate, time in system for pallet and utilization of the system components under equipment failures and repairs. The simulation results show that FMC performance measures are sensitive to robot speeds, machining rates, pallet rates and pallet capacity. Finally, conclusions are presented and future works are discussed

Keywords

Stochastic modelling; failure analysis; Arena modelling; Manufacturing cells; FMC productivity.

1. Introduction

A flexible manufacturing cell (FMC) consists of more than one machine served by a robot for loading and unloading of parts, and an automated material handling system. FMS have more revolutionary than transfer line, growing customer demand for quick delivery. In general, the flexibility of FMCs can lead to benefits such as adapted to these changes, increased productivity, reduced inventory, reduced production cost and improved quality.

(Sabuncuoglu and Hommertzheim 1989) and (Cogun and Savsar 1996) considered stochastic and simulation models for evaluating the performance of FMC with respect to system configuration and component speeds, such as machining rate robot and pallet speeds. The study of (Simeu-Abazi et al. 1997) uses decomposition and iterative analysis of Markov chains to obtain numerical solutions for reliability and dependability of manufacturing systems. (Adamyan and He 2002) presented a methodology to identify the sequences of failures and probability of their occurrences in an automated manufacturing system. They used Petri nets and reachability trees to develop a model for sequential failure analysis in manufacturing systems. The study of (Abdulmalek et al. 2004) presents a simulation model and analysis for tool change policies in an FMC with two machines and a robot based on ARENA simulation software by (Kelton et al. 2002) which allows flexibility in modeling manufacturing systems. The work of (Al-Titinchi and Al-Aubidy 2004) addresses an interactive hierarchical model based on colored Petri net (CPN) for general flexible Manufacturing system (FMS) Scheduler. (Srinoi et al. 2002) introduced scheduling model based on a fuzzy logic for the scheduling of a flexible manufacturing cell (FMC) with three different parts.

(Savsar 2004) introduced simulation models based on the SIMAN language for the flexible manufacturing cell with three different parts, which is operated under a variety of time between failure distributions and different operational conditions. (Kost and Zdanowicz 2005) presented the modeling process of a cell flexible system with the application of Petri network theory, involving the identification, modeling and simulation of the operation of flexible robotized manufacturing systems. (Savsar and Aldaihani 2008) studied performance of FMC that consists of two machines, served by a robot under different parametric conditions and equipment failures and repairs. They used Markov processes and determined closed-form solutions for the probabilities of system states that are used to compute system performance measures. (Maheshwari et al. 2010) introduced a mathematical model for unreliable flexible manufacturing cell (FMC), which is operated under stochastic environment and produces a variety of parts, for two machines that served by one robot and a pallet handling system. These performance measures are machine utilization, robot utilization, pallet handling system utilization and production rate.

(Tüysüz and Kahraman 2010) presented an approach for modeling and analysis of time critical, dynamic, and complex systems for FMC using stochastic Petri nets together with fuzzy sets. (Joseph and Sridharan 2011) developed Regression-based meta-models using the simulation results and found meta-models to provide a good prediction of the performance of the FMS within the domain of their definition.to investigate the effects of dynamic due-date assignment models (DDDAMs), routing flexibility levels (RFLs), sequencing flexibility levels (SFLs) and part sequencing rules. (Taha and Rostam 2012) presented a decision support system (DSS) to select the best alternative machine using a hybrid approach of fuzzy analytic hierarchy process and preference ranking organization method for enrichment evaluation (PROMETHEE). The proposed model has the capability of dealing with a wide range of desired criteria and to select any type of machine tool required for building an FMC.

(El-Tamimi et al. 2012) applied the concept and implementation of the Petri nets for measuring and analysis of performance measures of FMS, modeled in Visual Slam software and used mathematical model. They found that the simulation techniques are easy to analyze the complex flexible manufacturing system. Özkan Başak and Y. Esra Albayrak covers the concept of design and the implementation of a Petri net (PN) model for the control of a flexible manufacturing system (FMS) (Başak and Albayrak 2014). Afterward, the simulation with respect to existing deadlock prevention policies and different Petri net models is implemented on flexible manufacturing system by (Abouel Nasr et al. 2015, El-Tamimi et al. 2015)., which explores whether a liveness-enforcing Petri net supervisor can provide better time performance. (Jain and Raj 2016) analyzed the performance variables of flexible manufacturing system by different approaches, which are interpretive structural modelling (ISM); Structural equation modelling (SEM); Graph Theory and Matrix Approach (GTMA) and a cross-sectional survey.

Unfortunately, most of the above work does not take an unreliable FMC system with three unreliable machines served by a robot and pallet system using exact solutions methods, it is due to the complexity of the modeling of a flexible manufacturing cell with machine failures served by a robot. From the above review, no recent research found related to this type of problem so far. In this paper, simulation approach is used for performance analysis of FMC and an extension is made for the work of (Savsar and Aldaihani 2008). The research extension regarding FMC; consists of three machines, served by one robot. ARENA software is used to model and analyze the system. First, we have modelled the FMC in (Savsar and Aldaihani 2008), then the developed model is validated with their exact solutions. Second, the developed model has extended for three machines. Finally, the model is run to estimate the system performance measures such as production rate, time in system for pallet, and utilization of the system components under different parametric conditions and equipment failures and repairs.

Including this introductory section, the paper is organized as follows. Section 2 provides proposed methodology. The FMC operation is introduced in Section 3. The simulation techniques and model of FMC are presented in Sections 4 and 5, respectively. Section 6 shows verification and validation for the simulation model. Section 7 discuss the experimental analysis. Finally, Section 8 presents the conclusion and future work.

2. Proposed Methodology

This section presents the proposed methodology that used for modeling and performance analysis of a flexible manufacturing cell with machine failures. The proposed methodology steps are stated as follow:

Step1: Build the FMS model using simulation software. Simulation is a powerful tool for the modifications to existing systems, evaluation and analysis of a new system designs, and changes to operating rules and control systems. Simulation involves the methodology to provide the information from the model by observing the flow of the model using a digital computer. The simulation techniques can be used as a tool in the performance analysis of manufacturing systems. Simulation has an advantage over analytical or mathematical models for analyzing complex systems since the basic concept of simulation is easy to comprehend and hence often easier to justify to management or customers than some of the analytical models. There are many commercial of the shelf software that can be used to develop a simulation model. The software package divided into six types; manufacturing oriented software, general-purpose software, business process reengineering, simulation support software, and simulation based scheduling, animators. The manufacturing oriented software consists of ProModel, AutoMod, Taylor II, FACTOR/AIM, Extend+Manufacturing, and ARENA. While general-purpose software includes GPSS/H, SLX, SIMSCRIPT II.5, AweSim, SIMPLE++, and Extend. The business process reengineering includes BP\$im, Process Model, SIMPROCESS, Time Machine, and Extend+BPR. Simulation support software, which is used for input data analysis, includes ExpertFit, and Stat::Fit. Finally, under simulation based scheduling, software package that available are Tempo, AutoSched, and FACTOR. For animators, available software is only Proof Animation. In this paper, a

simulation model is developed using ARENA 12.0, a product of Systems Modeling Corporation. This software is an extendible simulation and animation software package. It provides a complete simulation environment that supports all steps in a simulation study. Arena is graphical modeling or animation system that is based on hierarchical modeling concepts. It allows users to create new modeling objects called modules, which are the building blocks of model creation. It also offers application solution templates that can be used to tailor the software to a specific animation. Besides that, Arena also includes the input analyzer, designed to give users the ability to read raw input data, and output analyzer for simulation data viewing and analysis.

Step2: Verify and validate the simulation model with available exact solutions. In this step, the simulation model validated with (Savsar and Aldaihani 2008) in term of components utilization and production rate, where they used stochastic Markov chain model for two machines and one robot.

Step3: Extend the simulation model to three machines.

Step4: Simulate the model. In this step, the model utilized to analyze the FMC performance such as production rate, time in system for pallet and utilization of the system components under different parametric conditions and equipment failures and repairs. Figure 1 presents the flow chart of the proposed methodology.



Figure 1. Flow chart of the proposed methodology.

3. The FMC Operation

In this section, the FMC system operation is shown in Figure 2. An automated pallet handling system delivers n blanks consisting of different parts into the cell. The robot reaches the pallet, grips the blank, moves to the first machine and loads the blank. While the machine starts operation on the part, the robot reaches the pallet, grips the second part and moves to the second machine and loads it, the robot reaches the pallet, grips the third part and moves to the third machine and loads it. Next, the robot reaches the machine that finishes its operation first, unloads the finished part and loads a new part. The loading/unloading operation continues in this way with preference given to the machine that finishes its operation first. After the machining operations of all parts on the pallet are completed, the pallet with n finished parts moves out and a new pallet with n blanks is delivered into the cell automatically. Machines are assumed to be unreliable and fail during the operations. Time to failure and time to repair are assumed to follow exponential distribution. Due to the introduction of different parts into the FMC, failures of machines and random characteristics of system operation, processing times as well as loading/ unloading times are random, which present a complication

in studying and modeling cell performance. However, because of random operations, the system needs to be modelled by a stochastic process.



Figure 2. A flexible Manufacturing Cell

4. Simulation Model of FMC

The FMC simulation model built on software "System Modeling Corporation's ARENA 12", which offers flexibility in modeling and analyzing the system with stochastic behavior and other realistic characteristics. In ARENA we can change the input parameter to analyze our system on different level of performance to make the "what if analysis". In the Figure 3 the model shows the robot and the machines are represented as resources and the parts as entities. Two create modules are used to model the pallet handling system. The "FIRST PALLET" (Create 1) module is used to model the movement of the first pallet into the system. Once n parts are processed, a signal is sent from Pallet Movement Signal module to the "NEXT PALLET" (Create 2) module to progress the next pallet into the system, which will experience a transfer pallet process of EXPO[1] representing the handling time to move the pallet into the cell with exponentially distributed time with a mean of one minute. Parts that come into the system will either advance to "ROBOT FOR MC1", "ROBOT FOR MC2" or "ROBOT FOR MC3" module. At the "ROBOT FOR MC1, MC2 and MC3" module, robot and machines are seized and the loading or unloading of the part for the each machine takes place with an exponential process time of [EXPO (0.25)]. Next part advances to "DISTRIBUTION OF UNFINISHED AND FINISHED PARTS" module to decide loading/unloading, for loading by next part "DISTRIBUTION OF UNFINISHED PARTS" module to decide loading for the idle machine for unloading to "FINISHED PALLET "module then to "PALLET MOVEMENT SIGNAL" module to give signal to take another batch from "PARTS TO PALLET 2" module. Simulation is run for an 8 hour-shift for 200 days (replications) in each experiment carried out.

5. Verification and Validation the Simulation Model

In order to test and verify the simulation model, the case problem is the first that we started for which exact numerical solutions have been obtained by (Savsar and Aldaihani 2008) using a stochastic model. The case problem is shown in Table 1 and Figure 4 and Figure 5 show Savsar and Aldaihani results and simulation model results for FMC with two machines. We performed the first experiment on the FMC with the same parameters that were used in the analytical results reported in the next section. These parameters have been specified below. We built a model for the same Savsar's case problem, two machines and one robot. Simulation results and exact numerical results for the machine and robot utilizations are shown in Figure 4, while the results for the production equipment utilization increases , with increased pallet transfer rate. In Figure 5, similar trend is observed in the case of production output rate, which increases with respect to increased pallet transfer rate. The simulation results were slightly less than the exact results. Simulation model was verified to give sufficiently accurate results so that it could be used for other cases with no exact solutions.





6. Experimental Analysis

In this section, we present numerical results for the case problem having different parameters. The parametric values for the unreliable FMC system are shown in Table 1. Values given in the table below are the mean values for various parameters in the case examples. It should be noted that the mean is the inverse of the rate in each case. Figure 6 and Figure 7 show the production rate and time in system for pallet as a function of the pallet capacity (n) at different robot loading/unloading rates, Z. As seen from the figure, they increase with respect increased pallet capacity and robot loading/unloading rates. While the rate of increase is high initially, it levels off at higher values of n. Figure 8 and Figure 9 show the production rate and time in system for pallet of the FMC system as a function of the pallet capacity (n) and different machine repair rates ($\mu = 0.05, 0.1, 0.5, 1$). Other parameters are kept constant as before. As the machine repair rates are increased, FMC production rate and time in system for pallet increase, but when m is changed from 0.5 to 1 repair per unit time, the increase is marginal. Figure 10 presents the effects of pallet loading rate (w) and pallet capacity (n) on time in system for pallet and FMC production rate. As w increases up to (w = 7) in this case, they increase. However, the effect on FMC production rate has little by wafter a certain value. Figure 11 illustrates utilizations of FMC components, including the robot and the machines. As shown in Fig. 10, utilizations of machine increase with respect increased pallet capacity n as well as with respect increased robot-loading rates Z. also, Figure 12 shows that robot utilization increases with respect increased machining rates and with respect increased pallet capacity. In both cases, after certain pallet capacity and other parameters, the rate of increase in utilizations levels off. Figure 13 presents the pallet utilization as a function of the pallet capacity (n) at different pallet loading rate (w). As seen from the figure, they decrease with respect increased pallet loading rates and pallet capacity. The results of unreliable FMC system performance obtained from the Arena model. Figure 14 shows machine utilization comparison for unreliable cell. Machine 1 has higher utilizations in either case because priority given to machine 1 during initial loading when a pallet moves into the cell. The utilization rates also increase sharply with respect to pallet transfer rate up to the rate of four pallets per time unit.

Parameters	Description
Operation time per part	1/Vm = 1 time unit, m = 1, 2,3 (for machines 1,2 and 3)
Robot loading time for the first part	1/lm = 0.25 time units, for machines $m = 1, 2, 3$
Robot load/unload time for subsequent parts	1/Zm = 0.5 time units, m = 1, 2,3
Robot unloading time for the last part	1/Um = 0.25 time units, m = 1, 2,3
Mean time to failure for machine m	1/lm = 100 time units
Mean time to repair the machine m	$1/\mu m = 10$ time units
Pallet transfer time	1/w = 110 time units per pallet
Pallet capacity	n = 4 units

Table 1. Parameter values for the unreliable FMC system (Savsar and Aldaihani 2008)

7. Conclusion and Future Work

In today's manufacturing environment, demand for products is changing continuously and production systems must be able to respond to the fast changes in customer preferences and requirements. Manufacturing systems, which have enough flexibility can respond to these changes quickly and offer advantages over non-flexible systems. FMC systems have been developed for machining a variety of products on the same equipment with little or no extra time required for changeover from one product type to another. In this paper, we have presented a simulation model that could guide engineers and managers responsible in designing and operating FMC systems. Several experiments carried out to illustrate possible investigations that could be implemented before designing or during operation of FMC system. The simulation results show that FMC performance measures are sensitive to robot speeds, machining rates, pallet rates and pallet capacity. Pallet capacity or batch size, which can easily be replaced with little cost, has a significant effect on cell production rates and time in system for pallet. In the future work, the simulation model developed in this paper can be further extended to several other types of FMC systems parameters with different characteristics, such as different operation time and robot time distributions. Moreover, it can be extended to simulate more than three machines. Finally, we can develop a layout of more than one FMC for the construction of an integrated system to analyze the performance.



Figure 6. Effects of pallet capacity (n) and robot loading/unloading rate (Z) on FMC production rate





Figure 7. Effects of pallet capacity (n) and robot loading/unloading rate (Z) on FMC Time in system for pallet

Figure 8. Effects of pallet capacity (n) and repair rate (μ) on FMC production rate



Figure 9. Effects of pallet capacity (n) and repair rate (μ) on FMC Time in system for pallet





Figure 10. Effects of pallet capacity (n) and pallet loading rate (w) on FMC production rate

Figure 11. Effects of pallet capacity (n) and robot loading rate (Z) on machine utilizations



Figure 12. Effects of pallet capacity (n) and machine loading rate (v) on robot utilization



Figure 13. Effects of pallet capacity (n) and pallet loading rate on pallet utilization



Figure 14. Machine utilizations of unreliable FMC for different pallet transfer rates

Acknowledgements

References

- Abdulmalek, F., Savsar, M. & Aldaihani, M., Simulation of tool change policies in a flexible manufacturing cell, WSEAS Transactions on Systems, vol. 7, no. 3, pp. 2546-2552, 2004.
- Abouel Nasr, E., El-Tamimi, A. M., Al-Ahmari, A. & Kaid, H., Comparison and evaluation of deadlock prevention methods for different size automated manufacturing systems, Mathematical Problems in Engineering, vol. 2015, 2015.
- Adamyan, A. & He, D., Analysis of sequential failures for assessment of reliability and safety of manufacturing systems, Reliability Engineering & System Safety, vol. 76, no. 3, pp. 227-236, 2002.
- Al-Titinchi, A. A. & Al-Aubidy, K. M., Modeling and analysis of an on-line FMS scheduler using colored petri nets, International Journal of Computing & Information Sciences, vol. 2, no. 2, p. 74, 2004.
- Başak, Ö. & Albayrak, Y. E., Petri net based decision system modeling in real-time scheduling and control of flexible automotive manufacturing systems, Computers & Industrial Engineering, 2014.
- Cogun, C. & Savsar, M., Performance evaluation of a flexible manufacturing cell (FMC) by computer simulation, Modeling Measurement, & Control B, vol. 62, no. 2, pp. 31-44, 1996.
- El-Tamimi, A. M., Abidi, M. H., Mian, S. H. & Aalam, J., Analysis of performance measures of flexible manufacturing system, Journal of King Saud University-Engineering Sciences, vol. 24, no. 2, pp. 115-129, 2012.
- El-Tamimi, A. M., Nasr, E. A., Al-Ahmari, A., Kaid, H. & Li, Z., Evaluation of deadlock control designs in automated manufacturing systems, Industrial Engineering and Operations Management (IEOM), 2015 International Conference on, pp. 1-10, 2015.
- Jain, V. & Raj, T., Modeling and analysis of FMS performance variables by ISM, SEM and GTMA approach, International Journal of Production Economics, vol. 171, pp. 84-96, 2016.
- Joseph, O. & Sridharan, R., Analysis of dynamic due-date assignment models in a flexible manufacturing system, Journal of Manufacturing Systems, vol. 30, no. 1, pp. 28-40, 2011.
- Kelton, W. D., Sadowski, R. P. & Sadowski, D. A. 2002. Simulation with ARENA, McGraw-Hill New York.
- Kost, G. G. & Zdanowicz, R., Modeling of manufacturing systems and robot motions, Journal of Materials Processing Technology, vol. 164, pp. 1369-1378, 2005.
- Maheshwari, S., Sharma, P. & Jain, M., Unreliable flexible manufacturing cell with common cause failure, Int J Eng Sci Technol, vol. 2, no. 9, pp. 4701-4716, 2010.
- Sabuncuoglu, I. & Hommertzheim, D., Expert simulation systems—recent developments and applications in flexible manufacturing systems, Computers & Industrial Engineering, vol. 16, no. 4, pp. 575-585, 1989.
- Savsar, M., Performance analysis of an FMS operating under different failure rates and maintenance policies, International Journal of Flexible Manufacturing Systems, vol. 16, no. 3, pp. 229-249, 2004.
- Savsar, M. & Aldaihani, M., Modeling of machine failures in a flexible manufacturing cell with two machines served by a robot, Reliability Engineering & System Safety, vol. 93, no. 10, pp. 1551-1562, 2008.
- Simeu-Abazi, Z., Daniel, O. & Descotes-Genon, B., Analytical method to evaluate the dependability of manufacturing systems, Reliability Engineering & System Safety, vol. 55, no. 2, pp. 125-130, 1997.
- Srinoi, P., Shayan, E. & Ghotb, F., Scheduling of flexible manufacturing systems using fuzzy logic, International Journal of Production Research, vol. 44, no. 11, pp. 1-21, 2002.
- Taha, Z. & Rostam, S., A hybrid fuzzy AHP-PROMETHEE decision support system for machine tool selection in flexible manufacturing cell, Journal of Intelligent Manufacturing, vol. 23, no. 6, pp. 2137-2149, 2012.
- Tüysüz, F. & Kahraman, C., Modeling a flexible manufacturing cell using stochastic Petri nets with fuzzy parameters, Expert Systems with Applications, vol. 37, no. 5, pp. 3910-3920, 2010.

Biographies

Abdulmajeed Dabwan is a Researcher and PhD Student in Industrial Engineering Department, College of Engineering, King Saud University, Saudi Arabia. His area of expertise is manufacturing systems. He received the BSc in Industrial Engineering from University of Taiz, Yemen in 2010. He received the Master degree in Industrial Engineering from King Saudi Arabia, in 2016.

Husam Kaid is a Researcher and PhD Student in Industrial Engineering Department, College of Engineering, King Saud University, Saudi Arabia. His area of expertise is manufacturing systems. He received the BSc in Industrial

Engineering from University of Taiz, Yemen in 2010.. He received the Master degree in Industrial Engineering from King Saud, Saudi Arabia, in 2015.

Abdulrahman Al-Ahmari is the Dean of Advanced Manufacturing Institute, Executive director of CEREM (Center of Excellence for Research in Engineering Materials), Supervisor of Princess Fatimah Alnijris's Research Chair for Advanced Manufacturing Technology, and Supervisor of CMTT (Center of Manufacturing Technology Transfer). He received his Ph.D. (Manufacturing Systems Engineering) in 1998 from University of Sheffield- UK. His research interests are in analysis and design of manufacturing systems; Computer Integrated Manufacturing (CIM); optimization of manufacturing operations; applications of simulation optimization; FMS and cellular manufacturing systems. Husam Kaid is a Researcher and Master Student in Industrial

Tariq Aziz is a Researcher and Master Student in Industrial Engineering Department, College of Engineering, King Saud University, Saudi Arabia. His area of expertise is manufacturing systems. He received the BSc in Industrial Engineering from University of Taiz, Yemen in 2010.. He received the Master degree in Industrial Engineering from King Saud, Saudi Arabia, in 2015.