A NEW DESIGN OF FMS WITH MULTIPLE OBJECTIVES USING GOAL PROGRAMMING

Berna Dengiz[a], Yusuf Tansel İç[b], Selin Coşkun[c], Nil Dağsalı[d], Damla Aksoy[e], Gözde Çizmeci[f]

[a] Department of Industrial Engineering, Faculty of Engineering, Baskent University, 06810, Baglica, Etimesgut, Ankara, Turkey.

[a]bdengiz@baskent.edu.tr, [b]ytansel@baskent.edu.tr

ABSTRACT

The operation of the Flexible Manufacturing System (FMS) includes complex and conflicted issues that result in the system performance. In the operational improvement studies in a FMS usually make in determination of a single-response measure. This paper presents an application for multi-response simulation optimization of a FMS via DOE (design of experiment), regression meta-model and goal programming (GP) together. A real FMS with four work stations is modeled by ARENA simulation software to optimize system performance measures considering five design and control parameters.

Keywords: Flexible Manufacturing System, Design of Experiment, Regression Meta-Model, Goal Programming.

1. INTRODUCTION

A Flexible Manufacturing System (FMS) is an automated group technology machine cell, consisting of a group of processing stations (usually CNC machine tools), interconnected by an automated material handling and storage system which is controlled by an integrated computer system (Groover, 2008). The operation and design of the FMS includes complex and conflicted factors that result in the productivity of the system (Park et al., 2001; Groover, 2008).

The operational and design factors are considered separately due to the complexity of system. However, most analytical and simulation modeling study finished so far has focused on mainly one or two decision problems among system loading, machine loading, part selection, machine grouping, tool allocation, and scheduling parts (Park et al., 2001). The following criteria have been most likely used in the FMS modeling studies: system utilization, job tardiness, due dates, production rate, work-in-process inventory, set-up time and tool changes, balance of machine usage, flow time, (Park et al., 2001; Savsar, 2005; Um et al., 2009). Most past study on the operation or design of the FMS considered only a single performance response as their objective function to optimize (Guo et al., 2003; Chan et al., 2007; Ozmutlu et al., 2004; Savsar, 2005, Kumar et al., 2011; Mahdavi et al., 2010). During last decade, however, a few researchers have used multi-objective decision-making approaches to solving FMS design problems with more than one response considering only hypothetical systems (Park et al., 2001; Kumar and Sridharan, 2009; Um et al., 2009; Joseph and Sridharan, 2011; Javadian et al., 2011). In this study, we focus on to improve of a real FMS achieve a global optimization in the improvement of a FMS performance with four work stations in a company in Ankara/Turkey considering design and operation related decision variables.

In the literature, Park et al. (2001) and Um et al. (2009) used hypothetical systems with hypothetical assumptions in their studies. Park et al. (2001) proposed a method for simultaneously optimization operational and design factors of a FMS with the multiple objectives via DOE, regression analysis and compromise programming. Eight operational and design factors were simultaneously optimized by compromising four performance measures that are obtained using regression analysis (Park et al., 2001). Also, Um et al. (2009) presented the combined study for the analysis of a FMS with an Automated Guided Vehicle system (AGVs). In their study to maximize the operating performance of FMS with AGVs, some factors were investigated, including the velocity, number, and dispatching rule of AGV, scheduling, work-piece types, and buffer sizes. They also considered the three performance measure namely minimizing the vehicle utilization, minimizing the congestion, and maximizing the throughput. Um et al (2009) used simulation-based optimization methods that are Multi-Objective Non-Linear Programming (MONLP) and Evolution Strategy (ES). MONLP obtained the design factors of the FMS through factorial design and regression analyses. However ES used to verify each factor for simulation-based optimization (Um et al., 2009).

Hypothetical models are useful to investigate system behaviors. On the other hand real systems generally need evaluating their own operating characteristics. In other words, hypothetical models seem to be inadequate to estimate a FMS performance in desired detail.

The main objective of this study is to present an operational improvement approach for existing real FMS design considering design and operational variables using simulation optimization integrated DOE, regression meta-model and GP

2. A DESIGN AND PERFORMANCE EVALUATION MODEL FOR AN FMS WITH MULTIPLE OBJECTIVES

Simulation models have been widely used to mitigate the restrictions of the analytical models for designing and analyzing the FMS (Park et al., 2001, Um et al., 2009).

The FMS performance is determined by running the simulation model via a DOE. Firstly a 2^k full-factorial design is applied in this study to DOE scenario for the multiple-objective problem. Secondly, performance responses of the FMS are determined using a simulation tool and DOE method, statistical analysis are applied by ANOVA to obtain main and interaction effects of the design factors. Thirdly, the FMS performance responses are then transferred in a mathematical form with the identified significant main and interaction effects through a regression. Finally, a goal programming (GP) model is used by setting the response functions as objective functions and including FMS constraints. After that, the most suitable levels of design parameters in the GP model are determined. The GP is a relatively popular methodology in the literature and it has been used by many authors in different areas (Badri, 1999; 2001; Yurdakul, 2004; Lee et al., 2010; Liang, 2009; Ic et al., 2012). The proposed FMS design and optimization process can be described as in Figure 1.

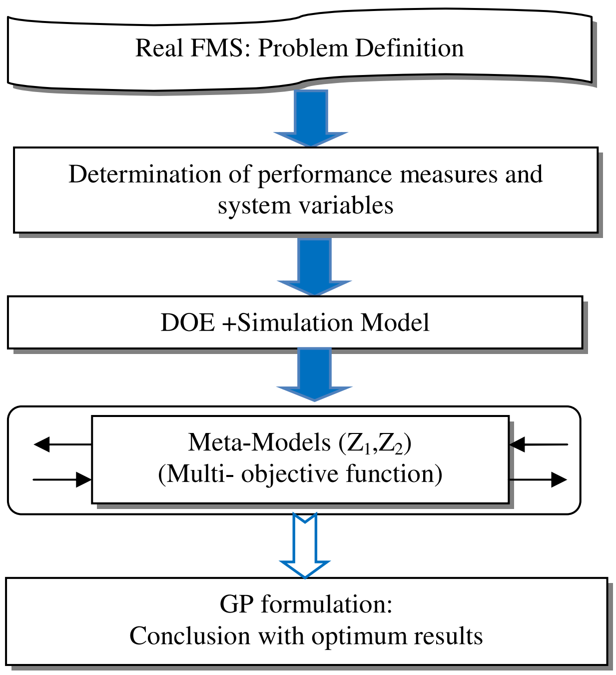

Figure 1. FMS design and optimization process

3. REAL CASE APPLICATION

This section presents an application for multi-response simulation optimization of a FMS via DOE, regression meta-model and GP. ‘X Manufacturing (Turkey) Co.’ is produces an extensive range of over 100 product varieties of automotive units, cams, cranks, shafts, motor blocks, pistons and transmission elements for world leading automotive manufacturers.

The FMS considered in this research, which is producing brake cylinder casing, gear box and flywheel housing for automobile manufacturers. FMS studied in this research is a dedicated type FMS which allows a dedicated process routing of parts to machining centers. There are four CNC machining centers (MAZAK FH6800) with one separate local buffer storages (20 pallet capacity) for work pieces. Work pieces in FMS are moved via transporting robot on bidirectional paths, and processed at one of the appropriate CNC machining centers. FMS layout is given in Figure 2. If there is no work pieces for the load-unload station the transporting robot is completed their process, then it stays idle at the current CNC. One of the attribute of the dedicated FMS system is its no-routing flexibility, which no allows work piece to be processed on more than one alternative CNC per process (Park et al., 2001; Groover, 2008). The alternative CNC machining centers for a specific process of a part are pre-determined via prior analysis to balance the workloads among CNC machining centers. Hence, when a work piece enters the FMS, the dedicated CNC machining centers for each process are already known based on the work piece type of the process (Park et al., 2001). The buffers feeding machining centers have same sizes.

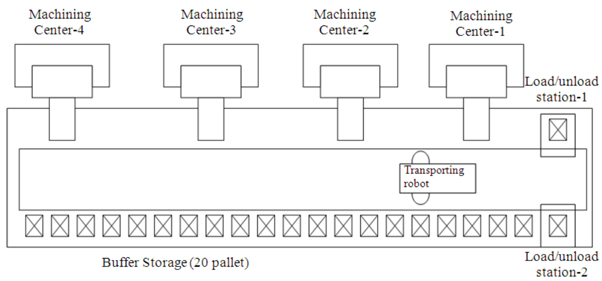

Figure 2. FMS layout

The company has applied employee training activities, line-balancing techniques for improvements of the FMS. However, the FMS still faced obstacles due to delay of product delivery to the customer for different causes. The main cause behind this delay is the long Cycle Time (CT).

Five design and operation variables determined based on system behaviors and expert opinions: number of operator in load-unload station, velocity of material handling robot, number of pallets, number of cutting tool, pallet routing scheduling rules (Table 1). Two performance measures such as maximizing throughput (units/h) and minimizing cycle-time (h) are considered.

Table 1. FMS design and operation factor's levels

Factors		Levels	
Symbol	Content	Low (-1)	High (+1)
x_1	number of operator in load-unload station	2	4
x_2	velocity of material handling robot (m/min)	1	2
x_3	number of cutting tool	120	200
x_4	pallet routing scheduling rules	Random	Dedicated to first non-busy pallet
x_5	number of pallet	20	40

3.1. Design of Experiments

Five factors are determined in the FMS design problem to optimize two performance measures of cycle time (h) and throughput (units/h). They include five design parameters so the DOE for the FMS problem involves five factors and two levels in each factor as given in Table 1.

3.2. System Modeling of the FMS via Simulation

The FMS presented in Figure 2 is modeled using the ARENA® Simulation Software by Rockwell Automation. Work pieces enter the system based upon exponential distribution. The number of process required for each job type is in the range of three to five operations, and then when a work piece comes into the FMS, the processes are assigned depending upon the job type.

The processing times in FMS vary from seconds to minutes depending upon the nature of required operations. The processing times of operations are pre-determined and fixed for each part type. Work piece handling time is computed by dividing the rectangular distance by transporter speed. Each simulation experiment was carried out for the operation of the FMS over a period of 2 month or 1152 h (48working days and 24h per day).

For validation and verification of the simulation model, all the necessary data are collected via DOE from the simulation experiments. To test its validity, the TRACE command, one of the ARENA output commands, is used to verify the model. This permits the user to watch step by step, generated and running the model on the time basis to see how well it represents the FMS under specific assumptions considering real FMS (Ayag, 2007).

3.3. Design of Experiment

Using the full-factorial DOE, 320 ($2^5 \times 10$ replication) simulation runs were conducted on MINITAB®. The ANOVA is applied to determine the significance of main and interaction effects of the five design factors (Park et al., 2001). It should be noted that since the significance level is set at 5%, effects with a $p \leq 0.05$ significantly contribute to the corresponding FMS performance measure. Functions of two FMS performance measures (cycle time and throughput) are obtained using regression analysis with identified significant main and interaction effects.

3.4. Validation of the Meta-Model

Simulation validation illustrates how well the model represents the real world system. Validation of the meta-model is obtained with respect to the underlying simulation (Dengiz et al., 2006). Therefore, the validation of a meta-model is obtained by making many comparisons between the outputs of the meta-model and the simulation model (Dengiz et al., 2006; Dengiz and Akbay, 2000; Kleijnen and Sargent, 2000; Dengiz and Belgin, 2007). To decide whether to accept a meta-model the Absolute Relative Error-ARE (see Kleijnen and Sargent, 2000 and Dengiz et al., 2006) is used. To assure the validation of the meta-model built in this study, the-meta model was tested against simulation runs at fifteen randomly selected design points within their permissible ranges (Dengiz et al., 2006). Then, the results obtained from this simulation runs were compared with the values obtained from meta-model using the same combination of parameters (Dengiz et al., 2006).

3.5 Multi-Objective Simulation Optimization

Regression models of two FMS performance measures (throughput and cycle time) are obtained using MINITAB. The FMS design problem can be formulated via a multi-objective programming technique as follows:

$$\text{MIN } Z = P_1 * d_1^- + P_2 * d_2^+ \quad (1)$$

Subject to

$$651.42 + 18.64*x_1 + 7.38*x_2 - 0.17*x_3 + 20.08*x_4 - 1.00*x_5 + 42.26*x_1*x_2 - 17.70*x_1*x_4 + 42.96*x_2*x_4 + 1.43*x_4*x_5 - 43.78*x_1*x_2*x_4 + d_1^- - d_1^+ = 800; \quad (2)$$

$$1.09787 - 0.03075*x_1 + 0.09345*x_2 + 0.00963*x_3 + 0.01978*x_4 - 0.00140*x_5 - 0.07315*x_1*x_2 + 0.05018*x_1*x_4 + 0.01586*x_2*x_3 + 0.03012*x_2*x_4 - 0.01318*x_2*x_5 + 0.01220*x_3*x_4 + 0.08693*x_1*x_2*x_4 + 0.01830*x_1*x_4*x_5 - 0.01417*x_2*x_3*x_5 - 0.01690*x_2*x_4*x_5 + 0.01355*x_1*x_2*x_3*x_4 + d_2^- - d_2^+ = 1; \quad (3)$$

$$2 \leq x_1 \leq 4 \quad (4)$$
$$1 \leq x_2 \leq 2 \quad (5)$$
$$120 \leq x_3 \leq 200 \quad (6)$$
$$x_4 \in \{0,1\} \quad (7)$$
$$20 \leq x_5 \leq 40 \quad (8)$$
$$d_i^-,\ d_i^+ \geq 0, \quad i=1,2 \quad (9)$$
$$x_i \in Z, \quad i=1,2,3,4,5 \quad (10)$$
$$P1 >> P2 \text{ (pre-emptive priority levels)} \quad (11)$$

The Goal Programming (GP) model has been solved using MS Excel® Solver tool. The model is admitted as a successful result, and the goal programming process terminates with the solution given below:

Number of operator	: 3
Velocity of transporter (m/min)	: 1.073792
Number of cutting tool	: 120
Pallet selection procedure	: Random
Number of pallet	: 31

4. CONCLUSIONS

This is the first kind of a model to solve a real case multi-response FMS performance improvement problem by using integrated DOE, regression analysis, and goal programming. It permits FMS planners to agreement interactively among conflicting goals while obtaining system performance parameters. The multi response approach with an integration of statistical tools and optimization theory can be used to other multi-response or multi-objective optimization problems that are too sophisticated to determine an objective function in a mathematical form. For future study, the proposed approach can be extended to incorporate the cost and economical issues and machine replacement analysis considering dynamic manufacturing environments such as machine reliability, technological level of CNC machines, mix of part types, utilization of facilities and logistical consequences of design changes. As a result of this study proposed approach can be able to improve FMS designs for determining the operation working conditions of the system.

REFERENCES

Ayag, Z., 2007. A hybrid approach to machine-tool selection through AHP and simulation. International Journal of Production Research,45(9), 2029-2050.

Badri, MA., 1999. Combining the analytic hierarchy process and goal programming for global facility location-allocation problem. *International Journal of Production Economics*, 62, 237-248.

Badri, MA., 2001. A combined AHP-GP model for quality control systems. *International Journal of Production Economics*, 72, 27-40.

Chan, F.T.S., Bhagwat, R., Wadhwa, S., 2007. Flexibility performance: Taguchi's method study of physical system and operating control parameters of FMS. *Robotics and Computer-Integrated Manufacturing*, 23, 25–37.

Dengiz, B., Bektas, T., Ultanir, A.E.,2006. Simulation optimization based DSS application: A diamond tool production line in industry. *Simulation Modelling Practice and Theory*, 14,3, 296-312.

Dengiz, B., Belgin, O., 2007. Paint shop Production Line Optimization Using Response Surface Methodology. *Proceeding of the 2007 Winter Simulation Conference*, pp.1667-1672.

Dengiz, B., Akbay, K.S., 2000. Computer simulation of a PCB production line: meta-modeling approach. *International Journal of Production Economics*, 63, 195–205.

Groover, M.P., 2008. *Automation, Production Systems, and Computer Integrated Manufacturing.* Third Edition, Pearson International Edition, USA.

Guo, Y., Chen, L., Wang, S., Zhou, J., 2003. A new simulation optimisation system for the parameters of a machine cell simulation model. *International Journal of Advanced Manufacturing Technology*, 21, 620–626.

Ic, Y.T., Elaldi, F., Pakdil, F., Ipek, N.E., 2012. Design of Experiment and Goal Programming Application for GMAW Process. *Welding Journal*, 91(4), 106-112.

Javadian, N., Aghajani, A., Rezaeian, J., Sebdani, M.J.G., 2011. A multi-objective integrated cellular manufacturing systems design with dynamic system reconfiguration. Int J Adv Manuf Technol, 56, 307–317.

Joseph, O.A., Sridharan, R., 2011. Effects of flexibility and scheduling decisions on the performance of an FMS: simulation modeling and analysis. *International Journal of Production Research*,1-21,In Press. DOI:10.1080/00207543.2011.575091.

Kleijnen, J.P.C., Sargent, R.G., 2000. A methodology for fitting and validating meta-models in simulation. *European Journal of Operational Research,* 120, 14–29.

Kumar, N.S., Sridharan, R., 2009. Simulation modelling and analysis of part and tool flow control decisions in a flexible manufacturing system. *Robotics and Computer-Integrated Manufacturing,* 25, 829–838.

Kumar, M.V.S., Janardhana, R., Rao, C.S.P., 2011. Simultaneous scheduling of machines and vehicles in an FMS environment with alternative routing. *International Journal of Advanced Manufacturing Technology*, 53, 339–351.

Lee, J., Kang, S-H., Rosenberger, J., Kim, S.B., 2010. A hybrid approach of goal programming for weapon systems selection, *Computers & Industrial Engineering,* 58, 521–527.

Liang, T-F., 2009. Fuzzy multi-objective project management decisions using two-phase fuzzy goal programming approach. *Computers & Industrial Engineering,* 57,1407–1416.

Mahdavi, I., Shirazi, B., Solimanpur, M., 2010. Development of a simulation-based decision support system for controlling stochastic flexible job shop manufacturing systems. *Simulation Modelling Practice and Theory*, 18, 768–786.

Ozmutlu, S., Harmonoskyz, C. M., 2004. A real-time methodology for minimizing mean flow time in FMSs with machine break downs: threshold-based selective rerouting. *International Journal of Production Research,* 42 (23), 4975–4991.

Park, T., Lee, H., Lee H., 2001. FMS design model with multiple objectives using compromise programming. *International Journal of Production Research*, 39(15), 3513-3528.

Savsar, M., 2005. Performance analysis of an FMS operating under different failure rates and maintenance policies. *The International Journal of Flexible Manufacturing Systems*,16, 229–249.

Um, I., Cheon, H., Lee, H., 2009. The simulation design and analysis of a Flexible Manufacturing System with Automated Guided Vehicle System. *Journal of Manufacturing Systems*, 28,115-122.

Yurdakul, M., 2004. Selection of computer-integrated manufacturing technologies using a combined analytic hierarchy process and goal programming model. *Robotics and Computer-Integrated Manufacturing*, 20, 329-340.

AUTHORS BIOGRAPHY

Berna Dengiz is the dean of Engineering Faculty at the Baskent University. Her field of study is mainly modeling and optimization of complex large sized systems besides heuristic optimization. She has received research funding for her collaborative studies from NATO-B2 program, TUBITAK (The Scientific and Technical Research Council of Turkey), Government Planning Center of Turkey and National Science Foundation's (NSF) of the USA. She has worked as visiting professor at the University of Pittsburgh and the Auburn Universities.

Yusuf Tansel Ic is an Assistant Professor of Department of Industrial Engineering at the Baskent University. He received a PhD degree in Mechanical Engineering from Gazi University Institute of Science and Technology. He has more than 10 years of experience in banking industry. His research interests include application of expert systems to manufacturing systems, modeling and analysis of production systems, multi-criteria decision making, and financial risk management in commercial banks.