◈ Application Papers

# An Optimal Design Method on system of Flexible Manufacturing Cells(FMCs) using Simulation Technology

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## Abstract

We are concerned with the optimal design of flexible manufacturing cells in this study, thus try to suggest the detail information for each resource on the optimal conditions. Object oriented simulation technology is used to write models more easily and to execute simulation running time more rapidly, and the optimal level of relevant decision variables is probed by response surface methodology(RSM), which is well known for the optimization technology based on experiment design and regression equation.

We investigate the optimal level for the number of pallets and the speed of AGVs of FMC systems, carry out the performance analysis of this system. Consequently we suggest systematic procedures for the optimization of FMCs in detail design stage.

## 1. Introduction

In the rapidly changing paradigm of production concepts, many production systems are trying to upset and discard the old-fashioned thoughts as for production, aggressively are receiving strategies of the more advanced production systems such as FMC systems, AGV systems and robotic cell systems. In literatures of this area, also, during the last decades, the subjects which are related to design and implement successfully and to operate flexibly and efficiently for this systems, have been the essential part of activities of many researchers.

K. E. Stecke[1] and L. L. Massay, C. O. Benjamin, and Y. Omurtag[3] suggested concrete procedures for FMSs successful design. J. Brown, W. W. Chan, and K. Rathmill[2] and Philippe Slot and Mario Van Vliet[4] classified FMSs design procedures into initial design stage and detail design stage, represented decision making issues at each stage. They also shown the related methodologies and tools to solve different problems at each stage of design.

As a result, issues of initial design stage is to cluster machines and parts, and to institute process plans for parts and parts family with the decision for flexibilities of the

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system. And the decision contents of the detailed design stage which are more important because they can critically affect the later stage, are to decide machine capacity like the number of machines and machine utilizations, transportation system capacity, layout of machine, local buffer and centralized buffer capacity, machine loading system, tooling strategy, control hierarchy, scheduling system, maintenance strategy and so forth. It is one of the most important things in this stage to find factors and levels of each factor capable of optimizing the objective function given to the system.

In other sides of the literatures, methodologies and tools for analysis and evaluation have been developed by different researchers. Philippe Slot and Mario Van Vliet[4], R. Suri[8] and Manjunath Kamath[9] classified various methodologies and tools systematically by the property such as possibility of optimization, purpose and process of decision making, and attributes of input data, etc.. Philippe Slot and Mario Van Vliet, especially, try to explain pros and cons of some methodologies based on the solution approaches. They classified manufacturing system modeling methodologies into analytical models such as Markov chain models, Queueing theory and Petri Nets theory, and simulation models.

These methods are frequently used for qualitative and quantitative analysis of the automated manufacturing systems. John A. Buzacott and J. George Shanthikurmar[18], Girswin[22], A. M. Law and W. D. Kelton[10], Narahari and Viswanham[29], etc., elaborated to set the norm to analyze the systems throughout using the above methodologies. Various definitions and interpretations of flexibility in terms of new performance measures was also a main subject of some researchers such as A. K. Sethi and S. P. Sethi[6] and Y. K. Son and C. S. Park[7]. Flexibility is the essential factor among performance measures of modern production systems, but there remain many parts for definition and qualification of this measures.

Simulation technology has been increasingly used by many researcher due to the development of computer related technologies and the specification of related packages. To recent, many achievements using this technology are reported by Hoove and Perry[11], U. Nandkeolyar and D. P. Christy[13], A. M. Bonvik and C. A. Couch[17], etc., and various trials of more different sides in the technology are also being executed by some researchers like H. Wang[12] and F. Azadivar and Young Hee Lee[14].

The system in simulation models is described in the logical relationship between events, which is like job arrival, task completion and machine failure, generally it is known that simulation models are appropriate for the quantitative analysis at the detail design stage. Simulation approaches, however, have some drawbacks. Creation of new models and modification of existing models are troublesome tasks, and verification of developed simulation models are time consuming one. Also output analysis is computationally expensive, so several long executions of a developed model are needed to obtain statistically accurate performance estimates.

In this study, we are concerned with the detail design of FMCs using simulation technology. In order to overcome some shortfalls of this technology, we accepted the concepts of an object-oriented simulation and used the Taylor II systems which is specified for it. So we investigate the optimal performance level of each resource consisting of FMCs by response surface methodology. We try to improve the limitation of previous studies in the system analysis area, which are mainly concentrated on comparisions among various alternative, and to suggest more realistic and integrated information of the system in the detail design stage.

## 2. OOP concepts and Optimization in the Simulation Technology.

Recently the simulation technology become widespread due to the development of computer related fields. In the relevant software engineering techniques, object-oriented programing(OOP) has contributed to the development of simulation programs(A. Kusiak[24], S. Adiga and M Grade[25], S. Adiga[26], P. Gu and D. H. Norrie[27]). It is possible, therefore, for the researchers to easily reuse the constructed simulation models, because of OOP concepts based on the class, in which capability of members like procedures or data storage is independently defined. Therefore the execution of a program can be performed by exchanging messages between all independent members.

Four key conceptions of OOP, which result in making software systems more understandable, maintainable and reusable, are Encapsulation which means an object's data and procedure are enclosed within a tight boundary, Data abstraction which consists of an internal representation added a set of procedures used to access and manipulate the data, Dynamic binding which delays the binding process until the software is actually running, and Inheritance which allows the construction of new objects from existing objects by extending, reducing, or modifying their functionality.

〈Table 1〉 Characteristics of Simulation Languages in the each period

| Periods | Used Language | Characteristics |
|---|---|---|
| 60's | GPSS, GASP, SIMULA<br>GPSSV, GASPII, SIMULA67 | · discrete event simulation language<br>· primarily written in general purpose language<br>· built-in procedures to perform may routine |
| 70's | SLAM, SIMAN/Cinema<br>SimFactory, SIMscriptII | · emerging and extending simulation language<br>· accepting AI technique and Expert Systems in the simulation language concepts.<br>· developing and adding the animation and graphic functions |
| 80's~90's | ARENA, SIMple$^{++}$, Automode | · simulation language based on the OOP<br>· surprising reduction of time and cost to develop the system modeling<br>· the implementation of the three dimension animation |
| 90's~now | AIM, TaylorII, ProModel<br>WITNESS, Quest | · emerge of simulator for modeling for specific system like manufacturing and logistics system etc.<br>· adding the optimizing tools and experiment design methods in output analysis<br>· capable of hierarchical cooperations & collaborations |

The application of OOP concepts in the simulation modeling help allow users to very easily write, test and debug programs. It has contributed to accommodate the simulation modeling work and to enable researchers to develop and evaluate the complex system model. The development of simulation language and the recent tools based on OOP is represented in the ⟨Table 1⟩ .

There are also many trials for offering the level of the optimal decision variables in the simulation model throughout output analysis, while increasing the extensibility of simulation modeling and suggesting the methodology to speed up the simulation running time. In this point, the applications of experimental design methods are considered by many researchers using simulation technology, because the output obtained by the execution of simulation model is much similar to that in the experiment design.

Response surface methodology(RSM) is one of very useful methodologies applying to find which factors are important, how they may affect the response, and what is the optimal level of each factor. RSM frequently use the regression equation and factorial design methods to search for the main effects of factors and the interaction between factors after the simulation execution. The researchers, then, survey the changes of response caused by the effect of specific factor and between the combination of concerned factors. Also the regression model on the ground of parameters considered as main effects and interactions, which is extracted in $2^k$ factorial experiment design, is involved for canonical analysis of response surface. The equation of response surface considering two factors is as follows :

$$R(i,\ j) = a + bx_i + cx_j + dx_ix_j + \varepsilon$$

$$\hat{a} = \text{mean of responses caused by factor } i,\ j$$

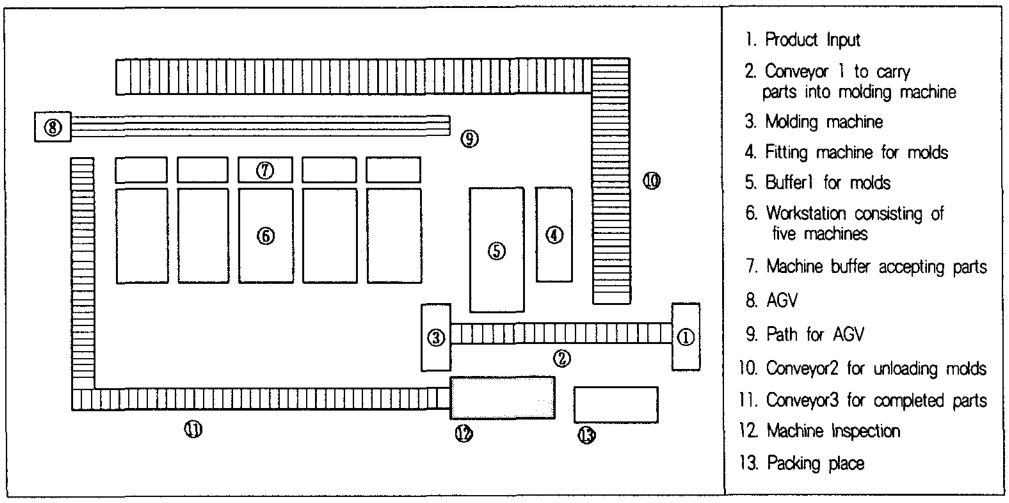
$$\hat{b} = e_i\ /\ 2,\quad \hat{c} = e_j\ /\ 2,\quad \hat{d} = e_{ij}\ /\ 2$$

where variable $i,\ j$ is transformed into $x_i = (i - \bar{i})\ /\ \sigma_i,\quad x_j = (j - \bar{j})\ /\ \sigma_j$ to express the value -1, 0, 1, and $\varepsilon$ is a random variable with 'zero' mean.

RSM is capable of dealing with optimization problems when all factors are quantitative variables which are assumed as numerical values throughout the regression model. The combination of factors level for optimizing the response can be also obtained through this methodology. Additionally RSM is known as requiring smaller numbers of simulation execution than other optimizing theories.

## 3. Simulation modeling of Flexible Manufacturing Cell

Before explaining for the specification of simulation configurations and the characteristics of used simulation package, we will manifest the simulation model - FMC lines organizing into workstation and other resources such as molding machine, machine inspection, conveyors and AGV. Parts for machining in the workstation, at the beginning, are guided by conveyor into molding machine where every part is set on the individual mold, and then parts on the mold are sent to the nearest machine in the workstation. Workstation, which is established by five machines and buffers, fabricate the part and send it to the local buffer. Parts in buffers waite for AGV to go to the machine inspection through conveyor 3 where inspecting the parts for the next stage, while pallets released by AGV must direct to fixing machine to be used by other parts. The layout carrying out this




〈Figure 1〉 The Flexible Manufacturing Cell

process is shown as 〈Figure 1〉 , functions of each resource are presented in the right side of this figure.

The specification of simulation configurations, which is used for the simulation and required for the selection of decision variables, come to the 〈Table 2〉 . In the 〈Table 2〉 , note that erlang distribution for machine job time is used, for describing different process sequences at the 'flexible' machine. As the simulation package, we used TaylorII 4.0 for window which is completely suitable to the OOP in the generation of models and is specialized to solve the problem occurring the area of manufacturing and logistics.

〈Table 2〉 Configuration & Specification of FMC

| Element | | Capacity available | Queuing discipline | Job time (seconds) | Speed (meters/second) | Distribution | Transport Control |
|---|---|---|---|---|---|---|---|
| Workstation | Machine | 1 part | distance | 300 | N/A | erlang(k=2) | auto loading & unloading |
| | Buffer | 1 part | FIFO | N/A | N/A | N/A | |
| Molding machine | | 1 part | FIFO | 30 | N/A | constant | N/A |
| Machine Inspector | | 1 part | FIFO | 50 | N/A | constant | N/A |
| AGV | | 1 part | FIFO | 52 | N/A | constant | auto pick auto place |
| Conveyor 1 | | 10 parts | distance | N/A | 1 | constant | N/A |
| Conveyor 2 | | 25 parts | distance | N/A | 1 | constant | N/A |
| Conveyor 3 | | 25 parts | distance | N/A | 1 | constant | N/A |

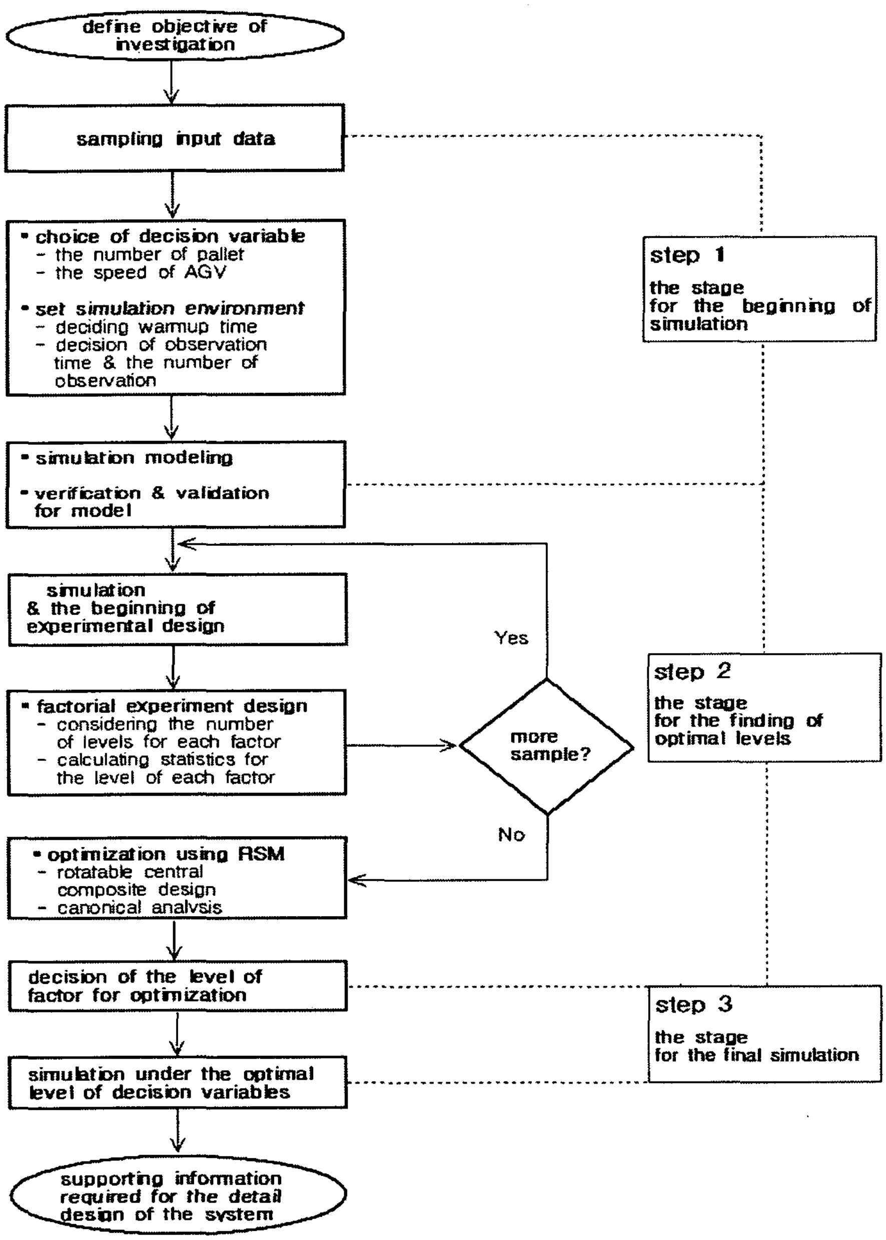
## 4. Evaluation and Optimization

To find the optimal condition for the detail design of FMC, we followed the next procedures :

Step 1 : the execution of the first simulation.

Step 2 : searching for the optimal level for decision factors.

Step 3 : the execution of the final simulation.




〈Figure 2〉 Flow diagram for the optimization using simulation

In step 1, the key process is to select the decision variable. In our analysis for FMC, the number of molds and the speed of AGV are chosen as the variables for maximizing the utilization of workstation. With the input data and information about decision variable, simulation model is established, validations and verifications are just followed. In step 2, various methods can be used for analyzing and evaluating the output of simulation. It is so essential, therefore, to select the proper method for the characteristics of problem. We select RSM and the results of response surface analysis are presented in 〈Table 3〉 . It is known that 1.96 meters/second in the speed of AGV and 12 units of mold can maximize the utilization of workstation. Therefore under the optimal condition, the FMC simulation model is again run, it is step 3. Contents of 〈Table 4〉 is the final result. 〈Figure 2〉 is the flow chart about the step 1, 2, 3.

〈Table 3〉 The results of analysis of Response Surface using SAS

**Canonical Analysis of Response Surface**

| Factor | Critical Value |
|---|---|
| T1 | -0.124833 |
| T2 | 1.948016 |

Predicted value at stationary point 98.330825

| Eigenvalues | Eigenvectors T1 | Eigenvectors T2 |
|---|---|---|
| -0.018008 | 1.000000 | -0.000298 |
| -0.502541 | 0.000298 | 1.000000 |

〈Table 4〉 Performance measures of each resource under the optimal condition

| Resouces \ Performances | | Production time (seconds) | Production rate (per seconds) | Utilization (%) | Average Queue (parts) | Max Queue (parts) | Average waiting time (seconds) |
|---|---|---|---|---|---|---|---|
| Work Station | Machine1 | 295.50 | 0.19865 | 97.83 | 0.98 | 1 | 295.50 |
| | Machine2 | 297.20 | 0.19696 | 97.57 | 0.98 | 1 | 297.20 |
| | Machine3 | 297.00 | 0.19629 | 97.16 | 0.97 | 1 | 297.00 |
| | Machine4 | 296.70 | 0.19519 | 96.52 | 0.97 | 1 | 296.70 |
| | Machine5 | 303.20 | 0.18981 | 95.93 | 0.97 | 1 | 303.20 |
| Molding Machine | | 30.00 | 0.97700 | 48.85 | 0.49 | 1 | 61.60 |
| Fitting Machine | | 50.00 | 0.97685 | 84.66 | 0.85 | 1 | 52.00 |
| Inspection Machine | | 50.00 | 0.97685 | 81.41 | 0.81 | 1 | 50.00 |
| Conveyor 2 | | N/A | N/A | N/A | 1.39 | 9.86 | 89.00 |
| Conveyor 3 | | N/A | N/A | N/A | 0.34 | 6.30 | 21.00 |
| AGVs | | 52.00 | 0.97667 | 32.56 | 0.34 | 1 | 21.00 |
| Buffer1 for molds | | N/A | N/A | N/A | 3.85 | 12.00 | 236.40 |
| Buffer 2 at the inspection Machine | | N/A | N/A | N/A | 0.8 | 1.00 | 48.90 |

## 5. Results

In the fields of manufacturing and other production areas, simulation technology is continuously advanced in the side of methodology and in the area of applications. Recent many studies of simulation technology are concentrating on the realization of the virtual manufacturing (VM) throughout the enhancement of computer related technology and the addition of optimization concepts in the output data analysis and evaluation. In this point of view, we model FMCs at the detail design stage, and evaluate the optimal performances using RSM.

In further research we will intend to continuously apply this concepts to the more complex and difficult manufacturing systems.

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