Parametric Layout Design and Simulation of Flexible Manufacturing System

KWAN HEE HAN[*1], SUNG MOON BAE[*2], SANG HYUN CHOI[*3], GEON LEE[*4], DONG MIN JEONG[*5]
Department of Industrial & Systems Engineering, Engineering Research Institute, Gyeongsang National University, Jinju, KOREA[*1,2,4,5], Department of MIS, Chungbuk National University, Cheongju, Chungbuk, KOREA [*3]
hankh@gnu.ac.kr[*1], bsm@gnu.ac.kr[*2], chois@cbni.ac.kr[*3], binjis@nate.com[*4], dongmin8606@hanmail.net[*5]

Abstract: As business environments are rapidly changing, the manufacturing system must be reconfigured to adapt to various customer needs. FMS (Flexible manufacturing System) is regarded as one of the most efficient methods in reducing or eliminating today's problems in manufacturing industries. In order to cope with current dynamic change of manufacturing system, it is quintessential to design and verify the layout of FMS rapidly and easily during the design stage. And it is also necessary that the existing 3D layout components for simulation-based verification should reused for other FMS layout verification tasks to shorten the design time of FMS.
The purpose of this paper is to propose the tool of rapid parametric layout determination and construction of 3D discrete event simulation model for FMS design. To be a parameter-driven solution, FMS is modularized by 'station' concept and resources within FMS are standardized in this paper. This approach can serve as a rapid prototyping tool of layout configuration for FMS design engineers as well as a communication tool for managers and other personnel involved.

Key-Words: - Flexible Manufacturing System (FMS), Simulation, Rapid Prototyping, Reconfigurable Manufacturing System (RMS)

1 Introduction

Nowadays the unpredictability of market changes, the growing product complexity and continuous pressure on costs force enterprises to develop the ability to respond and adapt to change quickly and effectively. In order to sustain competitiveness in such dynamic markets, manufacturing organizations should provide the sufficient flexibility to produce a variety of products on the same system.

This requirement was everlasting from past decades. Therefore, in order to cope with these challenges, the concept of FMS (Flexible Manufacturing System) was introduced during late 1960s. Since then, FMS was one of widely adopted solution to provide flexibility on the change of working conditions. The main cause of this change is as follows: production quantity, product types, introduction of new product, engineering change and machine failure and so on. Even today FMSs are regarded as one of the most efficient method to employ in reducing or eliminating problems in manufacturing industries. FMS can be defined as 'a computer-controlled system which consists of NC (Numerical Control) machine tools linked together by automatic material handling system'. In other words, FMS is a series of automatic machine tools or items of fabrication equipment linked together with an automatic material handling system, a common hierarchical computer control, and provision of random fabrication of parts or assemblies that fall within predefined families. The objective of a FMS is to make possible the manufacture of several families of parts, with shortened changeover time, in the same system. Currently, FMS technology evolves into RMS (Reconfigurable Manufacturing System).The major characteristics of RMS is called reconfigurability, which is the ability of rearranging and/or changing manufacturing elements aimed at adjusting to new environmental and technological changes. The objective of an RMS is to provide exactly the functionality and capacity that is needed, exactly when it is needed. RMS goes beyond the objectives of FMS by permitting: (1) reduction of lead time for launching new systems and reconfiguring existing systems, and

(2) the rapid modification and quick integration of new technology and/or new functions into existing systems [9].

To achieve a goal of FMS and RMS, it is quintessential to generate system design alternatives rapidly during design stage. Typical system design tasks include the layout of the hardware components (i.e., machines, material handling system, and buffers), the determination of optimal buffer sizes, the design of control procedures for the material handling system, etc [8].

Among these tasks, the early determination of physical layout is prerequisite to other tasks because other tasks majorly depend on layout configuration. Therefore, an efficient tool for layout configuration is required to be a rapid prototyping tool for FMS design engineers as well as a communication tool for managers and other personnel involved. To be a rapid prototyping, it is needed that layout configuration is generated by choosing and combining several layout design parameters. To do this, standardization of design parameter is also required.

Moreover, after initial layout design, it is necessary to evaluate the performance of designed layout. This task is usually conducted by 3D discrete event simulation. However, simulation modeling is also a time-consuming task. Therefore, it is needed to shorten the time for simulation modeling, especially for layout modeling. It can be achieved by standardizing the 3D simulation components for FMS, and reusing them multiple times.

The purpose of this paper is to propose the tool of rapid parametric layout determination in the design stage and construction of 3D layout model in the verification stage. In this proposed method, FMS layout is determined rapidly by choosing standardized design parameters in each FMS station. And generated feasible solution is viewed in a 2D graphical form. Finally, based on the layout result, commercial simulation software is invoked, and 3D layout model is automatically created.

The rest of the paper is organized as follows. Section 2 reviews related works. Section 3 describes FMS layout structure classification in view of functional station. Section 4 describes proposed procedure for rapid layout determination and simulation preparation for FMS design. Finally, the last section summarizes results and suggests directions for future research

2 Related Works

Research within manufacturing systems design has mainly been focused on finding improved models to solve particular problems or to extend existing modeling techniques.

FMS design is a problem concerned with the selection of: (1) system configurations from a wide variety available, and (2) control strategy alternatives in the light of several criteria (cost, production, flexibility), many of which are difficult to quantify [6]. The sub-categories of FMS design problem are as follows: control strategy, cost estimation, performance evaluation, flexibility measurement and layout configuration.

Mathematical programming has been frequently used for layout configuration for different types of manufacturing systems by various researchers. A simple quadratic assignment formulation was proposed to minimize the total distance between machines within manufacturing cells [6]. The method of determining the number of machines and part types for FMS design was presented using the closed queuing network and linear programming to maximize profit [11].

Several decision analysis techniques and models have been applied to the evaluation of FMS design. Intelligent decision support system was proposed, which selects from several configuration and control strategy alternatives of design the most appropriate one for specific case. It is assumed that the designer has (i) an initial configuration of the system, and (ii) an initial description of the control policies for this initial configuration [4]. AHP (Analytic Hierarchy Process) model [2] and fuzzy AHP model [1] was developed for the selection of layout configurations of an RMS to take account both quantitative and qualitative criteria of reconfigurability, cost, quality and reliability, and case study was conducted under the condition of three layout configuration alternatives for three machines.

As a modeling tool in the design stage of FMS, UML (Unified Modeling Language) was adopted for the graphical modeling tool for developing reusable, extendable, and modifiable control software [3, 5]. An object-oriented modeling framework for generic AMS (Automated Manufacturing System) was proposed. Its modeling tool was called JR-Net (Job Resource relation Net) which represents various perspectives of AMS comprised of layout model, functional model and control model [10].

3 Modular Structure and Standard Resources of Flexible Manufacturing System

Automated manufacturing systems (AMSs) come under different names depending on their generic functions: flexible manufacturing cell or system (FMC or FMS), flexible assembly system (FAS), automated storage and retrieval system (AS/RS), or automated material handling system (AMHS). However, manufacturing system under the category of AMS has a common generic structure.

Additionally, modern automated manufacturing systems have a modular and hierarchical structure and are constructed by 'assembling' standard resources (or catalog items). As flexibility and modularity become more critical in a successful operation of AMS, the general trend is to (1) use 'standard' resources in configuring AMS, and (2) use the modular design concept in which an AMS is decomposed into a number of stations.

Based on extensive observation and analysis, the standard resources found in modern AMS are grouped into 8 types according to their generic function as follows [10]:

1) Machine: for processing parts on its own table.
2) Robot: for handling or processing parts without its own table.
3) APC (Automatic Pallet Changer): for changing parts (i.e., pallets) at the machine table
4) Table: for putting a part on during processing or handling
5) Vehicle: for transporting parts among multiple ports
6) Conveyor: for conveying parts from one port to the other.
7) Diverter: for diverting part flows in a conveyor net.
8) Storage: for storing parts in.

Figure 1 shows AMS resource type and its corresponding standard FMS resource name.

FMS, which is a subset of AMS, can be also decomposed into several stations which provide a specific functionality. In this paper, we restrict our discussion to the machining-type FMS. In general, there are five stations for layout determination of machining-type FMS as follows: storage, transport, processing, preparation, tool handling:

1) Storage station is for storing parts in. Standard resource such as one-level buffer storage, multi-level single storage rack and storage rack with aisle belongs to this category. In the storage station, 'storage rack with aisle' parameter is usually implemented in a form of AS/RS (Automatic Storage and Retrieval System).

AMS Resource Type	Standard FMS Resources
Machine	• Machining Center • Washing Machine • Measuring Machine
Robot	• Worker (Operator) • Robot (Manipulator)
APC (Automatic Pallet Changer)	• Pallet Shuttle • Carousel-type Pallet Magazine
Table	• Loading Table • Pallet Stand • Unload Area
Vehicle	• A G V • R G V • Stacker Crane
Conveyor	• Roller Conveyor
Diverter	• Diverter
Storage	• Storage Rack • Buffer Storage

Figure 1. Generic AMS resource type and standard FMS resources

2) Transportation station (usually in a form of vehicle) is for transporting parts among multiple ports. Alternatives for transportation path are linear, loop, ladder and open configuration as depicted in Figure 2. Standard resources in this category are AGV (Automated Guided Vehicle), RGV (Rail Guided Vehicle), and stacker crane. In the transportation station, RGV is adopted for the default transportation resource in the linear and loop path configuration. AGV is adopted for the default transportation resource in the ladder and open path configuration. Stacker crane is adopted for the default transportation resource in the linear path and storage rack configuration.

3) Processing station is for processing of parts and input/output buffering of parts temporally. Processing operation consists of standard resources for machining, washing and measurement. The input/output buffer in the processing station has two types. Pallet stand has input and output buffer separately, whereas common buffer has common space for input and output to wait for processing.

4) Major operations of preparation station are loading, setup and unloading of parts. Common L/U (Loading/Unloading) station and separate L/U station belong to this category.

5) Tool handling station is for the provision of tools into machines. In-line tool handling system has no separate automated tool handling mechanism, and tool magazine and ATC (Automatic Tool Changer) is

embedded in the machine. Off-line tool handling station has independent automated tool handling mechanism comprised of tool storage and tool transporter. Off-line tool handling system is in charge of exchange tools between the tool magazine on the machines and a number of tool buffers.

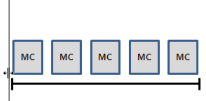
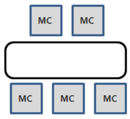
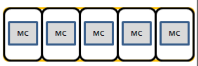
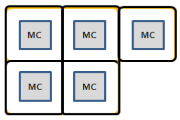
Path Type	Symbol	Path Type	Symbol
Linear		Loop	
Ladder		Open	

Figure 2. Transport path type of FMS

Station		Standard resource	Primitive Symbol 2D	Primitive Symbol 3D
Storage		Buffer Storage	BS	
		Storage Rack	SR	
		Storage Rack with Aisle	SRwA	
Transport (using Vehicle)		AGV	AGV	
		RGV	RGV	
		Stacker Crane	SC	
Processing	Machining	Machining	MC	
		Washing	WM	
		Measuring	MM	
	I/O Buffer	Common Buffer	CB	
		Pallet Stand	PS	
Preparation		Common L/U Station	L U ↓ ↑	
		Separate L/U Station	L U ↓ ↑	
Tool Handling	In-line	Tool magazine/ATC		
	Off-line	Tool Storage	TS	
		Tool Transport	TT	

Figure 3. Stations and standard resources of FMS

By selecting appropriate design parameters for each station, we can create various FMS layout design alternatives rapidly. Figure 3 shows the mapping of station and its standard resources, and their corresponding 2D and 3D primitive symbols.

4 Layout Design and Simulation Procedure

	Station	Substation	Configuration Parameter		# of alternatives
A	Storage		1	No Storage	4
			2	Buffer Storage	
			3	Storage Rack	
			4	Storage Rack With Aisle	
B	Transport Path		1	Linear	4
			2	Loop	
			3	Ladder	
			4	Open	
C	Processing	A : Machining	1	Machining Only	4
			21	Machining + Washing Machine	
			22	Machining + Measuring Machine	
			23	Machining + Washing Machine + Measuring Machine	
		B : I/O Buffer	1	No Buffer	3
			2	Common Buffer	
			3	Pallet Stand	
D	Preparation		1	No Station	3
			2	Common Loading/Unloading Station	
			3	Separate Loading Unloading Station	
E	Tool Handling		1	Off-Line	2
			2	On-Line	

Figure 4. Design parameters of each station

In the design stage of FMS, once a detailed part analysis has been made, the next step is to determine physical layout. The principal factors of part analysis are: part variety and physical characteristics, process plan, production quantity, and tooling/fixturing.

In this paper, one layout configuration is determined by choosing an appropriate parameter within each station and combining 5 parameters depicted in Figure 4. Therefore, there exist 1152 possible layout alternatives (4x4x4x3x3x2) by combining 5 station's parameter. Among these alternatives, 748 alternatives reveals infeasible configuration. Consequently, we can choose one layout configuration among remaining 404 alternatives.

The set of infeasible solutions are as follows: {(A1∩CB1), (A2∩D3), (A3∩B2), (A3∩B3), (A3∩B4), (A4∩B1), (A4∩ B3), (E1∩B2), (E1∩B3), (E1∩B4)} where A: set of parameters of storage station, B: set of parameters of vehicle-type transport station, C: set of parameters of processing station, D: set of parameters of preparation station, E: set of parameters of tool handling station.

For example, a storage station with no storage (A1) must have a buffer for part storage, so is incompatible with processing station with no buffer (CB1). Off-line tool handling system (E1) is only compatible with linear transport path (B1) because tool transport path can interrupt the path of vehicle transport. The storage station with storage rack (A3) is only compatible with linear transportation station (B1) because it usually adopts stacker crane as a vehicle.

Proposed procedure for rapid layout determination and simulation preparation for FMS design is as follows:

1) Choose layout design parameter within each station by using parametric layout generation tool developed in this paper as depicted in the left part of Figure 5. It is called LayFlex (Layout Designer of Flexible manufacturing system). And then, by pressing 'Result' button, it is determined whether this configuration is a 'feasible solution' or 'infeasible solution'.

2) If it is an 'impossible model', the reason is explained in the lower part message window shown in Figure 5. As an example, when FA engineer chooses A1-B2-CA23-CB1-D2-E2, this layout is infeasible because there exists no buffer in FMS configuration if A1 (no storage in storage station) and CB1 (no buffer in processing station) were selected together. It causes blocking of parts or deadlock situation.

3) If result is a 'possible model', its corresponding 2D layout model is displayed in the right part of window as shown in Figure 5 by pressing 'view model' button. In this example, feasible alternative is generated by selecting parameters as follows: A4 (storage rack with aisle): B4 (open transport path): CA23 (machining + washing + measuring): CB2 (common buffer in the processing station): D2 (Separate loading/unloading station): E2 (on-line tool handling).

4) After investigating 2D layout model, it is determined whether 3D simulation is conducted or not for verification of design result. If simulation model is necessary, by pressing 'Run Quest' button shown in right lower part of Figure 5, 3D layout model is constructed by combining 3D primitive symbols in the 'Quest' software automatically. In other words, 3D layout model corresponding to 2D layout model is invoked by LayFlex software as depicted in Figure 6. 'Quest' is a commercial package for 3D manufacturing simulation [7].

5) And then, by refining of initial 3D layout model and coding detail logic using SCL (Simulation Control Language) of Quest, FA (Factory Automation) engineers can execute simulation model for the verification of generated layout configuration rapidly and with ease.

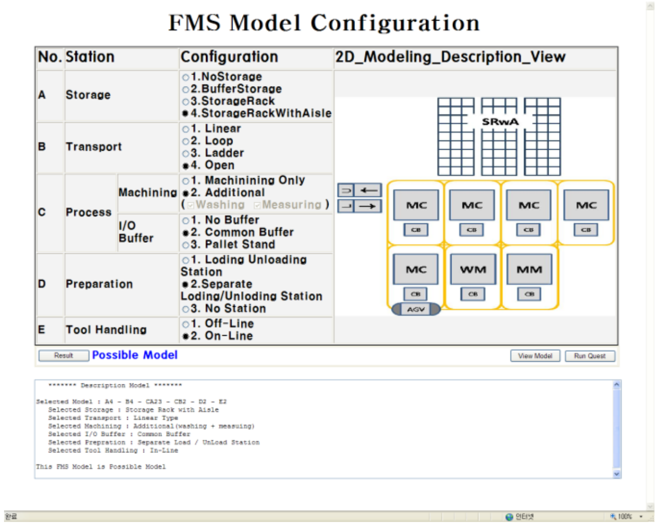


Figure 5. Input/output display of LayFlex

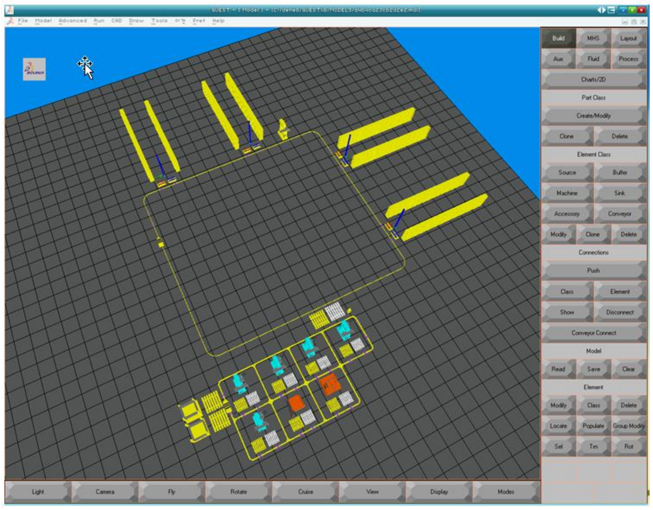


Figure 6. 3D layout model for simulation using 'Quest' software

5 Conclusions and Further Research

External environment of enterprise are rapidly changing brought about majorly by global competition, cost and profitability pressures, and emerging new technology. FMS is a business-driven solution leading to improved profitability through reduced lead times and inventory levels, rapid response to market changes, and improved manufacturing effectiveness. Especially,

ISBN: 978-1-61804-041-1

to achieve a rapid response to market changes in today's time-based competition environment, it is quintessential to design and verify the layout of FMS rapidly and easily during the design stage. And it is also necessary that the 3D components for simulation-based verification should be reused for other FMS layout simulation.

Purpose of the proposed tool for rapid parametric layout determination and construction of 3D discrete event simulation model by component reuse is to shorten the time for FMS layout design and verification. To be a parameter-driven-solution, FMS is modularized by 'station' and resources within FMS are standardized in this paper.

By proposed method, FMS layout configuration is rapidly generated by parameter selection. It also facilitates the construction of 3D layout model for simulation-based verification of generated FMS alternative. In addition, this approach serves as a communication tool for managers and other personnel involved.

Developed software (LayFlex) in this paper lacks the functionality of designing control logic for FMS. Therefore, as a further research, the UML-based design module for the control logic is required to develop an integrated tool for the design and verification of flexible manufacturing system.

References

[1] Abedi, M. R., "Layout configuration selection for reconfigurable manufacturing systems using the fuzzy AHP," *International Journal of Manufacturing Technology and Management*, Vol.17, No.1-2, pp.149-165, 2009.

[2] Abedi, M. R., "Selection of a layout configuration for reconfigurable manufacturing systems using the AHP," *Proceedings of 2005 International Symposium on AHP*, Hawaii, July 8-10, 2005.

[3] Berruet P., Lallican, J. L., Rossi, A., Philippe, J. L., "A component based approach for the design of FMS control and supervision," *Proceedings of 2005 IEEE International Conference on Systems, man and Cybernetics*, Vol.4, pp.3005-3011, December 10-12, 2005.

[4] Borenstein D., "Intelligent decision support system for flexible manufacturing system design," *Annals of Operations Research*, Vol. 77, pp.129-156, 1998.

[5] Bruccoleri M., Diega S. N. L., Perrone, G., " An object-oriented approach for flexible manufacturing control systems analysis and design using the unified modeling language," *International Journal of Flexible Manufacturing Systems*, Vol.15, pp.195-216, 2003.

[6] Cheng, C; H., Chen, Y.,"Autonomous intelligent agent and its potential applications," *Computers & Industrial Engineering*, Vol.31, No.1-2, pp.409-412, 1996.

[7] Delmia Corporation, *Quest User Manual V 5.17*, Delmia Corporation, Michigan, US, 2006.

[8] Heavey, C., Browne, J., "A model management systems approach to manufacturing systems design," *International Journal of Flexible Manufacturing Systems*, Vol. 8, No. 2, pp.103-130, 1996.

[9] Mehrabi, M.G., Ulsoy, A.G., Kore, Y., Heytler, P., "Trends and perspectives in flexible and reconfigurable manufacturing systems," *Journal of Intelligent Manufacturing*, Vol.13, pp.133-146, 2002.

[10] Park, T.Y., Han, K.H., Choi, B.K., "An object-oriented modeling framework for automated manufacturing system," *International Journal of Computer Integrated Manufacturing*, Vol.10, No.5, pp.324-334, 1997.

[11] Shin, H., Park, J., Lee, C., Park, J., "A decision support model for the initial design of FMS," *Computers & Industrial Engineering*, Vol.33, No.3-4, pp.549-552, 1997.

Acknowledgements

This research was financially supported by Ministry of Education, Science and Technology (MEST) and National Research Foundation of Korea (NRF) through the Human Resource Training Project for Regional Innovation.