Parameter-Driven Rapid Virtual Prototyping of Flexible Manufacturing System

Kwan Hee Han, Sung Moon Bae, Sang Hyun Choi and Geon Lee

Abstract— Most enterprises are struggling to change their existing business processes into agile, product- and customer-oriented structures to survive in the competitive and global business environment. In order to sustain competitiveness, manufacturing organizations should provide the sufficient flexibility to produce a variety of products on the same system.

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 changes of manufacturing system, it is quintessential to design and verify the layout of FMS rapidly and easily during the design stage.

And it is needed that supervisory control patterns for material flow should be categorized for later reuse in control programs. It is also necessary that the existing 3D layout components for simulation-based verification should be 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, and the categorization of control patterns of material flow within FMS. 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 and control program preparation for FMS design engineers as well as a communication tool for managers and other personnel involved.

Keywords—Flexible Manufacturing System (FMS), Rapid Prototyping, Reconfigurable Manufacturing System (RMS), Control Logic, Control Pattern, Discrete Event Simulation

I. 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 changes 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.

In a general sense, flexibility is the system capacity to efficiently respond technically and economically to variable conditions:

- *Technological:* changes of time and sequence of operations, diversity of technological tracks, variable production series;
- *Functional:* changes of the methods of cutting, of the transport routes, of the equipments/devices, the necessity of a variable number of various tools, levels of workloads as large as possible;
- *Economical*: the lowest cost, negotiated delivery times, requested quality [5].

Even today FMSs are regarded as one of the most efficient method to employ in reducing or eliminating problems in manufacturing industries. FMS brings flexibility and responsiveness to the manufacturing floor-when a part is required by the market and not when production deems it so.

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. FMS combines computer and mechanical engineering to bring the economy of scale to batch work. A central on-line computer controls the machine tools, other workstations, and the transfer of components and tooling.

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

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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 [18].

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 [16].

Among these tasks, the early determination of physical layout is prerequisite to other tasks because other tasks mainly 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 layout design alternatives. 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.

After determining the physical layout of FMS, it is necessary to write a control program for supervising FMS operations. Correct control program is vital to FMS operations by avoiding conflicts among resources and deadlocks of material flow. By re-using control patterns which is used repeatedly in FMS operations, prototyping time can be shortened considerably. It is facilitated by categorizing control patterns of material flow within FMS.

The purpose of this paper is to propose 1) the tool of rapid parametric layout determination in the design stage and construction of 3D layout model in the verification stage, and 2) categorization of control patterns of material flow within FMS. 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. After that, control patterns are selected, and used for writing supervisory control programs. Finally, based on the determined layout and control pattern, commercial simulation software is invoked, and 3D layout model is automatically created. And simulation model is executed for verification.

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. Section 5 presents the categorization of control patterns of material flows within FMS. Finally, the last section summarizes results and suggests directions for future research.

II. 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: (i) system configurations from a wide variety available, and (ii) control strategy alternatives in the light of several criteria (cost, production, flexibility), many of which are difficult to quantify [8]. The sub-categories of FMS design problem are as follows: control strategy, cost estimation, performance evaluation, flexibility measurement and layout configuration.

In an area of layout configuration of FMS, layout issues were surveyed in the FMS environment having emphasis on graph theoretic modeling techniques, heuristic approaches for special FMS layout types, and the queuing and dynamic aspects of the layout decisions [17]. 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 [10]. 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 [20]. Taboun *et al.* presented a mixed integer programming formulation of the problem, which aimed to minimize the cell configuration costs, machine capital investment cost, machine procurement and salvage costs, idle time costs, inter-cell movement costs and part subcontracting costs [21].

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 [8]. 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. Abdul-Hamid *et al.* suggested an AHP model for the selection of best layout based on three main objectives: flexibility, volume, and cost using a knowledge-based system [3]. Traditional cost and benefit method was presented for the evaluation of FMS [7, 13]

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 [6, 9]. An object-oriented modeling framework for generic AMS (Automated Manufacturing System) including FMS was proposed. Its graphical 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 [12, 19].

In an area of operations management, the possibilities afforded by the Witness simulation environment for the construction of models and the subsequent simulation of concrete manufacturing systems was suggested [11]. Scheduling problems in flexible manufacturing cells (FMC) were presented to minimize the makespan using a genetic algorithm (GA). A software tool, called HybFlexGA, was developed in this study [15]. A high-level programming approach was proposed for the control of flexible manufacturing robotics work cell utilized in assembling tasks. The overall control is achieved through low-level AML assembly routines in conjunction with high-level C programming modules, while at user interface Prolog predicates are used for interactive communication [4]. A simulation tool was developed to examine the effects of the different communication messages and to analyze how the different type of messages can be measured in a real FMS environment [5]. A generic Petri net (GPN) model and approach for the development of control software for FMSs was proposed [22]. The principle of this approach is based on checking the control parts of FMSs with the help of temporal relationships between physical operations, and the specification of the FMS controller with GPN.

III. 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.

As depicted in Figure 1 in a form of UML class diagram, generic structure of AMS is as follows: Plant consists of multiple stations. A station is defined as a generic and disjoint subset of AMS which performs a specific function such as part processing, material handling, and storage. Station consists of multiple standard resources which are catalog items belonging to one of resource types. A standard resource inherits common properties from resource type. Part flows through plant by using process plan and resource specification information. Process plan informs of processing sequence, and resource informs of processing capability. Operator monitors the status of station and manages controllers. Plant is controlled by controllers which regulate part flow, deal with various input/output events, and change the status of station.

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 [19]:

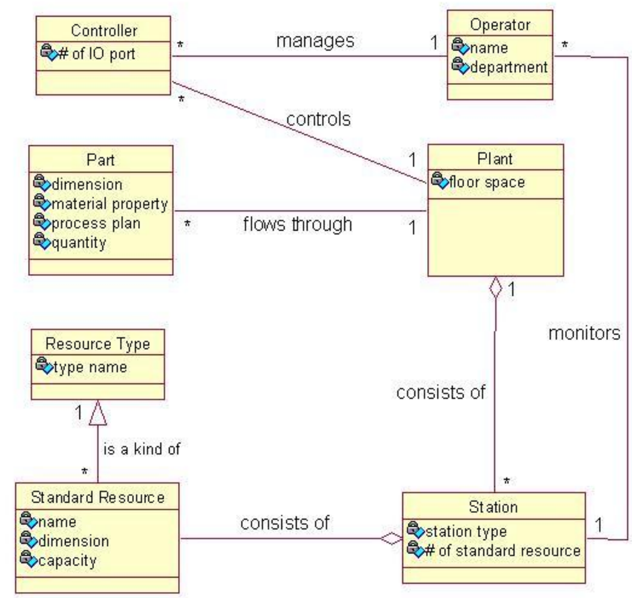

Fig. 1 Generic AMS structure

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

Fig.2 Generic AMS resource type and standard FMS resources

- Machine: for processing parts on its own table.
- Robot: for handling or processing parts without its own table.
- APC (Automatic Pallet Changer): for changing parts (i.e., pallets) at the machine table
- Table: for putting a part on during processing or handling
- Vehicle: for transporting parts among multiple ports

- Conveyor: for conveying parts from one port to the other.
- Diverter: for diverting part flows in a conveyor net.
- Storage: for storing parts in.

Figure 2 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, based on our previous research, there are five stations for layout determination of machining-type FMS as follows: storage, transport, processing, preparation, tool handling [12]:

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 belong 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).

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 3. 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.

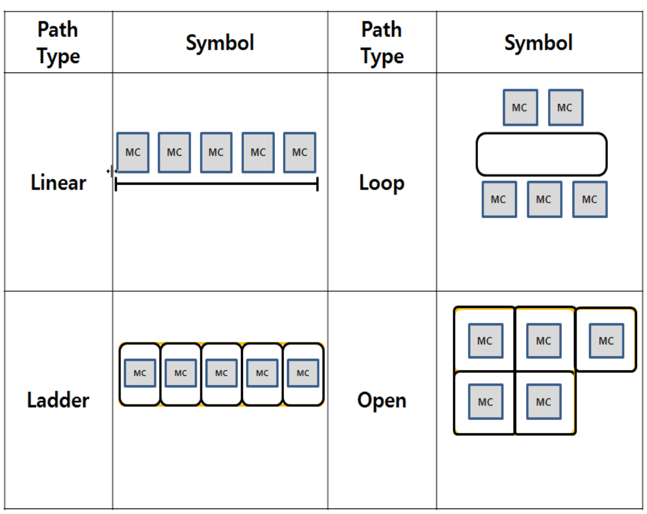

Fig. 3 Transport path type of FMS

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.

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	W M	
		Measuring	M M	
	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	T T	

Fig. 4 Stations and standard resources of FMS

By selecting appropriate design parameters for each station, we can create various FMS layout design alternatives rapidly. Figure 4 shows the mapping of station and its standard resources, and their corresponding 2D and 3D primitive symbols.

IV. Layout Design and Simulation Procedures of FMS

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

Proposed layout design and simulation procedure of FMS is shown in Figure 5.

In this paper, one layout configuration is determined by choosing an appropriate parameter within each station and combining 5 parameters depicted in Figure 6. Therefore, there exist 1,152 possible layout alternatives (4x4x4x3x3x2) by combining 5 station's parameters. Among these alternatives, 748 alternatives reveals infeasible configuration. Consequently, we can choose one layout configuration among remaining 404 alternatives.

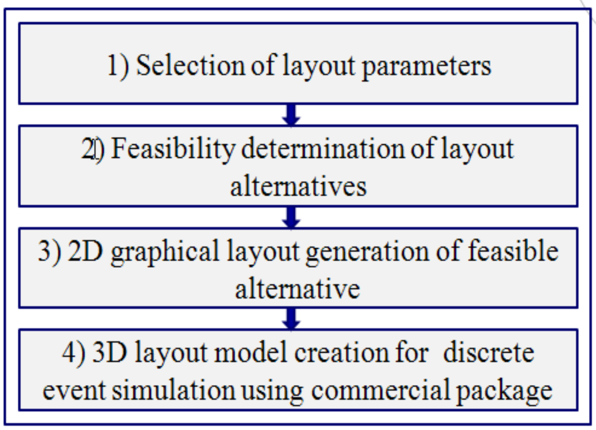

Fig. 5 Proposed procedure for FMS layout design

	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	

Fig. 6 Design parameters of each station

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.

Table 1. Part of whole alternatives list for FMS layout

No.	A. Storage	B. Transprt	C. Processing: A. Machining	C. Processing: B. I/O Buffer	D. Preparation	E. Tool Handling	Configuration Type	O/X
1			1. Machining Only	1. No Buffer	1. L/U Station	1. Off-Line	A1 - B1 - CA1 - CB1 - D1 - E1	X
2						2. In-Line	A1 - B1 - CA1 - CB1 - D1 - E2	X
3					2. Separate L/U Station	1. Off-Line	A1 - B1 - CA1 - CB1 - D2 - E1	X
4						2. In-Line	A1 - B1 - CA1 - CB1 - D2 - E2	X
5					3. No Station	1. Off-Line	A1 - B1 - CA1 - CB1 - D3 - E1	X
6						2. In-Line	A1 - B1 - CA1 - CB1 - D3 - E2	X
7				2. Common Buffer	1. L/U Station	1. Off-Line	A1 - B1 - CA1 - CB2 - D1 - E1	O
8						2. In-Line	A1 - B1 - CA1 - CB2 - D1 - E2	O
9					2. Separate L/U Station	1. Off-Line	A1 - B1 - CA1 - CB2 - D2 - E1	O
10						2. In-Line	A1 - B1 - CA1 - CB2 - D2 - E2	O
11					3. No Station	1. Off-Line	A1 - B1 - CA1 - CB2 - D3 - E1	X
12						2. In-Line	A1 - B1 - CA1 - CB2 - D3 - E2	X
13				3. Pallet Buffer	1. L/U Station	1. Off-Line	A1 - B1 - CA1 - CB3 - D1 - E1	O
14						2. In-Line	A1 - B1 - CA1 - CB3 - D1 - E2	O
15					2. Separate L/U Station	1. Off-Line	A1 - B1 - CA1 - CB3 - D2 - E1	O
16						2. In-Line	A1 - B1 - CA1 - CB3 - D2 - E2	O
17					3. No Station	1. Off-Line	A1 - B1 - CA1 - CB3 - D3 - E1	X
18						2. In-Line	A1 - B1 - CA1 - CB3 - D3 - E2	X
19			21. Washing	1. No Buffer	1. L/U Station	1. Off-Line	A1 - B1 - CA21 - CB1 - D1 - E1	X
20						2. In-Line	A1 - B1 - CA21 - CB1 - D1 - E2	X
21					2. Separate L/U Station	1. Off-Line	A1 - B1 - CA21 - CB1 - D2 - E1	X
22						2. In-Line	A1 - B1 - CA21 - CB1 - D2 - E2	X
23					3. No Station	1. Off-Line	A1 - B1 - CA21 - CB1 - D3 - E1	X
24						2. In-Line	A1 - B1 - CA21 - CB1 - D3 - E2	X
25				2. Common Buffer	1. L/U Station	1. Off-Line	A1 - B1 - CA21 - CB2 - D1 - E1	O
26						2. In-Line	A1 - B1 - CA21 - CB2 - D1 - E2	O
27					2. Separate L/U Station	1. Off-Line	A1 - B1 - CA21 - CB2 - D2 - E1	O
28						2. In-Line	A1 - B1 - CA21 - CB2 - D2 - E2	O
29					3. No Station	1. Off-Line	A1 - B1 - CA21 - CB2 - D3 - E1	X
30						2. In-Line	A1 - B1 - CA21 - CB2 - D3 - E2	X
31				3. Pallet Buffer	1. L/U Station	1. Off-Line	A1 - B1 - CA21 - CB3 - D1 - E1	O
32						2. In-Line	A1 - B1 - CA21 - CB3 - D1 - E2	O
33					2. Separate L/U Station	1. Off-Line	A1 - B1 - CA21 - CB3 - D2 - E1	O
34						2. In-Line	A1 - B1 - CA21 - CB3 - D2 - E2	O

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). Storage rack (A3) is only compatible with linear path type (B1) because transportation means for storage rack is usually stacker crane which moves linearly. The storage station with storage rack (A4) is incompatible with linear (B1) and ladder transportation path (B3) because it usually adopts linear or open path between machines and AS/RS. 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.

Table 1 shows the part of whole alternatives list and marking of feasible alternatives.

Figure 7 shows 2D view of feasible layout configuration examples. Configuration-A is a combination of A1-B1-CA1-CB3-D3-E1 parameters. Its transport type is linear and has separate input/output buffer in the processing station. Its tool handling system is off-line. Configuration-B is a combination of A3-B1-CA1-CB2-D2-E1 parameters. It has a storage rack for storing parts and transportation is done by stacker crane linearly. Configuration-C is a combination of A4-B2-CA1-CB2-D3-E2 parameters. It has AS/RS-based storage system. Transportation system between machining and AS/RS is RGV (Rail-Guided Vehicle). Configuration-D is a combination of A2-B2-CA1-CB2-D3-E2 parameters. It has independent buffer storage and transportation is performed by RGV. It has separate loading/unloading station.

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 Figure 8. 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 result is a 'possible model', its corresponding 2D layout model is displayed in the right part of window as shown in Figure 10 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).

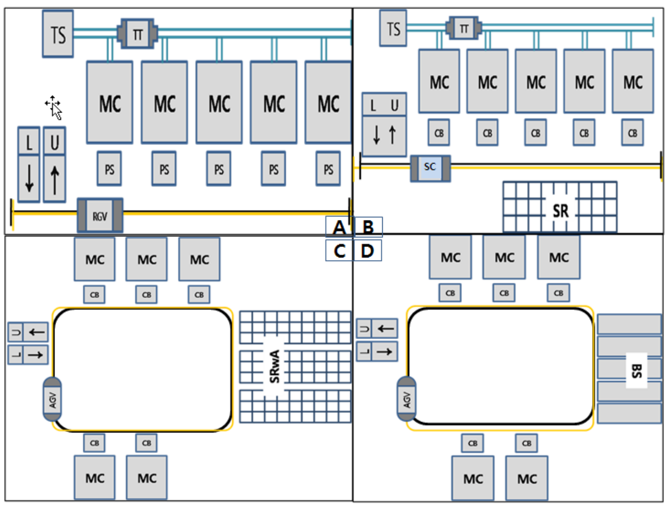

Fig. 7 2D view of feasible configuration alternatives

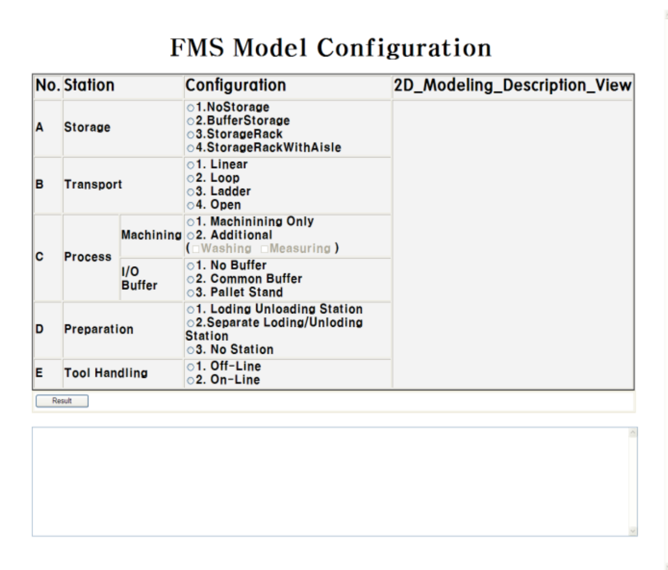

Fig. 8 Input Screen of LayFlex

3) 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 10, 3D layout model is constructed by combining predefined 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 11. Figure 11 depicts 3D representation of 2D layout of Figure 10. 'Quest' is a commercial package for 3D manufacturing simulation [14]. Figure 12 shows various FMS layout configuration in 3D forms using Quest software.

4) Finally, by refining of initial 3D layout model and coding detail logic using SCL (Simulation Control Language) of Quest based on supervisory control patterns, FA (Factory Automation) engineers can execute and investigate the simulation model for the verification of generated layout configuration with ease and less time.

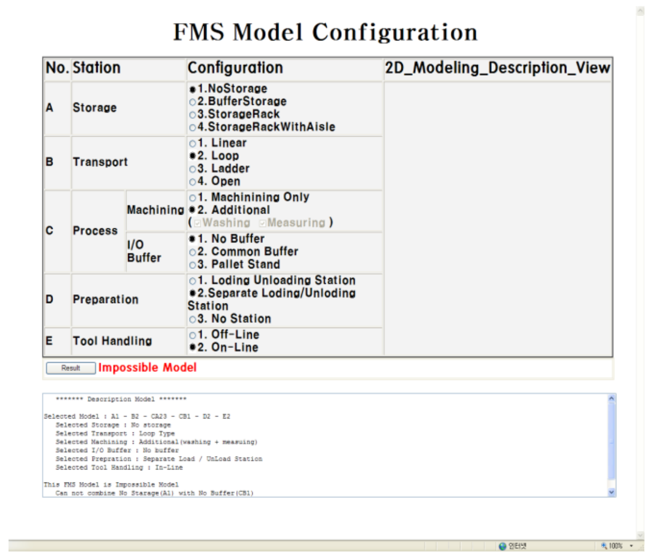

Fig. 9 Output display for infeasible alternative using LayFlex

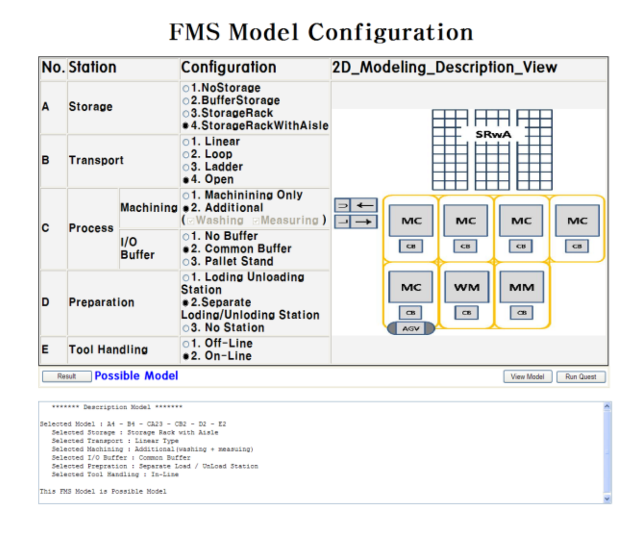

Fig. 10 Output display for feasible alternative using LayFlex

By using LayFlex, FA engineers can generate and simulate FMS layout alternatives rapidly in an earlier stage of FMS design. It helps manufacturing firms to adapt quickly to environmental changes. Well-designed FMS layout plays a vital role to maximize productivity and performance.

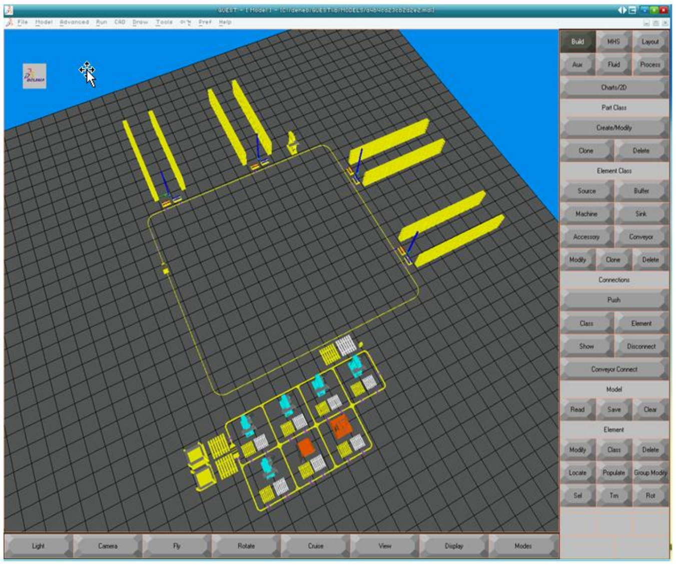

Fig. 11 3D layout model for simulation using ‘Quest’ software

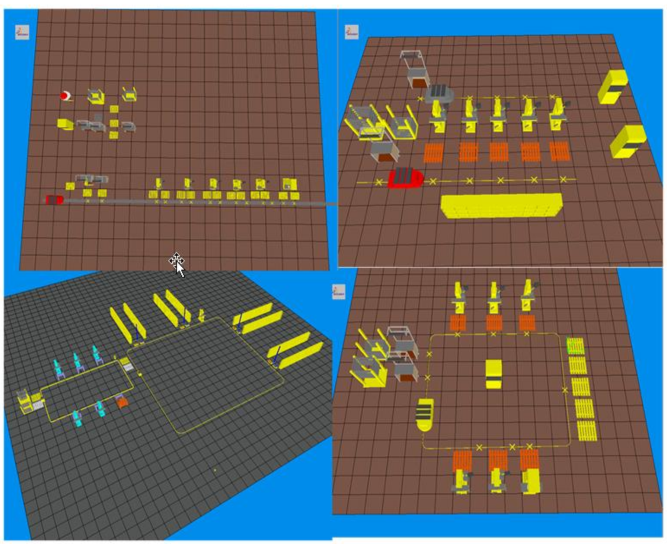

Fig. 12 FMS layout configurations in 3D form

V. CATEGORIZATION OF SUPERVISORY CONTROL PATTERNS

Categorization of supervisory control pattern for material flow, which is used repeatedly within FMS operations, is needed for rapid programming of control logic after determining the physical layout of FMS. Therefore, supervisory control patterns for material flows within FMS are classified according to their peculiar properties in this section.

When jobs flow within FMS to satisfy the machining requirements, their flow must be controlled properly to avoid blocking or deadlock situations. A job is a part or raw material requiring several processing steps. The tasks of job flow control are as follows: 1) mapping of source-destination facility, 2) job selection within job queue.

The mapping of source-destination facility is further classified into single flow and multiple flows from source to destination according to the number of invoked flows for transportation. Single flow is categorized to 3 sub-types: 1) Push mechanism control pattern which supplies jobs from supply place to demand places without consideration of demand-side state. 2) Pull mechanism control pattern which initiates material flow to demand place only upon receipt of demand request. 3) Matching control pattern which determines a pair of demand-supply place satisfying flow requirements among multiple demand and supply places.

Transfer synchronization control pattern, which invokes one or more other transfers by initiating one transfer from demand to supply place, stands for multiple flow control pattern. Transfer means movement of job between adjacent facilities.

The control pattern of job selection from queue chooses job(s) from job queue satisfying flow conditions.

In summary, there are five supervisory control pattern types for material flows within FMS as depicted in Figure 13. Figure 14 represents control mechanism of five supervisory control patterns by using several symbols.

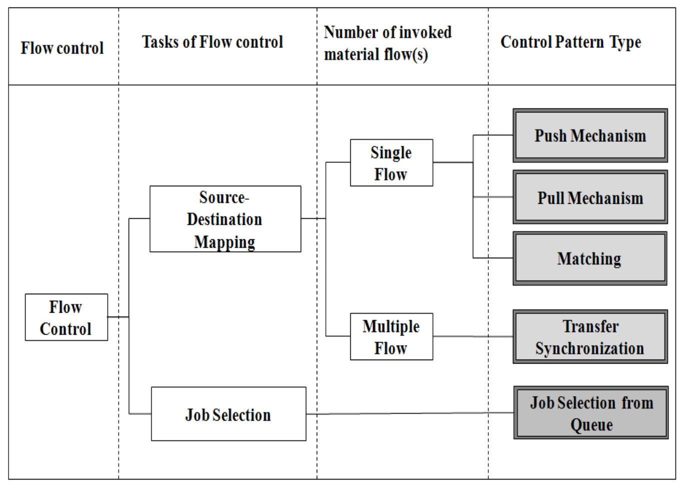

Fig. 13 Tasks of Flow Control

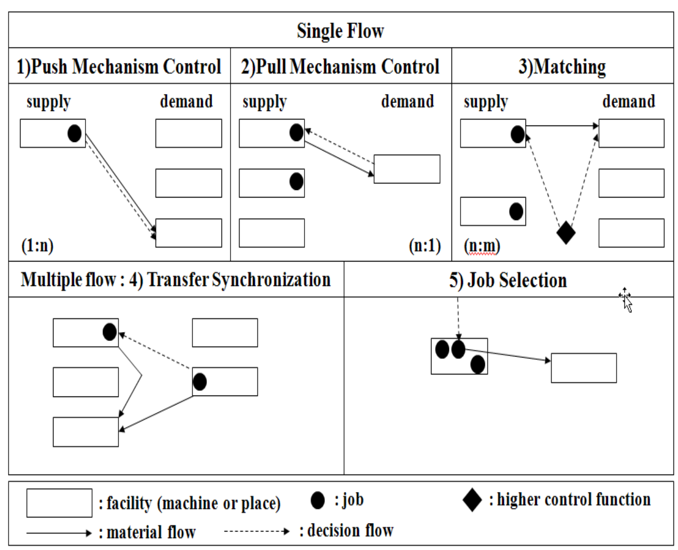

Fig. 14 Control Mechanism of Five Supervisory Control Patterns

As depicted in Figure 14, in the single flow, push mechanism control pattern occurs when the relationship of supply and demand place is 1:n. A pull mechanism control pattern occurs when the relationship of supply and demand place is n:1. And a matching mechanism control pattern occurs when the relationship of supply and demand place is n:m.

In Figure 14, rectangle stands for a facility or machine. Black circle means a job, and diamond stands for a decision making at the higher control function. Straight line stands for a material flow, and dotted line means a decision (or information) flow.

The characteristic of each control pattern is described in detail as follows: First, push mechanism control pattern is further classified into blocking avoidance and destination selection. Blocking avoidance control sub-pattern is for streamlining material flows. Blocking is resolved by reserving destination facility as depicted in Figure 15 in a form of Petri net. In Figure 15, square token means a job, and circle token means availability of facility. It means taking the priority of facilities' availability in advance. To flow without blocking to destination place, all facilities' availability within the route to destination must be preempted simultaneously before starting its movements.

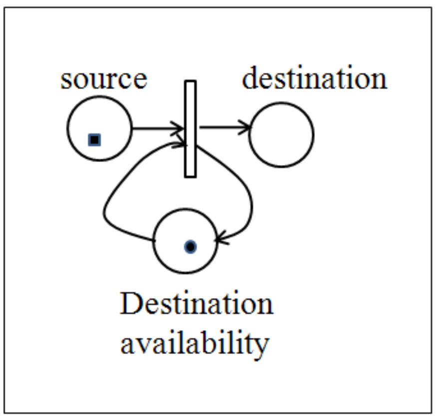

Fig. 15 Blocking avoidance control sub-pattern

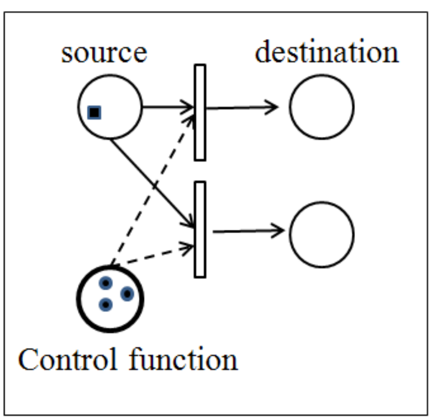

Fig. 16 Destination selection control sub-pattern

Destination selection control sub-pattern chooses one destination place among multiple available destinations as depicted in Figure 16. In Figure 16, the selection of destination is made by higher control function denoted by thick-rounded place and dotted line. The widely-used selection criteria are by priory, cyclic or max-capacity etc.

Second, pull mechanism control pattern initiates job flow only upon receipt of requesting jobs from demand place. When a job leaves demand place, it creates job request signal to supply place. In the supply place, this signal acts as a pre-condition for the job movement from source to destination place. This pattern is further classified to work-in-process control and supply selection. Work-in-process control sub-pattern is to control the number of jobs within a system or process. Kanban is a well-known typical work-in-process control pattern as depicted in Figure 17. Material flow from source to destination is only enabled if there is request of new job represented by Kanban. Supply selection control sub-pattern is to select one source place among multiple available places, and to continue to its flow as depicted in Figure 18. In Figure 18, the selection of source is made by higher control function denoted by thick-rounded place and dotted line. The selection criterion is by priority, utilization or cyclic etc.

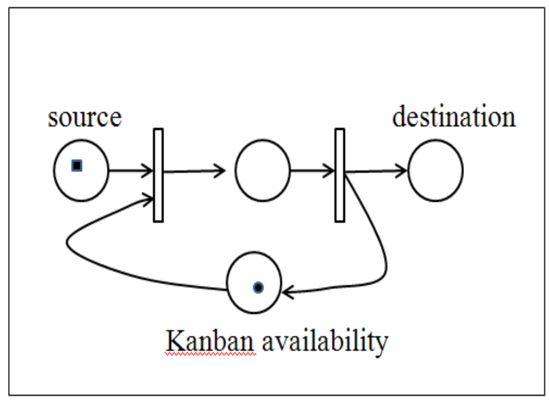

Fig. 17 Work-in-Process control sub-pattern

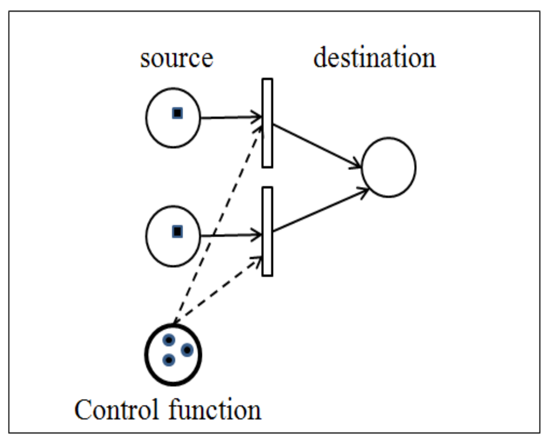

Fig. 18 Supply selection control sub-pattern

Third, matching control pattern is to select a pair of demand-supply place by certain decision rules when there are multiple supply places for multiple demand places. It is usually conducted by higher control function because real-time monitoring about demand-supply group status is needed continuously for selection of a pair satisfying required condition.

The primary condition for the matching is that there is a job in the source place for further processing and destination place is available for processing a job. Under this pre-condition, it needs two decision rules: a job selection from multiple sources to move, and a facility selection to process a selected job from multiple destinations.

Fourth, transfer synchronization control pattern is concerned with invoking one or more transfer(s) simultaneously by initiating one transfer operation. It is usually occurred between complimentary parts such as empty pallet and raw part. This control pattern is further classified to weak synchronization and strong synchronization. Weak synchronization control sub-pattern initiates a transfer after unconditionally sending a synchronization signal without checking the possibility of transfer synchronization. In the strong synchronization control sub-pattern, a transfer is delayed until synchronization with other transfer is possible by checking synchronization condition. Only when this condition is satisfied, transfer is initiated.

Fifth, job selection control pattern is concerned with choosing a job satisfying certain conditions from a queue or storage. The selection criteria are FIFO (First In First Out), LIFO (Last In Last Out), by priority etc.

VI. Conclusion

Manufacturing industries are under great pressure caused by the rising costs of energy, materials, labor, capital, and intensifying worldwide competition. In other words, external environment of enterprise are rapidly changing brought about majorly by global competition, cost and profitability pressures, and emerging new technology. In particular, agility separates the most successful businesses from those that simply get by in today's dynamic market environment.

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, 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. To do this, many manufacturing firms are making increasing use of virtual prototyping where a computer model is replacing the physical prototype. There are many benefits to this approach including more rapid development, lower cost, greater number of design alternatives evaluated and more optimal designs achieved.

In this paper, 1) rapid parametric layout determination, 2) construction of 3D discrete event simulation model by component reuse, and 3) categorization of supervisory control patterns for later reuse are proposed to shorten the time for FMS design.

To be a parameter-driven solution, our previous research [12, 19] is refined and extended in this paper. As a result, FMS is modularized by 'station'. Resources within FMS are standardized, and graphically symbolized. Proposed layout design and simulation procedure of FMS using LayFlex is as follows: 1) selection of FMS layout design parameters, 2) feasibility determination of layout alternatives, 3) 2D graphical FMS layout generation, 4) 3D layout simulation model creation for commercial simulation package, and 5) selection of supervisory control pattern and preparation of control program.

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

However, developed software in this paper lacks the functionality of designing detailed supervisory control logic for FMS. Therefore, as a further research, the UML(Unified Modeling language)-based design module for control logic based on the proposed control patterns is additionally required to develop an integrated tool for the design and verification of flexible manufacturing system.

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