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Modeling and Simulation of Manufacturing Systems in Unstable Environment

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***Abstract*—This paper proposes a new approach to model and simulate manufacturing systems in order to rapidly respond to the changes of the manufacturing environment, including the enhancement of the manufacturing processing, reconfiguration of the manufacturing resources and the dynamic control. A structural conceptual model is proposed to describe manufacturing systems, including product entity, processing unit and control center. Then, based on the structural conceptual model, the simulation system for the one specific manufacturing system is developed by importing the structural manufacturing information, and the result shows the contributions to the manufacturing management practice.**

***Index Terms*—Manufacturing System; Conceptual model; Modeling and Simulation**

I. Introduction

SIMULATION is one of the most frequently used techniques for the analysis and design of manufacturing systems, because it can save considerable time and money by viewing the dynamics of a complex manufacturing system, and provide insight into and a better understanding of those dynamics [1]. The literature is abundant in this filed, for example flexible manufacturing system (FMS) design, Just-In-Time system design, cellular manufacturing system design, performance analysis, real time control, operations and scheduling of manufacturing system [2]. As a result of adoption of innovative technology, increasing variety of consumer goods, and decrease in product life cycle, changes of manufacturing systems and environment are frequent and fast. Obviously, manufacturing firms have to quickly respond to these changes, and continuously improve the manufacturing systems in order to sustain their competitiveness [3]. That means all components constituted manufacturing systems are possibly changed. In such environment, the factors affecting the performance of the manufacturing systems, including manufacturing processes, manufacturing resources configuration, control policy and even organization mode, should be considered simultaneously. Furthermore, it requires reducing time of modeling. Consequently, the manufacturing system modeling becomes more and more difficult.

The object-oriented modeling language (OOML) can be used to reduce the time in simulation model design by reusing some simulation model [4]. However, the implementation of the simulation model is a difficult task, because OOML cannot guide the developers or users to transform system requirements into the simulation program [5]. Anglani et al [6] proposed an objected-oriented procedure, which provided developers of an integrated procedure that covers the whole development process. However, the general user still fail to collect the data and program the model because the shortage of the professional skills and experience in modeling and simulation. Serguei et al. presented a structure and components for complex manufacturing system and process control to support the on-line decision making [7], but they focused on only the control algorithm.

This paper proposes a new approach to build simulation models for manufacturing system in unstable manufacturing environment, and give a system to generate specific models from generic ones by retrieving the data from the manufacturing information system. The remainder of this paper is organized as follows. Section 2 presents the structural conceptual model of manufacturing system. In Section 3, an industrial application is described. Conclusion and future research is discussed in Section 4.

II. structural Conceptual Model

A manufacturing system can be considered as a group of different interacting components that are properly combined in order to process raw materials. The components of a system react to events by executing activities based on their roles and functions. The generic manufacturing system model constitutes the conceptual model of the simulator, which describes products, manufacturing processes, manufacturing resources, control and operational strategies, performance measurements. In order to structuring conceptual model, the corresponding conceptual objects are defined as following: the product entity (PE), the processing unit (PU), and the control center (CC).

The PE is the first conceptual object of the manufacturing system. It is a generic concept able to model all kinds of product, which is produced in the manufacturing system. Since the whole production is completed according to the manufacturing processing, which is describes the operations on the parts and their sequence, the PE has the following properties:

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- Product name: the product identification;
- Number of processing order: the sequence of the specific operation;
- Content processing: the description of the specific operation;
- Number of current processing order: the operation is going to be performed on the part;
- Current location: the current status of the part, in the workstation, the buffer, or the transportation device.

The PU is a generic object having all structural and functional characteristics of a manufacturing resource (machine, stock, conveyer …), and is able to model all kinds of resource. For simplification, according to the possible status of the part in manufacturing systems, three types of PU are defined as following: workstation unit, buffer unit and transportation unit, and their properties are presented as follows.

Workstation unit:

- Name: the identification;
- Manufacturing processing: the description of the operational function;
- Manufacturing resources: the bill of the consumed resources, including machines, worker, assistant tools;
- Processing time: the description of the time spent on the operation.

Generally, the processing time of the same workstation varies with the manufacturing processing and the resources configuration.

Buffer unit:

- Name: the identification
- Capacity: the description of the volume.

Transportation unit:

- Name: the identification;
- Starting point: the original location of the product;
- Ending point: the objective location of the product;
- Speed: the description of the time consumed in transportations.

According to the manufacturing processing constraints, the contextual relationship among workstation units can be identified. For generalization, one buffer is set in front of each workstation. The value of the buffer capacity can be set 0, and it means no buffer. All workstation units and buffer units are linked together by the transportation units to constitute the physical conceptual manufacturing system.

The CC is a generic object responsible for the locomotion of parts among workstations and buffers, and is able to model the structural operational decision. Its properties are presented as following:

- Name: the identification;
- Objective: the description of the expected outputs of the manufacturing system;
- Current system status: the description of the situation of the PE and the PU in manufacturing systems;
- Next system status: the description of the next time situation of the PE and the PU in manufacturing systems;
- Control algorithm: the description of the adapted control methods with the input and output parameters, which are represented by the situation of the PE and PU.

Given the manufacturing system and the objective, the CC makes decisions for the PE and PU. According to the type and the objective of the general manufacturing system, some specific control algorithms can be developed and associated with them.

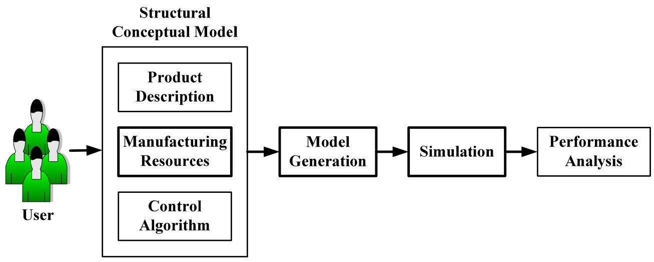

Fig.1 Modeling framework based on conceptual model

The main function of the structural conceptual model is to act as a template to support the generation of the customer's simulation model. An overview of the modeling framework based on structural conceptual model is shown in Fig.1. The conceptual object are created and linked to design the particular manufacturing system. It provides well-grounded means of developing hierarchical, modular analysis and evaluation models for manufacturing system. Even the general user can modify the manufacturing process, resources configuration and control policy to remodel the manufacturing system.

III. Case Study

A. Presentation

The case study was conducted by a simulation of manufacturing system using the structural conceptual model at one company producing the booster cable, located in Shanghai, China. It takes more than 15% of the global market, and the product variety is more than 200. Enormous amounts of money continue to be spent by the company to improve small-lot production with processes changed quickly from one product to another to better serve customers. Meantime, the company constantly adopts the new technology, upgrades the manufacturing processing, develops the new product, and reconfigures the manufacturing resources in order to keep the product competitiveness.

The manufacturing system consists of several production lines, and each line has the similar structure as following: the workstations are equipped with the buffer, the specific tools and several workers, and linked by one conveyer belt. The configuration of the manufacturing resources varies with the product and order in order to satisfy the manufacturing resources and keep the high performance of the manufacturing system. The objectives of the company also are adjusted to meet the customer's requirement, and accomplish the company strategy. However, in such unstable manufacturing environment, the company is faced

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TABLE I
MANUFACTURING PROCESSING OF PRODUCT

Sequence	Manufacturing Processing	Content Description
1	Assembly clip	……
2	Peel Cable	……
3	Rivet Cable	……
4	Refine	……
5	Rivet Tooth	……
6	Check	……
7	Pack	……

TABLE II
WORKSTATIONS OF MANUFACTURING SYSTEM

Name	Manufacturing Processing	Processing Time (Sec.)
AssClip1	Assembly clip	18
AssClip2	Assembly clip	17
AssClip3	Assembly clip	15
Peel1	Peel Cable	8
RivetCable1	Rivet Cable	8
Refine1	Refine	6
RivetTooth1	Rivet Tooth	21
RivetTooth2	Rivet Tooth	22
RivetTooth3	Rivet Tooth	21
Check1	Check	6
Pack1	Pack	32
Pack2	Pack	34
Pack3	Pack	35

TABLE III
WORKSTATION UNIT OF MANUFACTURING SYSTEM

Workstation	Type of Manufacturing Resources	ID
RivetTooth1	Worker	W0045
	Riveting Machine	RivM001
RivetTooth2	Worker	W004
	Riveting Machine	RivM022
Pack1	Worker	W017
	Worker	W021
	Worker	W041
	Packing Platform	PacP011
……	……	……

TABLE IV
BUFFER CAPACITY OF MANUFACTURING SYSTEM

Processing Stage	Manufacturing Processing	Buffer Capacity
1	Assembly clip	20
2	Peel Cable	10
3	Rivet Cable	4
4	Refine	10
5	Rivet Tooth	20
6	Check	4
7	Pack	20

with several challenges, a key one being to effectively manage the manufacturing system, including the analysis, evaluation and control.

B. Conceptual Model

One product, named HDP-B21H, is taken as an example to show the conceptual model and the development of the simulation system. Table I describes the manufacturing processing of the selected product. Since the processing content is too complex, and cannot spoil the model, the detail is not presented here. Table II presents the description of the workstation unit. The processing time is average. Actually, it is random, and even the average varies with the manufacturing resources configuration. For example, although RivetTooth1 and RivetTooth2 have the same resource configuration (See Table III), the average of the processing time is different as a result of the worker skill and the machine status. Table III describes the configuration of the workstation, RivetTooth1, RivetTooth2 and Pack1. Like the structure of the bill of material, other workstations have the same information structure. Of course, the real workstation composes of all kinds tools. We only consider the components that can significantly affect the processing time. Table IV describes the buffer capacity. Since the workstation at the same processing stage have the same function, one buffer is set in front of the processing stage and shared by the workstations of the same stage. In this case, the objective is to maximize the product capacity, and the production mode is the small batch. In order to keep the high efficiency of the workstation, the earliest idle workstation first rule is adopted as the control method.

C. Simulation system

Based on the above structural conceptual model, the simulation system (See Fig.2) is developed to support the management of the manufacturing system. All data in Table I to IV are saved in the Excel files. First, the data of the manufacturing processing is imported into the simulation system. Then, the files describing the workstations and buffers can be imported to generate the physical components as shown the upper part of the vertical line in Fig.2. The control method, the lower part shown in Fig.2, can be selected and loaded from the methods library developed for the simulation. When the model is run to simulate the manufacturing system, the product entity will generated and the properties will initiated. The performance analysis, including the product capacity, cycle time and WIP, can be conducted by the simulation.

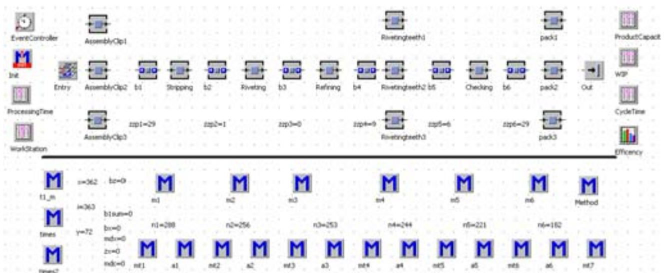

Fig.2 Simulation system based on structural conceptual model

D. Results

When the manufacturing environment is changed, the user can rapidly modify the workstation number, the processing time according to the reconfiguration of the resources, the capacity of the buffer, and change the control method to remodel the manufacturing system. The application shows that the system can effectively help the user to rapidly response to the change of the manufacturing environment.

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IV. Conclusion

In a post-industrial environment, changes of manufacturing systems and environment are frequent and fast, as a result of increasing variety of consumer goods and decreasing of product life cycle. The traditional methods modeling manufacturing system for simulation is a time-consuming ask, and cannot quickly response to the changes, which limits the usage of the simulation technology. A structural conceptual model is proposed to describe the components of manufacturing systems, including the product entity, processing unit and control center. One case simulation system is developed to show the efficiency of the structural conceptual model. Since manufacturing systems have the different structure, organization, and function to satisfy the different strategy, it is impossible that a generic model can be applied to all kinds of manufacturing system.

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