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Material-flow Modeling Technology and Its Application in Manufacturing Execution Systems of Petrochemical Industry*

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Abstract The management and control of material flow forms the core of manufacturing execution systems (MES) in the petrochemical industry. The bottleneck in the application of MES is the ability to match the material-flow model with the production processes. A dynamic material-flow model is proposed in this paper after an analysis of the material-flow characteristics of the production process in a petrochemical industry. The main material-flow events are described, including the movement, storage, shifting, recycling, and elimination of the materials. The spatial and temporal characters of the material-flow events are described, and the material-flow model is constructed. The dynamic material-flow model introduced herein is the basis for other subsystems in the MES. In addition, it is the subsystem with the least scale in MES. The dynamic-modeling method of material flow has been applied in the development of the SinoMES model. It helps the petrochemical plant to manage the entire flow information related to tanks and equipments from the aspects of measurement, storage, movement, and the remaining balance of the material. As a result, it matches the production process by error elimination and data reconciliation. In addition, it facilitates the integration of application modules into the MES and guarantees the potential development of SinoMES in future applications.
Keywords manufacturing execution systems, dynamic material-flow model, material-flow events

1 INTRODUCTION

Currently, the management and control of material flow is a topic that challenges the manufacturing execution system (MES) community [1, 2], especially in the processed product domain such as the petrochemical industry. A part of this flow may be simply treated with the method of the static material set, in which the primordial principle is the enumeration of the category and quantity of materials, but it is difficult to adapt the dynamic environment of changing material flow in this model. A much more smart technology needs to be discovered and refined to work well [3].

Smart MESs require the services of manufacturing entities, *e.g.* resources such as production-cells, equipments, and workers, so as to achieve their production needs [4-6]. These resources could smartly organize themselves, based on their own knowledge and on a flexible cooperation policy, to carry out the smart-product requests. However, this cooperation is difficult, mainly because the elements of the factory are heterogeneous.

The material-flow management and control in petrochemical industries seems to be a big challenge because there are physical and chemical changes of materials during the complicated and long production processes. Liquids, gases, and solid materials coexist. Materials flow or stay in the network of devices and storage areas, entering/leaving factory points, undergoing the various processes such as mixing, separating, alternating, recycling, and elimination of materials. This material path is considered as a microconcept of material flow. This diversity of modalities could be homogenized and integrated by their encapsulation, in an abstract manner, into models constructed through an adaptive and dynamic procedure. Hence, smart MESs embedded with these models could also serve as "holons", able to treat different kinds of dynamic problems occurring in complicated production processes.

The intention of this study is to propose a conceptual solution as a meta-model for adaptively-driven logistics-model construction. This solution is also used to improve a design and simulation tool for MESs of the Chinese petrochemical industry, called the SinoMES V2.0 [3], toward the evolution of a holonic manufacturing system (HMS).

A future objective is to present this meta-model and its automatic and adaptive construction method as an engineering tool that aids in the composition of such systems, using a set of holons and their relationship that has been previously developed and tested. The quality of the meta-model would allow a reduction in the time for system composition, and address more accurately real material-flow conditions in the production process. This is observable in the SinoMES V2.0 context, some experiments based on it demonstrating the potential of the solution.

2 BASIC ELEMENTS OF THE LOGISTIC MODELS

Process enterprises involve continuous or intermittent physical and chemical changes as their main production modes. Liquids, gases, and solid materials coexist. Materials flow or stay in the network of devices and storage areas, entering/leaving factory points, undergoing the various processes such as mixing, separating, alternating, recycling, and elimination of materials. The entire procedure is considered to be a microconcept of material flow.

According to the logistic management and control requirement of the computer integrated process

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system (CIPS) [7], the definitions of the basic elements in a logistic model are given as follows:

Definition 1: Set of production units

$$U=\{u_k \mid u_k \in (D \cup S \cup J)\}, \quad (1)$$

where devices are assumed to be the processing centers, d_a, constituting a processing center subset $D=\{d_a\}$; storage areas are assumed to be the storage centers, s_g, constituting a storage center subset $S=\{s_g\}$; factory entry/exit points are assumed to be the entry/exit centers, j_n, constituting an outgoing center subset $J=\{j_n\}$, including both the virtual recycling factory and the discarding factory; and $k=1, \cdots, K$; $a=1, \cdots, A$; $g=1, \cdots, G$; and $n=1, \cdots, N$.

Definition 2: Set of materials

$$M=\{m_i \mid m_i \in (R \cup C \cup P)\}, \quad (2)$$

where $R=\{r_w\}$, $C=\{c_y\}$, and $P=\{p_z\}$ represent the subset of materials, categories, and finished products, respectively, $i=1, \cdots, I$; $w=1, \cdots, W$; $y=1, \cdots, Y$; and $z=1, \cdots, Z$.

Definition 3: Set of moving relationships

$$X=\{\text{move}(m_i(u_k), m_j(u_e), \text{MQ})\}, \quad (3)$$

where the flow, alternation, recycle, and elimination of materials are considered as the logistic movement of the materials. move ( ) represents the movement relationships: $m_i(u_k)$ indicates the original material, m_i, output of the original unit; $m_i(u_e)$ indicates the terminal material, m_j, received by the terminal unit, u_e; MQ represents the material quantity; $m_i \in M$, $m_j \in M$, $u_k \in U$, and $u_e \in U$. Due to the fact that the same material in a logistic model can not have a moving relationship in the same production unit, it should meet the following requirements:

If $m_i=m_j$, then $u_k \neq u_e$; and if $u_k=u_e$, then $m_i \neq m_j$.

In addition, because the storage area is a regional concept and can not be considered as a network node in the material model, if $m_i(u_k)$ ($u_k \in S$), then m_i is selected as a logistic node of material. If $m_i(u_k)$ ($u_k \notin S$), u_k represents a node of device or the factory entry/exit point. It is thus the same as $m_j(u_e)$.

Definition 4: Set of deposit relationship

$$V=\{\text{deposit}(s_g, m_q, \text{SQ})\}, \quad (4)$$

where deposit(s_g, m_q, SQ) represents the relationship of the materials, m_q, in a storage center, S_g, and SQ is the storage quantity ($m_q \in M$, $s_g \in S$). If the relationship exists, m_q becomes a node in the model.

Logistic modeling aims to select elements of U or M to be nodes and to realize the right network connections on the basis of the logistic relationship of X and V. In the model, MQ and SQ describe quantitative data. On the contrary, static modeling, based on enumeration rules, is a process that enumerates and stores U, M, X, and V obtained from historical records and expert experiences, and thereafter creates models from these data.

3 LIMITATIONS OF MODELING BASED ON ENUMERATION RULES

In corporations, there are periodic production plans and optimization of the producing arrangement. Because of the possible unanticipated changes in factors such as the market demand, the raw-material supply, and the processing conditions at any time, the dynamic dispatch instruction on the basis of real-time issue immediately causes dynamic changes in the logistics structure [1, 2]. These dynamic changes mainly include multiple varieties and mixing dynamics of the raw material, the switching dynamics of the installation's processing plan, the choice dynamics of the finished product-congruousness plan (aimed at liquid products) and so on. In addition, because of continuous factory transformation, the production units, including the processing center, inventory center, and turnover center, also undergo changes along with the material system. Therefore, the static-logistics model encounters the following difficulties:

(1) The static state (X, V) obtained by the current enumeration can not completely cover the logistics condition-to-be; when the real relations go beyond the scope that (X, V) describe, it results in the failure of the logistics-data integration and the further application that is based on the former.

(2) The scope of the logistics model obtained through enumeration is too huge, which contains numerous nodes and relations that do not make sense, making the calculating process of the upper application module (*e.g.* logistics data reconciliation) more complicated, and consequently decrease the operating efficiency of the system.

(3) When both the production-cell construction and the material system change, the model must be reconstructed. All the possible movements and storage relations must be enumerated to renew (X, V). The model-maintenance load thus becomes heavy.

Therefore, it is necessary to design and set up a dynamic-logistics model, which changes with the needs and enhances the CIPS lifecycle, reduces the system-maintenance load, and promotes the operating efficiency.

4 DYNAMIC-LOGISTICS MODELING BASED ON INCIDENT RULES

U and M are used to describe the production unit that participates in the corporation's logistics constitution, whereas X and V are used to describe the logistics relation between U and V. According to the definition above, the information about the elements that constitute U and M is sure to be included in the elements of U and V that connect them, and whether the elements of X and V consist in the real logistics depends upon the material movement and the storage event, which is called a logistics event. Therefore, on the basis of the data-platform module, which is used to collect, integrate, and supply production data in CIPS [3], through constructing and capturing integrated logistics-event information, the elements of U, M, X, and V that occur in the current real logistics can be ascertained, and the production unit and material information about the events going beyond the described scope of the current U and M can be determined; the dynamic-logistics model related to time