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THE METHODOLOGY OF VIRTUAL FOUNDRY DEVELOPING

METODYKA TWORZENIA WIRTUALNEJ ODLEWNI

Systemic approach to design of factories requires that engineering, organisational and economic aspects should be considered concurrently. That prompts the need to develop a solution, based on the state-of-the-art IT technologies, to enable us to solve the problems associated with foundry production planning. The paper outlines a methodology of creating the simulation model of a virtual foundry, as a tool for foundry design. An integrative approach is suggested for development of a complete foundry model, enabling the design of more efficient production systems. The underlying principles of such models are discussed, the basic stages involved in the methodology are outlined and the range of its applicability is defined.
Keywords: Virtual foundry, Modeling, Simulation

Systemowe podejście do projektowania bądź rekonstrukcji systemów wytwarzania wymaga równoległego rozpatrywania zagadnień technologicznych, technicznych, organizacyjnych i ekonomicznych. Stwarza to potrzebę opracowania rozwiązania, opartego na najnowszych osiągnięciach technologii informatycznych, pozwalającego na kompleksowe rozwiązywanie problemu projektowania systemów produkcji odlewniczej. W pracy przedstawiono metodykę tworzenia (budowy) modelu symulacyjnego tzw. wirtualnej odlewni jako narzędzia projektowania zakładu odlewniczego. Zaproponowano iteracyjne podejście tworzenia kompleksowego modelu odlewni, dające w efekcie możliwość projektowania bardziej wydajnych systemów wytwórczych. Przedstawiono zasady konstrukcji takiego modelu, opisano podstawowe etapy metodyki oraz określono możliwości jej zastosowania.

1. Introduction

Systemic approach to design of factories requires that engineering, organisational and economic aspects should be considered concurrently. All stages of the design process and the decisions made are interrelated and must not be regarded as individual decision-making problems. Therefore, the design process becomes a complex-structured task requiring adequate methods of process control and techniques to help solve individual, partial problems. One of such techniques, widely employed for years, is computer simulation enabling us to verify several variants of solutions to the given problem and to evaluate their effectiveness and risk that each option involves.

A virtual manufacturing system or a virtual factory is an integrated computer system, emulating the physical and logical structure and the behaviour of a real system. The concept of a virtual factory can be interpreted in several ways, the interpretation which appears to best meet the case is the conventional one whereby it is viewed as a metaphor for integration of a variety of software, modelling tools and decision-making methods to support solutions in the field of manufacturing [4].

This paper briefly outlines the methodology of developing (creating) a simulation model (a virtual foundry) as a tool to be used in design of a foundry plant. The underlying principles of constructing a virtual foundry are given and the applicability of the proposed system is discussed.

2. Overview of available solutions

The literature on the subject abounds in reports on methods employed to create virtual plants, giving examples of problem solutions in various sectors of industry, however, there are few publications only having relevance to foundry engineering. Besides, they tend to focus on tool aspects, leaving aside the methodology. Thus no tools are available to effectively support virtualisation of foundry plants [5], which has prompted the need to develop a comprehensive methodology of a virtual foundry plant design, taking into account the system approach and new IT developments.

The general approach to the development of virtual factories involves the following aspects: information about the real manufacturing processes is collected and given in tables describing the process. The process description underpins the 2D simulation model of the production system. Simulation modelling of manufacturing processes typically uses commercially available software packages (such as Arena, eM-Plant, Catia, Plant Simulation) providing an integrated environment for the

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description of systems and the ways they operate (relationships and rules) as well as random number generators and statistical tools. Verification and validation of the model are followed by experiments which generate results and reports based on the simulation procedure. Besides, dynamic 3D models can be also created, in accordance with underlying principles of the virtual reality.

Wenbin et al. [7] presented the structure and architecture of an integrated simulation method (ISM) to support the virtual factory engineering. Combination of CAD, virtual reality and discrete simulation methods creates the environment of static and dynamic simulations for implementing the virtual factory throughout its entire life cycle. Static simulation is applied in evaluation of the production plant (location of machines and installations). Dynamic simulations enable a direct evaluation of the plant's ergonomic features, production capacity and performance of the work schedule, allowing for safe training of plant operators. The paper provides an overview of key method components, including the Virtual Factory Data Management Systems (VFDMS) and the static and dynamic simulation procedures. The quality of the ISM method was verified by investigating a case study of an assembly plant.

Chougule et al. [1] developed a web-based system to support the modelling of a virtual foundry plant, shown schematically in Fig. 1. In this approach a virtual foundry comprises information about the manufacturing processes and resources, the resources being the machines and tools used in production and in support activities. The equipment model captures the static information about the machine specifications and its operating parameters, in the context of manufacturing of particular products. The proposed virtual foundry concentrates on cast design and production planning. Nevertheless, the project is still at the stage of conceptual work and is not further developed.

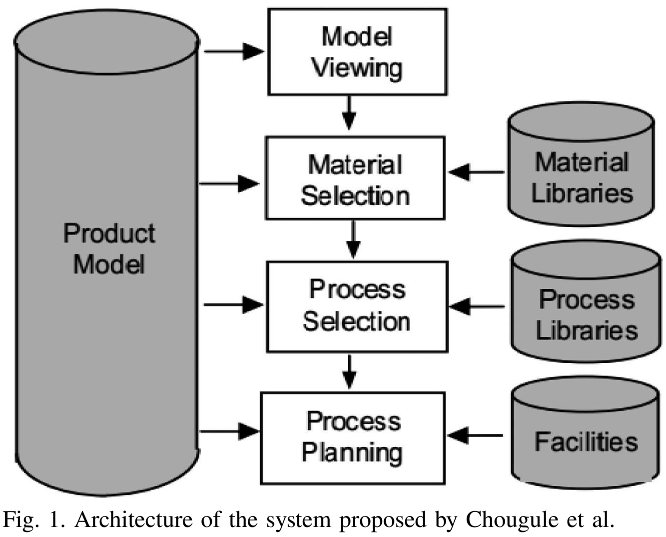

Fig. 1. Architecture of the system proposed by Chougule et al.

Manesh and Schaefer [2] presented an agent approach in the VR-HMS (Virtual Reality-Holonic Manufacturing Systems), an integrated methodology of design and operation of holonic agile manufacturing systems. HMS is a combination of hierarchical and heterarchical control structures by means of co-operating holons (agents), involving:

– creation of the virtual manufacturing environments based on functional and agent control requirements,
– identification of holons and holarchies for modelling holonic control MAS architectures in a wrapper model,
– performing distributed control of manufacturing devices and execution of control functions in VF operations.

Actually the methodology is based on integration of two crucial environments: the agent control sub-system and the Virtual Reality model. The VR model captures 3D elements of the production system whilst the holonic control model includes the agents and represents the basic operational and storage components.

The Virtual Factory Framework (VFF) developed under the European program 'Virtual Factory' [6] can be defined as an 'integrated collaborative virtual environment aimed at facilitating the sharing of resources, manufacturing information and knowledge, while supporting the design and management of all the factory entities, from a single product to networks of companies, along all the phases of their lifecycles'. In the context of methodology of creation of virtual factories, of particular importance is the VFDM (Virtual Factory Data Model) sub-system intended for modelling of manufacturing systems and for evaluation of their performance. The Virtual Factory Data Model extends the existing technical standards so that they should capture the key aspects of manufacturing systems: products, manufacturing processes and resources. The VFDM is mainly based on the IFC standard release IFC2x4 RC2 that was translated into a set of ontologies by employing the Semantic web approach.

This brief overview of the literature on the subject leads us to the following conclusions:

– there is no single methodology of a virtual foundry design,
– the proposed solutions are still incomplete, focusing mainly on product design and tool specifications without treating the foundry as a system.

3. VFSO methodology

This section briefly outlines the objectives of the Virtual Foundry Simulation and Optimisation (VFSO) system developed by the authors to support the simulations of the foundry system models. The system effectively combines the tools for modelling production systems, IT systems and decision-making systems. It is assumed that the following requirements should be met:

– the production structure, the IT structure and IT and decision-making processes must be modelled in a user-friendly manner,
– the system will enable a set of basic universal modules for modelling, simulation and analysis of results and which can be expanded to incorporate the components focused on problem solving,
– the tool should be able to support team work and management of knowledge about the project,
– the system should be open, to enable the data transfer from and to the required tools via generally available management information systems,
– the system should be provided with interfaces allowing

the use of systems supporting the decision-making and statistical analyses.

The VFSO methodology involves five subsequent stages:

1. Development of the general operating principle of the system and its sub-systems, taking into accept the flow of materials, energy, tools and information.
2. Creating the model of the basic system components (resources, processes, products) in accordance with the adopted ontology.
3. Relationships between the system components taking into account the flows of materials, energy and control.
4. Model validation and verification.
5. Conducting the project experiments and selection of the optimal foundry design.

The key aspect of the methodology is the model of the system components. A virtual foundry involves information about the products, resources and processes in the foundry plant. The resources include machines and tools used in casting. Information about the production resources captures mostly the static information, such as machine specifications and operating parameters of machine needed to manufacture a particular product.

Two methods are available to support the description of components of the virtual factories: database solutions and XML-based ontologies. In the first case the relational database is equipped with a set of ready-made objects in the form of predefined tables (containing the data on manufacturing units, products, orders, customers), which can be developed by the user by means of the data manipulation languages and the standard query language SQL. For our purposes, we needed a simple ontology focused on aspects of manufacturing system description and production scheduling. The methodology uses the PPS language, compatible with the XML standard, developed by the consortium of the leading Japanese manufacturers (Hitachi, Toshiba), universities and suppliers of IT systems [3]. This standard has been accepted by OASIS and has now become the basis for OASIS Production Planning and Scheduling specification (PPS).

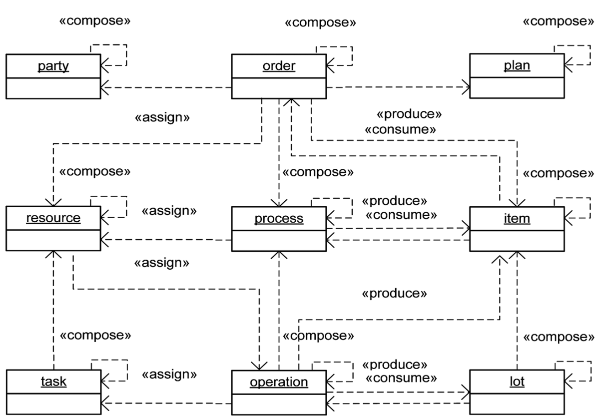

Fig. 2. Key objects of the PPS specification

The PPS ontology allows for storing information about the business partners, manufacturing processes, materials, products, resources, status events during the manufacturing process and cost calculations. The key items in the PPS specification are shown in the UML diagram (Fig. 2). The present standard of the language includes the definition of 9 basic and 5 relation-defining items. Besides, it defines 4 specific items (location, capacity, progress, spec) and 3 items relating to the status events (start, end, event) as well as 2 economic items (price, costs).

In the proposed methodology the PPS can be used in two modes: basic and extended. The basic mode involves the items sufficing to model the operation of the production system (resource, process, item), the extended method allows for modelling of the planning system (the remaining components).

This approach enables the virtual foundry to be created as a basic production system or as a system aimed to optimise the production plans and schedules.

4. A model of the sand preparation sub-system

The first stage of the proposed methodology is illustrated by the example of the sand preparation sub-system; this stage involves the general operating principle of the sub-system, taking into account the flow of materials, energy, tools and information.

The sand processing sub-system is a group of machines which receive and supply the moulding sand to tanks on the moulding stations, in a programmed manner. The sand has to be specially prepared to give it the required properties, so that it should meet the requirements imposed by the process technology. The process involves interacting machines and installations connected via the means of transport. The model of the sub-system and its environment, shown in Fig. 3, defines the structure of the process, regardless of the sand processing technology.

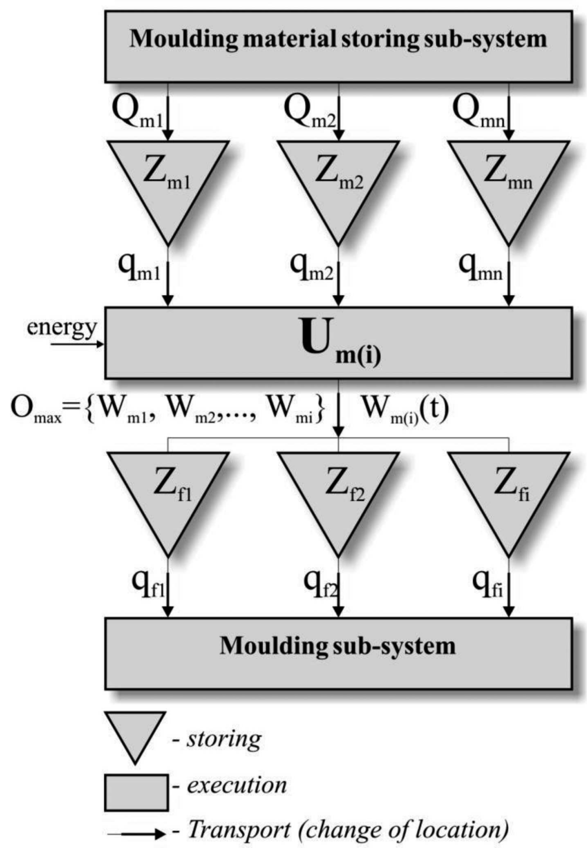

Fig. 3. Model of a process within the sand preparation sub-system

Designations:
$Q_{m1}, Q_{m2}, \ldots, Q_{mn}$ – amount and the type of sand components, capacity of the transport systems supplying the tanks over the mixers
$Z_{m1}, Z_{m2}, \ldots, Z_{mn}$ – parameters characterising the tanks over the mixers
$q_{m1}, q_{m2}, \ldots, q_{mn}$ – tank loads, percentage fraction of sand components in the function of mixers' operating time
$U_{m(i)}$ – characteristic of the mixer [(i) – ordinal number]
O_{max} – production capacity of of the sand preparation sub-system, where $O_{max} = \{W_{m1}, W_{m2}, \ldots, W_{mi}\}$
$W_{m1}, W_{m2}, \ldots, W_{mi}$ – efficiency of mixers
$Z_{f1}, Z_{f2}, ..., Z_{fi}$ – parameters characterising sand tanks over the moulding stations
$q_{f1}, q_{f2}, \ldots, q_{fi}$ – tank loading: the amount of sand received by the moulding stations

The formal description of the sub-system recognizes the relationship between input and output parameters (Fig. 4). Input data include the technological and operational aspects: flow of materials (loose and liquid ones), energy, installation, process control, information flow. Output parameters include some technological relationships: type of the process, the number of involved machines, production capacity, energy demand, organisational structure of the process. Thus prepared description, supplied with concrete data, becomes the starting point for developing the model of the sub-system, in accordance with the item specification *Resource*, available in PPS.

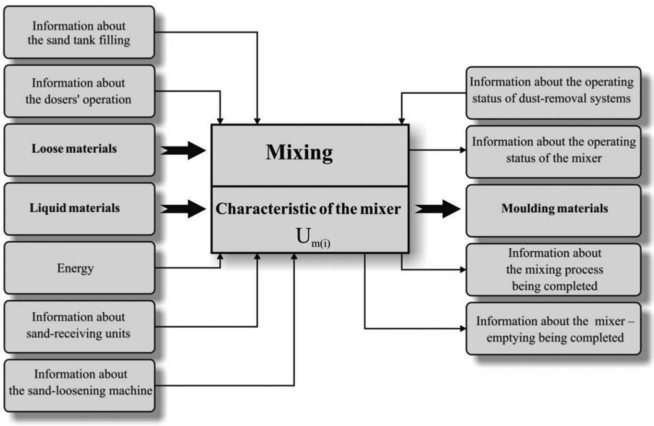

Fig. 4. Parametric description of the sand preparation installation

5. Directions for further research

The VFSO methodology is still being developed. It is mainly intended to support the modernisation of foundry plants and to help overcome a variety of design problems, such as:

- selection of the production capacity level depending on the accepted sales plan,
- harmonising and synchronising the manufacturing processes,
- evaluation of cost-effectiveness of projected solutions,
- selection of the optimal process technology,
- preparation of blueprints and technical documentation,
- verification of production planning algorithms,
- restructuring of business processes.

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