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Multi-level management of discrete event simulation models in a product lifecycle management framework

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Abstract

Discrete event simulation (DES) models imitates the behavior of a production system. Models can be developed to reflect different levels of the production system, e.g supply chain level or manufacturing line level. Product Lifecycle Management (PLM) systems have been developed in order to manage product and manufacturing related data. DES models is one kind of product lifecycle's data which can be managed by a PLM system. This paper presents a method and its implementation for management of interacting multi-level models utilizing a PLM system.

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Keywords: Discrete event simulation; Product lifecycle management; Multi-level simulation

1. Introduction

Virtual models have been widely used in industries due to the many advantages of utilizing them. They can reduce the time to market by reducing time for different experiments. Using virtual models are also cheaper than doing experiments in the physical world.

Discrete event simulation (DES) models as one type of virtual model had been used for many years [1]. In DES, the state variables' changes is tracked at a discrete set of points in time. In manufacturing industries, DES can be used

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for simulation of production systems in different levels of the manufacturing system's hierarchy such as plant, areas and production lines. Product Lifecycle Management (PLM) systems has been developed for managing product and production related data and management of DES models is a one type of that.

A methodology for managing of DES models for different levels of production system will be presented in this paper. With this methodology, an information structure will be built for saving, searching and retrieving, multi-level DES models. In traditional DES models, the whole manufacturing system had been modeled with all details, or a desired section of the system, had been modeled without connection to other sections or levels of that manufacturing system. In multi-level DES modeling, different sections and levels of manufacturing system, are modeled separately and in detail and later they are aggregated in the model of higher level.

In the following, at the beginning of the background section, PLM systems and DES are explained briefly, as two application areas of this research. Afterward, previous researches about multi-level simulation will be introduced and a gap which needs to be filled with this research will be highlighted. In the third section, a case study will be explained. In the methodology section, managing of multi-level DES models and their related data will be explained, step by step and last section is about conclusions and future works of this research.

2. Background

In this section, the background about PLM system and DES will be presented.

The PLM system as a platform for managing data, and DES models as entities which supposed to be managed, are two main parts of this multi-level management.

2.1. Product lifecycle management system

Anything that is manufactured and offered to the market is a product, and each product has a lifecycle. A product's lifecycle can be divided into different phases: Business idea, requirement management, development, production, operation, maintenance, and disposal. These are six typical phases during the product lifecycle, and PLM systems are managing product, process and resource data through these phases [2].

Since PLM is used for managing product, process and resource (PPR) data, then the Bill of Material, Bill of process and Bill of resources are three main information structures of a PLM system [3,4].

Bill of Martial (BoM) is the product's structure and consists of different parts and assemblies of a product. Bill of Process (BoP) shows different processes and their relationships for manufacturing a product. Bill of Resource (BoR) is a factory's structure and contains the resources which are needed for producing a product.

These three information structures are hierarchical structures and in the hierarchical structures entities at each level have been divided to sub-levels. These multi-level structures can be used later for the multi-level management of DES models.

2.2. Discrete event simulation

Simulation is a procedure of using a model to study the characteristics and behavior of a physical or conceptual system. In the simulations, one or more variables in a model are changed in order to see this affect the results [5,6].

Simulation models can be classified in different ways, but they are belong to two main groups; continuous and discrete. Continuous simulation models, simulating continuous systems which the state variable or variables change continuously over time. But in DES, discrete systems have been simulated. In the discrete systems, which the state variable or variables change only at a discrete set of points in time [7].

DES can be used in different application areas. In this paper, the focused area is a manufacturing application. Typically DES applications enables simulation, visualization, analysis and optimization of production systems and logistics processes, by modeling manufacturing processes. Since manufacturing processes are modeled based on the manufacturing physical equipment in the enterprise, this modeling can be done at different levels with respect to the hierarchical structure of manufacturing systems. Fig. 1 shows two hierarchical models of manufacturing systems that are defined in the ISO and NIST standards [8,9].

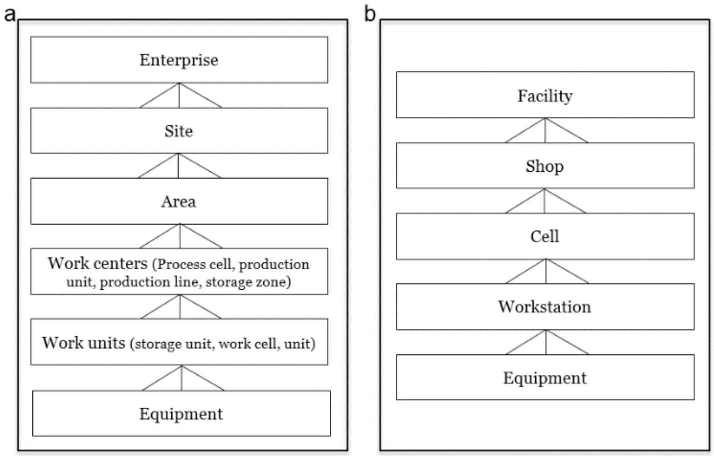

Fig. 1. Manufacturing system Models (a) IEC 62264-3; (b) NIST

DES software programs can model manufacturing systems at different levels, such as enterprise, site, area, etc. The scope of this paper is about managing DES models in a PLM context, hence the implemented case study limited to the site (factory) and area levels. The case study will be explained later in this chapter.

2.3. Multi-level simulation

Multi-level simulation methodologies have been used before in different types of simulations. As an example, multi-level simulation has been used for simulating the Internet of Things (IoT). A framework has been presented and employed that allows simulating large-scale IoT environments while keeping high levels of detail when it is needed [10].

Previous researches about multi-level simulation can be divided into two different types according to their application domains:

- Those researches which investigate in co-simulation of heterogeneous systems. They try to integrate different simulation systems on different levels of aggregations and provide proper interfaces to connect them to each other [11–14].
- Others, working on Multi-level simulation approaches for specific domains, like process and material flows domains, simulation modeling of complex robot systems and etc.[15–17].

This paper is about managing DES data, and it focuses on a specific domain. For DES In an aggregation technique suitable for manufacturing systems optimization is proposed, analyzed and tested by Pehrsson and their colleagues [18], [19]. The proposed technique focused more on simplifying a detailed low level systems into fewer objects and used those objects in the aggregated level, and it is more about processing data in and between different levels.

According to these literature review none of above researches focused on managing multi-level DES models and their related data for saving, searching and retrieving those models and data. This is a gap which can be filled with presented methodology on the PLM platform.

3. Case study explanation

For this study has, three simulation models been designed for two different levels of a manufacturing system; site level and work center level. The case study is a simulation model of a shaft plant at the top level, which consists of two production areas; machining area and assembly area (Fig. 2).

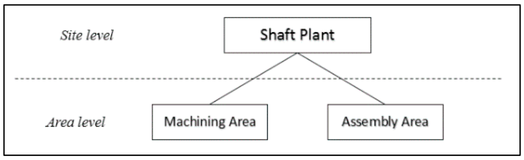

Fig. 2. Simulation levels of the case study

For each area, a DES model has been developed. In this case study, Siemens Teamcenter was been used as PLM system and Plant Simulation as DES tool [20], [21].

4. Methodology

The presented methodology for managing DES models and their related data is divided into three main steps;

- Preparation in the PLM system
- Discrete event modeling and simulation
- Information structuring in the PLM system

In the following, these steps will be explained combined with their implementation in the case study.

4.1. Preparation in the PLM system

There are some preparations needed to be done in the PLM system before starting DES. As previously mentioned, Bill of Material, Bill of Process and Bill of Resources have to be defined and structured in the PLM system as the core of PLM data.

Through the definition of these structures, some of required data for DES will be embedded in the product, resource and process items in the PLM systems such as 3D models, the breakdown times, availability, mean time to repair, start time, and work time, etc. This data and models with information about those three structures can be exported as PLMXML and JT files [22], which can be used by the DES modeler.

In the case study, the simplified Bill of Material consisted of two parts; a rod and a nut. The shaft plant is defined as a top level of BoR and it is divided into two areas; machining and assembly. The machining area is divided into a turning line and milling line. Two lathe machines are assigned as resources to the turning line and one milling machine is assigned to the Milling line.

For structuring the BoP, the shaft production is divided into machining processes and assembly processes. Machining processes consist of turning, threading and reaming operations, for manufacturing of rods and nuts. In a succeeding process step will the rods and nuts be assembled in the assembly processes, by two robots (Fig. 3).

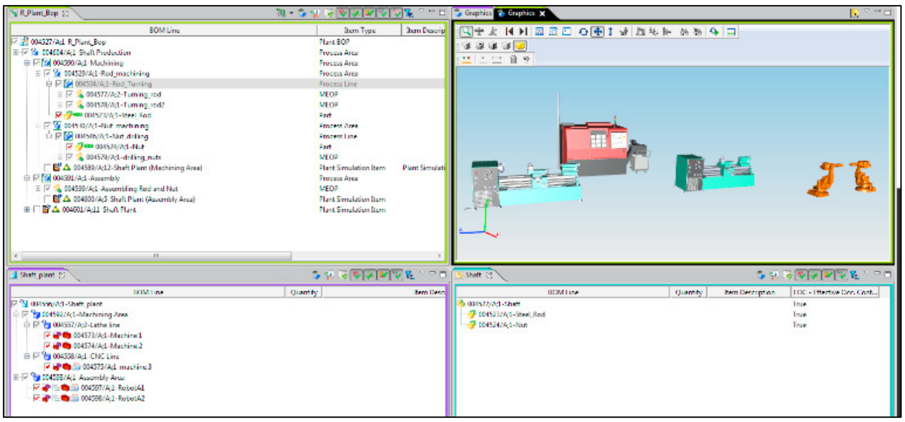

Fig. 3. BoM, BoP, BoR with 3D models of resources in Teamcenter

In addition to 3D models, some information such as machineries’ availability and their mean time to repair also added to their corresponding items in the PLM system.Information which includes the structures with simulation relevant properties and JT files was exported as a PLMXML file and different JT files. For this purpose an application interface in Teamcenter, which has been used for transferring data between Teamcenter and an external application, had been used. Thereby are, information, data and models prepared to be imported and used by the DES application.

4.2. Discrete event modeling and simulation

There is a “Teamcenter Object” available in Plant Simulation for importing data from the prepared PLMXML file and also exporting reports back to Teamcenter.

By using SimTalk and a coding in a “Method” object in the Plan Simulation software, the production line with 3D models can be modeled. In this case study, a table which consists of all data about product, processes and resources is created automatically from the PLMXML file.

Since, this paper reports on multi-level DES, for this case study three different simulation models were developed. All of those three models, used same exported PLMXML file from Teamcenter, but each of them used those data that are related to their modeled processes.

One of the files, modeled machining area and simulated processes in that area. The second one modeled assembly area and simulated assembly processes. The third file is used to aggregate those two models as the shaft plant model (upper level) (Fig. 4).

It is not possible in the Plant Simulation software for connecting or integrating these model files to each other in a way that if a user can modify one of the area’s model, the plant (overall) model also be updated automatically. Because of that, area’s models have been defined as libraries in Plant Simulation, and then these libraries are used in the plant model as frames.

With this method, if a user modifies an area’s model, and updates that model, then another user can update the libraries in the plant’s model and run the simulation with the updated model.

This multi-level simulation method provides this opportunity to the users that instead of simulating the whole plant which is time-consuming, only doing their experiments on the desired area and after finding favorable solutions, update the area’s model and see its effects on the whole plant. On the other hand, if the simulation of the plant’s model needs a modification in one area, then the detailed analysis of that area is possible by using the detailed model of that area.

As mentioned before, an HTML report can be directly exported to Teamcenter, by using the “Teamcenter Object” in Plant Simulation. The DES model’s file also can be added to the Teamcenter database as a “Plantsimulation Dataset”. All three files of DES models and their reports must be added and managed in the Teamcenter Software.

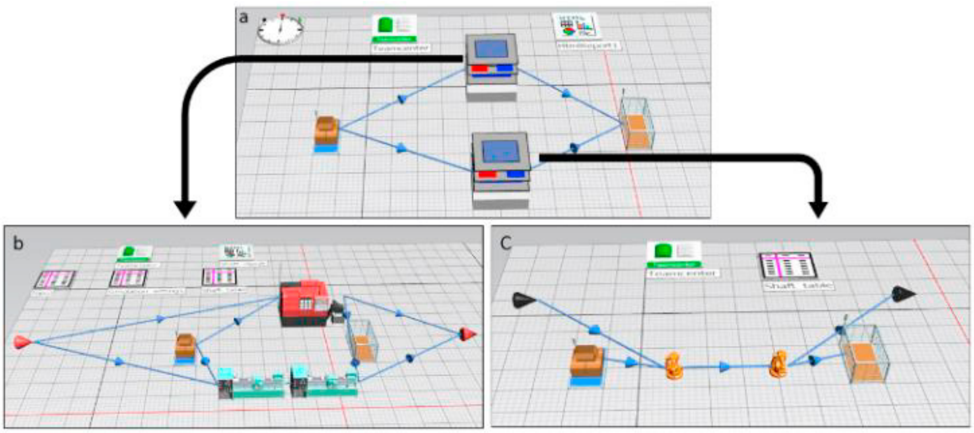

Fig. 4. DES models (a) Plant; (b) Machining area; (c) Assembly area

4.3. Information structuring in Teamcenter

For managing DES files in the PLM system, a specific item exists in Teamcenter, named "Plant Simulation Item". This item can carry "Plant Simulation Dataset". In Teamcenter a "Dataset" is used to represent a file from a specific software application, and the "Plant Simulation Dataset" is keeping the Plant Simulation file. The HTML report also can be attached to the Plant Simulation Item. Then, Plant simulation Item contains both the Plant Simulation files and the HTML report files. With the possibility of having different revisions for a Plant Simulation Item, different revisions of DES models with their output report can be saved and managed separately (Fig. 5).

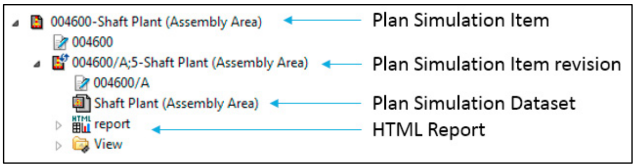

Fig. 5. Plant Simulation Item and its attachments

Through the Plant Simulation Item, the user can connect different revisions with their related data and reports, but these items are not yet structured. Since, BoM, BoP and BoR are three main structures in the PLM system, the Plant Simulation Items should be connected to these structures to make it searchable through those structures.

DES models have data about product, processes and resources. Because of that, they can be connected to all three structures. Since Bill of Process is the marriage point of product and resources (parts from the BoM and resources from the BoR had been added to the BoP), with connecting DES model to the corresponding process, the links of the model with product and resources are also established (Fig. 6).

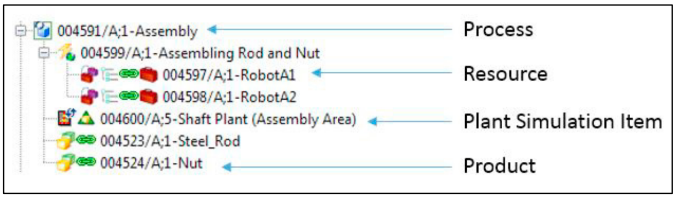

Fig. 6. Connection of Process, Product, Resource and DES model

For multi-level simulation approach, each simulation model should be attached to the BoP, at the corresponding process level. In this case study, the machining's DES model is attached to the machining process and the assembly's DES model is attached to the assembly process in the BoP. The Plant's DES model is attached to the "Shaft Production" item, in the BoP as the first aggregated level in the BoP (Fig. 7).

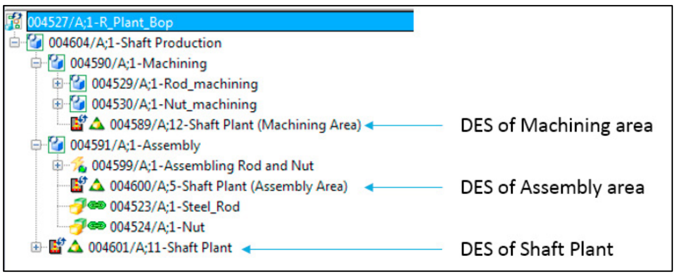

Fig. 7. Bill of Process for Shaft Manufacturing

With the regular search functions in Teamcenter, users can search for a specific DES model, but with this information structure, users can easily do the structural searching. If a user wants to search for a DES model of a specific process, he/she can find the latest revision with its report, in the desired process as an attachment. If a user searches for a DES model of a resource in the system, the model can be found through processes, which that resource had been used.

As mentioned before, BoM, BoP and BoR are three main structures in the PLM system, but it is also possible to define other structures in the PLM system. By using the “Structure Manager” application in Teamcenter, a hierarchical structure had been defined for the multi-level simulation models. Fig. 8 shows the information structure for the implemented case study.

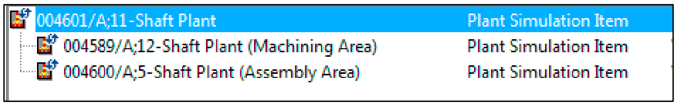

Fig. 8. Hierarchical structure of multi-level DES

With this structure and the variant management functionality in Teamcenter, it is possible to define different models’ structures for different variants of product, process or resources.

For example, if for a specific variant of a shaft, the machining process is not needed, the user can assign this variant to the machining area in the above structure. Consequently, when this variant has been selected, only the assembly model is visible in the structure.

Another functionality of a PLM system that can help users to manage their DES models is classification. By using the classification function in the PLM system, DES models can be classified according to their attributes. After classification of DES model, they can be searched faster and easier. For example, it is possible to search for DES models according to the types of their production flow methods.

All of these information structuring of DES models, help users to save, search and retrieve their model.

5. Conclusion and future works

This paper presented a methodology for managing multi-level DES models in a PLM system. Since PLM systems have been developed to manage product and production related data, DES models and their related data can also be managed by the PLM system.

It was explained before, that three main structures of PLM systems (BoM, Bop, and BoR) have to be defined as the initial step of the information structure. These structures, provide basic data for DES and simulation, and they are also used later for managing DES models and analysis reports.

The second step of the methodology is importing data into the DES software program and creating models for different levels and branches of the manufacturing system. The created models and analysis reports have to be exported and saved in the PLM system for managing them.

For the last step, an information structure suggested for structuring DES models, according to the corresponding level in the BoP. With this structuring, users can have different revisions of a model, besides its analysis report, which attached to the BoP. They can do structural searching to find the desired model for the specific process, resource or product.

An additional structuring for multi-level DES models also presented, for specifying of the hierarchical structure of those models. By utilizing variant and classification functionalities of the PLM system, saving, searching and retrieving of models is possible, in different ways.

As the future works, this methodology should be used and evaluated in a real manufacturing environment. The information structure needs to be further developed for managing different DES models for different scenarios. For model’s classification also, model’s attributes need to be specified.

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