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## 51st CIRP Conference on Manufacturing Systems

## Product lifecycle management with provenance management and virtual models: an industrial use-case study

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Saving and managing virtual models' provenance information (models' history) can increase the level of reusability of those models. This paper describes a provenance management system (PMS) that has been developed based on an industrial case study.

The product lifecycle management (PLM) system, as a main data management system, is responsible for receiving virtual models and their related data from Computer-Aided technologies (CAx) and providing this information for the PMS. In this paper, the management of discrete event simulation data with the PLM system will be demonstrated as the first link of provenance data management chain (CAx-PLM-PMS).

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**Keywords:** Discrete event simulation; Provenance; Product lifecycle**1. Introduction**

With respect to the high speed of digitalization's developments, the tools for virtual modeling and simulations have become more advanced and inexpensive. Industries also utilize digital capabilities to create virtual models from existing or suggested (prototype) systems. They are also using simulation tools to analyze systems' behaviors. All of these digitalization capabilities, help industries to develop their products and processes faster and cheaper than traditional methods. However still virtual modeling and simulation is time consuming and costly. This reveals the necessity of reusing virtual models and results of any other computer-aided activities over a products lifecycle.

Nowadays, product lifecycle management systems (PLM) are well-known for managing product-related data and information [1]. With the integration of PLM systems with different computer-aided technologies (CAx), different data and information created by those technologies can be saved and managed by a PLM system. In general PLM systems are not capable to manage all data about the history of those virtual

models, i.e. the engineering activities which resulted in a model. This kind of information is termed provenance data. Recording and managing the provenance data support the reusability of models and simulations. The Virtual confidence will also increase if the provenance data is known and retrieved [2].

This paper starts with presenting some backgrounds about models, virtual confidence, provenance and PLM system. Afterward, a case study will be explained to shows how the developed provenance management system (PMS) with a PLM system and a CAx software program can manage virtual model, their related activities, and their provenance information.

By completing the chain of CAx-PLM-PMS, an extended information about a virtual model and its related activities is provided to clarify if this model can be reused in a new task or not.

**2. Background**

In this section, the background of different parts of the CAx-PLM-PMS chain will be presented. For the first link in the

chain, a discrete event simulation (DES) model has been selected as a CAx virtual model. The definition of models, virtual models and discrete event simulations will be explained. Afterward, PLM systems and their structures will be explained, and at the end, virtual confidence and provenance definitions will be explained.

### 2.1. Model, virtual model and discrete event simulation model

A model has been defined as a representation of an object or a system of interest. Virtual models is a type of models which have been created by computer algorithms. Simulation is the imitation of some real object or system. Simulation is a process of using a model to study the characteristics and behavior of a physical or conceptual system. Therefore, one or more variables of a model are changed in simulation to see the results [3,4].

Bank classified simulation models according to different characteristics. Simulation models can be dynamic or static, stochastic or deterministic and continuous or discrete. In this paper, discrete event simulation model has been selected to be managed in the PLM system and PMS. In the discrete event simulation, the state variables' changes have been tracked at a discrete set of points in time [5].

The reusing of virtual models and simulations can help to save lots of engineering time. Prerequisite of reusing a model is to know, how the model had been generated and used, previously. This can be clarified according to the model's provenance information.

### 2.2. Virtual confidence and provenance data

The virtual confidence can capture the level of trust and utilization of virtual models and tools in an enterprise. The opportunity of reusing of virtual models increases the using of virtual models and subsequently, increases the level of virtual confidence [2].

The model's provenance information clarifies the history of a model for better reusing of that model. The 7W framework can capture provenance data by recording information about answers of these questions: Who, What, Where, Why, When, Which, and How [6,7]. This information identifies who creates this model, what the model is, where and why the model has been created, when it has been created, according to which criteria the model has been created, and how the model has been created [8].

In this project, these questions have been used as the basis for the Provenance Management System's data model.

### 2.3. Product lifecycle management

Anything that is produced and offered to the market is a product, and each product has a life cycle. Crnkovic divides product lifecycle to six phases: business idea, requirement management, development, production, operation, maintenance, and disposal [9].

Manufacturers use PLM for managing PPR (Product, process and resource) data, therefore Bill of Material, Bill of process and Bill of resources are considered as three main structures of a PLM system [10,11]. Bill of Material (BoM) is a

product structure that clarifies different parts and assemblies of a product. Bill of Process (BoP) is a structure that shows different processes and their relationships for manufacturing a product and Bill of Resource (BoR) is a factory and resources structures which are needed for producing a product.

These three information structures, prepare connection points for linking virtual models to the PLM system.

## 3. Case Study explanation

For demonstrating of CAx-PLM-PMS chain a case study was selected from car manufacturing industry. The case study was limited to one production line for crankshafts using discrete event simulation and management in the PLM and PMS systems.

Different links of the mentioned chain in this case study are:

- CAx: Plant Simulation as a discrete event simulation tool
- PLM: Teamcenter as a product lifecycle management system
- PMS: ManageLinks as a provenance management system

From these tools and systems, Plant Simulation and Teamcenter are both commercial software programs, developed by Siemens GmbH. Manage link is a system developed at the University of Skövde for managing provenance data.

The provenance management system consists of three parts (Fig. 1). The first part is Link DB and it is a high-performance database (Caché) developed by InterSystem. The provenance data model was implemented on this database for capturing and retrieving provenance data. ManageLinks is a user interface for adding activities and their provenance data.

Through this user interface, PMS' users can search in the PLM database and assign different entities in the PLM system such as models, files and product's entity to the activity, as an input or output data. An initial ontology was defined for all elements in the data set, as the third part of PMS. An open-source ontology editor (Protégé) used for defining ontology. The defined ontology can be updated whenever a user adds a new type of activity, a new type of provenance data or a new type of data from PLM system.

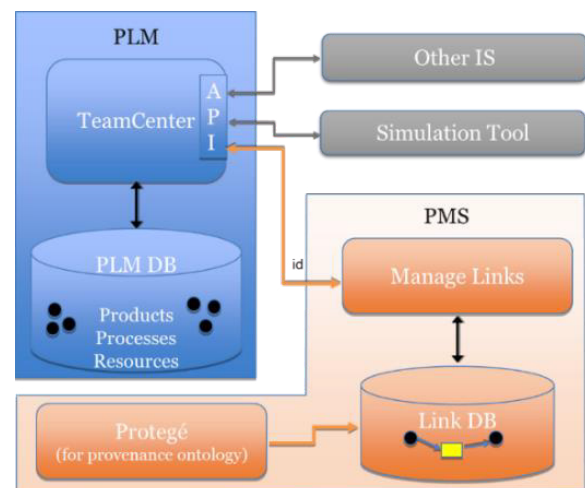


Fig. 1. Integration of PMS and PLM

With this provenance management system, whenever a virtual model is designed, the user can save extra information about activities that leading up to create that model. This helps users evaluate the possibility of reusing that model and also how to use them later in other problems if they are applicable.

#### 4. Methodology

With preparing this provenance management system and the existing PLM and CAX tools, the case study can be implemented according to the methodology shown in the Fig. 2.

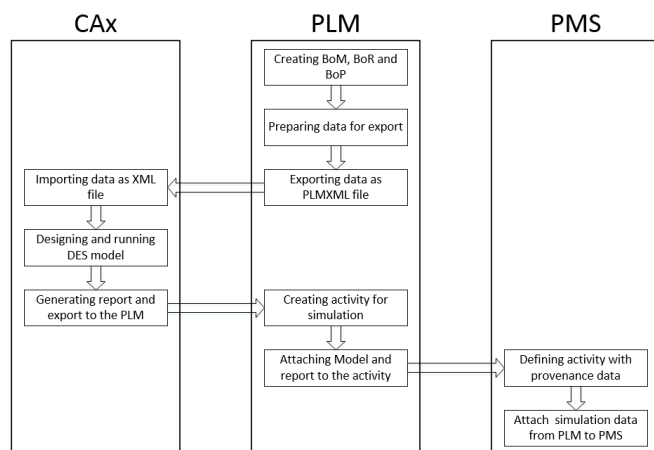


Fig. 2. The methodology for implementing CAX-PLM-PMS chain

For completing this chain, initially some basic structures should be prepared in the PLM system, including some data and information that are needed for discrete event simulation. Afterward, with this data, the simulation model can be designed and used. Since the PLM is the main system for storing and managing data, then the model and the results should be added to the PLM system. Finally, with using of DES model and other related data, in the PMS, provenance data also connected to this information chain. In the following, each step is explained separately with the case study.

##### 4.1. Creating Bill of Material, Bill of Resources and Bill of Processes

The PLM system provides a platform for providing required data for integrated CAX applications and also saving and managing the produced data from those applications. For preparing a PLM system three main structures (BoM, BoP and BoR) should be defined in advance. These structures are used as a backbone for the structuring of all PLM data.

Bill of material is a structure of different parts, assemblies and sub-assemblies of a product. Since in this project crankshaft is a unique part, then the BoP will be simple and consist of only one part, which is crankshaft (Fig. 3 Left-down).

Bill of resources is a structure that shows production line. For crankshaft manufacturing, the first level of the hierarchical structure of BoR is “Crankshaft Plant” and it had been divided

into four main areas. Each area consists of some stations and each station consists of one or several machines (Fig. 3 right-down).

Bill of Process is a structure of different processes for manufacturing of a product. Manufacturing of crankshaft had been divided into four groups of machining process in four areas. For each group of processes, some operations had been defined (Fig. 3 right-up). Since BOP is the meeting point of product and resources, then parts from the BoM and resources from the BoR should be added to the BoP. Since crankshaft is the only part of the whole production line, then it is added to the first level in the BoP. Each operation in the BoP has some machines which should be added from BoR to that operation as resources. These structures have data that are needed for discrete event simulating such as resources and processes with their specification.

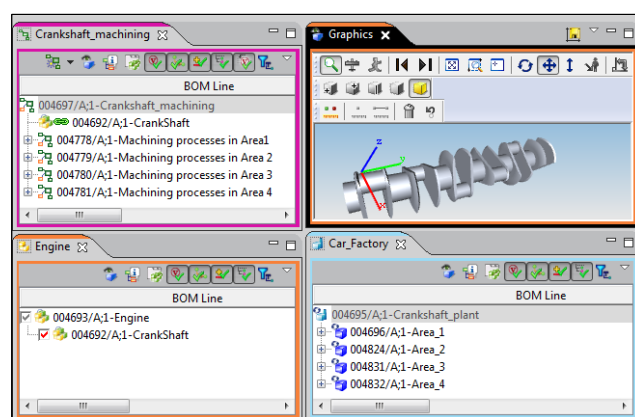


Fig. 3. BoM, BoP and BoR for crankshaft

##### 4.2. Preparing data for export

Before exporting data from Teamcenter to Plant simulation, BoM, BoP and BoR's structures should be gathered together in a data package called “Collaboration Context”. Collaboration context holds a collection of data contained in the structure and configuration contexts, and it can be used to share these data with a third-party application. In this case study a collaboration context for gathering BoM, BoP and BoR for crankshaft production had been created (Fig. 4).

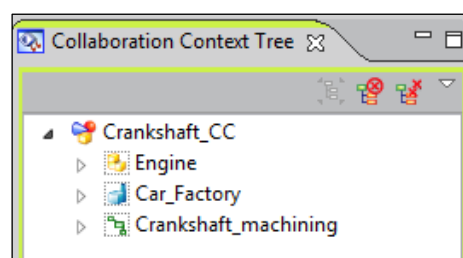


Fig. 4. Collaboration Context for Crank shaft manufacturing

#### 4.3. Exporting data as PLMXML file

For exporting data, a Teamcenter's "Application Interface" tool is used. Application Interface business objects are used to transfer data between Teamcenter and an external application. This Object consists of three Items:

- PlantSimulation Export: In this Item, the types of data which should be exported are specified. For example, it is possible to specify that MTTR (mean time to repair) of resources have to be exported to the PLMXML file.
- PlantSimulation Import: This Item specifies the import procedure from plant simulation to Teamcenter.
- Collaboration context: This is the collaboration context item which had been prepared before, and specifies PPR structures for the Plant Simulation software program.

Now, all needed data for discrete event simulation of crankshaft line has been prepared to be imported and used by Plant Simulation (Fig. 5).

Crankshaft_CC		
Name	Type	Owner
PlantSimulationExport	TransferMode	infodba (infodba)
PlantSimulationImport	TransferMode	infodba (infodba)
Crankshaft_CC_sync2	RequestObject	Iman Morshedzadeh (mori)
Sync3	RequestObject	Iman Morshedzadeh (mori)
Sync4	RequestObject	Iman Morshedzadeh (mori)
Crankshaft line S5	RequestObject	Iman Morshedzadeh (mori)
Crankshaft_CC	MECollaborationC	Iman Morshedzadeh (mori)

Fig. 5. Application Interface for exporting and importing data

#### 4.4. Importing data as XML file

From this part of the methodology, implementation has to be done in the Plant Simulation software program. There is a Teamcenter object in the Plant Simulation software that should be configured for transferring data between Teamcenter and Plant Simulation (Fig. 6). For configuration of Teamcenter object, the URL of Teamcenter server should be set and Teamcenter's username and password have to be used. Since data had been exported as PLMXML file from Teamcenter, a defined "Style sheet" had been used to convert a PLMXML file to XML. With the Import function, the user can specify a table for structures and data, and also retrieve a JT file of Teamcenter objects to a defined folder. By using SimTalk and a coding in a "Method" object in Plan Simulation software, the production line with 3D models can be modeled. In the crankshaft case study, a table consisting of all data about product, processes and resources, imported from Teamcenter, had been created in the model's frame.

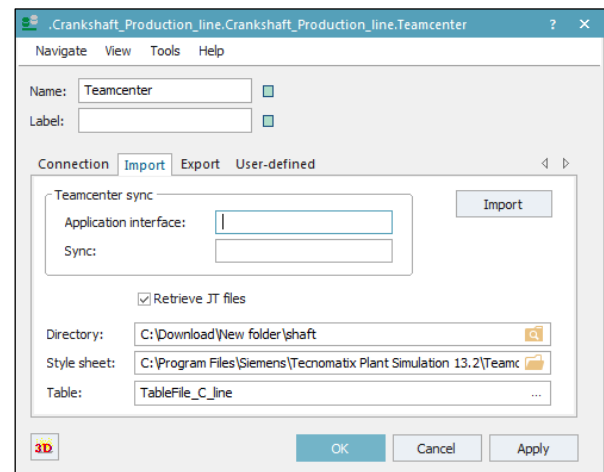


Fig. 6. The Teamcenter object in Plan Simulation

#### 4.5. Designing and running DES model

By using SimTalk and a coding in a "Method" object in Plan Simulation software, the production line with 3D models can be modeled. Afterward, the user can run the simulator, do experiments and analysis. For crankshaft case study, after creating the production line model, a bottleneck analysis had been done by simulation (Fig. 7).

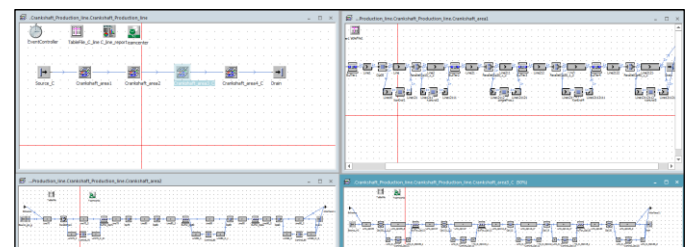


Fig. 7. Modeling and simulation of crankshaft production line

#### 4.6. Generation report and export to the PLM

An HTML report can be sent to Teamcenter from Plant Simulation software. After finalizing the DES modeling and simulation, the results can be saved as "HTML Report" object in the software. This report later can be sent to a defined folder in Teamcenter with the import function of Teamcenter object. The model can be saved in Teamcenter as a new model or as a new revision of the previous model (if the model had been saved before). The crankshaft production line model and the report of bottleneck analysis had been sent to Teamcenter.

#### 4.7. Creating activity for simulation

For structuring virtual models and all related data, a Teamcenter item (business object) had been defined in the PLM data model, named "Engineering activities". Discrete event simulation can be defined as an engineering activity in the Teamcenter and attached to the BoP, according to the



simulation level. If it is a line simulation then it should be attached to the line level and if it is simulating area, then it should be attached to that level, in the BoP. A discrete event simulation activity item had been created and attached to the crankshaft machining item in the BoP (Fig. 8).

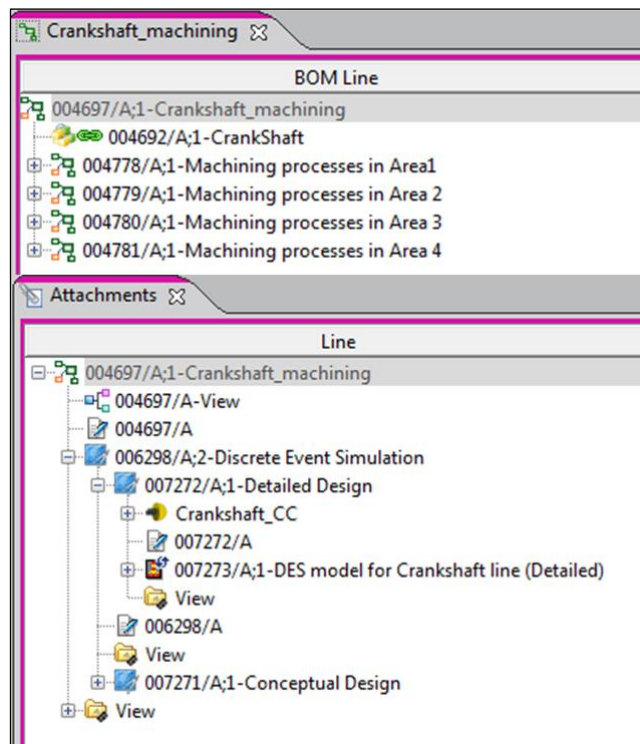


Fig. 8. Discrete Event Simulation activity item, which is attached to BoP, contains data and model

#### 4.8. Attaching model and report to the activity

Both DES model and reports can be attached to the activity item. Since this item represents discrete event simulation activity all data which are used for this simulation can be attached to this activity.

So far, the link of PLM and CAx is established, but provenance data needed to be saved in the PMS to complete the chain of CAx-PLM-PMS. In the case study, DES model, the simulation report, and the application interface item had been attached to the discrete event simulation activity item.

#### 4.9. Defining activities with provenance data

Final steps of this methodology must be executed in the provenance management system. ManageLink is connected to the Teamcenter server and retrieves data from the PLM database.

Fig. 8 shows the ManageLink user interface. It is consisting of different tabs for entering data. The “Activities” tab is a place to see a list of activities in the PMS, and users can add a new activity in this tab. In the “Entities” tab, users can search and add business objects from the PLM system as entities to the list of entities at the PMS. Users can store all ontological terms that are candidates to describe the classes (Entity, Purpose, Actor,

Method, and Activity) in the “Concepts” tab and refer them to where the terms are defined such as a link to a web page or a link to the WebProtege.

“Actors”, “Locations”, “Methods”, “Tools” and “Projects” are other tabs for entering data about activity to cover all 7Ws questions.

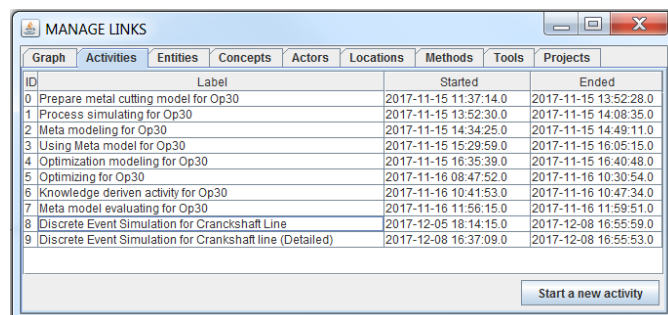


Fig. 9. ManageLinks user interface

In this case study have provenance information been added to that activity according to 7Ws which had been explained before. This data explained that, what the activity is, who did the simulation, when the simulation had been started and finished, which tool had been used, what method had been used, for what purpose this simulation had been done and where the activity happened. With this information, the history of the simulation activity stored for reusing efficiently in another project (Fig. 10).

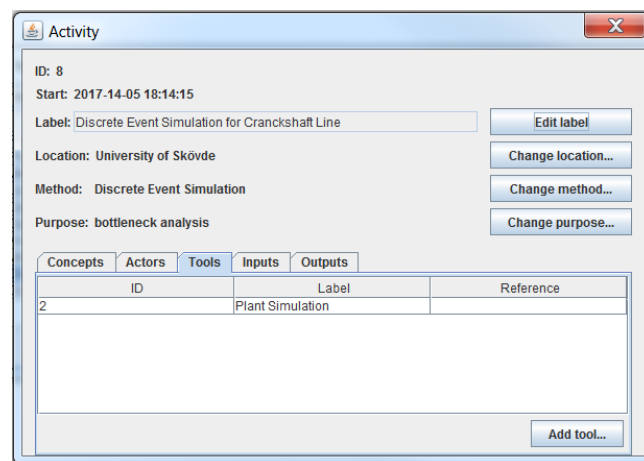


Fig. 10. Defining of DES activity in ManageLinks system

#### 4.10. Attach simulation data from PLM to PMS

Input data and output data of an activity, beside 7Ws can complete the provenance data. In this case study, process and machine data used for simulation was assigned to the activity as an input data. The simulation model and the HTML report are output data of this activity. All of these data are in the PLM system and with the integration of ManageLink and Teamcenter, they can be searched and retrieved from Teamcenter and be added to the activity.

The ManageLink application can execute Entity-Activity graphs from activities and data which are entered the database.

Fig. 11 illustrates the graph of discrete event simulation activity for Crankshaft line in the case study. Connected entities as input and output data are visible in the graph.

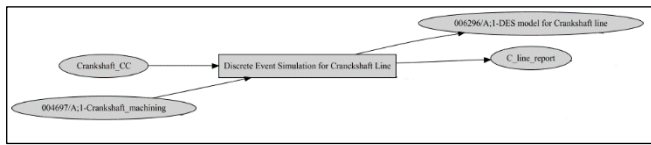


Fig. 11. Entity-Activity graph for DES activity

Output data of one activity can be used as inputs for another activity. For example, DES model and report as output data from previous simulation can be used as input data for a detailed DES simulation. Fig. 12 shows how these two activities connected to each other through their related data. In this graph rectangular boxes are activities and ovals are data. These activity-entity graphs illustrates the chain of activities entities. Users can track sequences of related activities and also identify how a virtual model developed through different activities.

## 5. Conclusions and future works

With executing of this methodology an information chain of CAX-PLM-PMS is completed. When this methodology is used for any engineering activities and virtual model, then there will be a complete information about them available. This information can help users evaluate virtual models for reusing them. With these extensive information, criteria for decisions

will be saved and they can be retrieved later, for support of new decisions. The industrial case study shows that the proposed methodology can be implemented in industries.

For future works, this methodology should be used for other CAX virtual models and can be more generalized. A detail information structure can be invented for specifying virtual model's management in the PLM system. This information structure should be able to manage virtual model's revisions and virtual model's utilization for different experiences.

As another future work, the contribution of CAX-PLM-PMS to the future digital twins is needed to be investigated. Changes to manufacturing systems can happen both planned and unplanned. In both cases, the digital twin of the system should be corresponding to the current status of that system in reality. CAX are used for generating and updating virtual models of digital twin. PLM systems are placed for storing of models with different versions and PMS is responsible for storing provenance data and future tracking of virtual models of digital twin and their histories. But for establishing the CAX-PLM-PMS chain for supporting digital twin with continues updating, an information structure needs to be established in the PLM system for saving data and linking the chain's links.

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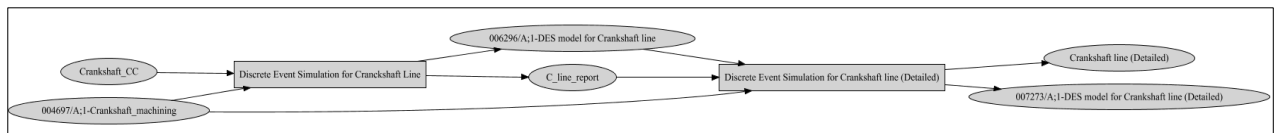


Fig. 12. Entity-Activity graph for two successive DES activities

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