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A STUDY OF DISCRETE EVENT SIMULATION PROJECT DATA AND PROVENANCE INFORMATION MANAGEMENT IN AN AUTOMOTIVE MANUFACTURING PLANT

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ABSTRACT

Discrete Event Simulation (DES) project data management is a complex and important engineering activity which impacts on an organization's efficiency. This efficiency could be decreased by the lack of provenance information or the unreliability of existing information regarding previous simulation projects, all of which complicates the reusability of the existing data. This study presents an analysis of the management of simulation projects and their provenance data, according to the different types of scenarios usually found at a manufacturing plant. A survey based on simulation projects at an automotive manufacturing plant was conducted, in order to categorize the information regarding the studied projects, map the available provenance data and standardize its management. This study also introduces an approach that demonstrates how a structured framework based on the specific data involved in the different types of scenarios could allow an improvement of the management of DES projects.

1 INTRODUCTION

According to Chari (2013), a large number of researchers conclude that DES has several issues which have not yet been solved. One of the fields within DES which can be improved is lifecycle data management for the reuse of models, data and results. Conducting simulation projects repeatedly, due to poor lifecycle management, forces companies to waste time and money. In contrast, if the experience and knowledge gained during the development of DES projects could be maintained, many more models and simulations would probably be reused, thus saving time and money.

Simulation project management is a procedure that involves several tasks and steps that aim to maximize the effectiveness of a simulation project. Traditionally, simulation project management models have been presented as a linear procedure which, in general, begins with a "Problem definition phase" and ends with a "Document and report" phase. Typically, a DES project generates large amounts of data which are difficult to document properly or reuse (CIM.data 2014 and Banks 1999). The reuse of data will automatically introduce a lifecycle for the data, models and simulations. Hence, the origin and key events must be preserved over the lifecycle.

Kloss and Schreiber (2006) state that one of the main obstacles for simulation in the manufacturing industry is the lack of provenance information. Such a lack limits the reusability of simulation information because it becomes untraceable and maybe even untrustworthy.

The origins of this study arise from the fact that many companies often regard DES projects as isolated events and fail to consider the preservation of provenance information, which can significantly impact a company's ability to rapidly advance DES projects and increase their competitiveness (Lee, Kang and Noh 2012). The competitiveness of a company involves the effectiveness in which the information is generated and implies the disposal of the right information at the right time. Consequently, the lack of a supporting framework between engineers and the provenance information reduces its traceability and increases the lead time of a project. Therefore, provenance data management for DES projects can improve their quality and contribute to saving time and money (CIMdata 2016; Robinson et al. 2004).

This paper presents a proposal for a provenance data and information framework that supports the reuse of DES projects and aims to achieve an increase in the efficiency of DES information management. The proposed approach will map the key data and information to common scenarios found in DES projects conducted at an automotive manufacturing plant, using a provenance management method that improves the reusability of the obtained data and information.

1.1 Methodology and Data Collection

Since one of the main parts of this study is based on the search for information from different sources in a standardized form, the research strategy chosen is Survey. The main aim of the survey is to find patterns and generalizations which can provide enough knowledge about the key simulation data of DES projects. The survey is supported by various generation methods, such as interviews and documents, which are used during the data collection stage. Accordingly, the survey strategy perfectly corresponds with the aims and approach of this study, providing the researchers with a set of steps and tools that permit simplifying the extraction of the information (Oates 2006).

2 LITERATURE REVIEW

2.1 Key Performance Indicators (KPIs)

According to Parmenter (2015), the aim of a KPI is to measure the performance of different processes. In order to determine the progress in a production line according to the company's objectives, various KPIs within the production processes are analyzed and evaluated. In the effort to identify the required measures and KPIs, this study has analyzed various sets of KPIs that are used to analyze and compare different solutions in DES projects.

2.2 Discrete Event Simulation Data Management

In the automotive industry, it has been acknowledged that the standardization of manufacturing and simulation data is essential. According to Johansson et al. (2007), the implementation of standardized methods for data management within DES will reduce the time spent in project processes and may also facilitate analytical tasks, which involves a cost reduction for the overall project (CIMdata 2011; Johansson et al. 2007).

As DES projects become more complex and detailed, they require the analysis of larger amounts of data. Consequently, due to the continuous increase in size and complexity of DES data, the improvement of data management has become a key aspect for many manufacturing organizations (NAFEMS 2017).

In order to distribute and manage DES data, different strategies can be implemented. For example, the data should be generated in clusters which can be easily categorized according to different scenarios. A DES data structure could facilitate the analysis of the performance of manufacturing systems, by providing a set of the main KPIs related to the process to be assessed. However, the information with respect to a model must be associated with one or more different DES scenarios, so that the clustering task can be simplified within a repetitive simulation environment (NAFEMS 2017; Leong et al. 2006; Lee et al. 2012; Kardos et al. 2013; CIMdata 2011).

Some of the main advantages that can be gained from good management of DES data include: the possible elimination of obstacles between working groups, the reduction of lead time and the use of standardization to facilitate the repetitive analysis tasks (CIMdata, 2011).

2.3 Reusability and Data Provenance

An important aspect to develop is the reusability of project data and information, in order to reduce the project implementation time and consequently the costs. Since there is a desire to reduce the time spent on the development of a project, this approach is being pursued as a goal among the simulation community (Ottino et al. 2015). One of the most basic cases in which data and information regarding a simulation project can be reused is when a project will be utilized for the same purpose for which it was implemented. This scenario can occur, for example, when a DES model from a project is used to support routine tasks. However, if the model is to be reused for a different purpose than the one for which it was developed, then the model's reusability cannot be guaranteed. Nonetheless, in order for the model to be reused, its information must be verified and validated. This may, in reality, take longer than the implementation of a new model. Validating and verifying the information is supported by establishing a provenance framework over the lifecycle for the model. Hence, determining the project data and information that must be stored or saved is a key aspect for allowing its reusability (Robinson et al. 2004; Ottino et al. 2015).

Provenance is becoming an interesting concept in DES, since it allows engineers to understand how results were obtained and to verify or repeat the processes (Moreno, Risco-Martin and Aranda 2010). Many simulation tools lack a traceability function which supports the validation of experiment processes. Without this information, the results produced by the simulations cannot be considered trustworthy when they need to be reused. A simulation data provenance framework would allow organizations to distribute the data used in simulation experiments, the data would thus be traceable and trusted (CIMdata 2011; Kloss and Schreiber 2006).

Data provenance reflects the origin of an artifact, including its specifications. Therefore, provenance information can be used to understand which type of data was generated and how it was collected, allowing data validation and process verification based on specific requirements (CIMdata 2011; Provenance Working Group 2017).

2.4 The W7 Provenance Model

DES projects can involve a large amount of data and information. DES project data must be followed by information related to its collection, preparation, handling, analysis and validation, together with any information that could facilitate its interpretation and use. Ram and Liu (2009) suggest that this provenance information can be captured by the W7 model, see Figure 1. A similar approach is presented by Inmon, Zachman, and Geiger (1997) in the Zachman Framework. The W7 model includes the information about the events that affect an artifact along its entire lifecycle. This approach is achieved through the association of seven essential elements composed of "what", "when", "where", "who", "how", "which" and "why" that permit tracing the history of data items by attaching the creation context to them (Ram and Liu 2009).

Based on the W7 model of Figure 1, every artifact must include the information obtained from the following questions: What outcome does the artifact have?; When (Time) was the artifact generated?; Where (Location) was the artifact generated?; How (Cause) is the artifact used?; Who (Agent) was involved in the artifact's creation?; Which (Instruments) tools, software, etc., were used?; Why (Reason) did this artifact occur?

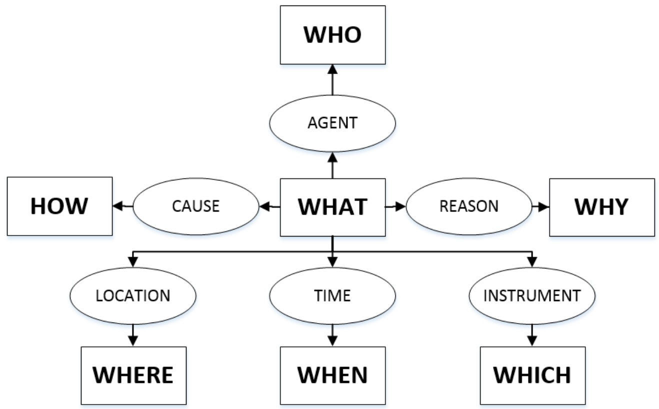

Figure 1: Overview of the W7 model (Ram and Liu 2009).

2.5 Simulation Project Management

Simulation studies are complex processes which therefore need to follow a procedure, in order to simplify the engineering tasks.

Banks (1999) and Law (2008) present two models for the management of simulation projects, the overall aim of which is to make simulation projects more efficient. In order to achieve their goal, their traditional, management approach representation has a linear structure. However, this structure does not emphasize any update and documentation tasks, when an extensive amount of data has been generated or changed during the process (CIMdata 2014). Moreover, the time spent on this process could also increase, if the procedure is not well documented, which can cause issues with the understanding of the information that needs to be reused. Consequently, standardization of the simulation project management and documentation is needed, in order to avoid these obstacles (Oscarsson and Urenda 2002; CIMdata 2014).

Both Banks (1999) and Law (2008) emphasize the importance of the documentation task, to allow the project reusability. They propose simulation project management models in which the documentation and presentation steps are performed at the end of their respective workflows. Banks states that if the project is to be reused by other people than those involved in the original study, the reporting task will play an important role, in terms of understanding the project information. In parallel, Law states that one of the most problematic steps during a simulation project is to document all the assumptions and descriptive information that influence its validation. Therefore, a project management method which stores all the necessary provenance data and information generated in and during the process would increase the reusability of the data and information obtained (Kloss and Schreiber 2006). This implies an improvement of the confidence and validity and offers a reduction of the lead time when information and data is reused.

3 INDUSTRIAL SIMULATION PROJECT SURVEY

In order to understand the requirements of the DES data provenance framework, an industrial case study was conducted. The survey included a total of 23 simulation projects conducted over four years at an automotive manufacturing plant. Each project was studied in depth by analyzing the models and model data, project documentation and interviews with the project stakeholders. The projects were categorized into different groups, according to their information and main objectives.

As a result of the survey of the 23 projects and the interviews carried out, the key information obtained regarding the most frequent scenarios performed was grouped into three main categories: general information, input data, and output data. The information related to these categories must be included when a project is carried out and documented. Figure 2 shows the three main information categories regarding simulation projects.

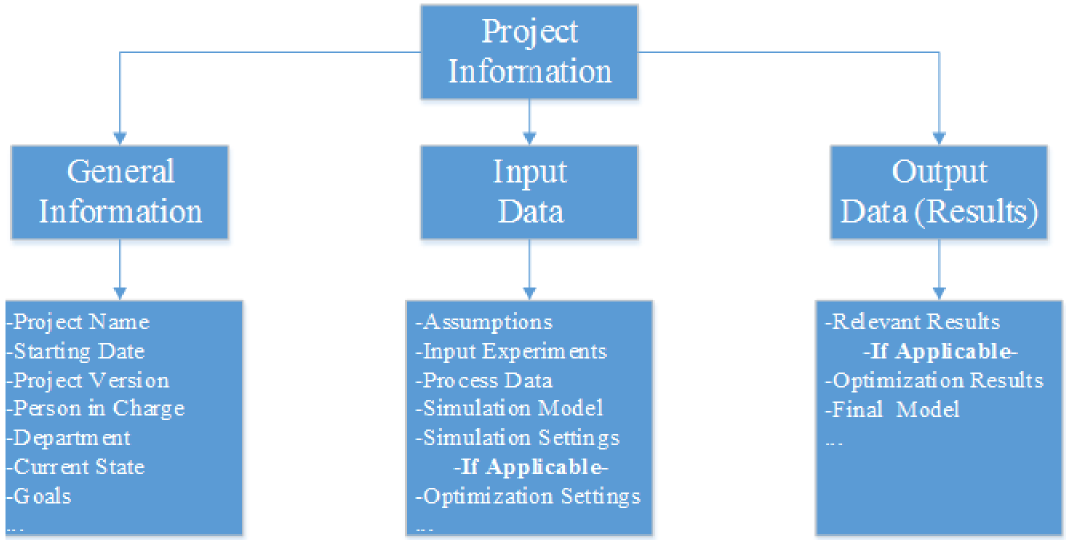

Figure 2: Project Information.

General Information concerns the basic description of the project, such as name, starting date, version, person in charge, department, current state and goals of the project. In order to properly provide engineers with the required information, the simulation projects must include the information regarding the aims of the project (goals) and the current state of the system or the model that the project intends to simulate, test, optimize or build.

Input Data contains all the information required to start the project. This category comprises:

- A variety of "Assumptions" about the model performance, made by the simulation team, which clarify some aspects of model behavior.
- "Input Experiments" which are designed by the simulation team in order to optimize the aims and/or answer the questions concerning the goals.
- "Process data" which covers the data regarding all the elements of the system (Operations, Machines, Buffers, etc.).
- "Simulation Setting" which refers to the simulation horizon, the warm-up time and the number of replications. In other words, the simulation experiments must be executed for a specific period of time, to obtain valid results.
- "Optimization Settings" which includes the optimization algorithm, the optimization objectives, the crossover and mutation operators, the crossover and mutation probabilities, the number of evaluations and all the relevant parameters that need to be set during the optimization process.
- "The Simulation Model" which must also be included in the input data, if it already exists.

Output Data comprises the resulting data that needs to be analyzed and presented in order to reach conclusions. This data must cover all the relevant parameters that allow the decision makers to understand the results of the experiments, formulate the right conclusions and thereafter make the right decisions.

- "Relevant Results" shows the main data on which the decision-making task is based.
- "Optimization Results" must be included as part of "Relevant Results" in the optimization cases. This attribute shows the chosen configuration according to the optimization objectives.
- "Final Model" is included if it has been changed or if a new model has been built from the beginning.

3.1 Scenarios Identification and Key Information

Once the study of the project documents provided by the automotive manufacturing plant was completed, the different scenarios commonly carried out were identified. The scenarios were determined on the basis of the goals and objectives of each project.

Table 1 shows all the studied scenarios and their related output data found in the documents provided. The relevant output data for each scenario is marked with an "X" if the specific KPI was found in the project reports. The KPIs are Throughput per Hour (THP), Work-in-Process (WIP), Lead Time (LT), Cycle Time (CT), Overall Equipment Effectiveness (OEE), Utilization of Operations, Optimization Data, and Specific Data. The "Specific Data" column is marked with a red cross because it refers to some extra data that may need to be shown, in order to a have a better understanding of the results. Additional KPIs are included, if the simulation engineers believe they can provide valuable information about the results.

In addition, the "Frequency" column presents the distribution between different scenarios found during the survey. It is important to note that the most frequent scenario, "Different Strategies/Configurations", covers different cases. The cases can range from just small changes in some part of the system to more significant changes in the operations' settings of a model, etc.

Table 1: Scenarios and Related Output Data.

		Related Output Data							
Simulation Projects	Frequency	THP	WIP	LT	CT	OEE	Utilization	Optimization Data	Specific Data
System Design	1	X	X	X	X	X	X		X
Bottleneck Analysis	3	X	X	X	X	X	X		X
New layout, Add Machines etc	3	X	X	X	X	X	X		X
SPC Frequency	2	X	X	X	X	X	X		X
Singlespindle vs Doublespindle	2	X	X	X	X	X	X		X
Different Strategies/Configurations	5	X	X	X	X	X	X		X
Batch Sizes Optimization	2						X	X	X
Introduce New Variants	2	X	X	X	X	X	X		X
Buffers Optimization	2						X	X	X
Different Suppliers	1	X	X	X	X	X	X		X
Total of Projects Studied	**23**								

A short description of each scenario follows.

- **System Design:** In this scenario, a system is modeled from the beginning which, through the model representation, simplifies the understanding of the real system. This allows the stakeholders to test and analyze different possible situations on which to base their decisions.
- **Bottleneck Analysis:** A bottleneck is a constraint in a supply chain that identifies which operations require the most time to process the resources. Since bottlenecks determine the THP of a manufacturing supply chain, bottleneck analysis and the eventual improvements are important, in order to ensure an increase of the THP and therefore the cash flow (Goldratt 1999).
- **New Layout, Add Machines, etc.:** This scenario assesses the system by using different layouts, in order to examine how it behaves, including whether the system performs better due to the introduction of new machines.
- **Statistical Process Control (SPC) Frequency:** This scenario addresses a standard method used to control quality within manufacturing processes. The control limits are determined by the

system capability, therefore, the system performance will depend on this statistical process. The evaluation of quality data must be carried out during a manufacturing process, in order to improve the system performance (Oakland 2008).

- **Singlespindle vs Doublespindle:** When two single machines are in parallel, the DES software provides the option of placing those operations in one station instead of two, see Figure 3. Therefore, it is sometimes necessary to evaluate and analyze such double operations for advantages/disadvantages.

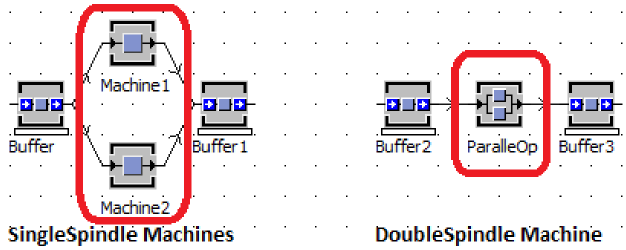

Figure 3: Single and Double Spindle Machines.

- **Different Strategies/Configuration:** This scenario assesses the behavior of a system under different configuration settings or operation strategies.
- **Batch Sizes Optimization:** This scenario calculates the optimal batch quantity of a variant, a process which has a major impact on production performance. The aim of calculating the optimal batch quantity of a variant is to improve the efficiency of the production process. Consequently, determining optimal batch quantity can reduce the excess of WIP and the manufacturing LT (Benjaafar and Sheikhzadeh, 1997).
- **Introduce New Variants:** This scenario evaluates the effect of introducing one or more variants into the system.
- **Buffers Optimization:** Buffer allocation problems occur in many manufacturing systems and can play an important role in the overall performance. It is important to know how to optimally allocate capacity to a buffer. As in batch size optimization, buffer capacity optimization is related to the desired system performance (Chaovalitwongse, Furman and Pardalos 2009).
- **Different Suppliers:** This scenario evaluates different suppliers in order to determine the most suitable according the system's requirements.

4 INFORMATION PROVENANCE FRAMEWORK

Figure 2 illustrates that the information regarding DES projects is included in the following three main information groups or categories:

- General Information
- Input Data
- Output Data or Results

In order to manage the provenance of the information regarding DES projects, these three categories are mapped to the W7 model. For provenance, the information extracted from the W7 model is called metadata. Consequently, this metadata provides the provenance information required to enable the traceability of a DES project.

Figure 4 demonstrates the proposed provenance framework. The provenance metadata can be found in the three project information groups. When the information from a completed simulation project is reviewed, the metadata can be extracted from different types of archives which, in turn, can be in different formats. In summary, the proposed framework maps the information groups (see Figure 2) to the W7 model.

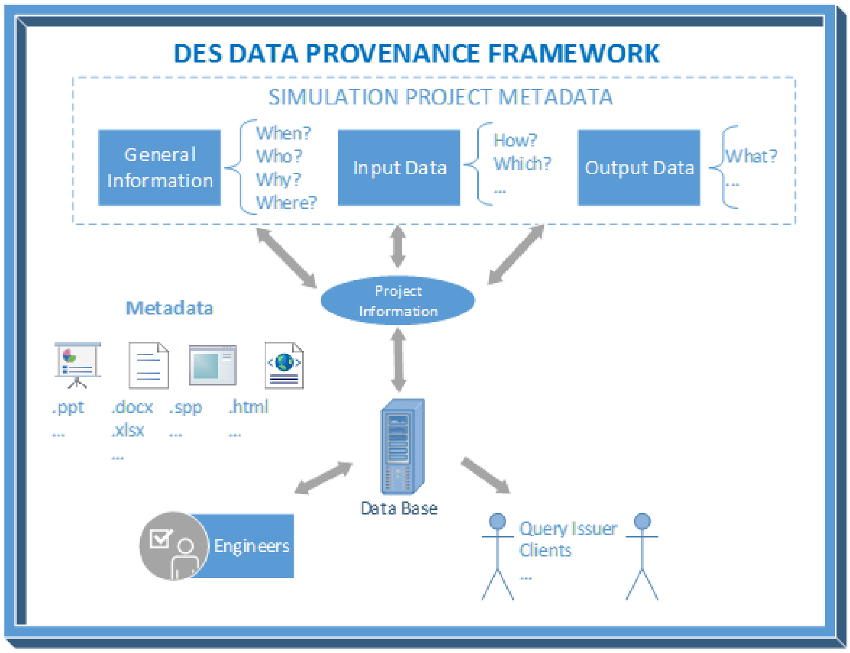

Figure 4: Provenance Framework.

In the domain concerning this study, the data contained in the three groups of information established in Figure 2 is mapped to the W7 model as follows:

- "What" includes the Output Data which consists of relevant results and, when necessary, the optimization results or specific data, such as final model, etc.
- "When" is the time or period in which the project was carried out.
- "Where" is the location or system being simulated which, in many cases, will be identical with the project name. It can also include information about the current state of the system.
- "Who" is not only the department or person in charge of the project, it also includes a list of all the people or other resources involved in the project.
- "How" plays a key role, since it specifies most of the input data used, which reflects how the results were obtained. This also includes assumptions, experiments, settings, limitations, simplifications, etc., made.
- "Which" completes the rest of the input data not covered by "How" and is meant to clarify the tools used for input data collection and for the creation of the output data, such as the simulation software.
- "Why" is probably the most important W because it specifies the goals and objectives of the project; Table 1 indicates the most common types of projects found in the survey. Furthermore, since, in some cases, the necessity of carrying out a project or certain type of experiments can be derived from the current state of a line or a plant, in such cases, the current state can also be found in the answer to that question.

In summary, Figure 4 illustrates that General Information provides the answers to questions two, three, four and seven. Input Data provides answers to questions five and six, while Output Data has the answer to question one. Therefore, all the metadata required can be extracted from the project information groups defined in Figure 2.

The Provenance Working Group (2017) defines important types of concepts related to provenance information. The three main concepts that compound a provenance structure are: Entity, Activity and Agent. In this case, Entities are the files or documents that contain the metadata. These files or documents store the simulation project information and represent the contents as general information, input data, and output data. Activities constitute the information extraction or modifications that can be performed by the engineers, clients or any query issuer. The Agent in this framework refers to the method responsible for the documents that generate the metadata, such as the simulation software, the different applications used to store and show the results, and the database that comprises all these documents.

4.1 Proposed Method of Provenance Management

A method was developed for the purpose of managing the provenance information regarding a DES project, thus allowing engineers and clients to trace and reuse this information, if it is required, see Figure 5. The proposed method consists of five different stages or steps for the management of the W7 metadata included in the framework.

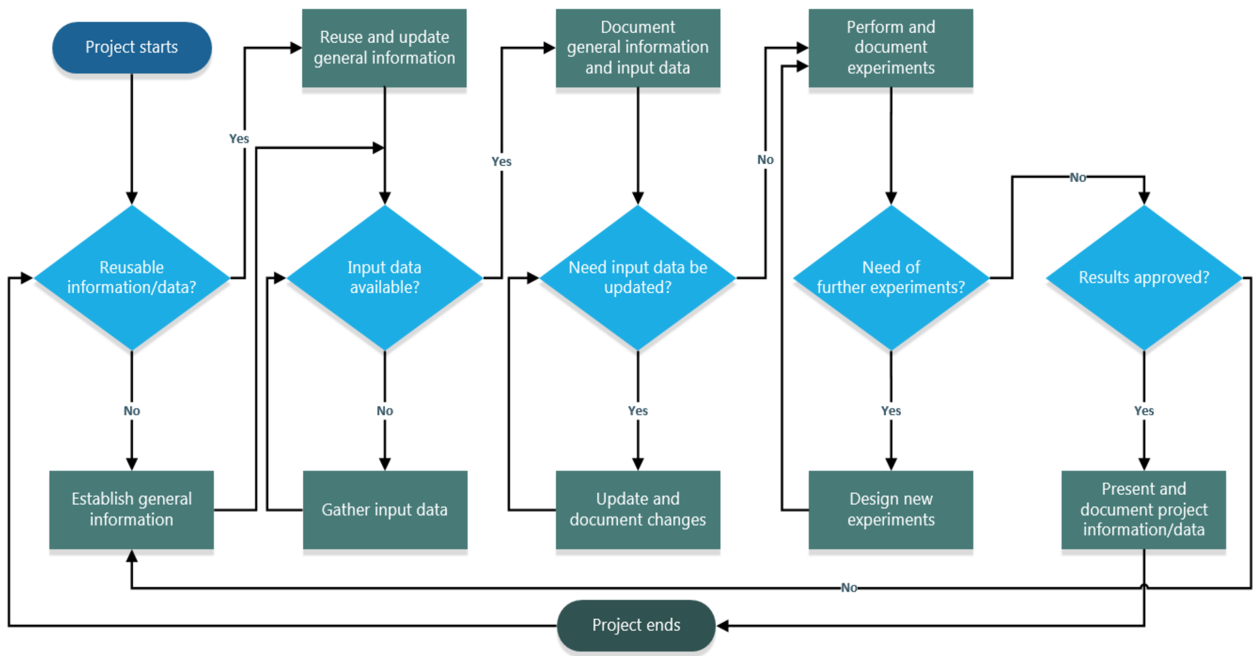

Figure 5: Proposed Method of Provenance Management.

- Stage 1: *"Is information or data available for reuse?"* One of the main reasons for developing this method is to allow the reusability of project data and information, compared to traditional linear methods. Hence, in the first stage, the task is to check if any relevant information or data regarding this project is stored in the system. If no information is available, the general information has to be established. Since some of the data and information generated in a DES project may not be reused for a different purpose than the one for which it was originally created, this first stage allows engineers to check whether all the stored information and data or just part of it can be reused for the goals and objectives set by the new project.
- Stage 2: *"Is input data available?"* In this stage, the availability of the input data is checked. If no relevant input data is available, it must be gathered.
- Stage 3: *"Need input data be updated*?" In this stage, the general information and input data available is documented. If new input data has been gathered this stage also verifies whether the

new input data is sufficient, otherwise, it is updated and documented. If input data has been reused, this stage verifies whether the input data needs to be completed or modified in order to be documented.

- Stage 4: *"Are further experiments required?"* Here, the designed experiments, previously established in the input data, are run and, if further experiments are required, they are designed, performed, analyzed and documented.
- Stage 5: *"Are the results approved?"* The aim of this stage is to analyze the results and determine whether they are satisfactory or whether the project should be sent back to the first stage to be redefined from a different perspective, due to wrong assumptions or errors during the process. If such is the case, any possible errors are well documented according to the steps followed in the flow of the management method, preventing their repetition.

The proposed method improves the management of the project data and information over a lifecycle, simultaneously with the simulation process. This is achieved by storing and providing all the required provenance information which supports the traceability of the project process, for future reuse needs.

5 CONCLUSIONS

One of the goals of this project was to investigate the essential task of properly managing and documenting the data and information obtained from DES projects, in order to support data and information reuse. If simulation models, information and data can be reused, project lead times and quality would probably be improved. The reuse of data and information from preceding projects requires the management of the simulation provenance data which captures the origins and key events of the projects' lifecycle. Based on an industrial survey, a framework which maps simulation information and data to the W7 provenance model has been developed. Maintaining provenance information is a key aspect that allows engineers to understand how results were obtained and therefore allows its reusability in a subsequent project. The metadata that answers the W7 is the appropriate provenance information that needs to be included and documented when a DES project is performed. A method of managing provenance data for DES projects, which supports model, information and data reuse, has been developed.

It is important to state that the current study is based on a limited number of projects that were undertaken at an automotive manufacturing plant. While this may have a limiting effect on the results, it should nevertheless be possible to use the findings and results on a general basis.

Future work will be directed towards input data. This is lacking in the current study and will include aspects on input data requirements, collection, analysis, etc. Reasoning information, such as assumptions, simplifications, etc., which are often part of a simulation project, will also be addressed. The proposed framework and methodology are subject to implementation in a PLM-system.

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