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UTILIZING DISCRETE EVENT SIMULATION TO SUPPORT CONCEPTUAL DEVELOPMENT OF PRODUCTION SYSTEMS

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ABSTRACT

Discrete Event Simulation (DES) is a well-reputed tool for analyzing production systems. However, the development of new production system concepts introduces challenges from uncertainties, frequent concept changes, and limited input data. This paper investigates how DES should be applied in this context and proposes an adapted simulation project methodology that sets out to deal with the identified challenges. Key adaptations include parallel and iterative methodology steps, and close involvement of the simulation team in the development of the new concept. The proposed methodology has been applied and evaluated in an industrial case study during the development of a new production system concept. The findings show that the methodology can reduce the impact of the identified challenges and provide valuable feedback which contributes to the development of both the simulation model and the production system concept. Further, an evaluation of investments in new technology can be better facilitated.

1 INTRODUCTION

A high degree of competition and increased globalization put high demands on the manufacturing industry with stricter requirements on the speed of innovation, cost of products and quality (Freiberg and Scholz 2015). Further, the importance of using modern technologies has come to play a big role in becoming a first-class manufacturer. Even though these technologies are becoming and remaining more and more affordable, Freiberg and Scholz (2015) state that many of them still get rejected due to difficulties in evaluating the profitability of investing in them.

Discrete Event Simulation (DES) has the potential to support the evaluations of new technology and can be an important tool for analyzing production systems (Skoogh et al. 2012). DES can be used both as a tool for identifying improvements in a current production system and for analyzing new production equipment (Skoogh and Johansson 2008). The use of DES studies in projects is well established and there are a number of systematic methodologies that are widely used and reputed (Banks et al. 2005; Carson 2005; Law and Kelton 2000; Musselman 1994; Robinson and Bhatia 1995).

The development of a new production system concept could involve fundamental changes and new production principles which differ from smaller system alterations during development of an existing production system (Bellgran and Säfsten 2010). This introduces conditions which indicate that an application of DES to support the conceptual development of production systems is a context with more challenges that have to be dealt with. These challenges are mainly connected to uncertainties in project prerequisites, frequent changes of the production system concept, and limited availability and quality of input data (Bellgran and Säfsten 2010; Flores-Garcia et al. 2018).

This paper investigates how DES project methodology should be adapted to deal with the contextual challenges presented during the development of new production system concepts. To do so, a simulation project methodology is proposed, that has been developed and adapted to better manage these challenges. Further, the proposed methodology has been applied and evaluated during an industrial case study within the development project of a new production system concept.

The remainder of the paper is structured as follows; first, the theoretical framework is presented, which covers theory related to an application of DES during the conceptual development of production systems. This is followed by an introduction to the proposed DES project methodology and the results from its application in a case study. The findings and applicability of the proposed methodology are then discussed before conclusions and recommendations for future research are presented. Following this point in the paper, the term simulation will be used synonymously with DES.

2 THEORETICAL FRAMEWORK

This section introduces theory to give an overview of the challenges and potential solutions related to an application of simulation during the development of a production system concept.

2.1 Challenges with Development of Production System Concepts

A production system is a manufacturing subsystem that can be defined as an independent allocation of potential and resource factors for production purposes (Rogalski 2011). Some of the common functions that are included are premises, humans, machines and equipment (Bellgran and Säfsten 2010). In this paper, a production system refers to these functions and how they interrelate during production.

During the development of a new production system concept, there are uncertainties concerning how the design, structure, and processes of the concept will function and evolve as the project progresses (Bellgran and Säfsten 2010; Flores-Garcia et al. 2018). As a result, there could be difficulties in establishing an understanding of the simulated production system and setting clear objectives and requirements for the simulation model and how it should support the development. (Carson 2005; Flores-Garcia et al. 2018; Scheidegger et al. 2018).

Further, as part of the development of a production system concept, the concept is expected to change over time during its development (Barker and Zupick 2017; Bellgran and Säfsten 2010). These changes in the modeled system could lead to a variation in the required inputs, outputs and design of the simulation model over time, which induces challenges in maintaining a verified and validated simulation model as it changes (Banks et al. 2005; Flores-Garcia et al. 2018).

Lastly, the development of a new production system often includes new and potentially not yet developed manufacturing processes, equipment and production principles which could lead to limited availability and quality of input data for the model (Banks et al. 2005; Flores-Garcia et al. 2018). As a result, data estimations are required and there could be difficulties in assessing the validity of both input data and simulation model behavior (Bärring et al. 2018; Sargent 2013; Skoogh et al. 2012; Wang 2013).

2.2 Classification and Collection of Input Data

Skoogh et al. (2012) state that the management of data in simulation projects methodologies often is a challenge due to the frequent use of input and output data in each step. The classification of input data is one approach to support the input data management and Robinson and Bhatia (1995) present three different categories of classification based on the availability and the collectability of the data. The different classification categories are presented in Table 1.

Table 1: Input data categories.

Category	Availability	Collectability
A	Available	-
B	Not available	Collectable
C	Not available	Not collectable

Skoogh and Johansson (2008) propose a methodology for input data management in simulation projects, where the relevant parameters for the simulation project are identified and defined in the three categories. The classification facilitates the process of how the data could be obtained, and there are significant differences in the approaches for data collection between the three categories.

As category A data is already available there is no need for collection and the data could be found in various systems, such as planning systems, or stored from previous projects. The data in category B data normally takes a significantly longer time to collect and could be obtained through various data collection activities, such as time studies or video analysis. Finally, category C data is neither available nor collectable and has to be estimated. These estimations should be performed in collaboration with people who have extensive knowledge of the system that is being developed (Carson 2005; Skoogh and Johansson 2008). Further, the estimations could be supported by discussions with process experts, historical data from similar systems or available standardized data (Robinson 2004). During the development of a new production system, an additional approach described by Skoogh and Johansson (2008) is to use process-oriented simulation or emulation tools to generate good quality input data.

2.3 Techniques for Verification and Validation

With regard to the validation of a simulation model, one preferable validation technique is to compare the simulation output with historical data from the real production system (Banks et al. 2005; Carson 2005; Robinson and Bhatia 1995). However, when no historical data of the system exists or a new system is being developed the validation process becomes more challenging and Barker and Zupick (2017) state the importance of including process experts and their knowledge during the validation process when systems are designed through simulation. Sargent (2013) further states that involving the user(s) and other stakeholders in the simulation project during the stages of verification and validation is a suitable approach to create a satisfactory and credible model when the model development team is small.

Wang (2013) states that limited possibilities in using objective validation techniques, such as comparisons with numerical data, could lead to a need to use subjective (informal) techniques for validation which rely more on the reasoning, insights, and intuition of experts on the modeled system. Several informal validation techniques are available and a selection of these are presented by Balci (2013) and Sargent (2013). Three commonly used techniques are described as *Animation*, where the performance of the simulation is visualized graphically, *Face Validation*, where the behavior of the model is reviewed by people with extensive knowledge of the system, and *Structured Walkthroughs*, where a single entity from the simulation model is validated by a peer group to which it is presented.

Related to the process of model verification, both Banks et al. (2005) and Barker and Zupick (2017) stress the importance of performing verification on smaller sections of the model continuously to enable frequent testing and reduce debugging efforts.

2.4 Simulation for Risk Management

Simulation enables an evaluation of production systems and the impact from system changes before these are implemented and is a well-suited tool for faster optimization of a system while reducing the risk of affecting the real system negatively (Banks et al. 2005). Further, the cost of a simulation study is often essentially less than 1% of the total amount for an implementation or redesign of a system (Banks 1999). Consequently, using simulation as a risk management tool can be a suitable and cost effective option.

3 PROPOSED DES PROJECT METHODOLOGY

The proposed simulation project methodology has been developed based on the challenges related to an application of simulation to support the conceptual development of production systems. Based on these challenges and the reviewed literature, several countermeasures have been developed and incorporated in the simulation project methodology with the aim to achieve a more suitable adaptation to the development of new production system concepts. The steps and basic procedure of the methodology are based on existing methodologies for conducting simulation projects and necessary adaptations have been performed where required. An overview of the proposed simulation project methodology is visualized in Figure 1. It is divided into two focus areas, *Overall Concept Focus* and *Iterative Multi-Process Focus*, to separate the methodology steps and adjust their scope to match the development of the new production system concept. The steps located in the *Overall Concept Focus* section should be performed based on the production system concept as a whole, while the steps located within *Iterative Multi-Process Focus* should be performed in parallel processes targeted at specific sections of the concept. Each step of the proposed methodology is explained further in the following sections.

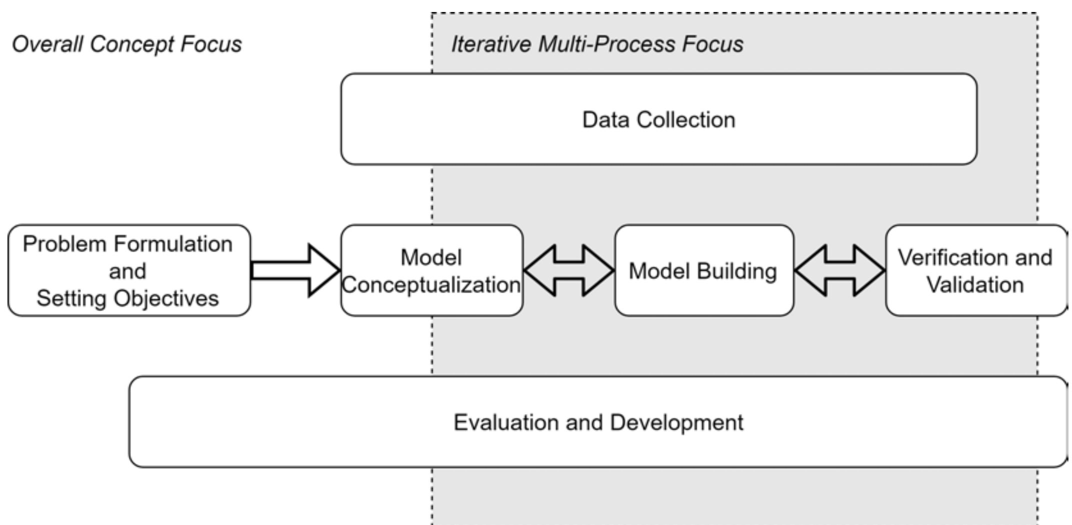

Figure 1: Overview of the proposed simulation project methodology.

3.1 Problem Formulation and Setting Objectives

In line with the methodologies presented by Banks et al. (2005), Carson (2005) and Musselman (1994), a problem formulation and setting of objectives should be performed in close collaboration with involved stakeholders as an initial step. This is aimed towards arriving at a mutual understanding and agreement of the project scope and puts a focus on straightening out the expectations and knowledge of all the stakeholders regarding the simulation and new production system concept. Based on the uncertainties related to the conceptual development of production systems, close communication is important at this step to reach an agreement and understanding of the objectives and avoid additional uncertainty in the project.

3.2 Model Conceptualization

To establish an early overall understanding of the new production system concept and how it should be modeled, a conceptual model should be created based on the previously set objectives. The depth of detail should be at a suitable level to deal with the uncertainty of the new concept and no extensive focus should be placed on data collection for the building of the simulation model at this stage. In line with Robinson et al. (2011), the conceptual model should specify the inputs and outputs of the simulation model to facilitate a better understanding of the possibilities and limitations for the simulation model and project.

A key difference in the proposed simulation project methodology is that the conceptual model does not have to fully cover the production system, but rather should be focused on the sections of the concept which are the most certain at the time. By targeting the areas which are the least likely to change, upcoming changes in the concept are accounted for and the impact they have on the simulation model and potential rework is reduced. When the certainty increases or concept changes affect the conceptual model, it should be updated to ensure that it matches the development of the production system concept. Consequently, the model conceptualization should be performed iteratively and in close relation to other steps in the proposed simulation project methodology.

3.3 Data Collection

Within an early phase of the data collection, it is suggested that a specification and classification of the required input data is done based on its availability and collectability, as presented by Robinson and Bhatia (1995) and Skoogh and Johansson (2008). The results from this process are meant to aid in quickly creating an overview of the input data requirements and functions as a support in the choice of simulation software. An important aspect to emphasize within the proposed simulation project methodology is the need to take consideration to the limited availability and quality of input data that is a part of the development of a production system concept, which leads to input data in category C. Consequently, a close collaboration should be established with process experts to support data estimations during the data collection. Further, this collaboration should be used to formulate accuracy requirements, in line with the approach described by Skoogh et al. (2012), to ensure an efficient and targeted data collection within the right areas.

As displayed in Figure 1, the process of data collection should be initiated simultaneously with the model conceptualization and be performed in parallel to the other steps within the proposed project methodology. Being one of the methodology steps located within the *Iterative Multi-Process Focus*, the majority of the data collection should be performed in multiple processes and be targeted at the sections of the production system concept which are the furthest developed at the time.

3.4 Model Building

The model building should be initiated by a choice of simulation software, which, in line with Robinson et al. (2011), should be the first time a specific software is considered unless previously specified. The selection should be supported by the results from the classification of input data and with limited availability and quality of input data, a suggested approach in line with Skoogh and Johansson (2008) is to choose a simulation software which is capable of generating data.

Once a suitable simulation software has been chosen, the building of the simulation model can be initiated. The strategy for the modeling should be to target sections of the new production system concept based on their level of certainty, which is aimed at creating a simulation model where the areas of the concept that have the lowest risk of changing during the ongoing development project are prioritized. Additionally, the detail level of the simulation model should be adjusted to suit the certainty of the production system concept as this increases throughout the project. This could mean that the simulation model initially is built using default data in the simulation software, before transitioning to more detailed data as the certainty of the production system concept increases.

By targeting different sections of the concept and model them separately before they are merged into one model and adapt the detail level as certainty increases, the model building is adapted to better deal with the challenges related to uncertainties and frequent changes. Within this step of the proposed methodology, close collaboration and frequent communication with concept developers are of significant importance to be able to pace the work with the simulation model to match the development of the concept.

3.5 Verification and Validation

In line with the theory presented by Banks et al. (2005) and Barker and Zupick (2017), the verification of the simulation model should be performed continuously to ensure that it is aligned with the conceptual model. This continuity of verification is emphasized in the proposed methodology to ensure swift adjustments to any changes that occur to the conceptual model as a result of frequent changes in the new production system concept. Thus, consideration should be taken to that previously verified sections of the simulation model might have to be re-modeled and re-verified as the concept is developed. Based on this potential model rework, the importance of prioritizing the modeling of the most certain sections of the production system concept to avoid future adjustments is further emphasized. Additionally, the steps of verification and validation are both included in the *Iterative Multi-Process Focus* and should consequently be performed in parallel processes. By iteratively building and verifying the simulation model in parts before merging them, the model functionality can be ensured.

Based on the limited availability and quality of input data during the development of production system concepts, an important aspect in the proposed methodology is that more informal validation techniques should be used for model validation. As described by Barker and Zupick (2017) and Sargent (2013), a close collaboration with process experts is of additional importance to facilitate this approach of assessing the validity of the simulation model.

3.6 Evaluation and Development

The analysis step in simulation project methodologies is often performed as one of the last steps in a simulation project (Banks et al. 2005; Carson 2005; Musselman 1994; Robinson and Bhatia 1995). A key difference within the proposed simulation project methodology is that this activity should be performed continuously throughout the simulation project and in parallel to other methodology steps. This approach aims to take full benefit of the insights gained from the simulation model and enables the simulation team to give continuous feedback which can support the development of the new production system concept at all stages of the simulation project. The model building is one step where there is great potential to identify areas of improvement, in which more focus should be placed on providing feedback. With a close collaboration and feedback loop between the simulation team and the development team, critical knowledge can be shared which further enables a better ability to handle uncertainties and perform swift adjustments to the frequent changes of the new production system concept.

4 CASE APPLICATION

As part of the evaluation of the proposed simulation project methodology, it was applied in an industrial case study. The study was performed at the company PowerCell Sweden AB which is active in the highly competitive automotive supplier industry, for which it manufactures fuel cell stacks and systems. In collaboration with the company Semcon AB, PowerCell Sweden AB is involved in a project aimed at developing a new production system concept with an assembly line for automated mass production of fuel cell stacks (PowerCell 2018). The new concept is aimed at transitioning from a manual to automatic production using resources such as robots, conveyors and processing equipment. The amount, type and composition of these automated resources varied throughout the project as the concept was developed.

The proposed simulation project methodology was applied in a simulation project within the development of the new production system concept, aimed at evaluating how the methodology deals with the identified challenges when simulation is applied during the development of production system concepts. The findings from the case study were supported by interviews with key stakeholders from the development project, which were weighed in for an overall evaluation of the project methodology.

5 RESULTS

This section presents the results from the application of the proposed simulation project methodology in the industrial case study.

5.1 Problem Formulation and Setting Objectives

A key aspect identified during the problem formulation was the uncertainty in how the new production system concept would perform if implemented. The capacity of the system and technical solutions for the new manufacturing processes were two contributors to these uncertainties and the purpose of the simulation model was set to investigate if the new concept would meet the requirements.

During the setting of objectives, several different expectations were identified and these are summarized in Table 2. One important factor was considered to be the detail level of the simulation. On one side there were expectations on a more detailed model to test clearances between resources during operation and generate cycle times from the simulation, thus requiring a simulation model with great visual details. On the other hand, there were requests on running simulations over a longer time to see statistical trends and metrics. Another outspoken expectation was the possibility to test multiple concept solutions against a set of different capacity demands, thus putting requirements on a scalability of the simulation model.

After discussions with the customer and development team, it was agreed that the main objective would be to create a simulation model detailed enough to be used to evaluate and improve processes while providing a good graphical representation of the system. Further, an additional expectation in relation to the project was the incorporation of the simulation team in the development of the new production system concept. The shared view among stakeholders was that continuous feedback from the simulation team would be of critical importance to improve the new concept during its development.

Table 2: Expectations of simulation model.

Expectations	Customer	Development Team
Detailed layout	X	X
Process cycle times	X	X
Selling visualizations	X	X
Continuous concept feedback		X
Simulations over long time period	X	
Statistics of uncontrollable factors	X	
Simulation model scalability	X	

5.2 Model Conceptualization

The required inputs and outputs for the conceptual model were specified with the main basis in the problem formulation and setting of objectives in the prior step of the methodology. Two examples of the input information which had been touched upon during discussion with stakeholders were the critical manufacturing processes and current stage of development for each section of the production system concept.

Even though uncertainties related to the new production system concept existed, a consensus and understanding of the general process flow could be established and used to create the conceptual model based on the specified inputs and outputs. Despite the approach to build the conceptual model with a focus on the most developed and certain sections of the production system concept, there were however cases where modeled processes had to be re-modeled due to the frequent changes and developments of the concept. Though, the adaptation of the detail level of the conceptual- and simulation model as the simulation project progressed meant that the changes in the concept only resulted in occasional and minor adjustments of the simulation model, such as process layout changes.

5.3 Data Collection

The classification of input data was based on a set of 31 different data points and the results are presented in Table 3, indicating a trend towards input data of category B and C. The data classified in category A mainly related to the product, as this already was a well-developed resource within the new production system concept. Two examples of data within this category were the bill of material and dimensions of the product, and these were available at the case company. Within category B the majority of data related to available machines and other standard equipment (e.g. processing times and dimensions) and was collected from studies of the existing manual production. Lastly, a substantial amount of the classified data was located in category C and related mainly to process details of the new manufacturing processes within the developed production system concept. The estimations of category C data were mostly done collaboratively with manufacturing process experts from the case company and experts on the new automation equipment from the development team. The close collaboration with process experts was stated by the stakeholders in the development project to be important for creating confidence in that suitable input data was used for the simulation model. Lastly, some of the cycle times for processes were generated by running the simulation model.

Table 3: Results from the input data classification.

	Category A	Category B	Category C
Common data type	Product data	Equipment data	Process details
Common data source	Case company	Available equipment	Process experts
Collection method	Available	Collected	Estimated
Distribution	13 %	23 %	65 %

To deal with the input data uncertainty, the simulation model was initially built in a way in which default simulation software data (e.g. cycle- and material handling times) was used to a great extent. As the development of the concept progressed and the certainty of the processes increased, the collection of input data was continued in more detail and this could be used to replace the default data used in the model.

5.4 Model Building

The sections of the new production system concept that were targeted to be modeled initially related mainly to material supply and material handling, which were the most certain areas of the concept at the start of the model building and considered to have the lowest risk of changing during the development project. As the development of the concept progressed, the number of processes at this level of certainty increased to include layout- and process details. However, the building of the simulation model advanced at a faster pace than the development of the production system concept which led to that the modeled sections of the concept had a lower level of certainty.

As the project progressed it became more frequent that changes in the production system concept, often related to critical processes and layout design, had to be re-modeled in the simulation model. While occasional re-modeling was required in the simulation model, the changes which led to this outcome were significantly fewer compared to the total amount of changes that occurred in the concept throughout the development project. Further, the communicated insights from the simulation model that contributed to the development of the production system concept were often the initiating factor behind a change in the concept. While this caused some additional work in building the simulation model, these were often smaller adjustments in the model as a result of an adapted detail level and the feedback was important for the development of the concept.

5.5 Verification and Validation

Any discrepancies between the conceptual- and simulation model were updated in the simulation model as these were identified during verification. The main reason behind these identified differences was updates in the conceptual model as a result of frequent changes in the production system concept, which created a need to adjust and re-verify sections of the simulation model.

To handle the challenges connected to limited availability and quality of input data the validation of the simulation model was limited to more informal validation techniques, such as animation and face validation. These were well facilitated by the graphical visualizations available within the selected simulation software and both the customer and development team expressed that the simulation model was an accurate representation of reality based on the set objectives. Some of the more frequent validation activities were carried out as the model building and verification were completed for one of the parallel sections of the production system concept. The validation was mainly done in collaboration with parts of the development team by displaying the behavior of the model and inspecting the processes included in that section. Further, some processes related to the new automation equipment were validated in more depth using face validation and structured walkthroughs together with developers and experts on those processes.

Additionally, a few larger validation sessions including several of the production system concept developers were held during the project. These often included multiple sections of the concept and facilitated discussions that contributed to the development of the production system concept as well as the simulation model. Similarly, validation with respect to the production system concept as a whole was carried out after completion of the simulation model.

5.6 Evaluation and Development

Based on the expressed expectation that the feedback from the simulation team was of great importance to the development of the production system concept, a continuous feedback-loop was used throughout the project. Some of the key feedback provided to the development team were restrictions of the manufacturing processes due to the layout design, indications of process cycle time and general suggestions on process improvements. This feedback gave the development team insights on the performance and design of the concept from an early stage of the project, which could be used to develop new solutions and system improvements. The significance and frequency of the suggestions for production system concept changes increased as the model building progressed. With an increased certainty and number of modeled processes, more conclusions could be drawn from the simulation model and its behavior.

Further, it was expressed by the development team that the visualizations of the simulation model behavior were a good tool for facilitating the understanding and internal communication regarding the new production system concept and how it should be developed. Additionally, the close collaboration and feedback-loop between the simulation team and the development team reduced the uncertainties concerning the concept while providing frequent updates on changes that affected the simulation model.

6 DISCUSSION

The proposed simulation project methodology was developed without consideration to case-specific conditions to reduce the risk of poor transferability, and the findings from the case study indicate that the methodology can be used to mitigate the contextual challenges. However, they are not completely eliminated and key aspects related to the applicability of the methodology are discussed in the following sections.

6.1 Setting the Direction of the Project

Through an early and collaborative setting of objectives, a better understanding of the expectations on the project could be created. Further, the input data classification was important for identifying potential challenges. By establishing an understanding of the limited availability and quality of input data, realistic expectations on the output of the simulation model could be set and communicated. Related to the uncertainties described by Bellgran and Säfsten (2010) and Flores-Garcia et al. (2018), an influencing factor is at what stage of the concept development that the simulation project is initiated. At an early stage of development, there is a risk that the modeled system is not developed enough to give a suitable representation of the final production. At later stages of the development, the concept is more certain and better insights can be provided, but the cost and difficulties in performing changes could be greater. By performing the study at a suitable stage of the development project, optimal support from the simulation can be facilitated and the risks related to an implementation of the production system concept can be reduced.

6.2 Dealing with Frequent Concept Changes

The potentially challenging verification and validation as a result of frequent changes in the concept and limited availability and quality of input data, as presented by Banks et al. (2005) and Flores-Garcia et al. (2018), are additional aspects that were managed by the proposed simulation project methodology during its application. By performing the different steps of the proposed methodology iteratively and in parallel sections, changes in the concept could be dealt with swiftly and the risk for major adjustments in the simulation model at later stages of the project was reduced significantly. Additionally, to perform frequent verifications enabled better flexibility towards changes in the production system concept and supported an early identification of its potential areas of improvement.

The flexibility towards dealing with frequent concept changes was further improved by increasing the detail of the simulation model as the concept was developed and became more certain. Although this approach is suggested, the case study findings also showed that modeling sections with higher uncertainty can provide valuable insights to the development of the concept. Even though there is a higher risk of re-modeling as a result of concept changes, these changes can also support the development of the production system concept. Difficulties are consequently introduced in the balance between modeling in more detail to support the concept development, with a risk of having to spend time adjusting details later, or modeling in less detail to avoid model adjustments, with a risk of not capturing important aspects of the process. However, a fundamental aspect of the development of a production system concept is that it will change and improve over time. Frequent concept changes are consequently partly encouraged and the simulation project methodology should be adapted to incorporate the changes rather than eliminating them.

6.3 Validating the Simulation Model

Despite the challenges related to limited availability and quality of input data described by Bärring et al. (2018), Sargent (2013), Skoogh et al. (2012) and Wang (2013), the informal validation techniques enabled a validity assessment of the simulation model. However, being based more on human reasoning than data, they could cause difficulties in creating confidence in the model. With limited data for comparison with the simulation model, it is consequently of absolute importance to involve process experts and developers at an early stage to enable feedback during the project and establish credibility in the simulation model.

The findings from the application of the simulation project methodology show credibility in the project results among key stakeholders from the development project and the potential difficulties in creating confidence in the input data and simulation model have been dealt with. Consequently, this is an additional indication that the proposed project methodology limits the impact of the challenges related to model validation and input data estimations. Further, the findings from the study show that the capabilities of the selected simulation software can be important to enable this type of validation. With good graphical visualizations, a better understanding and confidence in the simulation model can be facilitated.

7 CONCLUSIONS & FUTURE WORK

The utilization of simulation to support the development of production system concepts induces challenges related to concept uncertainties, frequent changes, and limited availability and quality of input data. This study presents a simulation project methodology designed to target and reduce the impact of these challenges. While the identified challenges can be mitigated by the methodology, they are not completely eliminated from these types of simulation applications and must still be taken into consideration.

Two important adaptations within the proposed simulation project methodology are to perform the steps of the methodology iteratively and in parallel processes. These should be targeted at the areas of the concept which are the furthest developed, with a detail that increases as the concept is being developed. Further, it is of critical importance with close collaboration and for the simulation team to be incorporated at an early stage in the development of the production system concept as this enables possibilities in developing both the simulation model and new concept.

This study has shown that the presented simulation project methodology is a suitable exploratory first iteration in how simulation should be used to support the development of new production system concepts. To provide more comprehensive insights regarding the applicability of the proposed methodology and develop it further, it is suggested that it is applied and evaluated in additional cases with different conditions compared to the industrial case used in this research.

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