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Analysing Discrete Event Simulation Modelling Activities Applied in Manufacturing System Design

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Abstract
In manufacturing industry, Discrete Event Simulation (DES) is applied in just a small fraction of the cases where it could give significant value. The complexity of the DES technology itself is one barrier to achieving its full potential in manufacturing system design. This paper focuses on methodologies which can be used in studying the modelling process, with the specific intent of integrating DES into the engineering design process of manufacturing systems. Ethnographical methodologies are proposed, as they are successfully applied to the analysis of the engineering design process. Observations from industrial practice indicate that visualisation in DES software is essential for the sequential verification of design activities.

Keywords:
Discrete Event Simulation, Manufacturing system design, Engineering design

1 INTRODUCTION

Why DES is applied in just a small fraction of the cases where it could give significant value is a frequently debated question. According to Banks [1], the complexity of the technology itself is the foremost barrier to the broad deployment of DES technology. Moreover, DES is also considered a time-consuming and expensive expert tool by potential users in industry [2]. Despite these negative attitudes, DES must be considered a top-ranked decision-making tool capable of capturing the dynamic complexity of manufacturing a system. DES is also a versatile tool and the potential areas of application in manufacturing industry include a wide range of examples, such as operative planning support, system analysis and system design.

This study has its particular interest in the integration of DES into the engineering design process of wood manufacturing systems. The engineering design process of such a system may include the construction and modification of equipment for the processing and handling of materials, the configuration of computerized control systems and automation, and the design of system layout. By using traditional design methods only static capacity analyses can be carried out. To manage the system complexity and the dynamics of material flow the employment of DES is needed. The intention is to integrate DES already in the early development stages as a design support tool and to verify design stages continuously, during the development of the system. This is in contrast to the most frequent situation where DES is used to verify the capacity and properties of an already completed system design which has been developed by traditional methods.

Many of the conditions typically encountered in wood manufacturing can also be of relevance to other industrial sectors. Typical characteristics of wood manufacturing include highly automated processing and an extensive material handling of large physical volumes on conveyors which come in a myriad of variations. Design details in these systems often have a decisive influence on the capacity and functionality of these systems. Therefore, a valid DES modelling of these systems must also include the functionality and logics that are associated with these specific design issues. Only a few DES tools enable this kind of detailed modelling; they are based on a “manufacturing-oriented simulation language” [3]. To comply with the requirement of detail modelling capability our reference projects were carried out in AutoMod from Applied Materials (http://www.appliedmaterials.com /products/automod_2.html). AutoMod has the capacity to deal with large models built in a flexible modelling language in a true-to-scale 3D model environment with collision detection between moving objects in the material flow. Objects drawn in 3D CAD (Computer Aided Design) can be imported, and the effects resulting from the geometry of moving objects and distance in layout are implemented with no extra calculation being involved.

To realize the intention of integrating DES into the engineering design process of wood manufacturing systems, the perceptions of engineering design methodologies are adopted. This also includes observation methods employed to study and analyse the design process. Analysis of the design process has been important for some time, but the changes in current engineering design practices brought about by the revolution in information technology makes it a more vital issue today than ever before. Virtual representation of 3D objects, many types of modelling and simulation applications, and the opportunity of working in geographically spread organisations, are some examples of the factors that have come into focus.

This approach, based on engineering design methodologies, stands in contrast to and complements other studies that see the matter of DES integration into the design process mainly in terms of DES technology.

The focus on the integration of DES into the engineering design process is, for example, extensively discussed in dissertations by Klingstam and Randell [4, 5], but in the context of the large automotive industries

The main purpose of this paper is to illustrate how observation methodologies and the perceptions of engineering design methodologies are applicable to a better understanding of the integration of DES into the engineering design process. Since DES modelling is a complex and iterative process of intermixed debugging and verification including validation tasks and exercises [6], it may involve a number of activities important for model design and the detection of design criteria that can be of value to the engineering design process.

2 THE ENGINEERING DESIGN PROCESS AND OBSERVATION STUDIES

For a long period of time, the engineering design process has been a subject for analysis, but mainly as an individual activity of technical character [7]. An increased complexity in working with industrial product development has, however, changed the character of traditional development and design work. Today, the need for collaboration between teams at a long distance from each other has become more important. Computer-supported activities and their ability to represent and share information in a virtual environment are also conditions that influence both local and distributed design work. Due to this dramatic change in the role of engineering design, there is an increased interest in studying and analysing the design process from a multifaceted perspective, which focuses on the collaborative work in design [8, 9]. The study and the analysis of the collaborative design process include interdisciplinary approaches which involve the social context, the language, the creation and use of artefacts, and other factors which form the design process [10].

To study the engineering design process, methods are simply “borrowed” from the social sciences and applied by engineers [11]. Some examples of these methods include open-ended and focused interviews, structured interviews and surveys, the documentation and the use of archival records, as well as observation studies. It should be emphasised that these kinds of studies and the subsequent analysis do not necessarily result in a model or a descriptive principle of work flow, as is often expected by engineers [10]. Instead, they are applied to provide frameworks for the understanding of the wide range of conditions in which the design process is accomplished in real-world industries. According to Larsson, engineering design is an “ inherently social activity, and the focus of interest is to study, better understand and describe how engineers actually carry out their work, in detail, not to prescribe how they should work”.

Observations collected by a qualitative method common in ethnography are often used by social scientists and are applicable to the discipline of engineering. An observer could obtain information without participating in activities or acting as the participant observer, fully participating in the studied activities. According to Larsson [10], the choice between these observational extremes is not necessary. Ethnographers often move back and forth between different degrees of participation. One way to obtain and document observation can be to take field notes. They serve more as ‘triggers’ to remember activities in a certain situation than as complete notes of experience and observation. An essential complement to such notes is videotaping since it is impossible to capture human activities and their complexity by observation alone since they happen so quickly. The playback of video taping is particularly valuable in analysing such situations. Informal interviewing allows the participants to create the dialogue in their ‘natural’ environment where they feel familiar and where they have access to the people and objects that might be of importance for the conversation. The foregoing summary of ethnographical methodologies refers mainly to Larsson [10].

3 WHAT TO OBSERVE?

To provide some insight into ethnographically informed fieldwork – arrangements, observations, interpretations – the article “Coordinating joint design work: the role of communication and artefacts” provides substantial examples [8]. Two independent design projects were studied by two separate observers with the shared objective to examine the significance of “social and organisational interactions, and the ongoing nature of the knowledge representation and transformation work that takes place through the use of design artefacts”. Findings from this work suggest “that design and engineering are constructed through the interactions of multiple actors, and that artefacts and representations of the design process have a key function in the organisation of this work.”

The creation and the use of artefacts have prominent positions in a large number of studies as they compose objects of interaction and have important roles as communicative resources. According to Perry and Sanderson, two categories of artefacts are defined: design and procedural [8]. Design artefacts include things like pen and paper sketches, tables of data, guidelines, cardboard models, and computer visualisation of objects in 3D. Procedural artefacts include change requests, office memos, letters, schedules, and Gantt charts. Artefacts are also forwarded as linguistic elements that help designers to bridge thought and object, function and structure [9]. The opposition between formal specification and work with prototyping explains how some organisations can be driven by specifications and others by prototyping [12]. An odd and interesting observation of artefacts is the extreme form of the spatial location defined as the “airboard” [13]: “On occasion, people explain things to others by drawing in the air”. Later in the conversation, people referred to ‘that idea’ by pointing to the spot in the air where they first had ‘drawn’ the idea.”

4 EXAMPLES OF OBSERVATIONS FROM COMPLETED DES PROJECTS

Experiences of performed DES projects from the perspective of engineering design and the analysis of the design process imply that a great number of factors determine the work progress. The following examples are based on the projects in wood manufacturing industries with their characteristics.

4.1 Distributed modelling activities

In one project, the industrial representative was an experienced computer user, and a spreadsheet model was already developed, which could be implemented as a part of the DES-model user interface built in MS excel. The need to collaborate became more and more accentuated, and to overcome the geographical distance a software application of “shared desktop” was used. By the means of a shared desktop over distance, spreadsheets, flowcharts, and layout drawings were developed with both parties involved simultaneously. The verbal dialogue was simply managed by phone, and the dialogue was truly enriched by the interactivity performed by the shared desktop. Early in the project stage, the industry also made a purchase of a so-called “runtime licence," which enabled runs of a DES model in an executable form. The industry could thereby verify the model design continuously during its development by various in-data scenarios defined in the excel user interface under development. It should be emphasized that the DES run-time license was applied frequently to verify the model in various design stages, not only applied to the completed model.

This is an example of distributed work in DES model design that was realized thanks to the industrial representative who became absorbed in the software technology involved. Subsequent project meetings turned out to be successful and inspiring to others by the unexpected progress in work without travelling. Time and money were saved, and the model design was verified, sequentially and by the involvement of industrial representatives and "run-time models." This simple example of a "shared desktop," at first glance considered doubtful, was used frequently and with success

4.2 Artefacts reinforce the dialogue

This example concern material handling in the process line and include nine object variations of rectangular geometries, rotated 4-5 times on the flat, along with positions of 90 degrees direction change. The relation between length and width is often double, which considerably influences the capacity of feed and conveyor logics. These sequences of material handling were not documented in prior by the industry, and after two unsuccessful attempts to model this part of the system, a new approach to solve the problem was needed. This time the support of business cards clarified the situation. They were moved and rotated along the layout until the logic could be documented step by step in a index structure that served the DES model logics.

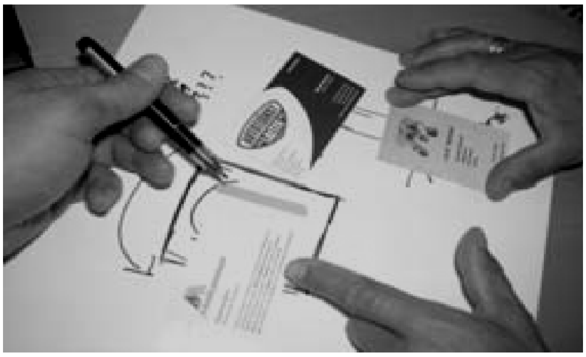

Figure 1: Material handling illustrated

The use of business cards constitutes an example of simple arrangements, without which it would have been rather difficult to systemize and document. Data collection is a time-consuming and difficult part of the modelling stage where the support by artefacts, in this case business cards, can make the process more efficient. Whether semantic differences were present in the dialogue was not observed, but if that was the case, common references in artefacts would also be of crucial importance to bridge dialectal variations between knowledge areas.

4.3 Detecting design criteria in a DES model

A case of material handling problem concerns a machine process which included objects of various dimensions on a conveyor with carriers. Carrier spacing was 500 mm, and the carriers moved objects by their leading edge. The objects next in line could not to be closer than 400 mm, which means that all carriers could not to be used for all objects in order to maintain a distance longer than 400 mm, as it is illustrated in figure 2. The feeding direction of the objects meant that there were 18 possibilities for dimensions between 400 to 1600 mm. At first, the industry did not provide these conditions, just the feed rate without information of carriers and their logic. On the other hand, the consultant was not aware of these conditions until it became clear that the capacity in the real system did not correspond to the feeding rate in the model. When it became clear that the system with carriers and objects of various dimensions could be represented in the DES model, a number of other aspects regarding the design and spacing of carriers could also be lively discussed between the individuals in the team of industry representatives. Before the DES project, the process technology with carriers had for a long time frequently been considered as a problem, and when it was clear that these conditions could be re-created in a model, further questions could be raised considering an alternative design for the spacing of carriers.

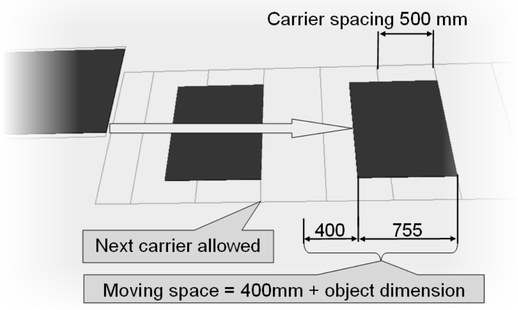

Figure 2: Detailed conveyor design

This example of a detailed modelling of material hand-ling, in specifics shown in the DES model, illustrates how collaboration between DES and system experts can be based on visual references in a DES model. It also illustrates how alternative machine design can be detected, modified and evaluated by the support of a DES model. In this case it points to a possible redesign for an optimal spacing of carriers according to object dimensions.

5 DISCUSSION

Implementing new technology into an existing organisation is challenging, and the dependence on the external competence of a DES consultant makes it even more difficult. The approach to solve this problem is, however, often considered to be of a technical character only, since technology is a concrete subject whose application is stimulated by its fast development. Nevertheless, in addition to technology, methodology and organisation are also two components that have to be taken into consideration in the quest to overcome barriers and hindrances. A saying is that it takes one part of technology, ten parts of methodology, and one hundred parts of organisation to manage the implementation of new technology [4]. In many cases, just the attitude towards new technology may be a decisive factor [14]. This can be the case in tradition-bound industries, of which wood manufacturing industries make a good example.

Figure 3, which illustrates specific capabilities in DES application, composes an applicable reference to the circumstances discussed. Unlike a number of attempts to systemise the modelling process [15], the approach here emphasises the collaboration between simulation expert, engineer, technician, and factors that maintain the integration between system and simulation know-how in the design process. Since collaboration can be of many different kinds according to the context of dependences and situations, it is important to tailor the specific needs in the setup of DES applications. This is complex work, however, which is also emphasised within the area of engineering design and its most recent development towards increased collaboration in distributed organisations. As a basis for clarity in collaborative work Ostergaard and Summers have proposed a taxonomy [16]. Such a taxonomy could in many aspects compose a starting point to adopt and tailor a taxonomy in the area where DES is involved [17].

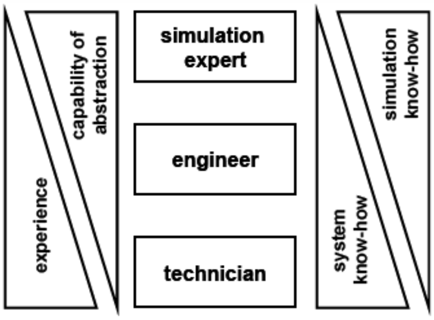

Figure 3 Specific capabilities [15]

While DES modelling is a complex and iterative process, it must contain a great deal of creativity for problem solving and collaborative processes that involve both system and simulation know-how. To bridge these two competences, a fundamental prerequisite is a dialogue that is based on mutual references to the two know-how areas. This is where design and procedural artefacts play their role. The simulation model, the factory layouts, the flowcharts, the paper sketches, or the usage of business cards compose some examples of vital artefacts that maintain this dialogue. At first sight, these artefacts and our examples of observations listed may appear trivial or obvious to a skilled DES user. However, with the introduction of DES technology to industries as a point of departure, any condition that makes DES technology concrete and involves industry personnel must be forwarded. From this perspective, one must remember that DES is a virtual and complex representation of math modelling. In the best case, according to the character of the problem and the DES tools used, visualisation in the DES model is provided as a support to bridge competences. If this is not possible, other artefacts, which present DES capabilities and model verification in concrete form, must be given a forwarded position. In the area of product design, such design artefacts, no matter their character – rough or complete, virtual or palpable, sketch or mock-up – constitute an essential medium which serves to bridge thought and object among the team members [9]. An essential quality of design artefacts is also their ability to express non-verbal characteristics [18].

It is, however, emphasised in DES literature [19] that the use of a tabletop scale model, embodying a system in focus for a DES analysis, is of great support. Moreover, the examples of observations from the performed DES projects compose facts that in the context of engineering design would have formed determining factors for further analysis of the modelling process. Today's development of DES model visualisation and flexible model design provides a comprehensive possibility of virtual representation in a concrete form [20, 21]. Figure 4 and 5 illustrates the capabilities of detailed DES modelling that would have been impossible without the visualisation of geometrical references that can be achieved in the DES model. Collision detection between objects in the material flow provides here a realistic and valid representation the material handling, and how objects are supposed to queue in front of a process, which is a common design solution in wood manufacturing systems. For the case of various material dimensions, collision detection becomes a determining factor for a valid model design and understanding of dynamic effects.

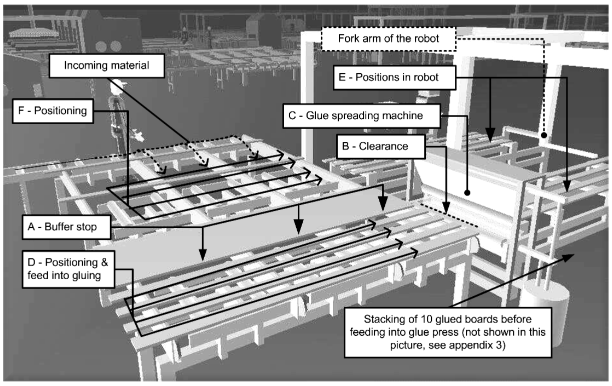

Figure 4: Details of cross-feeding system and glue-spread machine [22]

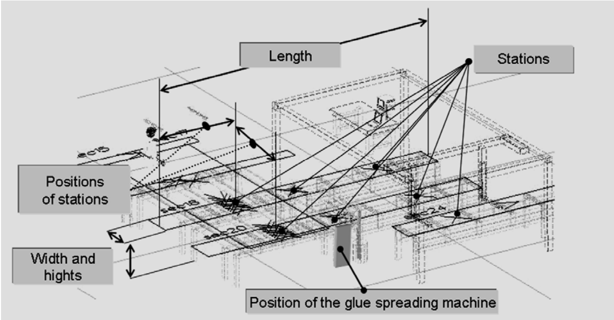

Figure 5: Geometrical references in the skeleton of the DES model, compare with Figure 4 [22]

An increased awareness of virtual design artefacts and their role in the modelling development process appears to be essential for the integration of DES in the design process. Observations show that features for detailed model design, provided by some DES tools, are significant for design criteria. The possibility to manage geographical distance constitutes another concrete example where visualisation is a fundamental prerequisite for collaboration in the design process.

A decisive factor for successes in distributed work was the positive attitude to experiments with various technical solutions to enable collaboration over distance. It could also be noticed that the social characteristics of the dialogue changed from formal to more relaxed and familiar and that ideas could therefore be deliberated without prestige. The importance of social factors in the design process is established [10, 23].

6 CONCLUSION

In the effort to integrate DES into the engineering design process of wood manufacturing systems, it has to be remembered that DES may appear as an abstract and complex technology to an industry uninitiated in the nature and benefits of DES technology. Therefore the importance of understanding the kinds of factors that support a more concrete form of DES technology is essential. In a context where DES is integrated into the engineering design process, the need for DES in a concrete form to support design issues and the related dialogue between competences is even more accentuated.

Examples of features in AutoMod that provide a more concrete form of DES which supports the design process are the visualisation of CAD-drawn equipment, moving material and collision detection between items of moving material. Furthermore, everything is represented in a 3D model environment that is true to scale. The value of the employment of this kind of visualisation for design purposes is proved by the case presented in part 4.3. This illustrates how shared references in a DES model enable a dialogue about specific design criteria between DES expertise and design engineers. The importance of visualisation is also proved in part 4 where the entire dialogue is related to visualisation on the shared desktop, which enables collaboration in layout design, among other things, over geographical distances. Simple physical objects can also be of importance in clarifying the complexity of material movement, as established in part 4.2.

In addition to the fact that the dialogue between competences can be greatly reinforced by design artefacts in physical and digital form, the essential insight in this study is associated with the adoption of the perceptions of engineering design methodologies. This provides an enriched perception on the design activities that occur in DES projects, as demonstrated in the case of a wood manufacturing system design. The application of observation studies in engineering design helps to focus on essentials in the design process. The importance of design artefacts is a typical example of the kinds of factors that are rarely mentioned in the context of DES applications. Within engineering design, design artefacts are frequently put forward as an essential factor in uniting thought and object, bridging competences, communicating design solutions, managing complexity and much more [8, 9, 12, 13, 24, 25].

Visualisation in the context of DES application is, however, often considered as cosmetic and common advice is not to “drown in visualisation”. Observations of the kind presented in this study may, in the eyes of a DES expert, appear trivial. Visualisation in DES is, however, of various kinds and cannot be generalized. It varies from simple 2D, through 2D with perspective icons graphics, 3D by predefined objects, to the CAD-like 3D environment provided by AutoMod [20]. It is obvious that manufacturing system design issues are placed in a different context depending on the capacities of different DES tools. A striking insight is, however, that only two DES software programmes appear to provide this kind of detailed and flexible modelling technique required. These are AutoMod and Quest [3]. Whether the development of DES in recent years has supplied the market with additional DES tools with these capabilities is not investigated in this study.

Finally, not only technology, but also methodologies and organisation constitute crucial factors in enabling efficient collaboration in design projects. The specific capabilities of DES are illustrated in figure 3, and demonstrate in many respects factors of relevance for DES consultant services in small industries, such as wood industries. Observation methodologies and taxonomy tailored in accordance with DES technology and manufacturing system design may be fundamental to further research into the integration of DES into the engineering design process. It is an urgent issue because DES is the only technology that manages system complexity and its dynamics, i.e. the effects of time.

7 SUMMARY

Using the perceptions of engineering design and its methods for analysing the design process, the integration of DES in manufacturing system design is illustrated from a multifaceted perspective. To exemplify the advantages of visualisation with geometrical references, DES modelling is here put in a context where design issues are concretisized and communicated among different competences. To achieve such insights, observation methodologies are used and successfully applied to the analysis of the engineering design process. Interpretations from observations provide us with a better understanding of what we do, why we do it, and what we could do better. This approach helps us to observe many aspects other than simply the technological, as is often the case. Seen in the general perspective of DES application in industry, this example of manufacturing system design is probably just one of many areas of application for DES where engineering design methodologies could bring support.

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