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USING SIMULATION TECHNIQUES FOR CONTINUOUS PROCESS VERIFICATION IN INDUSTRIAL SYSTEM DEVELOPMENT

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ABSTRACT

The purpose of this paper is to describe how discrete event simulation should be used as a tool for continuous process verification in industrial system development. Results include a specification of the working procedures to be used in each life cycle phase of a development project, as well as a definition of the areas where efforts are needed in the future. The approach assures continuous verification of the processes, which will lead to better decisions early on. Better decisions imply reduction in time and costs as well as systems with high quality. In conclusion, using simulation techniques for continuous process verification makes us more likely to develop an optimal industrial solution.

1 INTRODUCTION

During the last decade, the automotive industry has gone through some fundamental changes when it comes to increased frequency of product releases and shorter development lead-times. Cutting development lead-times require an integrated approach, including concurrent development of product and manufacturing and logistical systems. Moreover, it requires high quality decisions to be taken during the whole life cycle of a project. To do the right thing from the beginning is crucial for both time and cost, which is a reason for companies to intensify their focus on early project phases where many cost critical decisions are taken. According to Kosturiac and Gregor (1999), decision-makers need supportive tools to aid the search for answers to basic questions like: What is to be changed? To be changed into what? How to change it?

Discrete event simulation (DES) is a technique that is well suited to support these type of decisions, since it has the ability to model dynamic processes and answer what-if questions to enable evaluation of different scenarios. Furthermore, simulation can help us to foresee the consequences of a new product in our future manufacturing or logistical system.

However, Williams (1996) states, that few companies have managed to make simulation a “corporate norm” to achieve the ongoing, long-term benefits with using the technique. This statement is well in line with the authors’ experience from Volvo Car Corporation where simulation has not been used at its full power. At Volvo, simulation has mainly been used in late project phases to verify an already decided alternative solution or to influence improvements on an existing system. The reasons for this way of working are many, for example lack of people with simulation experience and knowledge and limited integration of the technique into the projects (due to absence of well-defined simulation strategies and working procedures).

However, lately DES has got a lot of attention from management at development departments as well as in the assembly plants, due to the challenge of developing concepts for and implementing the “Virtual Factory” in the company. To reach the “Virtual Factory” requires putting a lot of effort into modeling and simulation in early project phases and to continuously improve and update models and input data.

1.1 Objectives

This paper describes research that positions discrete event simulation as a tool for continuous process verification in industrial system development at Volvo. The objective of the paper is to outline a way of working with discrete event simulation throughout the life cycle of a development project.

This is accomplished by describing the general idea about continuous process verification and thereafter providing more precise working procedures for each life cycle phase in a project. A discussion on the needs for the future concludes the paper, followed by an appended example in the area supply chain modeling and simulation.

2 CONTINUOUS PROCESS VERIFICATION

As mentioned above, simulation has mainly been used in late project phases at Volvo and is not well integrated into product and process development projects. To solve this problem, the proper approach is to work towards using simulation as a tool in the daily work to verify the processes continuously throughout a project (not using it as a stand-alone-tool). However, this is no easy task since it requires effort in many areas.

Most important is to define and document the new working procedures. This section provides an outline for such new working procedures.

Another important issue is that system design evolves during a project. We have to keep the models up-to-date so that they can provide sufficient and true decision support at all times. The solution is to work in a similar fashion as do product design in the CAD world. Proposed changes in product design are *first* modeled and evaluated in the CAD world, *then* a decision is taken and the modified design can be approved. We must learn to work with simulation in the same way, *before* the decision is taken.

Even if models are to be up-dated continuously, there is no need for doing simulations (to verify the process) all the time. Simulations should therefore be connected to frozen checkpoints when we really need to verify the processes, see Figure 1. These frozen checkpoints must have a connection to the project plan in some way. At Volvo, a "Project Gate System" guides every project in the right direction by defining which decisions and documents that must be approved to go on to the next project phase.

Therefore, the frozen checkpoints for process verification should be connected to this Gate System. Verification at frozen checkpoints will provide a measure of how well the project corresponds with the planned outcome at a certain time.

To summarize the general approach for continuous process verification:

- There is a strong need to define and document the new working procedures.
- Simulation must be carried out *before* decisions are taken.
- Models must be up-dated continuously as system designs evolve.
- Process verification should be carried out at frozen checkpoints in connection with the project plan.

In Sections 2.1-2.3, the project life cycle is divided into three blocks, see Figure 1 (Concept & Pre-study, Design & Industrialization, and Production). The reason for this division is that both the working procedures for using simulation, the model type, and the responsibility for carrying out simulations differ substantially for the different blocks.

2.1 Concept and Pre-Study

The first block, called *Concept & Pre-study (CP)*, refers to the early phases in a project where the industrial structure is elaborated, finding out the requirements to put on the manufacturing and logistical systems (Figure 2). In this block, simulation should be used for supporting strategic decisions.

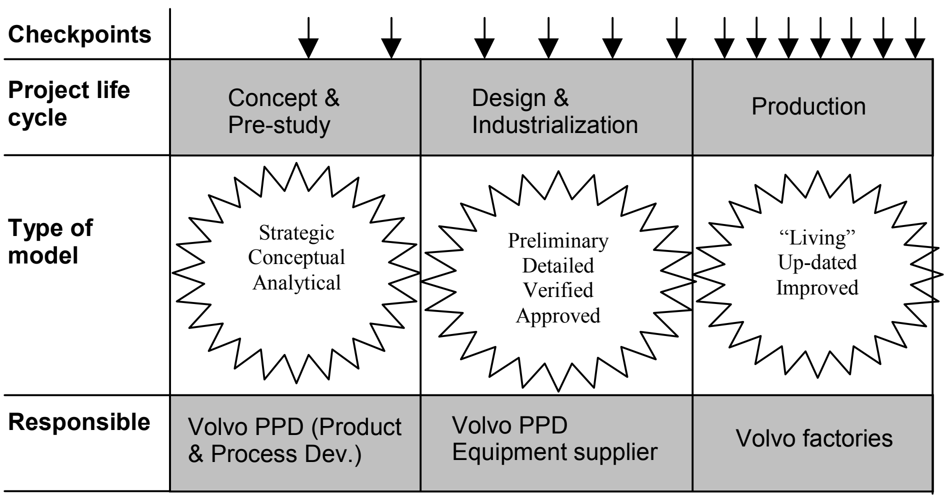

Figure 1: Continuous Process Verification with Frozen Checkpoints in the Project Life Cycle (including three main life cycle blocks, Concept & Pre-study, Design & Industrialization, and Production, with differences in type of model and responsibility)

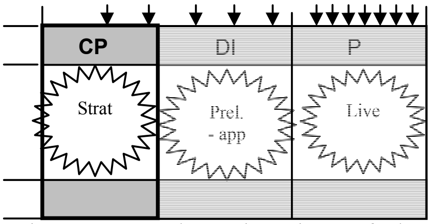

Figure 2: Schematic View of the *Concept & Pre-study* Block

Since simulation hardly has been used at all in these early phases at Volvo, much effort is spent on defining the questions and tasks to be supported by the technique. However, it is not obvious that simulation is the right tool for the job. The characteristics for the CP block are constantly changing prerequisites and input data, due to for example strategic decisions at enterprise level on which suppliers and factories to use. These decisions are often based on cost estimates for different alternative solutions and not on dynamic models.

In this sense, logistics is an interesting area to explore, see Appendix, looking at the external flow, for instance to estimate the number of racks (special packaging) needed in the flow or to dimension the goods reception area (traffic problem).

Today we are using certain tools to support the decision-making process, but they do not have the ability to take the dynamics of the systems into account. Furthermore, these tools do not consider overall system performance even if they fit their specific area very well. Therefore, we have the feeling that *flow oriented thinking* can provide valuable insight and support in these early phases even if simulations are not always performed.

The approach taken by the *Flow Analysis and Simulation Group* at Volvo Product & Process Development (responsible for DES in early phases) is firstly to promote *flow oriented thinking* and secondly to provide the tools and knowledge needed to perform analysis and simulation tasks. Concretely, this approach follows a common working procedure described below.

2.1.1 Working Procedures

Meeting: Technical specialist sits down together with process or logistical engineers to understand the task. This includes asking the right questions, focusing overall system performance.

Structure: Focus on areas/stations to be 1) changed or 2) moved and 3) current bottlenecks. Look at availability figures. Assure that the new concept/system is better than existing one. Create alternative scenarios.

Data: Collect the data needed for analysis. Explore the possibilities with using existing tools.

Visualize: Build conceptual model to visualize the flow e.g. in a process mapping or simulation tool.

Analyze: Evaluate the different alternative scenarios, listing the pros and cons. Establish decision support material.

Simulate: For detailed problems, where the system dynamics are crucial, simulations should be performed (following a common methodology, see Robinson and Bhatia 1995). Examples of such tasks are rough throughput analysis and rack flow analysis.

There is still a lot to do before this approach is fully accepted by manufacturing and logistical engineers, but there is a true need for a technique that provides decision support in the early project phases. Analyzing the problem in a structured way can solve much, but there is a need for a tool that can speed up this process. In this sense, it is possible to use DES tools, but they are not well suited for providing rapid answers on a conceptual level. This implies the need for easy-to-use, special purpose tools at this level.

2.2 Design and Industrialization

The second block, called *Design & Industrialization (DI)*, refers to the pre-production phases in a project, from the offer to equipment suppliers, via design and engineering, to installation and try-out of the systems (Figure 3). These are the phases where the industrial structure is transformed from requirements into the physical system. In the DI block Volvo works closely together with equipment suppliers (supplying equipment, stations, and/or whole lines).

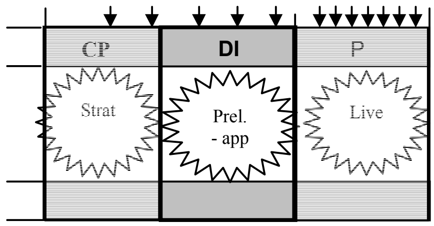

Figure 3: Schematic View of the *Design & Industrialization* Block

Simulations carried out in this block are mainly done early on by the supplier (to verify the capacity of the equipment) and these simulations are not up-dated properly. This leads to the fact that the simulated system usually is not corresponding very well to the system delivered.

Therefore, it is Volvo's intention to specify how to work on building accurate simulation models together with the suppliers, to be able to verify the processes continuously throughout these project phases. This type of working procedures should be included already when the offer goes to the suppliers. All modifications during the project have to be verified in a simulation model before approval. This approach reassures that equipment/station /line performance requirements are met properly. However, the approach also put new demands on the equipment suppliers, since the model should be a "living" documentation of the system until the system is approved and delivered.

The model must go through several transitions, as the input data is refined along the way, see Table 1. First a *preliminary* model is built based on the project prerequisites (e.g. process description, product mix, volumes). In the engineering phase, more detail is added into a *detailed* model (e.g. control rules, safety zones). Thereafter, in the installation phase, the model should be fed with verified data into a *verified* model (e.g. measured/tested cycle times and availability figures). Finally, before the takeover of the system, there is a need to finalize the model, into an *approved* model, so that it corresponds with the delivered physical system.

The simulation model should be up-dated continuously, but the specific simulations (process verifications) are performed only at the end of each project phase (offer, engineering, installation, and try-out). These phases are specified in the overall project plan and thereby connected to the Gate System, which assures proper follow-up of the progress in the project.

At each checkpoint, the simulation runs are documented with respect to for example model name and release, date and time, reason for and type of change, influence on throughput, actions taken depending on the change, and input data used. This issue is further discussed in Section 3.3. There are also specific output goals defined for each checkpoint, see Table 1.

The approach outlined in this section also puts new demands on Volvo. We need to provide the supplier with an accurate requirements specification on how we want the system to work (e.g. proper control rules, cycle times, availability figures). Furthermore, Volvo is still responsible for the overall performance, since the equipment suppliers usually only provides parts of the overall system. This implies that Volvo must find a way to manage the process verification of the parts working together in the overall system.

Donald et al. (1999) have addressed the same issue: "*The challenge will be to develop the design processes that will allow systems to be designed independently and then tested collectively.*"

It should be possible to test partial systems together if all equipment suppliers use the same tool, where stations/lines can be pasted in to create the overall model. However, due to the complexity of such a large model, we will probably encounter some performance difficulties with running such a model properly. Therefore, areas like distributed simulation, High Level Architecture (HLA), and especially the IMS MISSON project (HLA application in manufacturing, see Rabe 2000) are very interesting to follow.

At the moment, there are no initiatives at Volvo trying to implement the HLA thoughts. The first goal is to get the approach described above to work properly, getting accurate partial models from our equipment suppliers for continuous verification of the processes.

Table 1: Type of Model, Input and Output Data Requirements for the Different Phases of the Design & Industrialization Block

Parameters		Offer	Engineering	Installation	Try-out
Model	Preliminary flow simulation model.	X			
	Detailed flow simulation model.		X		
	Verified (up-to-date) flow simulation model.			X	
	Approved flow simulation model.				X
Input	Project prerequisites.	X			
	Control rules, transports, stations, safety zones.		X		
	Up-to-date model and up-to-date input data.			X	
	Measured cycle times and availability values.			X	
	Measured and approved cycle times and availability values.				X
Output	Layout with workload balancing, number of stations, and buffer sizes.	X			
	Verified layout with workload balancing. Decided number of stations and buffer sizes.		X		
	Sensitivity analysis of the current production line.			X	
	Frequent status reports. Approved documentation.			X	X

2.3 Production

The third block, called *Production*, refers to the operational phase in a project (Figure 4). In this block, simulation is an established technique at Volvo. There are models of all factories for vehicle operations (body shop, paint shop, and final assembly) and they are up-dated and improved continuously. It is important to have a "living" model to be able to replicate the behavior of the physical system, which is the goal.

The approach used in the operational phase is similar to the approach described in the previous section. Models are up-dated continuously and simulations are also performed continuously to analyze proposed improvements to be introduced in the plant. New ideas for how to run the production are tested on a weekly basis. Furthermore, there

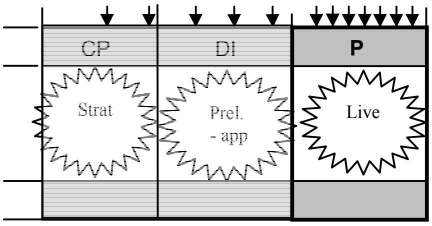

Figure 4: Schematic View of the *Production* Block

are attempts at using simulation for the weekly planning of the production mix.

Lately, new working procedures have been introduced in some of the factories to ensure that simulations are carried out before decisions are taken. The approach is rather simple:

- Simulation is used to identify possible bottlenecks.
- Thereafter, simulation is used to verify the impact of a proposed improvement to increase the throughput of the plant by eliminating the bottlenecks.
- Then, simulation results are presented at weekly meetings together with maintenance and production personnel.
- If the simulations show that an improvement has great impact on the throughput, the change is implemented in the physical system.

Even if this approach works well it has not yet become the standard procedure for how to work in the operational phase, since it is just being introduced. However, it is a step in the right direction, since it provides the possibility to prioritize changes to be made in the system.

3 CHALLENGES FOR THE FUTURE

To implement all aspects of the approach outlined in previous sections requires a lot of effort in many areas. This section provides a brief discussion on the needs for the future to implement the continuous process verification working methods. The key word in this section is *"structure"*. An overview of the future challenges can be seen in Figure 5 below.

3.1 Input Data Structure

One of the crucial elements for doing accurate simulations is to understand *what* input data is needed and *when*. Mainly, this depends on the specific simulation task to be performed, its purpose, and the level of detail needed. Of course, these issues are closely related to the time in project when the simulation is to be carried out.

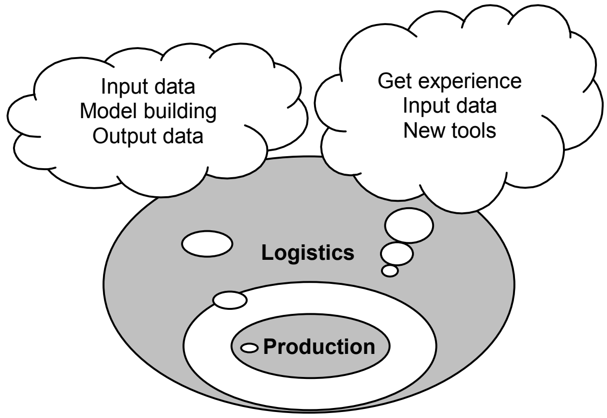

Figure 5: Overview of Future Challenges for Discrete-event Simulation in Production and Logistics

Additionally, the typical input data questions remain to answer: How do we collect input data correctly? How do we ensure that the input data is correct? How do we choose the proper distribution to reflect the input data?

Therefore, it is vital to have a high-quality input data structure, which means to have a documented and standardized way to handle input data. Such a structure should include at least the following aspects:

- Lists of important parameters to consider for each type of simulation task.
- A connection between these lists and the time in project when the simulation is to be carried out.
- A specification of where input data should be taken from (e.g. PDM, Databases).
- A standard library of distributions that reflect the reality. Proper tools for analysis of input data and fitting of distributions.
- A specification of how automatically gathered breakdown and availability figures can be used directly in the simulation.

3.2 Model Building Structure

Another area of interest is the way we build models. This was not a problem some years ago when only few models were built, but as we want to include more people and models in this process it is becoming important to build models in the same fashion (especially when equipment suppliers are to be included). For us to understand the models built by others, we must provide guidelines for how to build. Such a *model building structure* should include for example:

- A standard library of common building elements (including e.g. defined standard parameters and naming of objects).

- A specification of where standard objects can be found (e.g. PDM, Databases).
- Guidelines on how to build models and which tools to use, following a generic methodology.

3.3 Output Data Structure

The third area of interest, is how to handle the output data properly. In this case, we are not referring to the output data analysis aspect, but the interests are focused on how results from the simulation runs are presented and documented throughout a development project. Since models are up-dated and continuously improved, there is a need to document these changes. The simulation runs should be documented with respect to for example:

- Model name and release
- Date and time
- Reason for and type of change
- Influence on throughput
- Actions taken depending on the change
- Input data used.

This approach offers a standard presentation structure that provides possibility to look at the progress in a project. Therefore, it is a valuable source of information on how a system development project is proceeding. It also provides a base for comparing alternative solutions in different projects.

3.4 Logistics

The fourth challenge briefly discussed here is simulation in logistics. We feel that using simulation in this area has great potential, since so little has been done up to now. It is essential to note the importance of getting the bigger picture of the external flow early on in a project. At Volvo, we are just in the beginning of structuring the thoughts on how to use simulation in this field, see Appendix. Challenging areas to cover in logistics are:

- *Get Experience*: There is a need to specify which tasks to support with simulation and to build pilot models. Also important is to define the working procedures needed.
- *Input Data*: There is a need to understand the needs in logistics and to specify the explicit input data parameters for this area.
- *New Tools*: There is a need for easy-to-use tools that fits the area on a conceptual level. It is important to include functionality to estimate and compare costs in this type of tool.

4 LONG-TERM BENEFITS

As can be seen in previous sections, there is still a long way to go before the approach *continuous process verification* is realized in a large scale. However, we feel a sense of direction towards this type of working procedures. To summarize, the long-term benefits with working this way are:

- *Time and cost reduction*: Virtual verification of concepts and alternative solutions will support decision-making. This leads to better decisions early on, which will reduce the development lead-time and costs.
- *Robust and high-quality systems*: Alternative solutions can be tested earlier, which makes it possible to do the right thing from the start and to foresee the consequences of changes to be made.
- *Continuous process verification*: All modifications to a system are verified with simulation before approval. This leads to a better system, fulfilling the project requirements posed in the beginning of a project.

5 CONCLUSIONS

To meet the new demands for efficient development of industrial systems in the automotive industry, this paper describes a way of working with discrete event simulation continuously throughout a development project. This approach assures continuous verification of the processes in manufacturing and logistics, which will lead to better decisions early on. Better decisions imply reduction in time and costs as well as systems with high quality. In conclusion, using simulation techniques for continuous process verification makes us more likely to develop an optimal industrial solution.

APPENDIX: SUPPLY CHAIN MODELING AND SIMULATION

To exemplify the approach described in the paper, this appendix will give a brief overview of a study on supply chain modeling and simulation in the early project phases. The objective of the study has been to develop working methods for verification of the external material flow. The study included the following steps:

- Develop a generic flow description
- Define key parameters
- Develop generic simulation input/output shell
- Conducting a pilot study
- Anchor findings in the organization

The first step in this work has been to develop a generic flow description, mapping the different type of material flows, from supplier all the way to the assembly lines, where parts are consumed. Figure A-1 presents the top level of the hierarchical flow description, which has been refined into an appropriate level of detail.

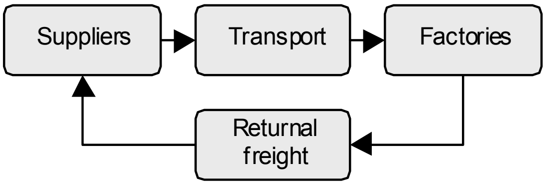

Figure A-1: Generic Logistic Flow Description at Top Level.

The second step of the study was to connect the flow description with important key parameters to consider for each building block. For example, the transport block includes parameters like transport time, frequency, type of transport, freight load, and transport cost.

The third step was to combine the flow description with the parameters to develop a generic input/output shell for discrete event simulation.

The fourth step was to conduct a pilot study to verify the approach and to make sure that the defined parameters are the right ones to use. The pilot concerned the external flow of racks for roof mouldings and give answers to questions like: How many racks do we need in the system at different volumes? What is the optimal transportation frequency? How is the system influenced by major disturbances? Results from the pilot have not been completely analyzed yet, but the parameters together with the flow description provide good support to the model building process.

The final step, which has also been the toughest, has been to anchor the findings in the organization by presenting the generic approach and to make people aware of the advantages of using this type of reference model as an input for carrying out simulations. There are still many things to do when it comes to more detailed flow descriptions, for example in the internal logistics area. Furthermore, there is a need for conducting additional pilot studies in e.g. the goods reception and pre-assembly areas to verify the applicability of the approach.

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