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PRODUCTION SIMULATION EDUCATION USING RAPID MODELING AND OPTIMIZATION: SUCCESSFUL STUDIES

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ABSTRACT

A common issue facing many simulation educators is that students usually spend excessive time to struggle with the programming and statistic parts of the simulation courses, and simply very little time to learn running systems analysis. If the students are coming from industry, and not the campus, then the problem becomes even worse. We observed this problem around 2005 and started to develop a new simulation software, a factory conceptual design toolset, partly aimed to address this problem. A new set of educational courses has since then been developed around the software for teaching production systems analysis, with both the campus students and managers/engineers from industry in mind. In this paper, we briefly introduce the software and share our experiences and some representative, successful studies conducted by the students in the past years.

1 INTRODUCTION

The time spent to build a Discrete Event Simulation (DES) model can be really long, even for experts (Tako 2011). A possible pitfall of teaching simulation is that too much attention is put on learning how to build simulation models rather than on the understanding of system behavior and what simulation can be used for. The idea here is rather to focus on why and when it is important to use simulation in the first basic course. However, when using more advanced simulation software, the step for a novice to build a simulation model even over a smaller production line may seem impossible. Furthermore, students seem to get stuck in details that may not be important for the purpose of the study. There is however a trade-off between what the students learn in modeling and the reduced time they spend on building detailed models, but on the other hand they may be able gain a broader understanding of DES if they avoid programming details. Industry also has many questions related to future production lines or complete plants, of which a detailed simulation model would be unnecessary and take too long time to build.

Originated by the concept that DES could be “frontloaded” to support the early stages of production systems design, a research project funded by VINNOVA, Sweden, and supported by major Swedish automotive manufacturers, a new simulation software was developed in 2005. The main purpose of the software toolset is reflected clearly by its name, FActory Conceptual design Tools using Simulation Analyzer, or simply FACTS Analyzer (Ng et al. 2007). In fact, one of the project objectives was to promote manufacturing executives to play the role of simulation users, particularly in the conceptual phase, by using the new software (Jägstam and Klingstam 2002). The first version of FACTS Analyzer was completed in 2008 and tested for the rapid modeling of a truck assembly plant (Ng, Svensson, and Urenda 2008). Later, through additional funding from VINNOVA, an extended version, called FACTS Analyzer 2.0 was delivered in 2011 (Ng et al. 2011). The key features that FACTS Analyzer 2.0 added were more complex product variant and setups handling as well as additional modeling objects, like Selections, for rapidly comparing different scenarios by switching the connections to different sub-models. Started already in the first version, simulation-based optimization (SBO), particularly multi-objective optimization (MOO), has been an integral component of FACTS Analyzer to facilitate managers/engineers to run their own optimization runs in order to seek the optimal combinations of model variables so that more confident decisions can be made by analyzing the Pareto-optimal solutions, as demonstrated in Ng et al. (2011), Pehrsson and Ng (2011) and Pehrsson et al. (2013) with real-world applications.

Despite the development of FACTS was originally targeted mainly to industrial users like manufacturing executives/engineers, it was very soon discovered that it could be used readily to be an effective toolset for teaching production systems analysis in universities and industry. As will be introduced in the next section, there are several unique features that when combined together can offer the students the opportunity to put their focus on learning production systems analysis, instead of simulation programming and statistics, especially if well-designed course materials and well-planned laboratory moments are also developed around this software. There are much experiences and successful studies accumulated in 7-8 years, regarding the applications of FACTS in education, both in undergraduate, post-graduate courses, final year projects, and industrial-based educations. The aim of this paper is therefore to briefly introduce why specially designed software like FACTS is crucial to education regarding the use of simulation for production systems analysis and share its benefits by providing some successful experiences/examples.

2 FACTS ANALYZER: AN EDUCATIONAL PERSPECTIVE

Following is a list of features that renders FACTS Analyzer to be unique simulation education software:

- Rapid modeling and analysis of common objects found in production systems.
- The use of the concept of Effective Processing Times (Jacobs et al. 2003) to ease the modeling of uncertain input data, which was identified to be the common obstacle in building simulation models for conceptual design phases.
- Rapid modeling and analysis of different production control concepts, including different material flow control mechanisms like Push, Takt, Kanban and Constant Work-In-Process, CONWIP (Hopp and Spearman 2001).
- Multi-objective optimization with built-in performance measures regarding productivity e.g. throughput, cycle time and WIP, readily to be set as optimization objectives.
- Automatic bottleneck detection using various bottleneck detection techniques.

Above all, FACTS Analyzer was designed with the principle of rapid modeling (Urenda, Ng, and Svensson 2008) by letting the users to build simulation models without the need of any programming skills. Compared to an advanced simulation software, in which programming is necessary even for the simplest logic and object control, FACTS Analyzer offers novel modeling concepts to solve many common production logic and product flow scenarios that otherwise require programming. Background and more information about FACTS Analyzer can be found in Urenda, Ng, and Svensson (2008) and Ng et al. (2011).

3 SIMULATION EDUCATION COURSES

In this section, we describe several new courses developed around FACTS Analyzer since 2008. There are different focuses in these courses, but problem-based learning (PBL), i.e. having simulation projects based on real-world problems, is what they have in common. The focus in this chapter is on the hands-on contents of each course and mainly the simulation project tasks and what kind of problems those are possible to solve using FACTS Analyzer.

3.1 Different Courses – Different Focuses

There are currently three courses teaching DES within production at the University of Skövde. Two of those are at a basic level and one of them is at an advanced level. The two basic courses both teach the basics of DES using the software FACTS Analyzer, but the focus otherwise are different, since the students attending the courses belong to two different groups, namely (1) ordinary University students (Course U1) and (2) Industry students (Course I1). The third course (Course U2) is focused on the ordinary undergraduate students, but pays more emphasis on programming, and is over the scope this paper because it uses ordinary simulation software.

3.1.1 Learning Objectives, Activities and Tasks

The learning objectives of the two courses using FACTS Analyzer have similar learning objectives including: "explaining the purpose of using discrete-event simulation and its fundamental concepts and meaning" and to "demonstrate ability to model and simulate, and evaluate logistics systems using simulation". The differences are found mainly on the theoretical depth of simulation and system flows, where Course U1 has objectives of a greater theoretical depth related to the objectives presented above because it is a larger course. Furthermore, other differences are that Course U1 also requires "knowledge of production engineering" and "knowledge of current research", and Course I1 requires "knowledge about different types of process flows" and "to conduct basic optimization of logistics systems".

When it comes to educational design there are different learning activities in these courses. Both courses have the following learning activities: pre-recorded lectures, campus lectures, simulation exercises and project assignment. Whilst Course U1 has more simulation exercises and lectures, Course I1 has one additional assignment (project specification) related to data collection and conceptual modeling which is the starting point of their simulation projects.

There are four assessment tasks that evaluate the students' performance on the learning objectives in Course U1: (1) basic simulation exercises, (2) advanced simulation exercises, (3) individual examination (online quiz) and (4) simulation project. There are also four assessment tasks that evaluate the students' performance on the learning objectives in Course I1: (1) simulation exercises, (2) project specification, (3) individual examination (online quiz) and (4) simulation project.

Skoogh, Johansson, and Williams (2012) describe how constructive alignment can be applied in simulation education and strongly believe that it can help strengthening the simulation education world-wide. This opinion is also shared by the authors of this paper. Currently the learning objectives, learning activities and assessment tasks of all three simulation courses are revised and improved according to "constructive alignment" and the SOLO taxonomy (Biggs and Collis 1982).

3.1.2 Overview of the Practical Hands-on Contents of the Courses

Based on typical steps in a simulation study (Banks et al. 2010), the modeling topics listed by Tako (2011) and the learning objectives of the course, the different courses practical contents (hands-on) can be divided into the following categories and topics under each category:

1. Understanding of system objectives and behavior (UND):
    a. System behavior (SB). How do buffer allocation, variability, product sequence, batching, and production strategies effect the system?
    b. Problem Structuring (PS): What is the problem? What are the objectives of the study?

2. Modeling and data collection (MOD).
    a. Conceptual Modeling (CM): What should be included in the model and what level of detail should be used?
    b. Data collection (DC): What data are required to solve this problem? How to collect the data? How to analyze and use the data?
    c. Model building (MB): How to build and code the simulation model? How to present the output data? How to verify the simulation model?
    d. Validation of the simulation model (VA). How to validate the simulation model?
3. Experimentation and analysis (EAN).
    a. Experimentation (EX). What experiments are required to answer the objectives of the study? Bottleneck analysis, Design Of Experiments (DOE), etc.
    b. Optimization (OP). What simulation-based optimization (SBO) is needed to answer the objectives of the study?
    c. Analysis (AN). How can the results of the experiments and optimizations be analyzed? What conclusions can be drawn based on the analysis?
4. Documentation (DOC):
    a. Model documentation (MD). Documentation within the simulation model to describe the functionality and model assumptions.
    b. Report documentation (RD). Project report documentation describing objectives, literature review, system description, data collection, project progress, simulation model, verification, validation, steady state analysis, replication analysis, experimental study, and conclusions.

Based on these areas the courses practical (hands-on) attention or focus in different areas can be summarized and further divided into different topics in Figure 1.

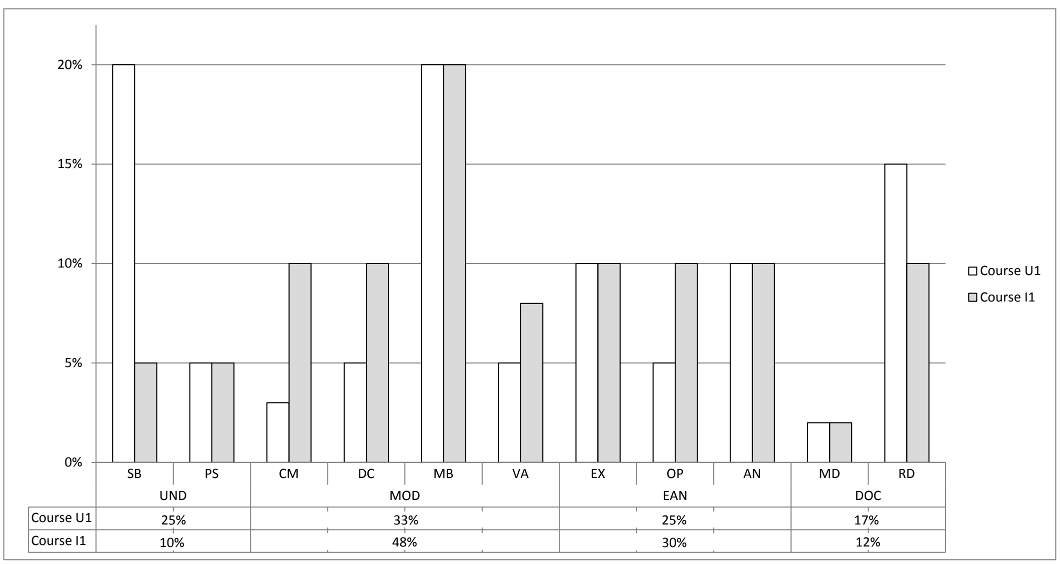

Figure 1. Different focus areas and topics of the courses.

As shown in Figure 1, the different courses have different focuses regarding the level of hands-on training based on the student groups, i.e. ordinary university students and industry students. FACTS Analyzer makes it possible to have greater focus on other parts of a simulation project than just the part of model building (MB), since it allows the users to quickly learn how to build simulation models, without the need to learn programming. The university students in Course U1 need to focus on the understanding of system behavior (UND) and put greater focus of that when compared to the industry students in Course I1. The focus of Course I1 is however different because it is more important to teach the industry students how to model and optimize their own systems. As they already understood much of the system behavior, they are able grasp the theories faster. Course I1, on the other hand, also benefits from using FACTS Analyzer, since the industry students can learn how to build simulation models in a matter of 2-3 days, so that after one week they are able to carry out industrial-scale studies using simulation-based optimization. Course U1 makes the students ready to solve problems for industry by equipping them to conduct a thesis project using FACTS Analyzer.

3.2 Practical Hands-on Contents of Course U1

Course U1 has 200 evenly distributed hours over ten weeks and use the software FACTS Analyzer. The course has exercises and a project assignment in order to learn the practice of DES. The exercises have been created to teach the students the software, DES, and systems behavior. This has been accomplished by having different tasks (questions to answered) connected to the exercises of which require the students to think and apply their previously learned skills. The project assignment is a complete simulation project over a fictional production system, based on a real-world production system producing tables. The students have the same project, but use different input data such as different customer demand. Examples of simulation models based on the project assignment are shown in Figure 2.

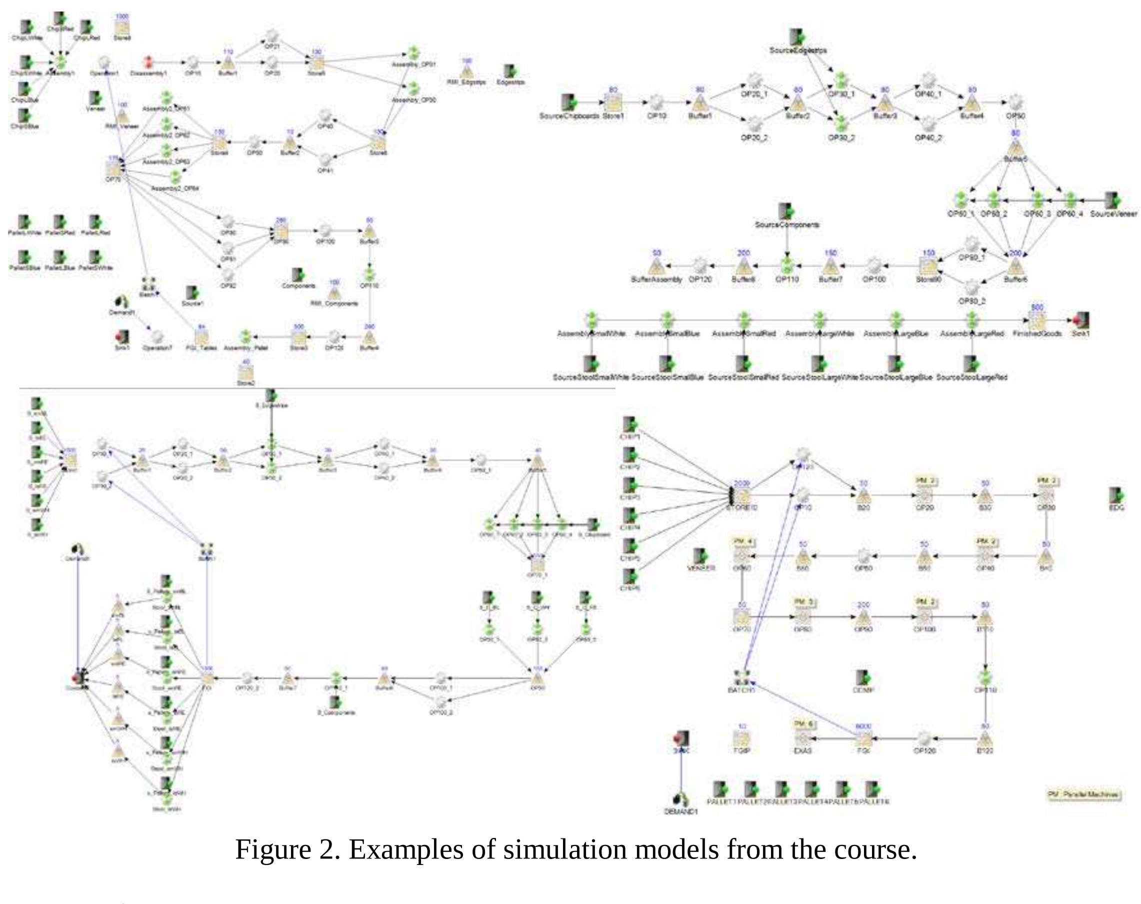

Figure 2. Examples of simulation models from the course.

The goal for the students is to build a model over the table production system and decide the buffer capacities and the number of parallel machines needed in each production stage. The problem here is that there are six different product variants, two sizes and three colors, which generate sequence-dependent setup times. Therefore, they also have to think about the sequencing and batching, as well as whether all products should be produced in all machines or not. Furthermore, the customer demand also makes it difficult for them to produce and deliver the right product variants at the right time, forcing them to consider a push versus a pull strategy. To learn report writing to document the various steps in the simulation project in a structured way is also emphasized in the course.

3.3 Practical Hands-on Contents of Course I1

Course I1, 107 hours over seven weeks, is for teaching DES to the industrial students. This course begins the first week with one lecture (on-line or on campus) and after this lecture they have an assignment to find a problem to solve at their own company. This first task also includes writing a problem specification, including background and objectives, and data collection. When the students come back in the second week, they have four-day training on FACTS Analyzer. The fifth day in the second week, they start with the project assignment and continue in part-time mode during the following five weeks. A great strength is letting them solve their own problems because it is easier for the students to relate to and make necessary assumptions, simplifications as well as validation.

39 simulation project reports handed in between 2013 and 2015 were analyzed regarding the type of problem solved. The persons attending this course were mainly production engineers, but there were also technicians and managers attending the course. This is also reflected in the categories selected to compare the studies as well as the objectives of the studies. The simulation studies have been categorized according to Figure 3 with more details about their problem types and main results listed in Table 1, in which "A" stands for assembly, "M" stands for machining "O" stands for other, "L" stands for low level of detail (very detailed), "M" stands for medium level of detail, "H" stands for high level of detail , "L" stands for the number of production lines, "S" stands for the number of production stages (with one or more parallel resources), "SS" stands for the number of serial production stages, "F" stands for future focus, and "P" stands for present focus.

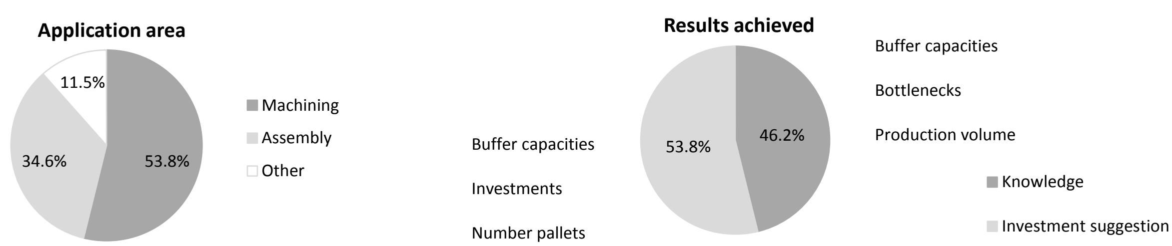

Figure 3. Application area and results achieved.

Most of the simulation studies had one main objective – throughput (TH). Only three simulation studies considered cost or return on investment. Most studies also had average work in progress (WIP), average lead time (LT) or number of changes, i.e. number of investments, as secondary objectives. The main result of each study is presented in Table 1, and they can be classified as (1) contributed knowledge and (2) direct investment suggestion, see Figure 3. Contributed knowledge can typically be exemplified by traditional bottleneck analyzes in which the user gets information of what or which resources that are the bottlenecks but do not get information of what is needed to be changed in order to get a better result. Using the same scenario, a direct investment suggestion gives the user an answer of what are needed to be changed on the bottleneck resources, i.e. availability increased by 3% and processing time decreased by 5%, in order to get a better result. The most common types of results of the category contributed knowledge are how buffer capacities, bottlenecks and production volumes affect the system. The most common types of results of the category investments suggestions are buffer capacities required, investments required (several interconnected investments to achieve a better result), and number of pallets required.

Table 1: Simulation projects carried out in Course I1.

Type of problem				**Types of experiments and optimizations**											**Results**
Application area	**Level of details**	**No. of workstations**	**Present/Future**	**Num operators or skill of operators**	**Shift forms and breaks**	**Production volume and variant mix**	**Abstraction and modeling**	**Availability and MTTR**	**Processing time**	**Bottleneck analysis**	**Pallets/carriers**	**Buffers**	**Machine alternatives**	**Other What-If**	**Main results achieved**
A	H	9L	F				x	x				x			Impact of buffers
A	M	29SS	F								x		x	x	Machine investment requirements
A	M	17SS	F							x	x			x	Number of pallets
M	M	23SS	P				x	x	x						Modeling and abstraction
M	M	3L, 25S	P						x	x				x	Automated transportation system required
M	M	6S	P									x	x		Buffer capacities required
M	M	7S	P							x		x	x		Buffer capacities required
M	M	8S	F				x	x		x					Impact of MTTR
M	M	16S	P					x	x	x	x				Investments required
M	M	8S	P							x					Bottleneck analysis
A	M	8S	P							x					Bottleneck analysis
A	M	15SS	F		x	x									Variant mix thresholds
A	M	9SS	F							x	x	x			Number of pallets
M	M	13S	P					x		x		x			Availability required
M	M	11S	P							x		x			Buffer capacities required
M	M	23S	P									x			Buffer capacities required
A	M	20SS	P	x				x	x						Impact of variability
M	M	6S	P			x									Impact of production volumes
A,O	L	24S	P		x	x	x						x		Modeling and abstraction
M	M	8S	P							x		x	x		Buffer capacities required
A	L	22S	P											x	Impact of disturbances
A	M	7S	P						x						Impact of balancing
O	L	1S	P	x			x								Number of operators
M	M	5S	P						x	x					Impact of decreased processing time
M	M	22S	P					x		x					Impact of operator waiting times
A	M	14SS	P	x				x							Impact of the skill level of operators
A	M	11S	F					x		x	x	x			Number of pallets required
O	L	6S	P							x	x	x			Buffer capacities required
M	M	37S	P						x	x		x	x		Machine investment requirements
A	M	19SS	P			x				x				x	Impact of buffers
M	M	5S	P					x	x	x	x	x			Investments required
O	M	3L	P				x				x	x		x	Impact of production volumes
O	H	4L	P		x							x			Impact of buffers
M	M	8S	P					x		x		x			Availability required
M	M	15S	P					x	x	x					Investments required
A	L	12S	P						x	x	x	x			Processing time required
M	M	9S	P		x			x		x					Bottleneck analysis
M	M	18S	P		x			x		x		x			Buffer capacities required
M	L	12S	P				x	x	x	x		x			Investments required

4 REPRESENTATIVE EXAMPLE MODELS AND RESULTS

In this chapter, some representative models developed by the students are shown with some brief descriptions. The main purpose here is to demonstrate the scale of complexity that the students and level of results analysis they could can handle, not the details of each model.

With complex traffic control, Automated Guided Vehicle (AGV) models are usually very demanding to build in whatever simulation software. Therefore, one of the most impressive models developed by 2 students was a complex AGV system connected to an assembly line of 24 production stages as shown in Figure 4.

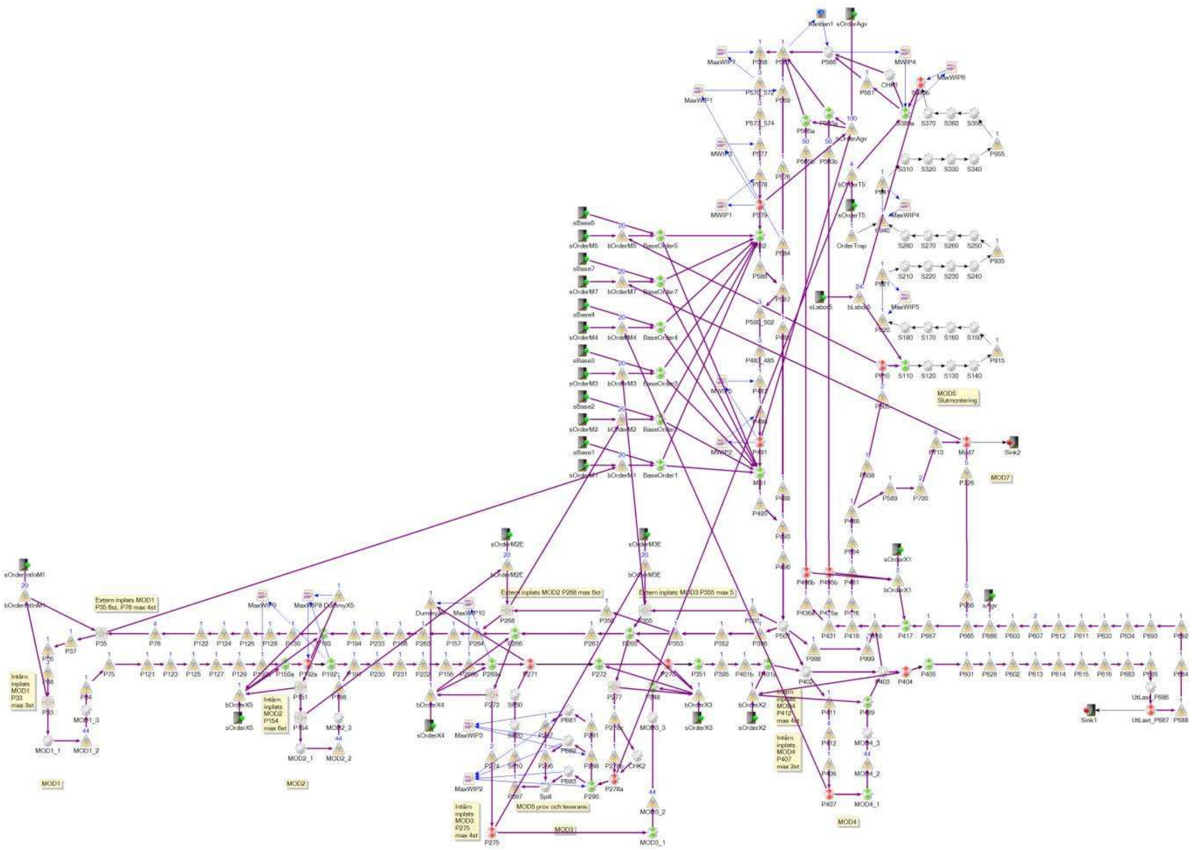

Figure 4. Simulation model over an Automated Guided Vehicle system.

Another best study accomplished was a simulation model for a machining line of 12 production stages served by a single gantry robot (Figure 5). This simulation model shows how it is possible to simplify complex behavior without losing important functionality. Most parts of the model were possible to be abstracted by using mainly one object to represent one resource or cell (medium detail level), but one of the cells was needed to be modelled in details. This production cell can be seen at the right side of Figure 5, in which the gantry robot handles the movement of all of the parts within the production cell. A special built-in exit logic that keeps track on previous movements for each product in order to simulate re-entrant loops, e.g. for re-manufacturing or when several loops are required through some of the stations. The robot cell uses this exit logic in combination with MAXWIP-objects (restrict the number of parts allowed) to represent the gantry robot that serves the sequential workstations.

In this study, MOO experiments were also conducted to generate the Pareto-optimal solutions with the objectives to minimize the investment and simultaneously maximizing the TH. Through studying the solutions using Parallel Coordinate Plot (PCP) and Clustering (Figure 6), it was discovered that it is possible to increase the TH by 13.7% with a return on investments of only 2.4 months by decreasing the processing time of one machine and increasing the availability of one buffer and two machines. Furthermore, the study also showed that it would be possible, but not required at the moment, to increase the TH by 18% and still have as low return on investment as 5.3 months.

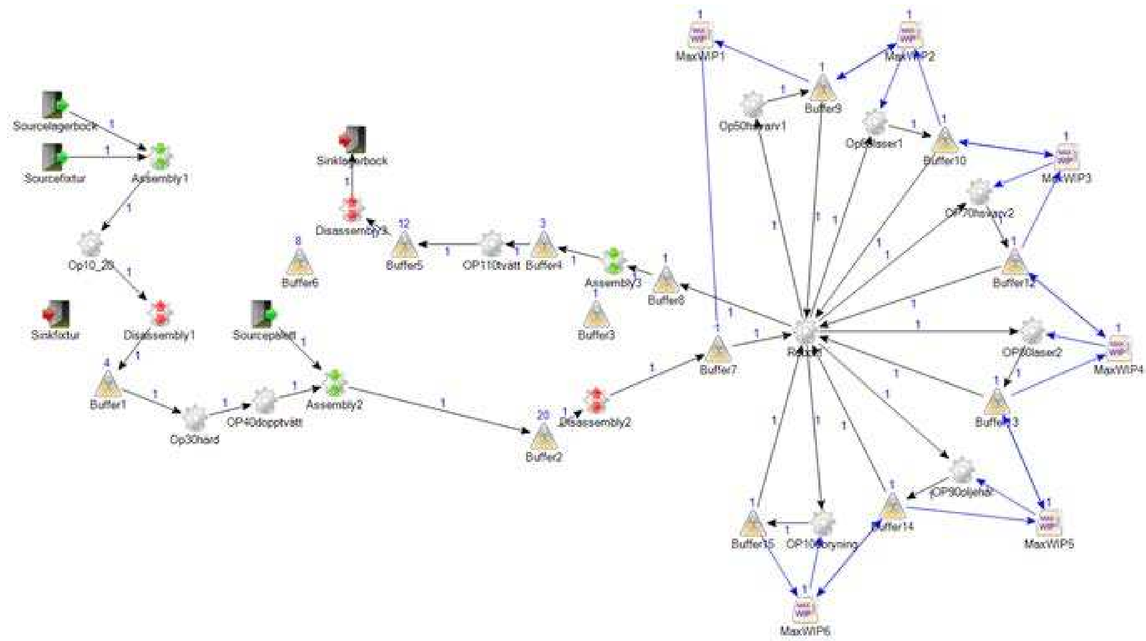

Figure 5. Simulation model for a machining line served of a gantry robot.

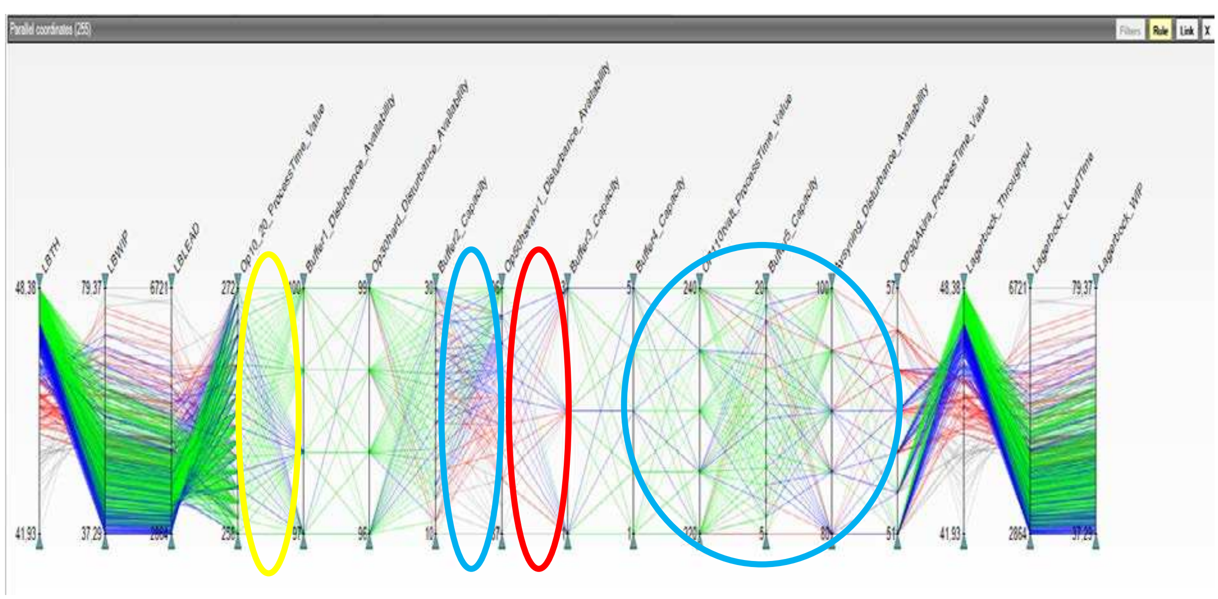

Figure 6. Analyzing the Pareto-optimal solutions using PCP and Clustering.

Another simulation study was about the modeling of the detailed tasks of operators with an aim to the relationship between the utilization of workstations and the number of operators (Figure 7).

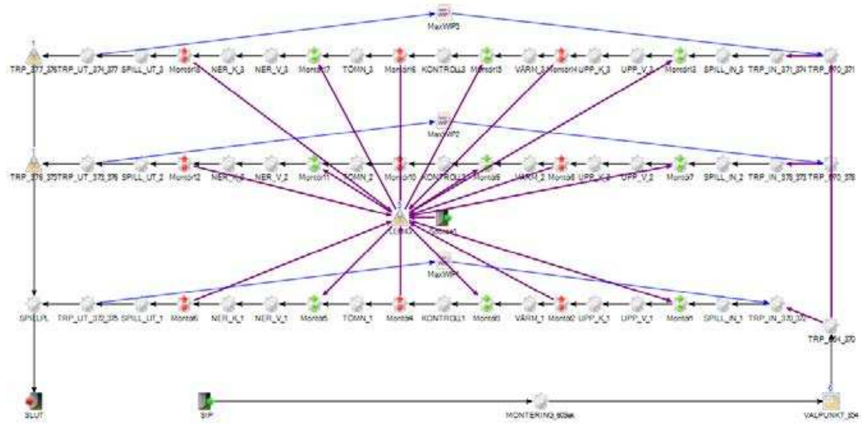

Figure 7. Simulation model for studying system behavior with different number of operators.

A big simulation model was built for a machining line with 23 production stages. There are several sub-models (called templates in FACTS Analyzer) in the simulation model as shown in Figure 8. The objective was to optimize the buffers between the production stages.

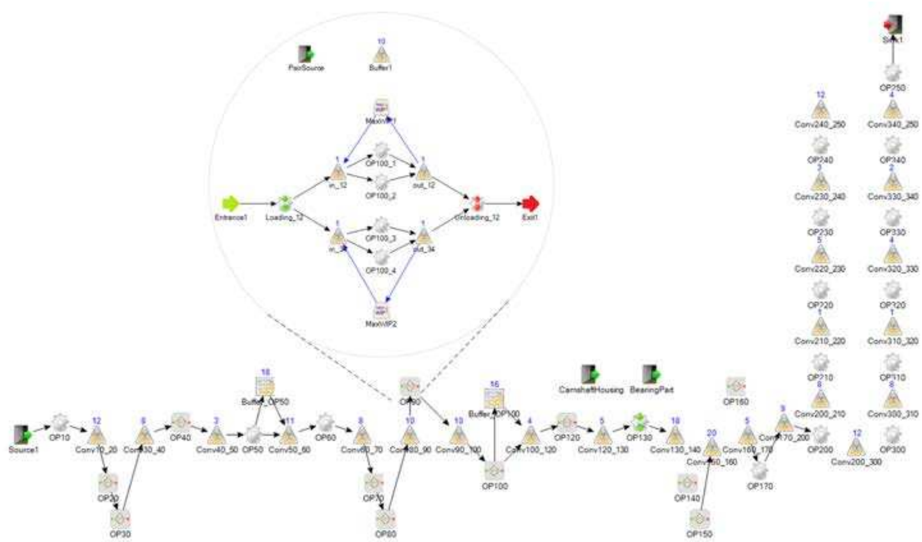

Figure 8. Simulation model of a machining line using sub-models (templates).

Other representative, successful results of these simulation projects are summarized below:

- Simulation-based optimization experiments of a future assembly line of 9 serial production stages showed that it was possible to decrease the number of pallets by 61% and total number of buffers by 44% and still reach the targeted TH.
- Simulation experiments of a present assembly line of 20 serial production stages showed that it crucial to reach balanced production stages, especially when the number of operators are increased and there is little room for buffering to reduce the effects of variability. The conclusion was that it is important to reduce or eliminate variability for both the manual assembly time and the availability.

- Simulation experiments of an present machining line of 8 production stages showed that it is possible to increase the TH by 10% by either adding a new parallel machine of the bottleneck stage or increase to the buffer before the bottleneck stage. However, the conclusion was that a buffer would be economically beneficial because investing in a new machine would be ten times the investment cost.
- Simulation experiments of an existing assembly line of 7 production stages showed that it is possible to increase the TH by 8% by only having better balance between the assembly stages.
- Simulation experiments of an existing machining line of 22 production stages showed that it is possible to increase the TH by 4% by prioritizing the failures of the bottleneck machines and thereby decrease the operator waiting times.
- Simulation experiments of a present assembly line of 14 serial production stages showed that one slow operator has a substantial effect on the results. Going from ten medium operators down to nine medium operators and one slow operator results in a productivity drop of almost 9 %. It doesn't matter if all of the medium operators are exchanged against faster operators, the result still remains. As long as there is one slow operator it will affect the total productivity. A balanced workforce seems to be advantageous in order to utilize the personnel in an effective way. Consequently, an operator should probably be trained at a few assembly stations first in order to master them before taking on several assembly stations.
- Simulation experiments of a present machining line of 5 production stages showed that it is possible to increase the TH by 11% if the availability is increased and the processing time is decreased of the bottleneck station. However, SBO experiments showed that it was possible to decrease the lead time through the system as well, but it would require several more investments.
- SBO experiments of an present machining line of 8 production stages showed that it is possible to increase the TH by 7.5% if most machines reach an availability of at least 93% and that the average mean time to repair of the machines are decreased by 5-10%.

5 CONCLUSIONS

In order to find out the impact of this course in industry, a questionnaire was sent to the production managers/engineers who completed the courses between 2013 and 2015. The answers received have reflected that most of the participants believe that there is now a greater understanding for DES in the companies. There is also a consensus that more people in the companies have started to use DES and some of them even pointed out that their way of handling daily work has been changed regarding the use of DES when new product variants and production flows are to be tested. Furthermore, some participants, mainly production technicians, use DES independently without any help from the simulation experts (available usually in large automotive companies). The most successful experience, however, is that there are production engineers who have continued to make use of the same simulation models they developed in the course for the purpose of continuous improvements by running SBO in a weekly basis, through keeping the input data of the simulation models updated, also in a weekly basis. These successful stories have strengthened our belief that good simulation educations that have the purpose of teaching systems analysis and problem solving in industry have to be facilitated by a software toolset that can support rapid modeling and advanced experiments in a handy way, like SBO.

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