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Simulation and Evaluation of Alternative Workflows at Cross Laminated Timber Factory

Developing a DES Model Aiming to Improve the Loading Process in a New Factory

Degree project in mechanical engineering

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Cover: CLT panel and CLT factory in Värö, picture by (Dittmer, n.d.). Published with permission.

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Preface

This report is written by David Ljung & Tore Sandström as a part of our degree project as mechanical engineer students at Chalmers University of Technology. The project consists of a simulation study conducted at Södra Skogsägarna in Värö Sweden, during the spring term of 2024.

Acknowledgements

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Sara Alberth for her expertise regarding the production at Södra and Matyas Horvath for his guiding as well as his patience teaching us ExtendSim.
We would also like to thank our supervisor Qi Fang & examiner Mélanie Despeisse at Chalmers as well as everyone else who helped us. Special mention to Lisa for her support.

Abstract

Discrete event simulation is a method to virtually program a model of a factory or a production line and to evaluate the results, that is done to learn more about the production or evaluate before an investment. The purpose for this thesis work has been to evaluate changes made to a line producing cross laminated wood panels, to enable alternative transport for safer and swifter assembly at the construction site. To perform the project, a base model of the existing production line was modelled in the simulation program ExtendSim. A new concept was developed with two main changes to the production, enabling alternative transport. From the concept three new scenarios were modelled and simulated with the changes implemented: two models with one of the changes each and one with both changes. Thus, a total of four scenarios were tested and experimental results collected. The outputs from the four simulation models were compared and analyzed. Measurements compared were activity state on the CNC machines, utilization of overhead cranes and operators, cycle times for panels trough production and cycle time between trailers and the number of products produced. The results indicates that the changes have a positive impact. The scenario with both changes has lower utilization of the overhead crane and operators and shorter lead time than the base model. In conclusion, the changes can be implemented to the production without disturbing the workflow. With the ability to load and transport type A panels in an alternative fashion to the construction site, the assembly becomes efficient and more important safer.

Keywords:
CLT, Cross-laminated timber, Södra Skogsägarna, Simulation, Discrete event simulation, ExtendSim, Data collection, wood panels, activity state, utilization, production simulation

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1. Introduction

Under introduction, a background to the project is given and Södra Skogsägarna is presented. The issue and limitations are specified as well as what the project hope to achieve.

1.1 Background

Södra Skogsägarna economic association is in the business of producing wood related products. Their latest investment is a factory producing building elements for the construction industry. To further satisfy their customers, changes to the new facility needs to be implemented. Södra is looking to see if the changes can be evaluated using computer simulations.

Simulation is a method increasingly used in the manufacturing industry. Preferred for the non-disruptive nature of the experiments on the real production and its fairly accurate results, companies view simulation studies as a good tool to use in several phases of a process, for example early on layouts and machines can be evaluated while a finished production line can be analyzed and optimized. The drawback, however, is that a simulation requires highly accurate input data (Robinson, 2014).

1.2 Description of current production area

Södra has constructed a new factory to produce cross-laminated timber (CLT) panels on their Värö site outside Varberg. CLT is a type of construction material where sheets of timber are glued together perpendicular, in Södras case the timber comes from the plant's sawmill in forms of planks that are first glued to each other side-to-side to form the sheets. These panels can be up to 3.5 meters in height, and 16 meters in length and are used to construct the framework for houses, consisting of type A panels and type B panels (Södra, n.d). Prefabricated CLT panels have the advantage of speed, compared to traditional materials like concrete that needs to harden after pouring, the wood panels just need to be lifted into place. Wood also has a smaller environmental impact, lowering a buildings carbon footprint. They are however more exposed to the elements, and they need to be protected from moisture. To minimize moisture penetration into the wood, time is an important factor to keep down during the building process.

1.3 Aim

The aim of the project is to evaluate alternative workflows of the CLT factory using discrete event simulation and to answer the question if any of the alternatives is better than the current state. The project should contain a concept were type A panels are loaded in an alternative configuration.

1.4 Specification of Issue Under Investigation

Today the process of after-treatment and loading is a highly manual operation that uses a substantial portion of the limited space and requires operators to work on each panel in an awkward fashion. *Are there any alternative workflows that could in some way streamline the current process and reduce waste according to lean principles i.e. extra processing, waiting, etc?*

Södra have developed an alternative workflow. This is the first case to be evaluated, after that other cases can be developed and analyzed.

1.5 Limitations

- The project scope investigates only alternative flows between the CNC-machines and the loading of trailers. The factory building cannot be changed e.g. the placement of walls, beams, and doors.
- The project is limited to use data from one production project.

The simulation has been done in the software ExtendSim 8. This program is already used by Södra meaning that the model can later easily be integrated into other systems. It also means that there is a lot of knowledge about the program, and the inevitable help needed were never far away.

2. Theoretical Background

In this chapter the methods and techniques used to execute the project will be presented. Details about the technology explained to cover the needs for understanding the project.

2.1 Conceptual Model

“One of the most difficult issues in simulation modelling is determining the content of the model” (Robinson, 2014). It is not just what type of data that will be used in the model but also how the functions of the simulation program will be used to create an accurate depiction of the real production line, the logic.
To make this easier a method known as conceptual modelling can be used (Robinson, 2014). A concept model is a non-software-specific description of the simulations layout that clearly shows each event needed and the data for each event (cycle times, distributions, etc) needed to build the simulation. The conceptual model is the first documentation of the problem that is to be modelled and is an effective way to verify and check that everybody has the same understanding of the problem.

According to Robinson (2014) a good conceptual model:

- Is a simple model.
- Is a model that shows the logic relation between elements.
- Work as a discussion tool to create an understanding of the problem.
- Guides development of simulation model.
- Minimises errors.
- Minimises risk of forgetting parts and steps of the process.

2.2 Simulation

“Simulation is the imitation of the operation of a real-world process or system over time” (Banks, 2000). It is used every day; an example is simulations for the weather in the forecast. Simulation is a way to experiment and validate if a concept of a system will work or to get a better understanding about it. This is done by making experiments and asking “what if“-questions. Simulation allows for a lower financial and material resource intense alternative to real testing with the advantage of not disturbing daily operations (Ondov, et al., 2022).

Although simulation has been used in the manufacturing industry since the second half of the twentieth century with manual calculations, having to recalculate the entire process after each small alteration is not a desirable workflow. The growing capabilities of computers have since shifted simulations studies to take place in digital software, making it a far more useful tool (Robinson, 2005).

Most simulations studies and implementations follow a set of steps like those presented in figure 1 based of Banks, Carson, Nelson, and Nicol (2000).
This project follows these steps with the exceptions that a real production run (red box) will not be conducted due to previously mentioned limitations.

Rectangular boxes represent processes and activities for the project group to complete, and rhombus shapes represent decisions mainly taken by Södra. It is worth to mention that the *Experimental design* step that in this case consists of three alternative scenarios, is also verified, and validated.

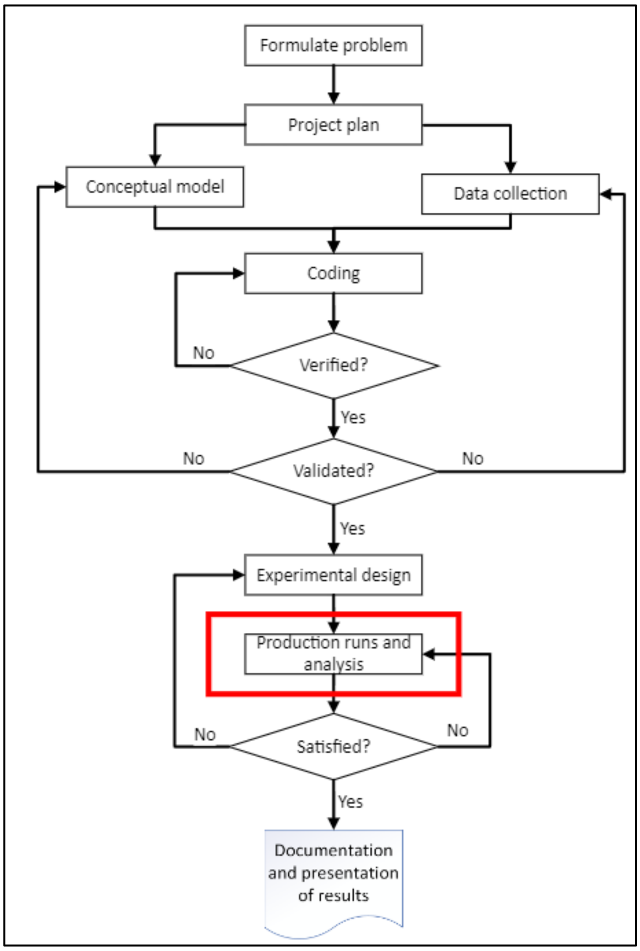


Figure 1 – Simulation steps based on Banks, Carson, Nelson, and Nicol (2000)

2.2.1 Different types of simulation

The most common types of simulations used in processing industry is continuous simulation, in manufacturing industry producing separate products discrete-event simulation is used. A continuous simulation constantly measures values in an interval. The method of continuous simulation is often used in the process industry for example to make food, chemical plants or as in Södra's case they use continuous simulation for their paper pulp production.

In this project discrete-event simulation is used to simulate manufacturing of cross laminated wood products. Robinson (2014) writes, "Discrete-Event simulation (DES) is used for modelling queuing systems." It can be described as a flow of items/entities through a system and queuing to get through. In DES changes only occurs at specific points and the time jumps between events. A visualized comparison between the two can be seen in figure 2 as events over time.

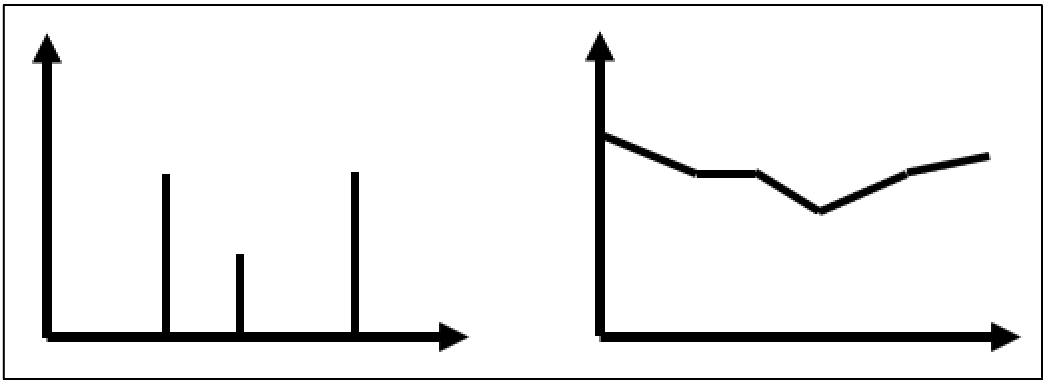


Figure 2 – Visualization of DES (left) and continuous simulation (right)

2.2.2 Verification and validation

To ensure the models accuracy and reliability, the model need to be verified and validated. A simulation model can never be 100% accurate but it can be sufficiently accurate to perform tests and understand the reality (Pidd, 2009).

Verification is the process of making sure that the model is working as intended and matches the concept model (Kleijnen, 1995). This step makes sure that there are no bugs in the simulation. The verification is continuously performed under the construction of the simulation model, as the model is built following the conceptual model.

Validation is the process of ensuring that the data in the model is correct. In an existing system this not only includes the input data but also the output data.

Robinsson (2014) writes about different methods and validate the simulation model.

- *Conceptual Model Validation:* Ensuring that the conceptual model contains the right details to fulfil the simulation purpose.
- *Data Validation:* The measured and provided data should be investigated to ensure that it is accurate to the real-world system.
- *White-Box Validation:* A check to see that the content put into the model are accurate to the real-world production.
- *Black-Box Validation:* A check to determine if the overall behavior of the model is accurate.
- *Experimentation Validation:* A method to test the simulation model by making changes and see if the results are matching expectations.

2.2.3 ExtendSim

Compared to other simulation software such as Siemens Tecnomatix Plant Simulation, where 2D or 3D views can be applied for DES,- or the Visual Components software where DES models are in a 3D environment, ExtendSim can be used for both DES and continuous simulation. This makes the user interface a bit hard to read and understand. The function blocks that make up a model in ExtendSim can be connected in two main ways: the flow of items which is represented by a thick line or information represented by a thin line. Items can be seen moving along the connectors and if an item is located inside a function block it will be indicated in some way. An explanation of the function blocks used in ExtendSim can be found in the appendix.

2.3 Data requirements for simulation

Data collection is one of the most important steps in the simulation process. Robinson (2014) writes that all the time and effort put into the development of conceptual and computer models are wasted if the data input to the simulation is inaccurate, because then the result will also be inaccurate.

Robinson (2014) describes three types of data. *Contextual data*, data for *model realisation* and data for *model validation.*

Contextual data is the data that are needed to make an understanding of the problem that are to be simulated. Examples can be pictures over the layout and some simple data over the process that explain today's process and what the simulation aims to achieve. This data is then used for the development of the conceptual model.

Data for model realisation is what is needed to develop the computer model. To build the computer model, detailed data about all parts are needed. For instance, speed and length of conveyors, machining times and data about the products. To find the type of data required to build the simulation, a concept model is used. In this case the visual concept model is supplemented by lists and matrixes containing data taken from a real project already manufactured in the factory. More about concept models is to be found in the method chapter.

Data for model validation is used for validation of the model and to make sure that the model is representative to the real-world system.

Robinson (2014) writes, "Having identified the data requirements the data must be obtained." How much data that must be collected depends between projects. Some are available because it has been collected earlier others have to be collected now.

2.4 Lean production

Lean production is a concept originally based on Toyota production systems (TPS).
Jeffrey Liker describes in *The Toyota Way* (2004) lean production as 14 principles consisting of not only methods and tools, but also cultural changes that need to be implemented.
Taiichi Ohno, an employe at Toyota that helped to develop TPS highlights the importance of embracing all parts of lean: "*The belief that it is only a production method is fundamentally wrong. . . those who decide to implement the Toyota production system must be fully committed. If you try to adopt only the "good parts", you'll fail."*

Likers second principal "*Create a continuous process flow to bring problems to the surface."* Contains a tool called 7+1. This tool is used to find and eliminate wastes in a production. The wastes listed below can be reduces or eliminated relatively easy at a production without the need for extensive cultural change.

- Waiting
- Over production
- Over processing
- Unused creativity
- Excess inventory
- Unnecessary transport
- Defects
- Unnecessary movement

3. Method

In this chapter the methodology used in the project is presented in several steps shown in figure 3 and then later explained.

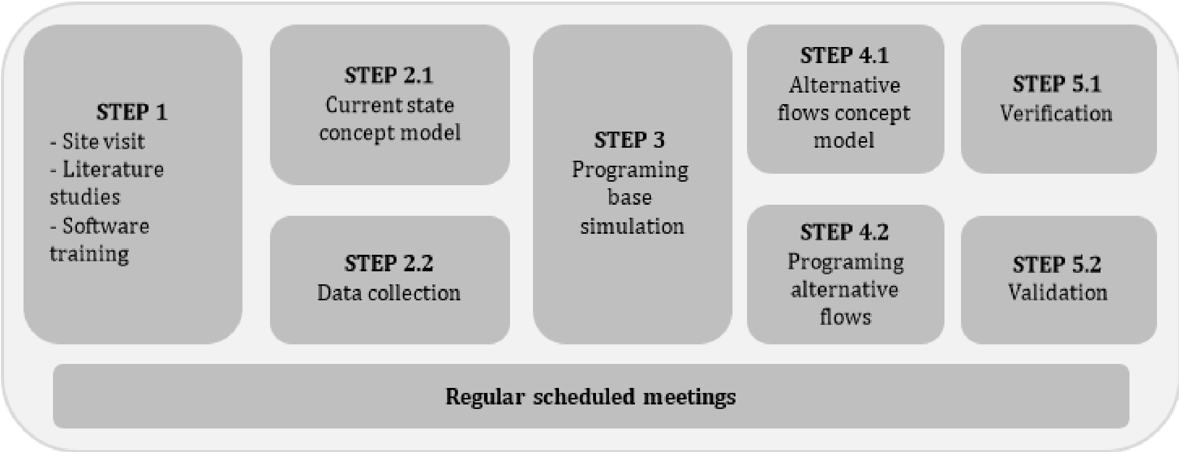


Figure 3 – Methodology steps

3.1 Information gathering

3.1.1 Understanding the manufacturing process

Site visit
To get a good understanding of the production and meet all people involved in the project at Södra, an initial visit was made at their site in Värö. A more detailed presentation of the project was made by Södra, where the process was explained and what they hope to achieve with this project. To get an even better understanding a tour of the factory took place and the production line was followed from start to end.

During the course of the project, the production line was visited a further couple of times to collect data from the factory shop floor, discuss data files and get answers on parts needed to make a suitable and sufficiently detailed simulation model.

Regular scheduled meetings
Meetings have been arranged with Södra for information gathering every week, typically lasting around 45 minutes. The format of these meetings has been a presentation highlighting the progress that has been made since the previous meeting, followed by a discussion addressing the questions and issues that has risen during the week. This has also been a good opportunity to get help with the simulation model, since Södra's simulation expert has been attending these meetings. The simulation expert has given a lot of advice about how to think when building the logic of the model as well as resolving issues beyond the project groups competence.

3.1.2 Literature studies

Research was done on how to develop a suitable concept model, how to think when building the simulation, what data that are needed to build the simulation and information about validation and verification. Information was also searched about other CLT productions to learn from them. The information in the literature study was found in old lecture notes, academic search portals and the book: *The practice of model development and use* by Robinson (2014). Academic search portals used were Google Scholar and the Scopus database, keywords searched where “Validation” “Verification”,” Simulation data”, “CLT AND Simulation AND Production”, “Simulation model”, “ExtendSim” and “conceptual model”. The information that was found has been referred to in the text and have been used as inspiration for certain parts of the project.

3.1.3 Software training

The process of learning ExtendSim began with watching video tutorials about the basics of the program. Some demos were downloaded and tested to learn about the different items. After the site visit a learning session with Södras expert took place. From there on learning by doing has been the method used, starting with the basics, and gradually adding more advanced elements to the model. Throughout the process, numerous problems and questions emerged due to low experience with the program, but they were solved by assistance from Södra’s simulation expert. At one-point Södra’s expert visited Chalmers to help with the model, that turned out to be a good session as it was much easier to work face to face than over an online video meeting.

3.2 Developing a concept model for the current production line

The first concept model (figure 4) depicts the current state of the production line and is to be used as a base to compare the alternative flows to. There are several different ways to construct a concept model, for this simulation process a flow diagram (process map) were chosen. The reason for this was that Södra had already developed a value stream map (VSM) in the process flow shape. After analyzing Södra’s VSM, the concept model was constructed with some modifications, mainly combining some activities, and creating some new ones.

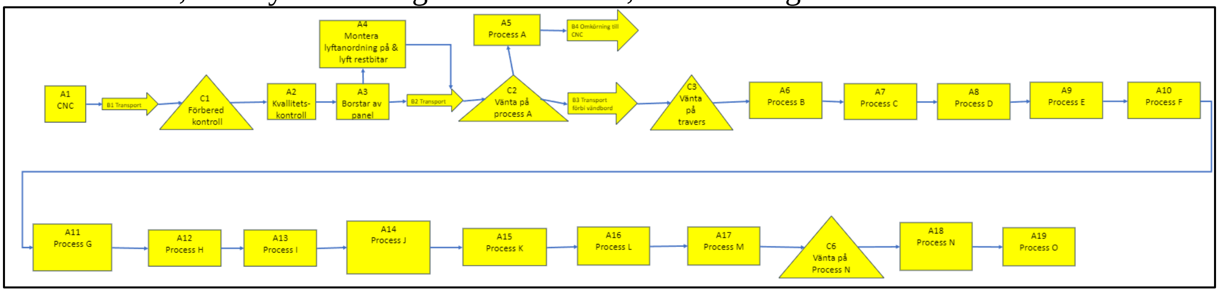


Figure 4 – Concept model of the current production line

After presenting the concept model to Södra and making some adjustments it was time to begin the data-gathering and processing. Parallel to this the programming of the simulation model also started.

3.3 Collecting and processing the Data

Södra has been running their new production line for CLT for over a year, allowing them to collect plenty of data. However, because of the factory being new and somewhat unoptimized, only the recent months data were considered representative. The VSM made by Södra contained data over cycle times at various stations. They also had extensive Excel files filled with various production data.

The machining times and other cycle times that were missing from Södras VSM was gathered by visiting the site in Värö and timing the production machines. To get a somewhat statistically accurate time, the cycles were measured several times on each machine.

Initially four production projects were analyzed. Distributions for the number of child panels, number of cutouts and whether the panels were designed to be a type A panel or type B panel was calculated. This was done because of the big variation in the production of the different projects. However, due to the data being random distributions, it would only provide an approximative result. That would make the output from the simulation hard to validate, since there would not be a real-world case for comparison.

The data had to be processed to ensure usability. Firstly, an Excel table was made containing the key information about the master panels, the master panels number, the quantity of child panels resulting from that master panel, the time it took to perform that operation in the CNC machine. The same table also contained a matrix giving the child panels the number in what order it is to be loaded (table 1). A second table was made giving the key data needed for child panels (table 2). Starting with what master panel that child panel is from, loading order, if it is a type A panel or type B panel and lastly the number of cutouts. The shift-times for the week were converted to minuets.

Table 1 Master Panel Data

Panel nr	Master panel nr.	Loading order	Panel A =1, Panel B = 2	Nr of cutouts
W-11038	78	1	1	2
W-11036	78	2	1	3
W-11037	77	3	1	0
W-11035	77	4	1	0
W-11034	74	5	1	0
W-40001	76	6	1	0

Table 2 Child Panel Data

Master panel nr.	Nr of child	CNC-time (min)		Master panel nr.	Child 1	Child 2	Child 3	Child 4	Child 5	Child 6
78	2	27		78	1	2	0	0	0	0
77	2	9		77	3	4	0	0	0	0
74	2	16		74	5	11	0	0	0	0
76	1	30		76	6	0	0	0	0	0
75	2	17		75	7	8	0	0	0	0
72	2	24		72	9	13	0	0	0	0

All this data were provided by Södra except for the number of cutouts. To get that number all the drawings of child panels had to be analyzed. All cutouts bigger than 400x400 mm had to be removed and counted as a cutout.

The model can only read time passed since the start of the simulation run so the weekly schedule of the operators and the press was converted to minutes starting from Monday 00:00 and repeated after 10,080 minutes (one week). The press roughly presses one panel every thirty minutes during operational hours. The operators work in two shifts.

3.4 Programming the base simulation

The process of programming a simulation is one of constant iterations and improvements. First the concept model was programmed, gradually the program was expanded and refined often after consultation with Södra. As mentioned before the data collection and analysis were conducted parallel to this step, this means that data were put into the program as it became available.

3.5 Alternative flows

The concept developed by Södra of an alternative workflow consists of two major changes. The first change is to implement a separate after-treatment station for type A panels. Secondly building a station X, enabling to load type A panels alternatively on trailers. To truly understand the changes, they must be separately validated. To validate them separately they must be simulated separately. To make the simulation process easier three new concept models was constructed for the new scenarios.
The scenarios share section 1 and 2 with the base model in ExtendSim and they share the same start for the concept model up to the station X

3.6 Verification and Validation

To ensure that the simulation model is working as intended and that the results are dependable, the model was verified later validated. The methods used for this are the steps that are explained earlier in the theoretical background, chapter 2.2.2.

4. Results and Analysis

In this chapter the results from the simulation will be presented and analyzed.

4.1 Base model

The base simulation has the same structure of the concept model, but it looks different due to all the supporting function blocks that are needed to build the logic simulating reality, see example in base model section 4.

Due to the size of the model (see figure 5) the model is presented in smaller divided sections, the red lines and box indicate splits and the sections can be seen in figure 6-11.
The sections depict major functions of the model.

Table 3 Five sections of the base model

Section 1	Start of base model (master panels generated)
Section 2	Master panels are split into child panels, and cutouts are removed
Section 3	Process A + resource pools for operators and overhead crane
Section 4	After-treatment
Section 5	Base model finish

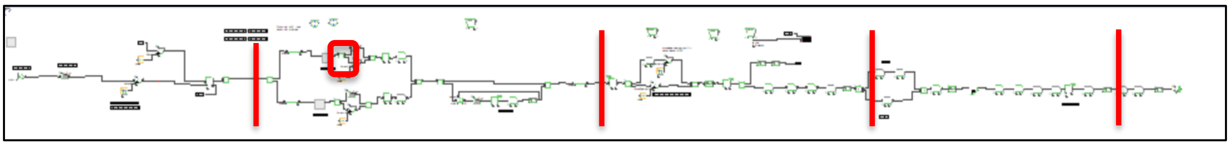


Figure 5 – Base model in its entirety with sections

<u>Base model section 1</u>

Figure 6 shows the start of the base model. The data for the panels are attributed to the items using databases which in turns import their content from table 1 & table 2 mentioned in the data collection chapter. The data from table 1 is assigned the moment the master panels are created according to the press-schedule. The only data that is not defined are which panels are going to process A and how many of them that return to the CNC or continue to the loading area. These decisions are made with a random distribution using a **set** & **random number** block. Currently, 10% of panels will go to process A, and 10% of those will go straight to loading. Returning panels pass through a **set** & **constant** block, ensuring that they can be turned into child panels.

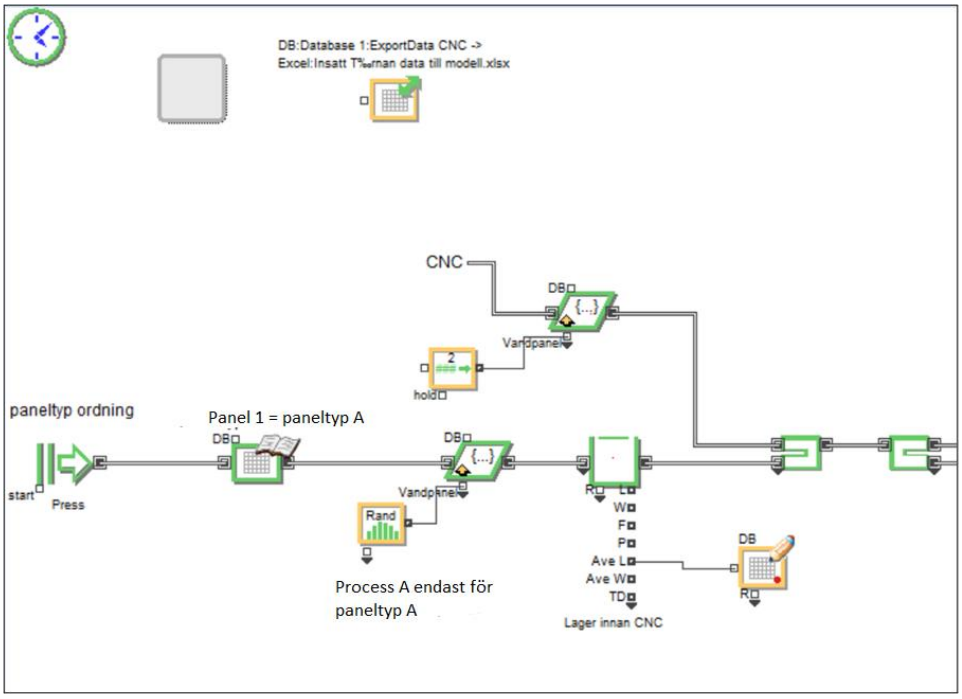


Figure 6 – Start of base model

Base model section 2

The CNC-machines and the overhead cranes removal of cutouts is depicted in figure 7. The grey block is called a *hierarchical block* (HB) and is described below. Several **set** blocks are used after the *hierarchical block* to assign the child panels the right attributes one of which is *CycleTime* that timestamps panels. The overhead crane is modelled with a **resource pool**, **gate** & an **activity block**. They are also connected in series to accurately represent reality.

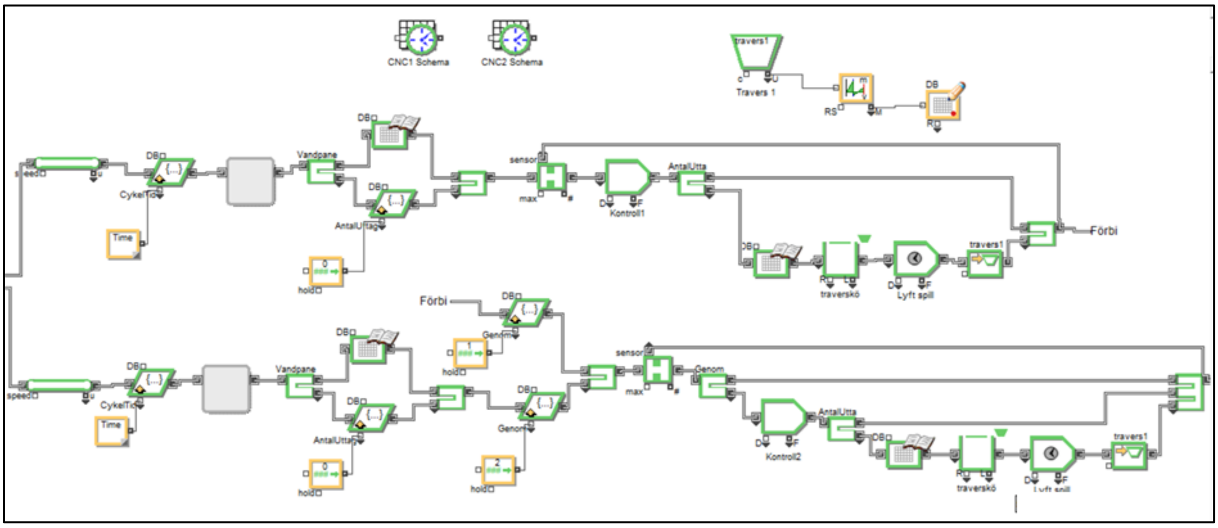


Figure 7 – CNC HB + cutouts

The most complicated section of the model is the division of master panels into child panels. This is done in two identical Hierarchical blocks called *ChildDelning* to organize the workspace, see figure 8. The hierarchical block Contains an **activity** block that acts as an CNC-machine where each panel is delayed the assigned CNC-time in table 2. After that the item passes six **read** blocks numbered 1-6 (maximum of six child panels) that checks with the matrix in table 2 how many child panels that should be created from the master panel, the **unbatch** blocks then created the right amount and the master panel is removed from the simulation in the **exit** block. The **activity** blocks that represent the CNC-machines are bound to the two **Shift** blocks *CNC1 Schema* & *CNC2 Schema* (blue cross indicates offshift). The machines are both stopped for maintenance once per shift and to ensure that the stop does not concur simultaneously, different **shift** blocks are used.

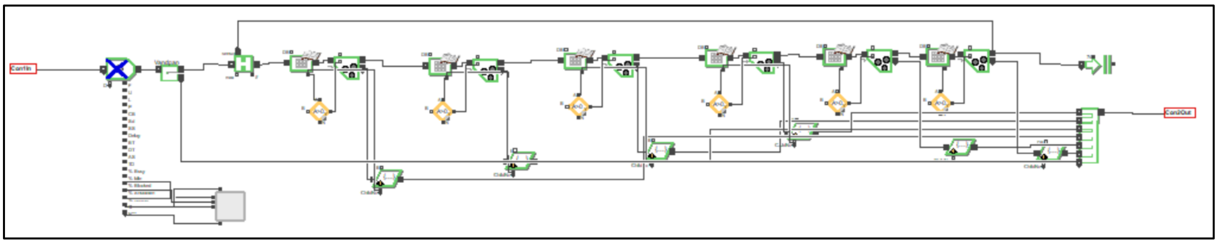


Figure 8 - Hierarchical block "ChildDelning"

<u>Base model section 3</u>

Panels that in section 1 have been assigned the *Process A* attribute is routed to the *Process A* **activity** block, see figure 9. Regardless of if the panel is to be used in *Process A* or not it needs to pick up a resource to continue, this is to simulate that only one panel can fit on the *process A* and to ensure that a panel doesn't make it past the station A when it is in use. Using a resource block allow for more freedom in experimentation compared to a gate. Another **set** & **random number** block is then used to determine if the panel will continue to the loading bay or backtrack to the CNC-machines. As in section 1, a 90/10 distribution is used with 90% continuing without backtracking.

The after-treatment and packaging blocks in section 5 starts here with an **activity** block called *Tidstjuvar* (unforeseen delays) as well as the resource pools for the two loading bay overhead cranes and the three operators.

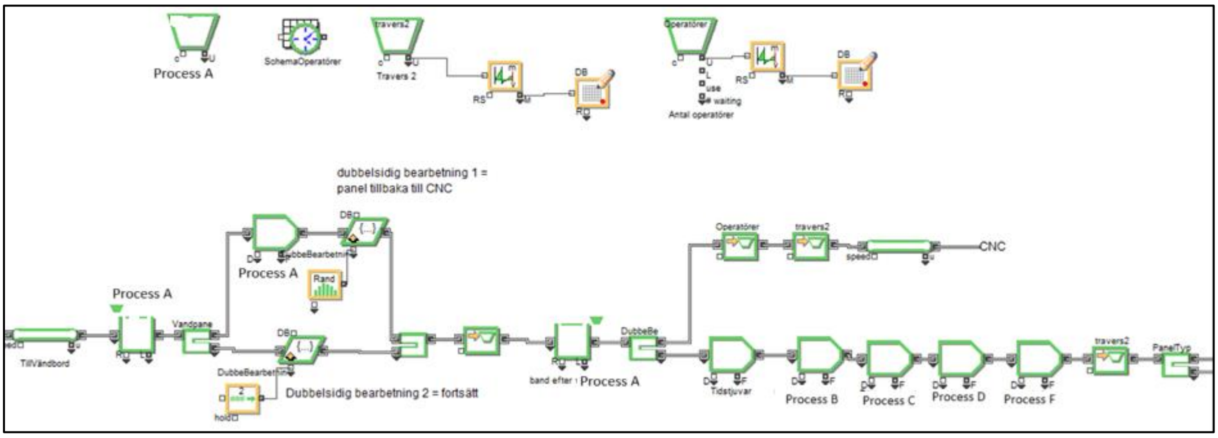


Figure 9 – Process A and resource pools

Base model section 4

In this section (figure 10) the panels are after-treated. Type A panels take the upper route and type B panels take the lower. The **information** block (yellow i) reads the *CycleTime* attribute and outputs it to excel, a new cycle time for packages starts recording right after.
The packages are created in the **batch** block, in the base model a package contains a mix of seventeen type A panels and type B panels.

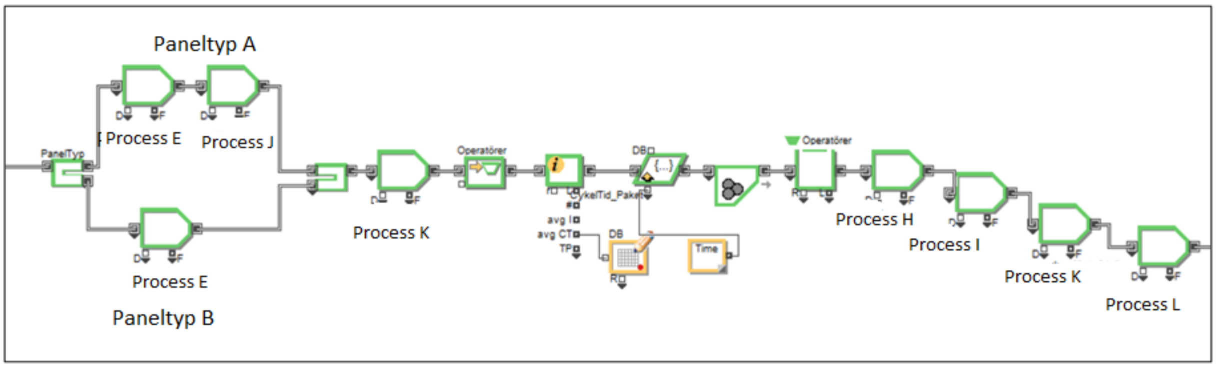


Figure 10 – After-treatment and packaging

Base model section 5

Figure 11 shows the packages leave the simulation in the **exit** block in this section after having read the package cycle time.

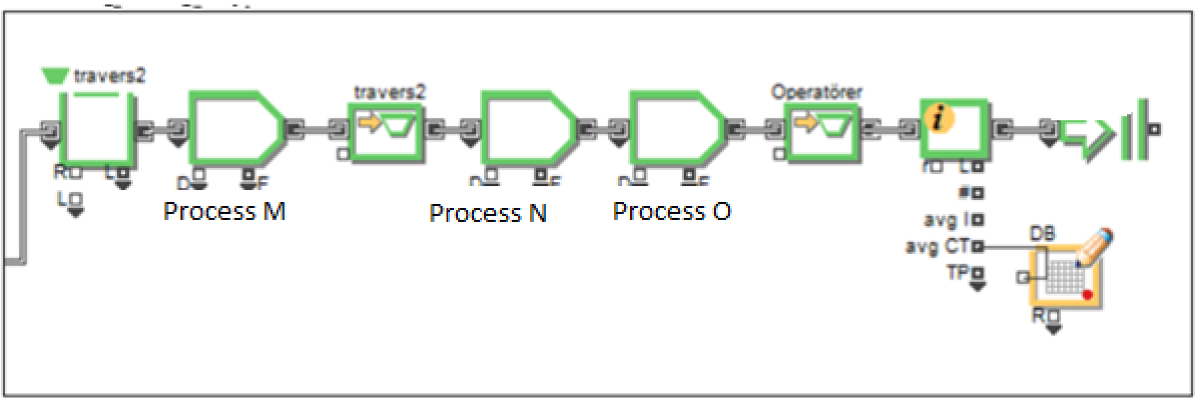


Figure 11 – base model finish

4.2 Alternative workflows

This chapter describes the results from the programming of alternative workflows described earlier chapter 3.5. Three new scenarios were made with a concept model and a simulation model in ExtendSim, and they are:

- Scenario 1: Alternative loading for type A panels (station X).
- Scenario 2: A separate after-treatment station (station Y).
- Scenario 3: A separate after-treatment station (station Y) for type A panels leading to a station X enabling alternative loading on trailers.

The changes do only affect the later sections of the production line, sections 3-5.

4.2.1 Scenario 1

The station X is added to the factory. The panels follow the same path as in the base model up until they reach process F. Once treated, the type A panels are lifted by the overhead crane to the Station X where they are handled and loaded alternatively. This scenario enables alternative transportation of type A panels without making big changes in the factory, see figures 12-15.

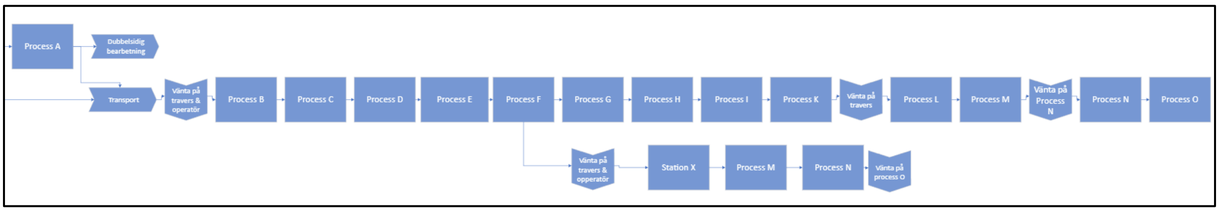


Figure 12 - Scenario 1 concept model

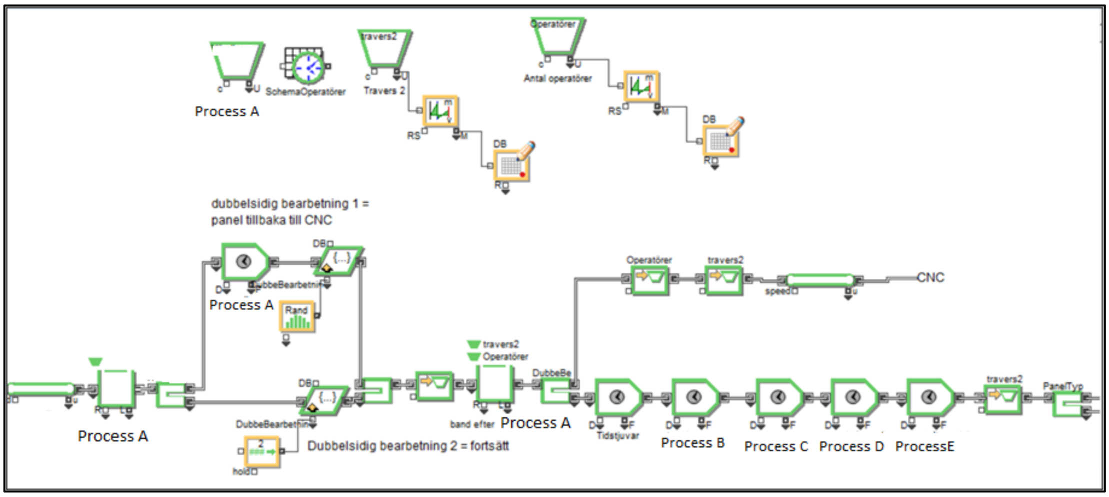


Figure 13 - Scenario 1, Section 3: Process A and resource pools

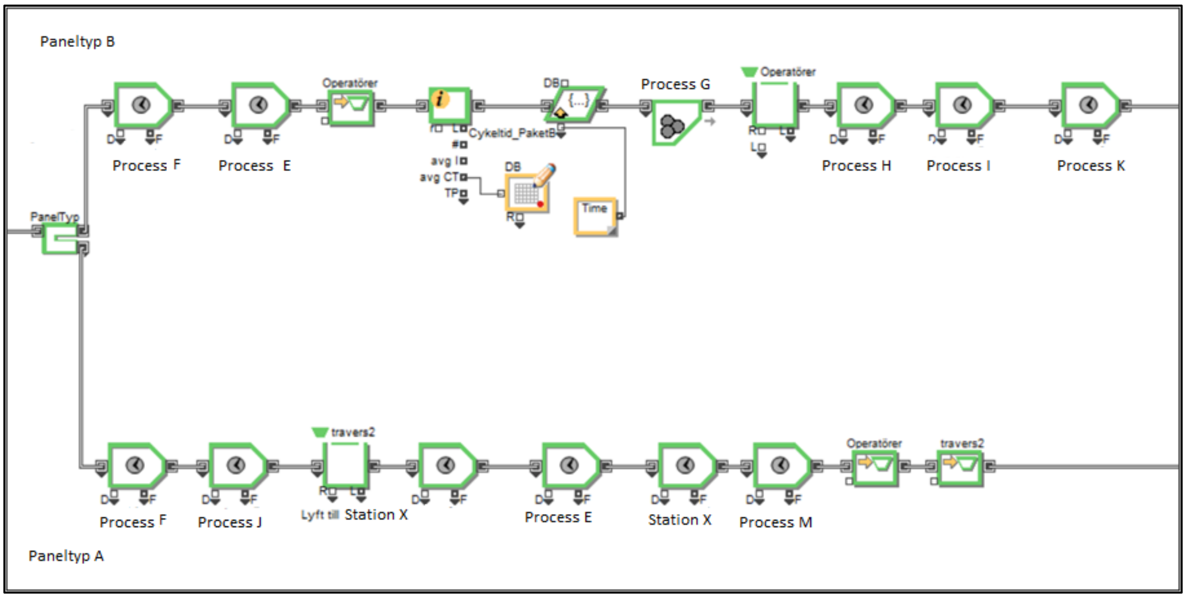


Figure 14 - Scenario 1, Section 4: After-treatment

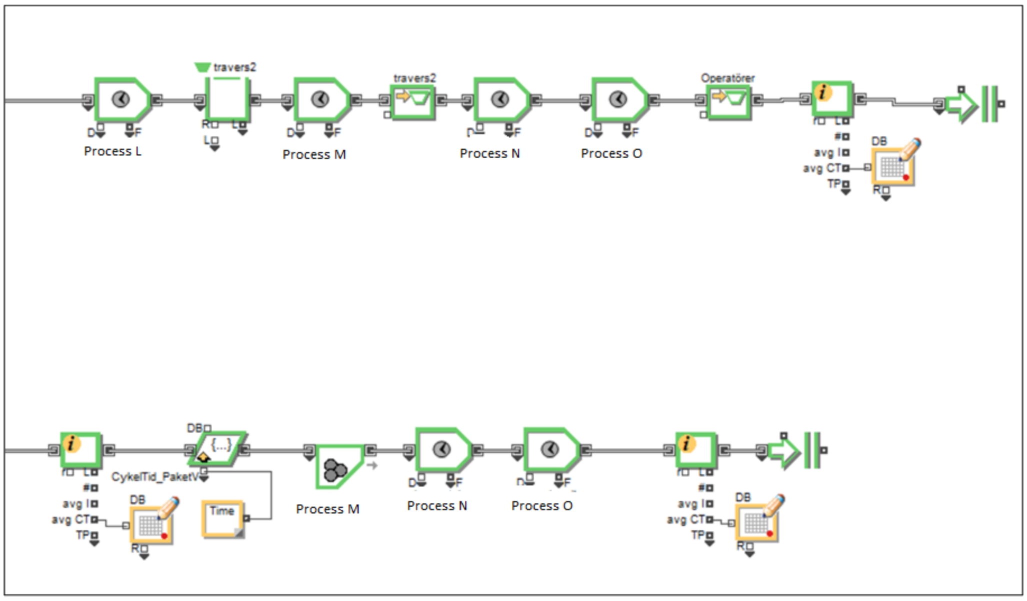


Figure 15 – Scenario 1, Section 5: finish

4.2.2 Scenario 2

A separate after-treatment station for type A panels is added to the factory called station Y. Type A panels are split up from the type B panels and are then after-treated on station Y in the production line. This scenario frees up space in the normal after-treatment area and requires one less lifting operation by the overhead crane. Building an after-treatment station will also enable panels that has to be processed on both sides to have two different routes to take back to the CNC, if the normal route is blocked, they can pass through the new after-treatment station, see figures 16-19.

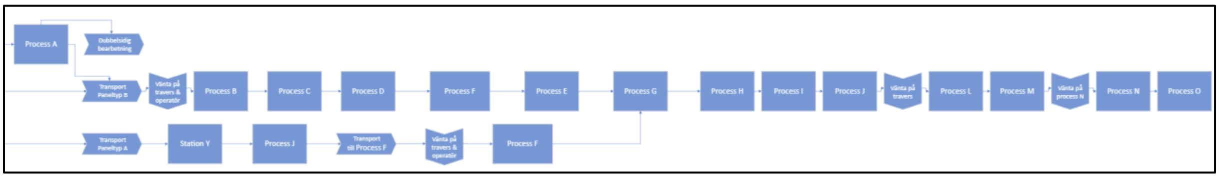


Figure 16 – Scenario 2 concept model

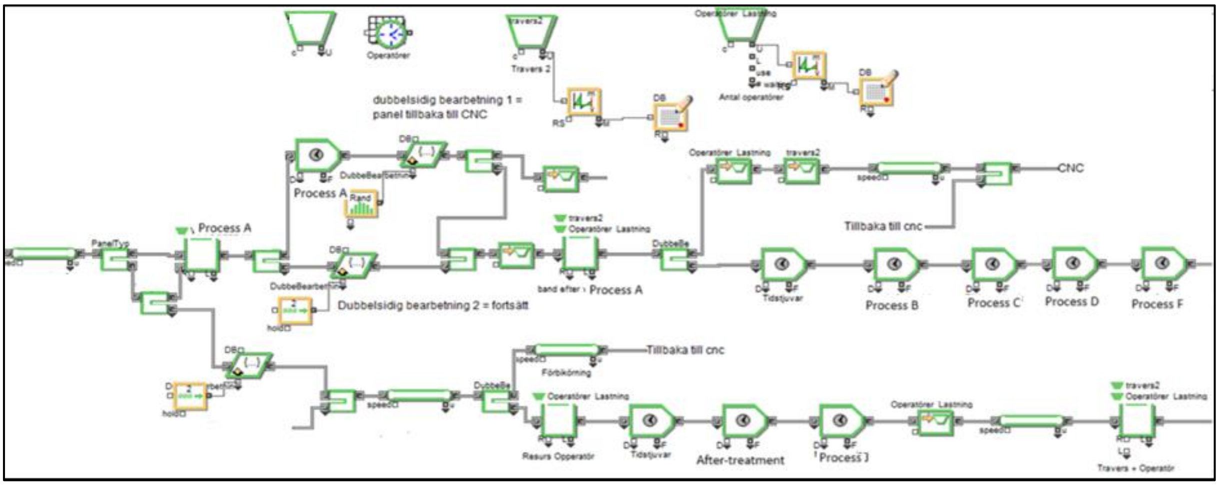


Figure 17 – Scenario 2, Section 3: Process A, resource pools and after-treatment of type A panel

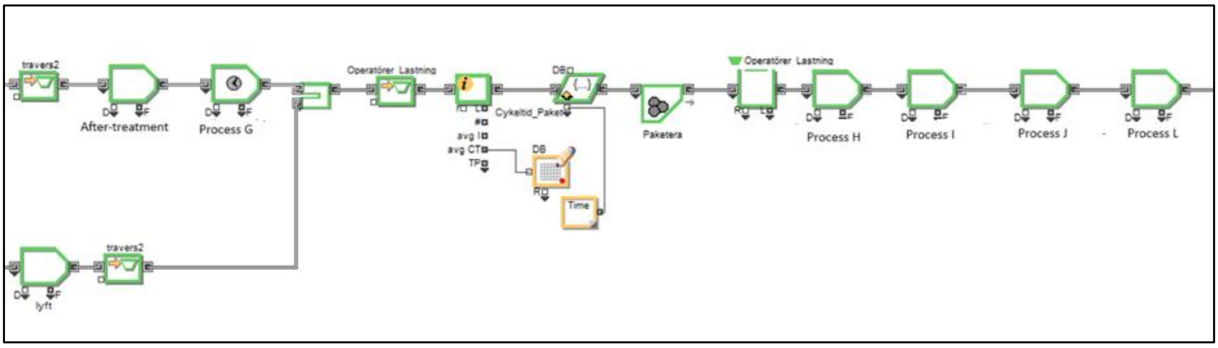


Figure 18 – Scenario 2, Section 4: After-treatment of type B panels and Process G

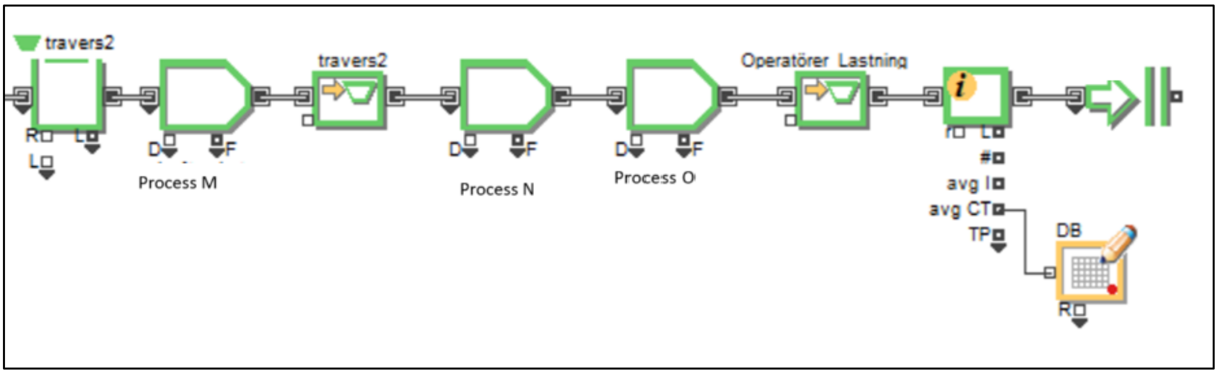


Figure 19 – Scenario 2, Section 5: Finish

4.2.3 Scenario 3

The concept with both after-treatment station and station X. Type A panels are split up from the type B panels in the same way as in scenario 2. After-treatment is applied in the after-treatment station a conveyor moves the panels to the station X, the overhead crane lift them up and load them in an alternative fashion on the trailer. This scenario will also have the benefit of panels that has to be processed on both sides can pass through the after-treatment station, see figures 20-23.

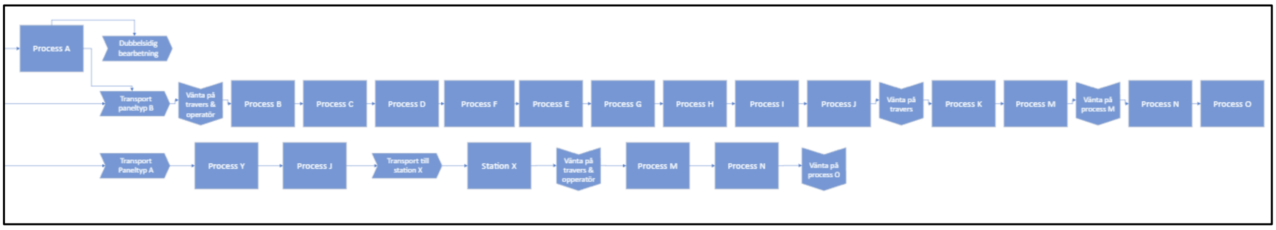


Figure 20 – Scenario 3 concept model

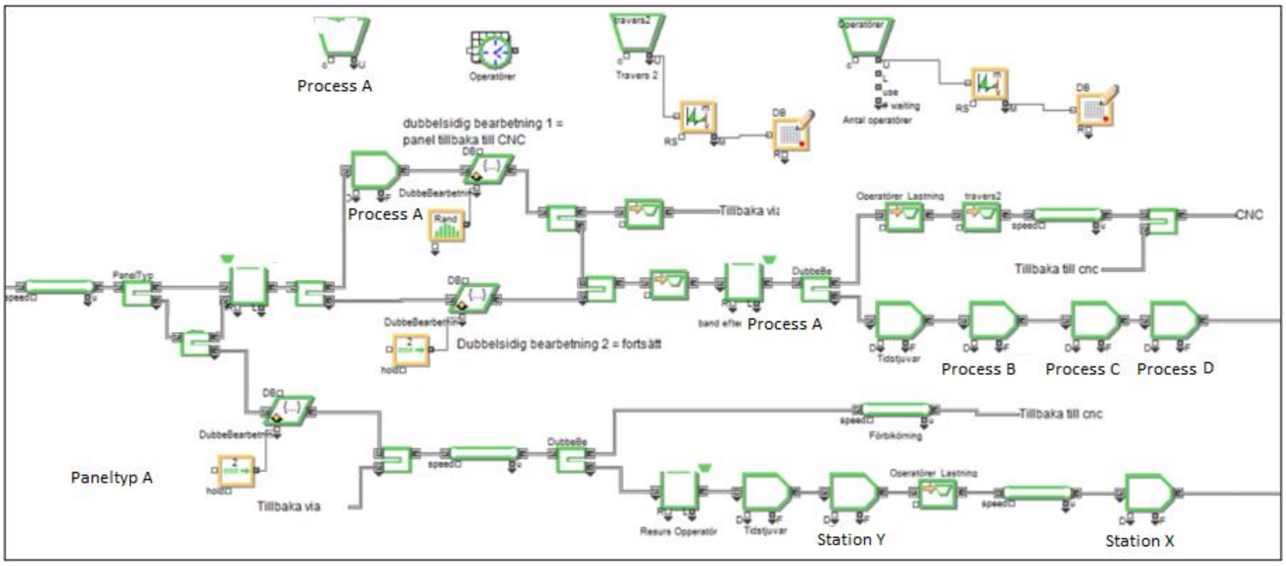


Figure 21 – Scenario 3, Section 3: Station X and resource pools

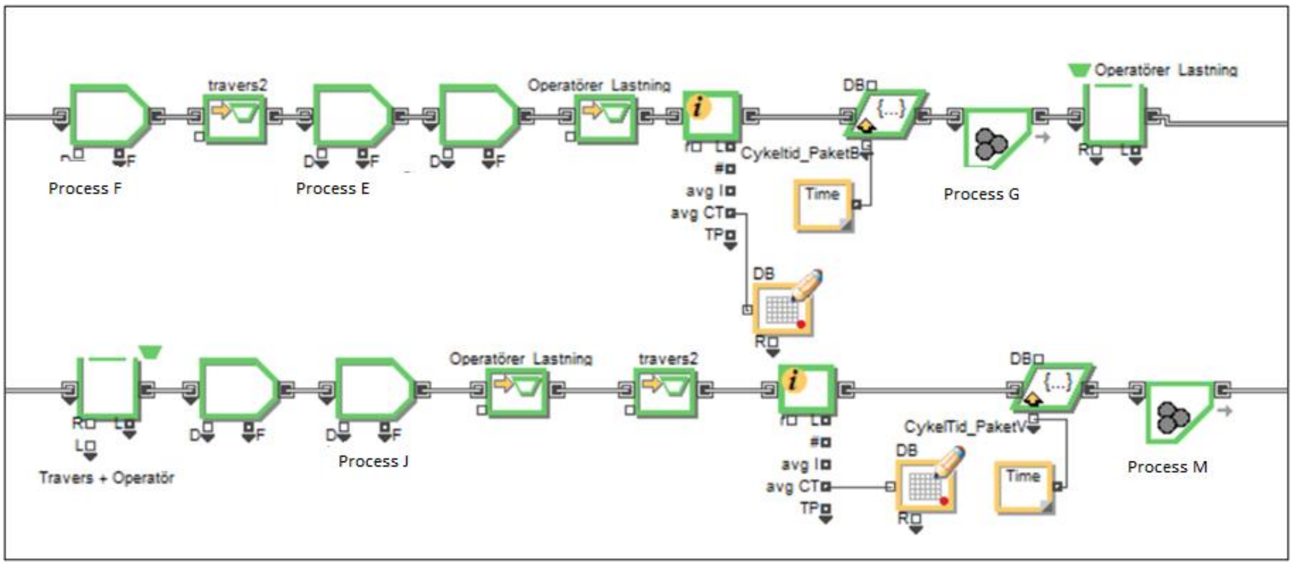


Figure 22 – Scenario 3, Section 4: After-treatment and process G

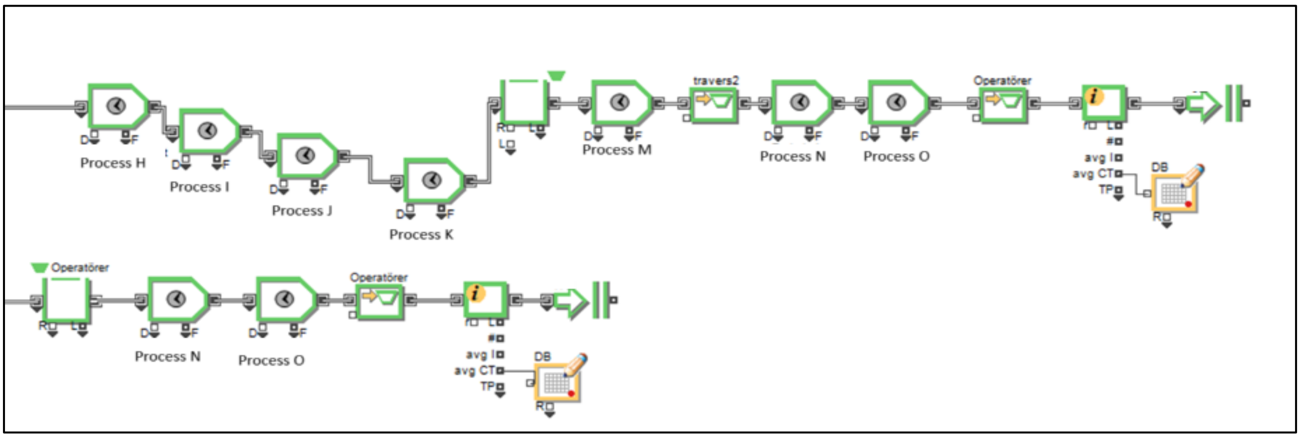


Figure 23 – Scenario 3, Section 5: Finish

4.3 Verification and Validation

Verification

To ensure that the simulation model represented the real production it was constructed following the concept model. During the programming of the simulation, the model has been verified continuously each week in the consultation meetings with Södra, by showing them the model and explaining what happens. This meeting has been a valuable activity to the verification of the model as Södra helped limit the project to focus more on the objective. The model has been developed further and further until Södra accepted it as a good representation of the real production line.

Validation

To validate the simulation, the steps described in the theoretical background were used.

Conceptual Model Validation

To validate the simulation the steps described earlier under theoretical method were used. The group and Södra constructed the conceptual model together, limiting the project to focus more on the objective. The resulting conceptual model contains all the important activities that are made to produce a wood panel.

Data Validation

The input data have been validated by taking measurements of the real production and using that data for the model, the measurements have been compared to the data provided by Södra. Data requiring estimation have been discussed with people on Södra that had a better insight of the production. This enables the input data to be trustworthy.

White-Box Validation

The simulation model has on several occasions been looked through with Södra. Mainly on the weekly meetings on Teams but also at the site visits. Various aspects of the model have been checked and discussed, cycle times, buffer sizes, shift patterns, logic, process flows and distributions. This has been a good activity to ensure that the model is a good representation of the real production.

Black-Box Validation

The output data have been validated by running the simulation for a week (10 080 minutes in ExtendSim) with the same shifts and stop times as the real production and then count the number of master panels in the exit blocks. The result of that has been accepted as a sufficiently accurate number to what the real production can produce.

Experimentation Validation

During the construction of the model a lot of testing has been done, e.g., how will the simulation react if another operator is added or removed from the model, buffer sizes are changed, and unforeseen delays are added. When making the changes the simulation model has reacted as expected.

4.4 Outcome of simulation

To compare the results between the three different scenarios and the base model the following parameters where analyzed:

- Activity state percentage of machines and stations.
- The total cycle time for a panel to go through the production.
- The number of master and child panels produced.

The results are measured after running the simulation one week. This is repeated in twenty runs and a mean value is calculated in Excel of the measurements giving a result in the form of diagrams.

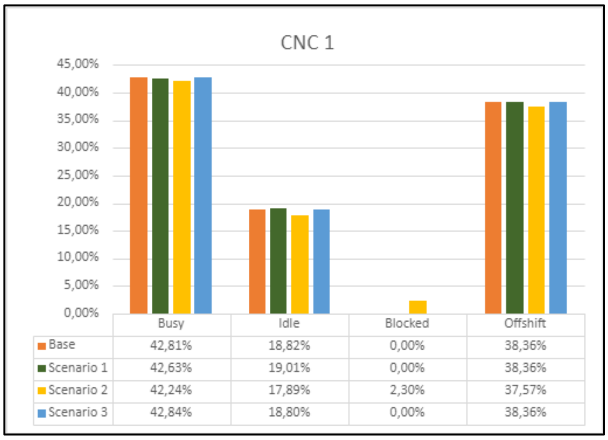
4.4.1 Activity state percentage

In the simulation program ExtendSim there is a tool measuring the activity state percentage of activity blocks. The tool measures the time the machine is busy, idle, blocked, shutdown and offshift.

- Busy: Time the activity block is spending delaying an item passing through it (working)
- Idle: Time the activity block is ready to work but is missing items (waiting)
- Shutdown: Time the activity block is not working due to fabricated stops like random breakdowns or maintenance. The maintenance schedules each day for the CNC-machines is regulated in the shifts.
- Offshift: The time the activity block is not working due to being switched off by a shift block.

CNC-Machines

The result of the activity state percentage measured on the two CNC-machines are shown in figure 24 & 25 below. The diagram shows that the changes made on the different scenarios does not change the activity state of the machines more than plus minus a half percentage point. The fact that there is close to no change in activity is because the machines never being blocked, except for some blockade in scenario 2 where panels must queue to get in and out of the after-treatment station.



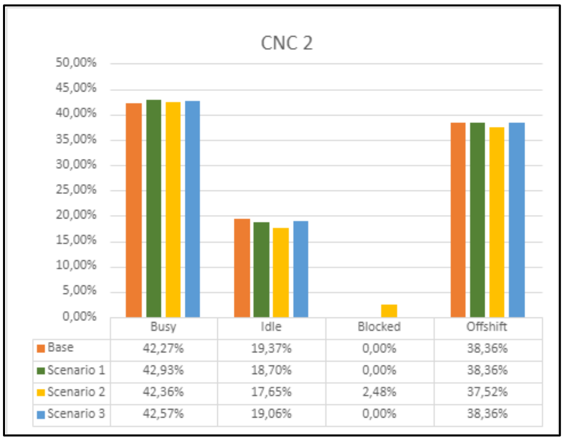
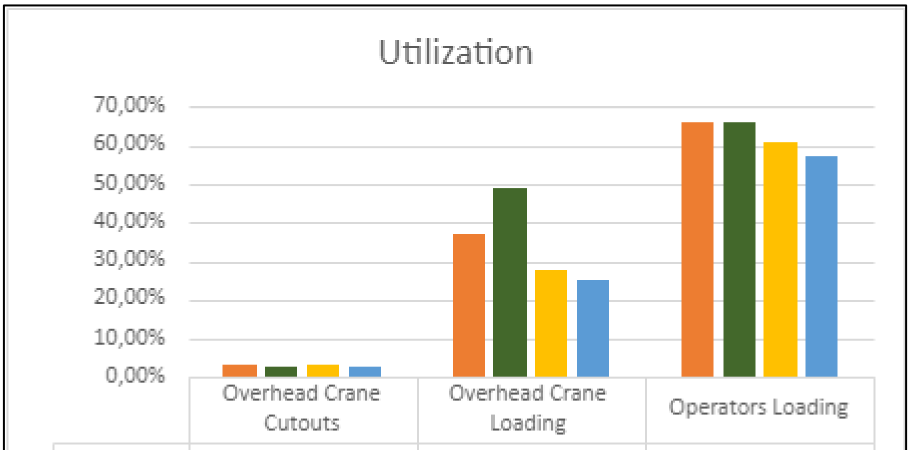


Figure 24 & 25 Activity state percentage CNC 1 and CNC 2.

4.4.2 Utilization

The utilization of the overhead cranes and operator are presented in the table below, figure 26. The usage of the overhead cranes affects the utilization of the operator, since one operator is needed to operate an overhead crane. The operator that works in the new after-treatment station in scenarios two and three are taken from the same resource pool as in the base model for the loading area, which makes it possible to measure how much the changes affect the operators.

In this case a reduction of utilization is good because it means that less time is spent on moving panels with the overhead cranes, a goal specified in chapter 1. The operators will also have more time to spend on other value adding activities. As the figure shows below scenario three with both after-treatment and station X (scenario 3) has the lowest utilization and that scenario 1 utilizes the overhead cranes in the loading bay to a greater extent. This can be explained by the need to lift each panel to Station X to process the panel and then back to the loading bay.



	Overhead Crane Cutouts	Overhead Crane Loading	Operators Loading
Base	3,30%	37,17%	65,92%
Scenario 1	2,81%	48,99%	66,14%
Scenario 2	3,24%	27,91%	60,84%
Scenario 3	2,72%	24,91%	57,07%

Figure 26 Utilization of overhead crane and operators.

4.4.3 Cycle time up to packaging

Cycle time to packaging is the total measured time for a panel entering the CNC-machine until it is packaged, see figure 27. The base model and scenario two only provide one cycle time due to the type B panels and type A panels are loaded on the same trailers. In scenario one and two type A panels and type B panels are loaded on different trailers going different routes in the production giving two different cycle times. Scenario 3 stands out by being the only scenario with a cycle time lower than the base model.

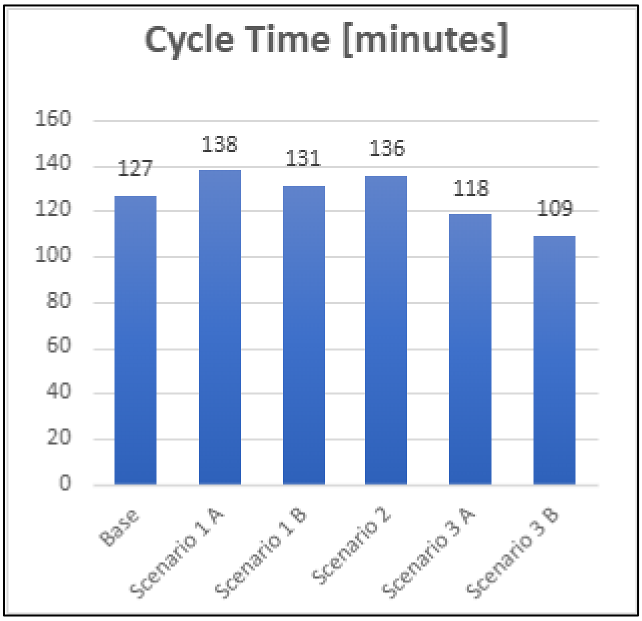


Figure 27 Cycle times

4.4.4 Cycle time between trailers

In figure 28 the cycle time is the total measured time between a panel entering the packaging station and exiting the simulation (and factory) when the trailers are full. The base model and scenario two only provide one cycle time due to type B panels and type A panels are loaded on the same trailers. In scenario one and two, type A panels and type B panels are loaded on different trailers taking different routes in the production giving them two different cycle times. Higher loading capacity on trailers also explains the longer cycle times as they must wait longer to be fully loaded. This makes it a bit hard to compare scenario 1 & 3 with the base model and scenario 2.

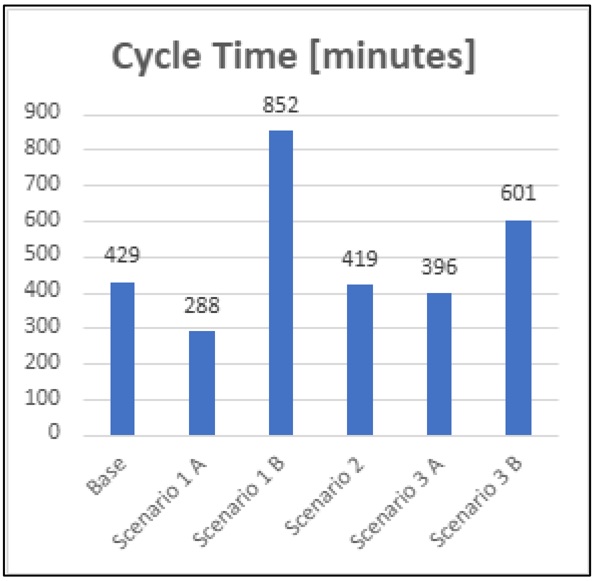


Figure 28 Cycle times trailers.

4.4.5 Master and child panels produced.

The number of master panels produced are dependent on the press-machine before the CNC-machine and it produces a master panel every thirty minutes. Therefore, the factory maximum is thirty-two master panels per day when working on two shifts of total sixteen hours per day. During the simulation run of the base model and the three scenarios this number never deviated indicating that no serious blockage occurred, which the active state diagrams also show.

5. Discussion

In this chapter the results and purpose of the project are discussed. A reflection over the model's future potential is made. The methods and techniques used to perform the project are analyzed.

5.1 Interpretation of simulation results

From the outcome of the simulation, it is shown that scenario 3 is the best concept with both a new after-treatment station and station X enabling alternative loading of panels. From the staple diagrams it can be seen that by only installing one of the changes, the results will both improve by some aspects and worsen by others. E.g. scenario 2 with only the after-treatment station the utilization for overhead crane and operators are better than for the base model but the cycle time through the factory is longer. This is a result that the group expected as the benefits of installing both station X and a new after-treatment station (station Y) is that a lot of transportation are removed, but the interesting information was to know how big the difference would be.

The figures of the CNCs activity state shows that there will be close to no change upstream in the production effected by the changes. In the results from the utilization diagram (figure 26), the overhead cranes utilization is reduced with 12% points and the operators 9% points between scenario 3 and base model. For scenario 3 the cycle times to packaging are separated because of the type A panels and type B panels taking separate routes, for both times they are reduced, with 7% points respectively 14% points compared to the base model. The reduction of cycle time through the production is good as it is one of the principles of lean and a prerequisite to quicker find defects (Liker, 2004). For the cycle time between trailers (figure 28) it shows that type B panels in scenario 3 are waiting longer than the base model to be shipped away. The reason for this is because of the panels being loaded on different trailers, that makes it almost impossible to compare with the base model as the conditions are not the same. But in general, it is good to have a short waiting time and running smaller lot sizes (Liker, 2004). Scenario 2 & 3 also reduces transports with fewer lifts (lower utilization of overhead crane), which is another waste described by Liker. One solution to reduce the time between trailers could be to reduce the number of panels loaded on the trailers, but that would also increase the cost for transportations, this is something that would be good to investigate in the future.

Södra is not necessarily looking for a result that indicate a more productive workflow. The overarching goal for this project is to investigate if an alternative loading of type A panels is viable and can be made without having a negative impact on productivity or in other ways disturb the production.

5.2 Future potential use of the simulation

This project has only extracted a small portion of the available data in the ExtendSim model. With some modifications the model can be integrated with Södra's existing models of previous steps in the factory to complete the virtual production. Here are some of the data that could be available and of use.

Energy consumption

The machines can be assigned a rate of energy consumption, creating data about how much energy is used. This can later be used in cost calculations.

Material consumption
The machines can be assigned a rate of material consumption, creating data about how much material is used. This can later be used in cost calculations.

Total cycle time
By combining this model with those previously made by Södra, a total cycle time from cutting the planks to delivering panels to the customers can be made.

Wastes
To complement the energy and material consumption waste, Time can also be measured and used to compare different flows.

Evaluating alternative layouts
Different placements of stations and machines with the focus of shorter transports or better ergonomics can be tried and evaluated.

For future usage of the simulation, it would be good to run the model with different input data as this project has been limited to only use data from one real production project. Södra has earlier produced projects with 100% panel B, and it would be interesting to see how the simulation would react on that or running 100% type A panels.

This project has only looked at today's case with one press that feeds the two CNC machines. In the future the need for a third and fourth CNC machine might arise. The space used for the after-treatment station is in an area where a fourth CNC would need to be placed. This case needs to be evaluated to ensure that the after-treatment station does not block a future expansion of the production.

The current state of the production can handle a bit of wrong arrival sequence of child panels in the packaging area. The new scenario has no buffer between the station X and the trailer, this means that it could be hard to handle panels arriving in the wrong sequence. Alternatively positioned panels would however facilitate rearrangements of panels.

5.3 Reflections on programming the base model

It was difficult to estimate how much time each part of the project would take. One step that took longer than expected was the development of the base model. The miscalculation was caused by four aspects.

- Inexperience with ExtendSim. The simulation software that Chalmers uses in teaching are all 3D based DES programs and while ExtendSim can and is used in DES mode it still looks and operates like a process flow. This clash in simulation strategy slowed down the project on several occasions and requiring help from Södra's simulation expert.

- All manual work with processing and collecting data. The numbers of cutouts are needed in order to know how long the overhead cranes are occupied on a panel and that is not data that Södra had. Consequently, drawings of over six hundred and fifty panels hade to be gone through manually and the data had to be put into tables that are easy to import to ExtendSim.

- The need for an accurate model created a need for more data to replace distributions. When the larger datasets got processed some opportunities for additional functions in the model were discovered. This turned out to almost be a spiral to a never-ending amount of work but in discussions with Södra a limit to the scope was made that allowed the project to continue.

- Communication difficulties in the form of unaligned project goals that on several occasions led to the need to rework the data collection and simulation modelling parts of the project.

These delays effected the project to the degree that the plan to develop additional cases to simulate (see chapter 1.3) had to be cancelled due to a lack of time. It’s hard to estimate how these new cases would have affected the end results as it can be argued that the existing size and placement of equipment and building features severely limits the options to rearrange the layout, and therefore making disruptive changes difficult.

6. Conclusion

At the end of the project, the main task of the project which was to evaluate how changes to the existing production enabling type A panels to be loaded alternatively, would impact the planned production and shave off time at the construction site while minimize the risks of injuries associated with raising type A panels both for the operators and customers, have been completed.

After gathering information and knowledge about Södra Skogsägarna and their operations followed by a deeper dive into their CLT facilities. The evaluation was to be done using *discrete event simulation* and the program ExtendSim. Using a concept model as a reference for the model layout and by processing data, a simulation of the current state could be programmed. The results from the base model were then used to compare with three alternative production flows.

The result seems to indicate that most changes does not have a severe negative affect to the production, which would make it hard to motivate the adjustment to an alternative loaded type A panel. On the contrary they appear to show signs of some positive effects, especially scenario number three with an after-treatment station and an alternative loading of type A panels. The lower cycle time in this scenario is closer to the takt-time and the levels of utilization suggest that there is more potential for improvement.

The way forward of this project probably consist of further analysis of the data output of the simulations and more experimentation in the form of more alternative cases to simulate. These cases could be based on new production philosophies, different layout designs or addition of new machinery. The model could also be refined with more extensive and accurate input data from other planned projects or real production. By integrating the model with existing ones or models made in the future, ultimately a complete process flow from raw resources to decommissioning could be simulated.

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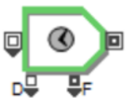
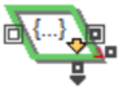
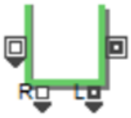
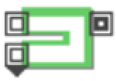
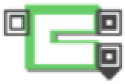
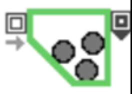
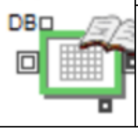
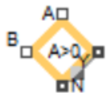
Appendix

ExtendSim function blocks

Name	Symbol	Description
Create		Is used to spawn items in the beginning of the system. Number of item and arrival times can be set.
Activity		Represents work activities or machines with a cycle time that can be changed along with its distribution.
Exit		The end of the system that deletes items after counting them.
Set		A block that attaches one or more attributes to an item passing through.
Get		A block that reads attributes of a passing item.
Queue		Acts as a buffer for items. Have the option to acts as *Resource Pool Queues* where a resource is assigned to an item.
Resource Pool		Contains a finite resource that in the simulation symbolizes the overhead cranes and operators.
Resource Pool Release		Returns a resource to the **Resource Pool**.
Select Item In		Merges two or more connection lines.
Select Item Out		Splits one connection line into two or more. Can have different output selections based on conditions like attributes.
Unbatch		Splits an item into several items based on given conditions.
Random Number		Generates a random number that can be used in the assignment of attributes or as a base of distribution. Can be linked to a database
Data Import Export		Imports data from an Excel-sheet to a database.
Constant		Outputs a constant value.
Read/Write		Reads/writes a value from/to a database linked to an attribute of a passing item.

Decision		Compares input values and can be used to build logic.
Shift		Generates a schedule that can control another block's worktime.
Gate		Limits the number of items in an area.
Information		Records selected attributes.
Batch		Combines several items based on given conditions.

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