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A streamlined simulation workflow for emulation projects

A Case Study in a project oriented organisation

Master's thesis in Master Program Production Engineering

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Gothenburg, Sweden 2020

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Abstract

The interest of the concept digital twins and virtual commissioning has been increasing in the industry during the last decade. Tools for simulation and emulation are existing in software with a high complexity. However, while the methods for simulation is highly developed, the same type of methodology for emulation projects in inconsistent and seems to be missing by the industry. At the same time, simulation studies struggles with a high resource consumption and results in high costs for the companies. To provide efficiency in the design and realization of automated material handling systems, this thesis investigates how the simulation studies can be more streamlined by eliminating waste. This is done by identifying the non-value adding activities and suggesting an approach to remove them from the process. Further this thesis is investigating how the streamlined approach for simulation studies, can be applied to emulation projects within the same company. The research was conducted with a case study in the logistics company Swisslog AB in Partille, Sweden. The departments investigated was the simulation department and controls department.

Keywords: simulation, emulation, digital twin, virtual commissioning, process management, waste management, automated material handling system, project organisation.

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Elin Hybert, Gothenburg, January 2020

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List of Abbreviations

CAD	Computer Aided Engineering
CAM	Computer Aided Manufacturing
DES	Discrete Event Simulation
FAT	Factory Acceptance Test
HIL	Hardware In the Loop
LOI	Letter Of Intent
PLC	Programmable Logic Controller
SSAT	Subsystem Site Acceptance Test
TC	Technology Center
VFAT	Virtual Factory Acceptance Test

1
Introduction

In this chapter, the work of this thesis is introduced. It starts with Background and Purpose followed by Limitations. The chapter ends with a Definition of targets and Research questions.

1.1 Background

Swisslog Logistics Automation is one of the largest supplier of automated material handling systems worldwide. Swisslog AB is a project oriented organisation which delivers to customers in the Nordic countries. The customer value is added in logistic solutions provided by Swisslog, when material are distributed to the next step in the value chain in the production of goods. By automating this production step, *"We shape the future of intralogistics by introducing a new era of flexible, robotic and data-driven automated solutions that create exceptional customer value"* (Swisslog Logistics Automation 2019).

Today, the customer project workflow starts in the sales phase, where several iterations of drawings are performed and in some cases also simulation studies to verify the design. The simulation environment enables a tool for verifying function and capacity, testing scenarios and experimenting before the system is built physically. One possibility in the simulation is to test specific part of the plant to get familiar with the behaviour of the system during e.g. high load or ordinary circumstances. The aim of a simulation can also be to provide visibility of the system for the customer during sales phase.

Then the project transfers in to the next phase which is the realisation phase where the detail engineering specifies the detail design and controls team develop the controls software. The system is put together with engineers from Swisslog AB, the Technology Centers (TC's) and external suppliers. Emulation has been used in a few projects to ensure quality before going on site. A bachelor thesis from Hvistendahl et al. (2019) has investigated the possibilities of using an emulation software in some parts of the commissioning process in an reversed engineering approach. Swisslog is now interested in investigating how a strategy of implementing emulation in their workflow would look like.

Even though the simulation department are using the same software for simulation as for emulation, there has not so far been any cooperation between the departments. Investigations of how emulation should be worked with has started isolated from the simulation department and the controls department are now at the crossroads of either developing their own methodology or cooperating with the simulation department.

1.2 Purpose

The purpose is to provide efficiency in sales- and realisation phase and the transitions between them, to ensure fast and safe deliveries. By identifying areas of improvement, the effort in developing a digital twin can be reduced. Which in the long run will lead to efficient production in workflow from sales- to realisation phase. A digital twin that follows throughout a plants life cycle will also reduce the time for modelling of existing plants, which will speed up the sales process and minimize the time for commissioning during modernisation, changeovers and extensions.

1.3 Limitations

As the thesis will collect data from the knowledge and experiences of people in the organisation, projects with the characteristics that will provide the most quality to this study will be investigated. That will mean keeping to new build projects and limit the technology to heavy goods pallet conveyor systems. The thesis will also limit the simulation- and emulation software investigated to the licenses Sim3D and Emulate3D, which runs in the software Demo3D.

1.4 Definition of targets

Targets of this master thesis:

- Create a process flowchart of the design, simulation and emulation process.
- Identify the gaps and double work in the process.
- Suggest a strategy for the future development processes of design, simulation and emulation.
- Brief investigation of methods that could be applied in the strategy in future improvement work.

1.5 Research questions

RQ1: How can the current simulation study workflow become more effective in a value adding activity approach?

RQ2: How can the methods of a traditional simulation study be applied to an emulation project?

2
Theory

In this chapter, the theoretical framework of this thesis is presented. Firstly the concepts of Simulation and Emulation is described, following with a comparison of Simulation vs. Emulation. It is followed by a description of waste management and a brief review of Related Work in the field of study. The theoretical framework was used as a basis to produce the result and draw the conclusions of this thesis.

2.1 Simulation

It was during the post war era, in the beginning of the 1950s, that the simulation technology was first used, as there was a need for analyzing randomness in the military (Gunal 2019). In the beginning of the 2000's, the Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) became a part of product design and manufacturing. Today simulation can be used to objectively evaluate the system and provide insight into its optimal configuration and operation (Gunal 2019).

A simulation model is the representation of an actual system, with a complexity that is appropriate to the aim of the simulation. Which is complex enough to answer the sufficient questions, but not too complex which could slow down the operational time (Banks 1998).

Variability and complexity are usually interconnected and subjects to most operational systems (Robinson 2004). As the factors variability, inter connectivity and complexity could lower the predictability of the performance of any system, the combination of all three will make the predictability almost non-existing. If these characteristics of a system could be represented in a simulation model, it could be used to evaluate the performance of such a system.

A simulation study is usually performed due to the frame of a question about a system. The system that is to be tested could both be an existing system or a system that still is in the planning phase. For the simulation study to be successful and to gain all of the advantages without wasting resources, a detailed specification about the study should exist prior to the study.

In *Discrete Event Simulation (DES)* the simulation is run over a certain time with events occurring making the system change state. Most discrete-event models are dynamic, which makes the passage of time a relevant factor, while mathematical and statistical models are considered as static and corresponds a fixed point in time (Banks 1998). As could be interpreted from Figure 2.1, the simulation study is performed iterative during both the model development and the experimental part of the study.

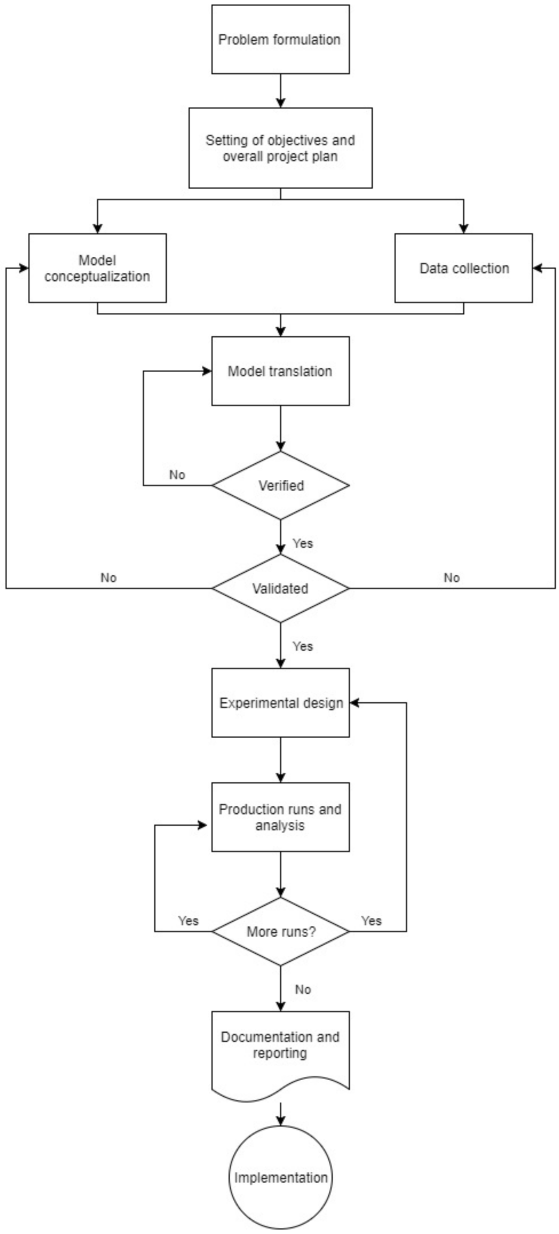


Figure 2.1: Steps of a simulation study (adapted from Banks (1998))

2.1.1 Concept modelling

Included in the specification mentioned in Section 2.1 is a conceptual model. Robinson (2004) defines the conceptual model as:

“a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model”

The purpose of the conceptual model is to work as a base for the developing of the computer simulation model, which will be bound to a specific software and could also be referred to as the functional specification of the computer software (Robinson 2004). If the conceptual model is not developed sufficiently accurate, it might lead to the computed model not achieving what is required and could in the other end lead to the model being partly redone and in worst case scenario, being completely redesigned. The complexity of the software might tempt the engineers to build a model more complex than necessary (Robinson 2004).

2.2 Emulation

Virtual commissioning (VC) is a concept used to describe all types of testing of the function of a physical system with a virtual model in a virtual environment. The real physical system could be existing parallel to the virtual model or only existing in the planning phase. Reinhart & Wünsch (2007) states that there are two different approaches of a virtual prototype for control software during virtual commissioning:

- Full simulation of machinery
- Hardware-in-the-loop (HIL) simulation

Full simulation includes both a simulation of the production equipment as well as the control software and this type of simulation will further in this thesis be referred to as *PLC - simulation*. HIL - simulation uses the real control hardware and the virtual model simulates the production equipment in real time and will in this thesis be referred to as *Emulation*. Emulation enables the control software to be tested under more realistic conditions as no changes to the software has to undergo any changes after the testing, as could be the case in PLC - simulation (Reinhart & Wünsch 2007). Reinhart & Wünsch (2007) suggests the following three factors as drivers for virtual commissioning: *Time*, *Quality* or *Cost*.

2.3 Simulation vs. Emulation

The concepts of emulation and simulation might easily be confused and mixed up, due to their many similarities. But the differences are many and to successfully implement the methods of emulation it is important to understand the meaning of the concept emulation. Emulation is used mainly to test the operation of the control system under different system loading conditions and work as a risk-free test environment (McGregor 2002). In contradiction to simulation, emulation is also not used for experimenting in the same extent as it usually runs in in real time, which will make the experimenting time consuming and resource heavy.

2.4 Waste management

Weiss (2013) is suggesting how the seven wastes defined by the lean practitioner Taiichi Ohno, could transfer to engineering and development, which are presented in table 2.1.

Table 2.1: Waste in engineering processes (adapted from Weiss (2013))

Waste	Definition
Overproduction	Producing too much material
Inventory	Having more material than necessary
Transportation	Moving material or information
Unnecessary movement	Moving people to access or process material
Wait	Waiting for material or processing operations
Defective output	Errors or mistakes with outcome of correct or redo
Overprocessing	Processing more than necessary for the produced output

When dealing with engineering the product can be considered to be represented by information (Weiss 2013). In other words, the waste is the type of handling of information that will not result of adding value to the information and moving towards the target of for example the engineering project. On the other hand, the waste does not have to be considered as unnecessary, therefore when dealing with waste management each source of waste has to be evaluated. According to Weiss (2013) there are two types of waste in reality, necessary and unnecessary. Waste is defined as activities that are not value creating to the customer, nevertheless some activities are necessary to the organisation even though there are no value added directly to the product or service.

2.5 Related work

This master thesis was introduced as a continue of the bachelor thesis that was conducted at Swisslog by students in the Oslo Metropolitan University, Oslo (Hvistendahl et al. 2019).

Hvistendahl et al. (2019) was investigating the workload of modelling an existing system and use it for emulating the plant with the real PLC-program. The aim of the thesis was also to develop a library of equipment to use in further modelling work.

The conclusions of Hvistendahl et al. (2019) was that to make emulation efficient, a naming convention to be used during both electrical drawings and CAD is necessary. The names should include sufficient information about the component type, area and addresses of the PLC. To create an emulation model of an existing system, it was concluded that some fieldwork was necessary to validate the measurements of the physical equipment. It proved that the drawings available was not updated with the current state of the system and its control software, which made it diffucult to continue the work with them as an input.

A further conclusion was that emulation could reduce commissioning time up to 75 percentages but to achieve this high number of efficiency, more work should be conducted to gain experience with the software Emulate3D. The possibilities for using emulation is Virtual Factory Acceptance Test (VFAT) is also discussed, which possibly could eliminate the need of PLC testing during commissioning. Hvistendahl et al. (2019) states that even though emulation can save resources in means of travel time, accommodation cost and time on site, it still requires additional work during the project. Therefore it cannot be determined whether the total amount of time in the project will be reduced, but since the work can be performed parallel to commissioning, the length of the commissioning can be argued to be held shorter.
Another study of modelling a system with the aim to use in PLC integrated modelling was performed in a master's thesis by Engström & Liao (2017). In this thesis, Engström & Liao (2017) investigates how it is possible to run a simulation model with the PLC - code integrated.

Älegård & Knutsson (2017) is in their thesis investigating the current status of virtual commissioning with the challenges and possibilities with a small interview study. The interviewees are people from the production industry with different experiences of Virtual Commissioning (Emulation). A conclusion from this study is that the work processes in testing of PLC code in virtual models are still not really mature and there is a lack of methods and work processes. It seems that companies tend to use their own methods as there are no standard way of performing such a project.

Älegård & Knutsson (2017) is also expressing that there is more to ask from the available software and that a lot of effort is still required in the modelling phase of the project, which is suggested to be simplified with standard elements that could be drag-and-drop'ed in to the model.

3 Methodology

In this chapter, the methodology for this thesis is presented. It start with the general research method followed by a section about Data Collection and Data Analysis. The chapter ends with a brief description about the Improvement Work.

3.1 Research method

This master thesis consisted of two parts of a case study. Firstly, investigated the current state of certain work in the organisation in a process management structure, which is described in section 3.1.2. Secondly, a hypothetical theory was formed and the case study aimed to find empirical evidence to prove that the theory could be applied to a real world context. For this master's thesis the theory was that the traditional methods of Simulation studies can be applied to Emulation projects in a project organisation. The real world context in this certain case study will be represented by the organisation of Swisslog AB and the areas of investigation will be the processes of Sales- and Realisation phases where simulation and emulation occurs. To get a wider and more objective view of these two processes, other processes that interferes with those two processes will also be looked at. Interfering processes are for example the design process within a sales project as well as the design process in the later realisation part.

3.1.1 Case study

A case study was used as the primary research method in this thesis, due to its relevance as a method in research work where the primary question to answer is *How?*- and *Why?*-questions (Yin 2014). Furthermore, this masters thesis aims to study the real world phenomena in an organisation which is suitable to apply on a case study. Yin (2014) also states that even if case study has recently been considered as only to be the explanatory stage of some other method or just fieldwork, it is now considered as a research method and is defined as "*an empirical inquiry that investigates a contemporary phenomenon in dept and within its real world context*".

The case study was designed as a single-case study, which only focused on the specific processes within Swisslog AB's project organisation. Yin (2014) is suggesting that if possible, the researcher should always aim to perform a multiple case study, due to the simple fact that it will increase the chances of the case study to succeed. This study was designed as a single-case study, as the research question aimed to investigate the specific current state of a process and also design a realistic proposal for the future for the company in question. The *Units of analysis* in this case study is the simulation study process within the sales phase as well as the controls testing process within the realisation phase.

The workflow of the case study was alternating between empirical observations and theory, which will expand the understanding between the real world phenomenon and theory, and give the research an abductive approach (Dubois & Gadde 2002). Theory collected from the literature review was used to make generalizations to perform the research design, form the research questions and draw conclusions from the empirical findings made in the data collecting phase. When turning back to the theory from the observation, the data collected was used to draw generalizations from the theory as well. This gave the research an iterative design. An illustration of the plan for performing the research can be found in figure 3.1

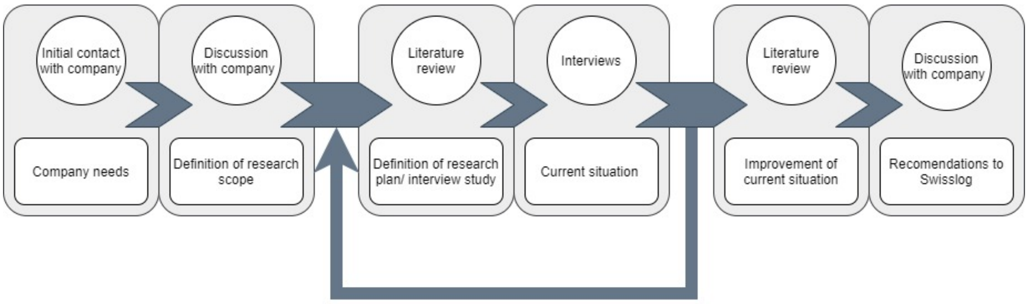


Figure 3.1: Workflow of research plan

Two proper research questions was formulated to initiate a direction of the study, which was followed of a logical plan on what should be examined and where in theory to start looking for evidence. Yin (2014) points out the importance of the research design being logical and not logistical, which means focusing on which questions should be studied, what data are relevant and to be collected and how to analyse the results.

3.1.2 Process management

In a company perspective, processes are often described in two classifications of different processes - *horizontal*- and *vertical* processes - depending on who are involved (Bergman & Klefsjö 2010). The activity in the organization can be described as a horizontal main process that is crossed by several vertical support processes that corresponds with the processes of each department, see figure 3.2. Main processes are the process within an organisation that is creating value for an external customer, and are usually what the company builds its operation around. The support processes has the mission to provide resources for the main process. Support processes deals with internal customers inside the organisation and includes several individual processes which represent the activities carried out by each individual in the company. To understand and improve the current process of simulation and emulation in Swisslog the methodology of the Process Management Method (Bergman & Klefsjö 2010) was applied.

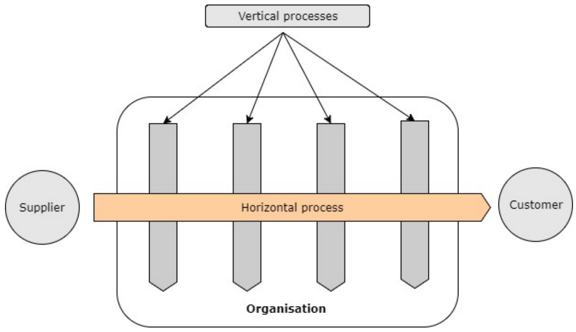


Figure 3.2: Illustration of vertical and horizontal processes within an organisation

To properly understand the current processes before suggesting approaches for approving it, Bergman & Klefsjö (2010) suggest that an important part of gaining knowledge about a process is to map it. Several options are available in terms of mapping techniques, for example Value Stream Mapping, which is covered in section 3.3.1. Furthermore, a *flowchart* could be used to illustrate activities within a process.

Benchmarking is a methodology for improving processes. The basic idea according to Bergman & Klefsjö (2010) is to make a careful comparison of a process at the company with the same or similar process at another company or division of the own company and then make advantages of the experiences. This master thesis will implement *Internal Benchmarking* when mapping the two processes of simulation and emulation and investigating the correlations and methods that will transfer from one to the other process.

3.2 Data collection

In this master's thesis, the data collection was done partly by a literature study and partly by an interview study. As described in Section 3.1.1 Figure 3.1, the literature was extensively reviewed before the interviews to plan the direction of the research. Also after the interview study the literature was reviewed to analyse the data and developing the future approach.

3.2.1 Literature study

The theoretical part of this master thesis was collected from literature. Early in the process of this study, the literature was review with the aim to gain theoretical knowledge about the methods and technologies that should be studied. After the interview study, the literature was once again reviewed with the aim to find correlations about what could be analysed from the interviews and the literature. The literature was then a part of the framework when designing he future state workflows. During the qualitative data collection which is covered further in Section

3.2.2, the literature was lightly reviewed parallel with the aim to plan the direction of the interviews.

The strategy of the literature study was to search for relevant topics in books and scientific articles through Chalmers library's search function. The keywords used for the search was mainly *Simulation, Emulation* and *Virtual commissioning* and findings published during the last few years was prioritised to scan through. Also, previous master thesis's and studies was scanned through with the aim to get an understanding on the status of the concepts. To find further relevant sources, the reference list of interesting articles was reviewed. Sources used for pointing out interesting points was especially of interest.

3.2.2 Qualitative data collection

As the Process Management Method indicates, an important step in improvement work is to understand the process before starting to implement improvements (Bergman & Klefsjö 2010). To gain knowledge of the process, data should be collected and illustrated i.e. with a flowchart, which will provide visibility. Qualitative data from the process will also be used for process improvement later in the improvement part. The qualitative data will stem from interviews with the purpose to identify the workflow and activities within the process (Damij & Damij 2014). There are several ways of organising interviews, depending on what the outcome is, from a structured to an unstructured format (Denscombe 2014).

3.2.3 Interviews

When needing peoples experiences, knowledge and opinion as data for a research study, an appropriate method to collect that data is through interviews (Denscombe 2014). Data collected for process management will describe the process and the people operating in the process will be sources of that data. As interviews will spend other peoples time it is important that the researcher performing the interviews has a goal with each interview and to plan them well.

Characteristics of the data requested in the research decides on the design of the interviews. The design of interviews involves the structures *Structured-, semi-structured- and unstructured interviews* (Denscombe 2014). Semi-structured interviews will keep the focus on the issues addressed by the interviewer, yet still allow for open ended questions. Moreover, the unstructured interviews will open up for a discussion with only the topic addressed by the interviewer. Both the semi-structured- and unstructured approach work developmentally and each interview will follow a different line, depending on the interviewees in each interview.

The data collection of this project was performed with semi- and unstructured interviews with key people of the process. Semi-structured interviews was making it possible to follow a structure which put the focus on answer the questions formulated by the interviewer. However, it was also opened up for discussions about the topic which gave a broader view with respect to the interviewed persons point of view (Denscombe 2014). Instead of asking what people need, the focus should be on how things are done and why they are done in that way.

The interviews was performed parallel to the literature study and the goal was to gain knowledge about the current process and the strategy was to perform them iterative. This will enable the possibility to analyse the performed interview and then setup a new interview script based on follow-up questions from the previous one. For this to be practically achievable with peoples tight time schedule, the interviews should be aimed to be held short. The iterative approach will bring deeper knowledge to the process.

The list of which persons that was supposed to be interviewed was composed together with the supervisors at Swisslog. Until the next iteration of interviews, the list was reviewed. Depending on the direction of next interview iteration, the people interviewed could be of different background and competences. Also, if some competence was missing in the previous interview, this was corrected until the next.

Each iteration of interviews was conducted with different aims, as could be seen in Table 3.1. In iteration 1 and 2 the interviews was recorded and later transcribed and analysed, during the last iteration the researcher in this thesis had already gained some understanding about the processes so the need for a carefully scanning was not equally important.

Iteration 1:	Gain knowledge about the organisation and the processes
Iteration 2:	Gain detailed knowledge about the processes
Iteration 3:	Validate the knowledge and discussion of problems and improvement potential

Table 3.1: Aim of interview iterations

Iteration 1 was conducted with six people in the organization which somehow is part of the design, simulation or controls process. The purpose of this iteration was to gain the first knowledge about the processes and to understand what was not yet understood by the researcher. This approach was done to work as an foundation to the next iteration and suggest what the next appropriate people to interview could be. Also, to get an understanding of what these people should be asked, so their experience could add value to this study. The aim was to find similarities in the interviewees' experiences and relate to their difficulties.

Iteration 2 was done based on the output from iteration 1 where the aim was to gain more detailed information about the processes, this iteration was done with four people where three people where new interviewees and from new departments. The results from this iteration was used as a basis for the mapping of processes in the data analysis phase, described in Section 3.3.

Iteration 3 was the last iteration and the focus on that interview section was to validate the analysed data from the first iteration. Also, improvement potential was discussed and the interviews was conducted in an unstructured format and the focus was the future workflow.

3.3 Data analysis

To organise the data collected from the interviews, transcripts of the interviews in iteration 1 and 2 was conducted for analyse in the next phase. Simplifying the interpretation of the interview data was done by coding the transcripts with different units that are interesting for scheduling the process (Denscombe 2014). The coding units represents the units of the process: *Events, Actions, Inputs and Outputs*, which means that the part of the interview that are connected to the same type of unit, will be coded with the same code (Denscombe 2014). In order to add visibility to the coding, it was performed with color coding, simply by using highlighters in different colors on printed transcripts. The transcribing and coding might be quite time consuming, but it was beneficial to have the data structured in the next step, where it was presented in a flowchart graph.

Generalization could be done alone from the findings in the collected data as well and by analysing the data collected from the case studied, the theory could be applied to the real world situation. Theoretical generalizations together with the analysis of the data will contribute to the conclusions of this case study. Generalizations and conclusions was made by over viewing the data from the interviews and recognising patterns. In practice this was done by highlighting specific areas of transcripts and putting out notes where pattern where recognised.

3.3.1 Value stream mapping

For the purpose to identify waste and non-value adding activities in the processes inspiration was taken from the lean tool *Value Stream Mapping (VSM)*. In a VSM the information flow of the process can be connected to the value adding activities within each process. Aside from working as a tool in the process management, this tool also provide visibility and knowledge about the processes for the employees of Swisslog. VSM is a method that originates from the lean world and the primary area of application has been on addressing value adding work in the physical production flow. The method could according to Keyte & Locher (2004) can also be used on business processes and the information flow between them. The processes are identified in the process box and focuses on the activity required to process information (Keyte & Locher 2004).

Once the processes was modelled in the VSM the researcher could start analysing the process and reflect about the stream. In comparision to a flowcart, the VSM will also contain a time axis which will indicate which activity on the other hand would contribute the most to an increased cycle time.

3.4 Improvement work

Damij & Damij (2014) suggests that the improvement work should start with an idea identification phase. In this innovative phase, people with experience from the processes should be involved, since they will contribute with tactical knowledge. The main focus in the suggested strategy for future work was to eliminate waste. By identifying waste in the current process, it could be reduced or eliminated and a strategy could be developed. Furthermore, the suggestions for future approach at the case company was developed with an aim to increase the value with less effort. In other words to design a streamlined workflow by reducing the wastes identified earlier in the process improvement work.

4
Results

In this chapter, the results will be presented. It starts with the Empirical findings in the current state, followed by an Analysis of the current state. The chapter ends with Suggestions to a future strategic approach for the case company.

4.1 Empirical findings

The horizontal process in Swisslog AB's organisation can be considered as the customer project process, that runs through the organisation and focuses on creating value to the external customers. The vertical processes crossing that project process, is represented by the sales process with design and simulation included as well as the realisation process with the detail design and controls of the system.

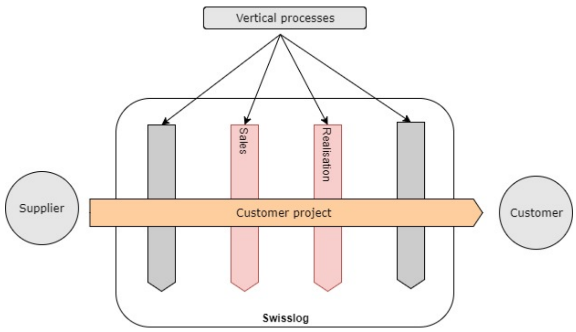


Figure 4.1: Illustration of the processes of Swisslog

Notably, the customer projects could be as different as building new systems, to add on's or modernisation's of already existing systems build by Swisslog or any other actor. All projects include standard solutions to some extent, but the customer demands and external factors could have an impact on the level of customise of the system, where special cases has to be considered.

During the interview study, the focus was to collect experiences and opinions from employees within the processes of design, simulation, detail design and emulation. This study resulted in some main points from each area together with a more detailed description of the processes simulation and controls with emulation.

When the initial contact with a customer has been established and the customer requirements are collected, a sales project is initiated. The sales manager, a solution engineer and a designer then develop a system iterative which will cover the needs of the customer. Within this process, the task of the designer is to produce the layout of the system, which includes taking the numbers from the capacity table and transform them to a layout.

Due to the nature of the design process, the layout is developed iterative with an increasing level of detail. The layouts has to be produced in several versions before the final system specification and design is decided, to serve as a basis to the ongoing sales process. Main points from people in this process is having the need to perform quick changes to the layout. The level of detail on the final layout could differ, depending on the presence of any critical points in the system, which usually is drawn with a higher detail.

When the system is detailed enough, a *Letter of intent* (LOI) is written between the parts, which is basically a formal declare of continuing with this project with Swisslog. After the LOI is written, the work proceeds towards a fixed price of the system and a contract with the customer. It is after the LOI, simulation is introduced to the sales project if there is a need for simulation, this process is covered in section 4.1.1.

The sales project continues to develop and settle on a solution of the system until the date for establishing the contract with the customer. Once the customer contract is signed, the project is handed over to realisation. Realisations main task is simply to realise the concept from the sales project. The details of the system could be of different level once it is handed over to realisation. The design process is continued in the realisation phase where the detail engineers is collecting drawings from the suppliers and complies them into one complete layout. This work includes interface checking between the suppliers equipment as well as the interfaces of the building.

The general view from designers in both sales and realisation was that the deliveries they use as an input could be quite dependent of the individual person delivering it. Several employees in both phases expressed the benefits of peoples extra knowledge because they had different job position within the company earlier. Furthermore, they also expressed some uncertainty about who was doing what and what their responsibilities was. Some of the employees also expressed insecurity in what roles they currently had. The concept *Go and ask* was mentioned in several interviews with people from both sales and realisation. Due to variations in deliveries it is sometimes necessary to go see the person delivered it and get it explained.

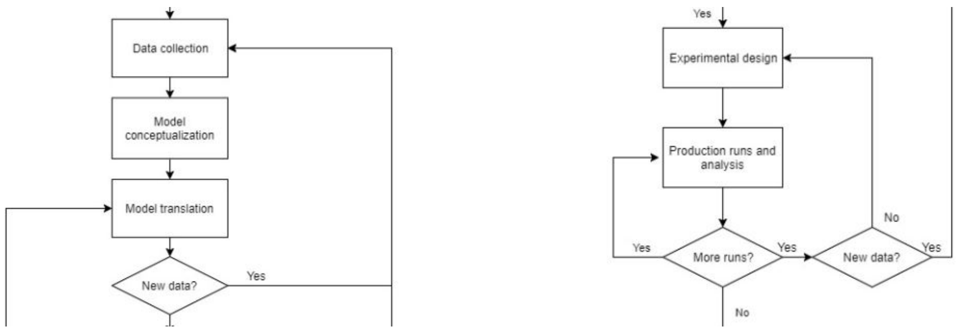
4.1.1 Simulation

Simulation studies is located within the sales project and will usually happen when there is a *Letter of intent* (LOI) from the customer. From getting a LOI to proposing a fixed price of the system and elaborating the details in a contract, the sales organisation will define the solution and verify the capacity of the system.

The simulation study is running parallel to the development of the solution and the aim is to verify the concept, run tests on the solution or provide visibility of the system for the customer. Inputs to the simulation study are layouts, a capacity table and a description of operation. The flowchart in Figure A.1 in Appendix A illustrates the current simulation work flow.

Based on the input data received from the sales project, the simulation computer model is built iterative until the function of the model is verified. When the computer model is completed, the simulation engineer performs the experiments requested on the model. This could be capacity test, tests on variables of the system etc. The simulation study is completed when the results has been printed to a report and presented to the sales project organisation.

As the system do not exists as a real physical system at the time of the simulation study, the validation with a real system has to be neglected and the verification is done with the concept from the sales project. The current state work flow has the gate *New data?* to symbolize the possibility of the customer, or somebody in the sales organization, interrupting the simulation study by adding more data. This new data is considered in decision gates at two places in the workflow, which is illustrated in Figure 4.2. Adding new data to an ongoing simulation study could be compared to the introduction of an *Change order* in a product development process. It cannot be ignored by the process owner, who has to consider the new data. The difference from collecting new data as a cause of the validation iterations, is that in the validation state, the simulation engineer has the power over the data.



(a) *New data?*-gate 1 **(b)** *New data?*-gate 2

Figure 4.2: Snap of workflow: *New data?*-gates in simulation.

The simulation engineers has expressed that a high effort is put on setting up the model of the system. An effort that is reduced if the systems consists of elements that is available in the global library. Due to the high level of customer customization in Swisslog projects, the problem could be that the number of “standard products” in a system is considered as low.

By looking at the flowchart, one can easily figure out that the simulation study will follow a straight and steady flow if the data collection and conceptual model is performed once and covers all the data that is sufficient to receive the requested result from the experiments. Naturally the simulation study will be performed in some iterations, due to the modelling phase where the computer model has to be verified against the conceptual model. When the aim of the simulation study is to investigate some parameters in the system, the model might be reviewed when there is a result of those experiments. If the aim of simulation is to verify the function of the concept and the function cannot be verified with the proposed solution, the simulation engineer could take the decision to perform some changes of parameters or design, which will force the model to change. When performing a simulation study on a system which only exists in the design phase, a risk is that the system change in the design process parallel to the simulation study.

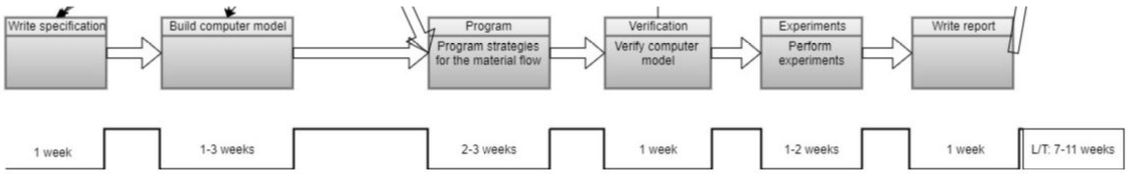


Figure 4.3: Snap of VSM: timeline in simulation process

In the VSM of the simulation process modelled in Figure B.1 in Appendix B the time perspective is added and by analysing that map, one can get an understanding of the consequences in terms of time, see Figure 4.3. The majority of the value is considered to be added within the activities where the strategies is programmed and the experiments are performed. The build of the computer model could be compared to activities connected to material transportation, which is necessary but do not contribute to any value added. The activity *Update model* is ignited by the appearance of a *Change order* from the concept development. If the simulation study is operating in the activity *Perform experiments* when the *Change order* appears, the time lost in the project will correspond to the total time consumed by the activities between *Update model* and *Perform experiments*, see Figure 4.4.

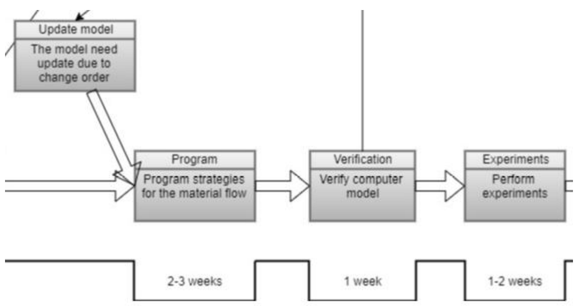


Figure 4.4: Snap of VSM: time consumption between the activities *Update model* and *Perform experiments.*

If the simulation study is performed without the appearance of a change order, one can simply calculate the lead time for the simulation study to finish, which according to the VSM would be 7-11 weeks for a new build system with standard equipment.

4.1.2 Controls

The current process of the control software developments is modelled in the flowchart in Figure A.2 in appendix A. The majority of the development of the controls software is developed iterative and parallel to the development to the internal test environment of the code. A large part of the code could be generated automatically like code for the basic transportation of goods. Whereas the system specific logical strategies, complex parts of the system and non standard functions demands manual editing. The total time of developing the controls software has been estimated to between 6-12 weeks depending on the size and complexity of the system. The time perspective of controls process is modelled in the VSM cart in Appendix C Figure B.2. A snapshot of the timeline from the VSM could be found in Figure 4.5 where the three first activities is representing the development of controls software.

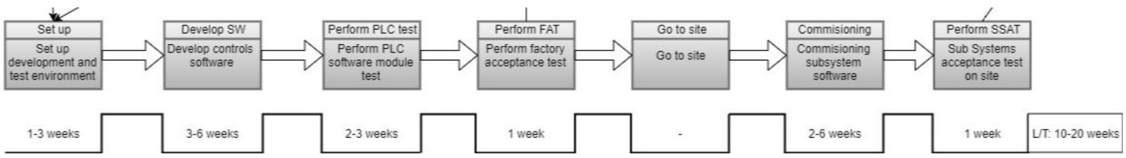


Figure 4.5: Snap of VSM: timeline in emulation process

Usually, a Factory Acceptance Test (FAT) is performed by running the developed code against internal test code to test the functionality, so called PLC - simulation. Swisslog AB has used emulation in a few projects, and the engineers experience with it is limited. During the interviews some of the engineers express the unawareness about the possibilities with emulation and sees it as additional work to an already time consuming process. One of the Tech Centers (TC) has worked more with emulation in pallet projects, both in customer projects and during development of their products. This has provided them a lead in the knowledge of the possibilities of the software and also the tools to lower the effort to build models. The work flow used in the TC can be studied in Figure A.3 in appendix A. The modelling phase of this process is illustrated in a snapshot of the workflow in Figure 4.6. The generation of the emulation model is done parallel to the generation of the PLC code, as the TC has a working automatically generation of the 3D model, for one of the controlling platforms. When starting the controls phase of a project, the software and the model is generated and with some modications the emulation study could start running in a few days.

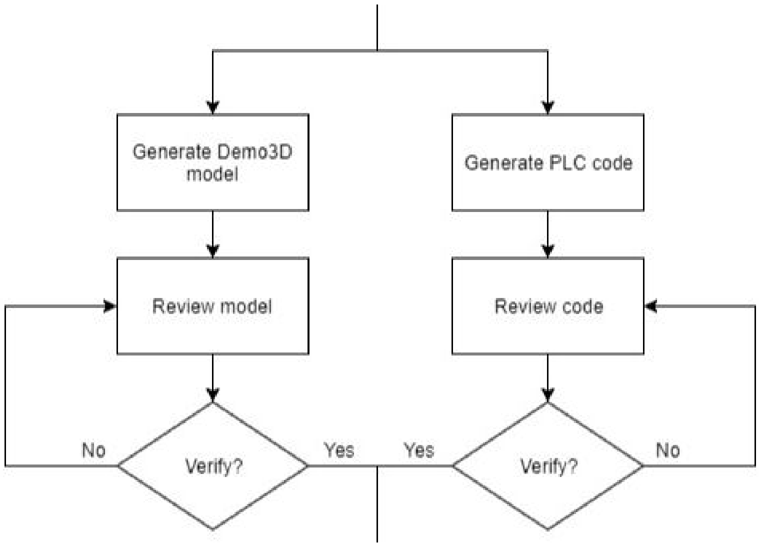


Figure 4.6: Snap of workflow: modelling phase of emulation workflow in TC

The engineers interviewed at the TC have a positive attitude towards emulation of controls software, and suggests many benefits of emulating the system before going on site. One benefit mentioned is that it could be a good method for involve new people in the project in a quick way. Their knowledge about the software will in some extent be used as a reference when suggesting the strategy in decision for emulation in Swisslog AB.

When the FAT is performed, an evaluation of the results is conducted. Depending on if there where any errors and the complexity of them, the FAT could be run again after some modifications. If the errors are of low severity, the errors are put on an open case list with cases that will be worked on continuously until the Subsystem Site Acceptance Test (SSAT). When moved to site, the commissioning of controls software could start and is usually performed parallel with the commissioning of the hardware. Typical types of errors that might occur is fault positions of sensors, I/O's that are inverted etc. Naturally, since this activity is the last step before the SSAT and hand over to the customer, the time window available could be affected of earlier delays in the project.

In conclusion, the status of today is that emulation has been used successfully in a few customer projects with support from the TC. The emulation projects has been motivated by the criterion's very short commissioning times in systems stopped for rebuild, very complex solutions or shorten onsite work in remote locations requiring long periods away from home. The strategy has then been to add emulation as an extra project activity and the total project time is therefore increased. However, there is an uncertainty about whether these projects would have succeeded anyway without emulation. Together with the lack of strategy for emulation projects there are no clear path on how and why to perform them.

4.2 Analysis of current state

Based on an analyse of the findings in the empirical data, from Section 4.1, improvement areas and waste could be identified. The analyse consist on reflections and patterns in the qualitative data and also from understanding of the phenomenon based on findings from the literature study.

4.2.1 Common language

During the interviews with employees it appears that the usage of the words *Simulation* and *Emulation* is used with non consistency inside of the organisation. The employees perception of the words differ in comparison to the definition of *Simulation* and *Emulation* mentioned in section 2.3. *Simulation* is mostly referring correctly to the activities performed by the simulation department. *Emulation* on the other hand is commonly used when referring to the internal test loop that are integrated in the PLC-software, which adds confusion in to the discussion as *Emulation* also is used correctly when referring to the 3D-emulation in the Demo3D software.

4.2.2 Problems within current work flow

The seven wastes described in section 2.4 are in this section translated the corresponding waste categories in the simulation- and controls processes.

The sources of waste are for simulation and emulation represented by the following:

Overproduction: Simulating more parts of the system than required to obtain the target of the simulation study. Modelling more than the actual subsystem/-s to be emulated is considered as waste and should be reduced. This might be caused by the non-existence of a target when starting the study.

Inventory: By supplying the simulation-/controls engineer with an extensive amount of information about the system. The data then has to be reviewed to fit with the scope of the study or project.

Transportation: Data required by the simulation-/emulation project that is supplied by several sources. The information is moving between several people in the project. Transportation has not to be physical.

Unnecessary movement: People walking between offices to ask and explain the data delivered. This might cause the people being interrupted and preventing them to plan these types of meetings. Unnecessary movement is physical.

Waiting: A project that is ready to be started, but the required data is not yet ready. This might tempt the simulation- or controls engineer to start the project without the required data, which will not eliminate the need of the data - but simply increase the risk for rework.

Defective output: Performing a simulation- or an emulation study with incorrect inputs will give incorrect and worthless output. For the simulation study, the results cannot be considered as trustworthy and for emulation projects the PLC-code cannot be verified.

Overprocessing: Making the model too detailed for the purpose of the simulation study is to be considered as overprocessing. Also testing the same functionality in two different environment will be considered as overprocessing, which might occur in controls when PLC -simulation and emulation is performed on the same system.

All these waste categories has in common that they spend resources and produce no direct value for the customer. Some of them might produce indirect value by give benefits to the organisation. This can be concluded as some of the identified sources of waste has potential to qualify as necessary and could therefore be argued for not to be eliminated from the process.

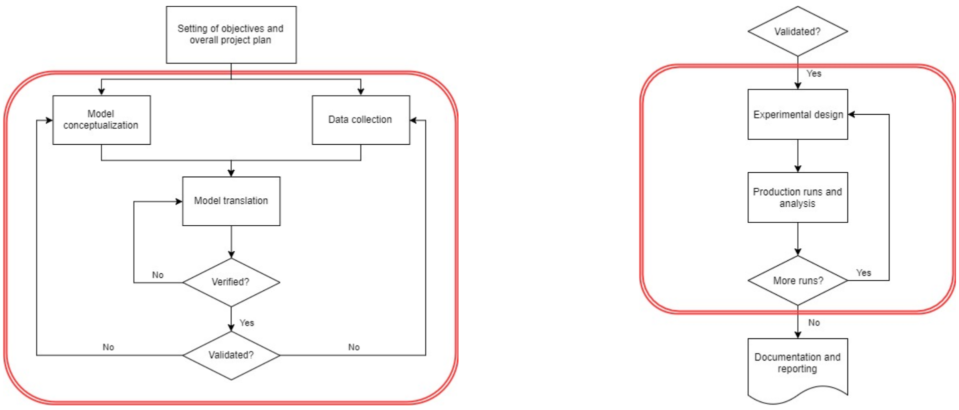
4.3 Suggestions to a future strategic approach for the case company

Based on the analyse of the empirical data a suggestion on the approach the case company should aim to work with simulation and emulation in the future is presented below.

4.3.1 Simulation

Since the main problem in simulations projects is not the lack of strategy, the focus of improvement will not be to suggest a completely new workflow for simulation projects. Some suggestions will be made on how to work with the simulation study to reduce and/or eliminate waste. This will streamline the process and create a more value adding workflow. The most obvious wastes identified in section 4.2 was *Overproducing*, *Defective output* and *Overprocessing*. By eliminating the causes of this wastes in the process, the process will become more value adding and resource efficient.

The appearance of a *Change order* in simulation studies was pointed out to be the main cause for waste and non-value adding activities in rebuilding of the model. Considering this, a new workflow is suggested where the "*New data?*" decision points are eliminated to illustrate a more streamlined process. The workflow suggested for future approach is presented in Appendix C Figure C.1. In this new work flow, the *Model conceptualization* and *Data collection* activities are located parallel and performed in iterations until the conceptual model is validated against the system solution, illustrated in a snap shot in Figure 4.7a. The parallel setup of these activities will enable for the conceptualisation of the model to be done accurately. Which then will result in the model being validated and the study can proceed without further iterations of the modelling phase. The experimenting phase of the study are the second and last iteration part of the work flow, as pointed out in the snap shots in Figure 4.7. By isolating these iteration loops to events occurring in the simulation study, the simulation engineer gains more power to influence the amount of iterations. Whereas in the current workflow the engineer had no control over the iterations due to the influence of new data added to the study.



(a) Modelling phase **(b)** Experimenting phase

Figure 4.7: Iterations of simulation study

For the simulation study to add value to the external customer the purpose of simulating the system should be formulated. By motivating the study with the objectives following in table 4.1 the purpose of the simulation study is evaluated and formulated prior to the study. *Quality* and *Cost* are two appropriate factors for evaluating the needs for a simulation of a project. By preparing the objectives prior to introducing the simulation team in to the sales project, the introduction will be motivated and the resources is used because there is a need for it, and not only because they are available. How the objectives *Quality* and *Cost* should be considered in a simulation study is proposed in Table 4.1.

Quality	Validate the solution against the needed capacity, stress tests, evaluate waiting times.
Cost	Evaluate some cost driving parameters, for example, numbers of cranes/robots/operators.

Table 4.1: Objectives for simulation

Naturally, *Quality* will be the most obvious reason for simulation a project, as the value in simulation is to add quality to the customer in sense of reliability and robustness of the system.

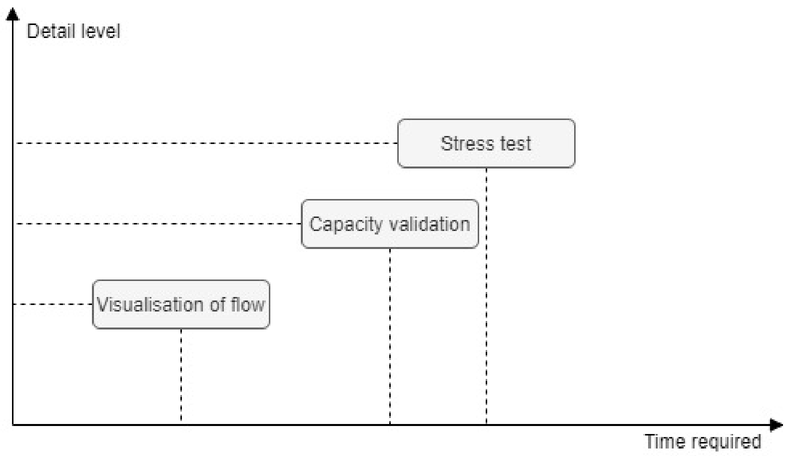


Figure 4.8: Graph over detail level increase over time

While preparing for a simulation project, the specification should be composed describing the objectives, the scope and what the aim of the simulation is. To avoid waste by the category *Inventory* the simulation engineer should not be provided with more input data than needed to cover the scope of the simulation study. Preferably, the specification is delivered together with an estimation of the time set for the simulation study. Notably, depending of the scope of the study and the objective for the specific simulation study, as could be seen in Figure 4.8 the detail level of the simulation can differ. If the simulation study should be used to visualise a flow for a customer, the detail level would be lower, while performing capacity validation and stress tests will require a higher level of detail, aslo illustrated in Figure 4.8. Note that this detail level is the detail level on the simulation study and thereby required specification and results and not the detail level of the model. The detail level of the required simulation result will also be a driver for the time required for the study. Therefore the time scope for a simulation study might be required to consult with a simulation engineer before setting. This will prevent the time window for the simulation to be smaller than actually required.

4.3.1.1 Specification for simulation studies

The complexity of the computer model is set by the conceptual model. As mentioned in section 2.4, a higher complexity than necessary will be considered as waste and prevents the process to be streamlined. The waste is reduced by the model being detailed enough.

Secondly, when the sales project team has decided to go for simulation on a system, the simulation team should be provided with the sufficient amount of data needed to perform the study. This input data will further in this report be referred to as the *Specification*.

Table 4.2: Specification for simulation

Objective	The objectives for the simulation, formed by the sales project.
Target	What questions should be asked to the simulation model. Could be verifying the capacity, stresstest, evaluate different parameters of the system
Scope	Which parts of the system that should be included in the study. Could for example be both pallet and light goods systems or only one of them.
Description of solution	A detailed description of the system and components included.
System logic	A detailed description on how the system priorities, sorts etc. orders and goods in the system.
Assumptions	What open ends are there, that needs to be assumed. For example number of operators, speed of conveyors etc.
Limitations	What is known but does not need to be modelled.
Results and documentation	What is the expected output of the delivery from the simulation study. Includes the reporting of results and the presentation of it.

4.3.1.2 Simulation report

As well as the input to the simulation study should be delivered as a specification from the sales project, the outputs from the simulation study should be delivered to the internal customer in form of a report. In this report the inputs, assumptions, experiments performed and the results of them has to be presented. The target group of this report has to be considered and whether or not this group has taken part of the specification. If the target group has not taken part of the specification, the report has to put a light on the assumptions, simplifications and limitations suggested by the specification. Assumptions, simplifications and limitations suggested by the simulation engineers during the simulation study should also be brought to light as these may be of crucial importance for the functionality of the system. Any simplifications that is made to the model, has to be considered when evaluating the results of the simulation.

The simulation report is to be considered as the output of the simulation and by ensuring the quality of this output, waste of the category *Defective output* is eliminated.

4.3.2 Emulation

With the purpose to make the emulation project an value adding activity, the utilization of resources should be thoughtfully planed. Due to the already existing PLC - simulation software, resources are already spent on carefully testing of the software. By testing the controls software with both emulation and PLC - simulation the activity will fall in the waste category *Overprocessing*, due to excessive use of testing software. With this in mind, the decision of whether or not to emulate the system should be done before the development of controls software starts, as could be seen in the snap shot in Figure 4.10, of flow cart of suggested workflow in Appendix C.

4.3.2.1 Objectives for emulation

First of all, during the setup of a controls project it should be decided whether to emulate the system or not. This decision is taken by the Controls Manager/Project leader. Secondly, the available material as basis of decision should contain enough data to cover the objectives that is evaluated for decision making. The objectives will describe the purpose of the emulation project and will include the three factors - *Time*, *Quality* or *Cost*. Specifying the drivers for emulation, each emulation project will be motivated. Table 4.3 shows how the drivers for emulation is defined.

Table 4.3: Objectives for emulation

Time	The cycle time of the projects risks to be exceeded. Eg. the time window for commissioning is considered as small or earlier phase of the project has been over due. Inexperienced engineers might also be a factor extending the time for commissioning.
Quality	The software quality could not be reached. Due to complexity of system or inexperienced engineers.
Cost	The cost limits may be exceeded. Site is located in a far geographical distance.

In order to define *Time* as a driver for emulation, the factors *Efficiency of resources* and *Availability of site* is of importance. A suggestion on how the these factors could be expressed is presented in Equation 4.1 and 4.2 where a value less than one on each of the equation might motivate for emulation.

$$Efficiency\ of\ resources = \frac{Time\ required}{Estimated\ time\ required} \tag{4.1}$$

Time required	The time an experienced engineer will perform the commissioning on that specific system.
Estimated time required	The time the planned engineer estimates to perform the commissioning on.

$$Availability\ of\ site = \frac{Time\ available}{Time\ required} \tag{4.2}$$

Time available	The time that is available with access to the system on site.
Time required	The time an experienced engineer will perform the commission on that specific system.

On the other hand, *Quality* as a driver has to be considered as a probability factor of the SSAT succeeding and the ramp up capacity being reached. Something that would lower the probability could be inexperienced engineers or high complexity of the system or a combination of both. Therefore a stand-alone estimation of each system has to be done, where one should consider the customize level together with the competence on the controls software engineers.

A *Quality* perspective can also be to emulate the system in order to assure that the capacity of the system will be reached even under realistic circumstances. In this case, the emulation project can be performed with similarities with a simulation study, but with the possibility to run the system with correct mechanical times and in real time with the control unit (PLC). The mechanical times could correspond to the startup time for a chain transfer or the acceleration time tolerated for specific friction coefficients on goods and transporter.

Thirdly, the *Cost* could be defined as included travel costs, which can be high in cases where the site is located in a far geographical distance, the country requires expensive visa - applications or the site is located on a position with long travel time and bad connections.

Finally, the impact of these three factors together will form the objectives for emulation. Considered one by one the factors might have a low impact but combined they might motivate the decision to emulate. One factor can alone be enough as motivation to emulating a system.

4.3.2.2 Specification for emulation projects

Similarly with the simulation project, avoidance of waste in emulation projects will be achieved by a detailed specification of what the emulation should include. The specification will include a conceptualization of the model and include a detailed description of the scope, time schedule, inputs, outputs and details about the system, such as assumptions and simplifications. In an emulation project following is proposed as described in Table 4.4:

Table 4.4: Conceptual model emulation

Objectives:	The aim of performing the emulation project, presented in section 4.3.2.1. Includes drivers *Time, Quality* and *Cost*
Inputs:	Layout, I/O-list, FAT - checklist
Outputs:	FAT- checklist, Open case-list
Content:	Subsystems, control units, interfaces, parent systems
Assumptions:	Uncertainties, friction coefficient of goods, cycle times of manual processes and static equipment etc.
Simplifications:	Ways of reducing the complexity of the model, cycle times of static equipment.

The inputs to the model will be the same despite how the model of the emulation will be built, and should not differ from the inputs that are required in a controls project with PLC – simulation. Additional inputs to provide a model with credibility, some information about the physical environment should be known. This will include friction coefficients of boxes and pallets and expected weight of goods for example. During projects where this type of information is not available, the information has to be assumed or simplified. Furthermore, the content of the emulation model will be presented in the specification, including which control units to be emulated and by that which subsystems that should be modelled.

4.3.2.3 New flow

Implementing this new method on how deciding on emulation or PLC - simulation during development of controls software will change the flow of the process. Also, when benchmarking methods from simulation projects, the model of the future process flow will be a combination of the old flow chart adapted to the simulation modelling steps. Future flow chart can be seen in Figure C.2 in appendix C. The gate where emulation or PLC - simulation should be decided is added, snap shot in Figure 4.9.

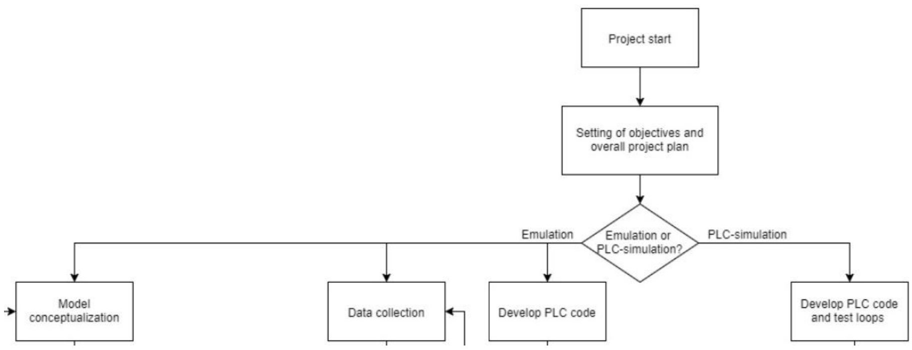


Figure 4.9: Snap of workflow: gate where test environment is decided

In case of PLC - simulation, the work flow from current state map (Figure A.3, appendix A) is followed. Added to the flow chart is the process flow in case of emulation. This part of the process is adapted from the modelling part of the simulation work flow, which was presented in Figure 4.7a. Parallel to the modelling phase of the emulation model, the activity "*Develop PLC code*" is added which is illustrated in Figure 4.10.

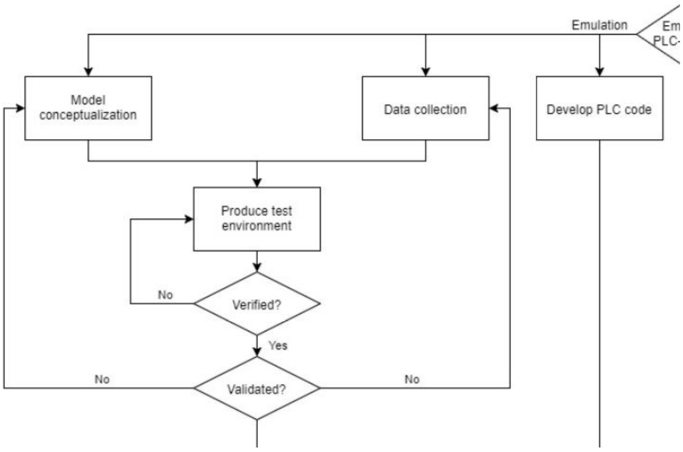


Figure 4.10: Snap of workflow: parallel activities modelling phase and development of code

Moreover, the workflow adapted from the simulation theory, presents how the specification is conducted by the activities *Model conceptualization* and *Data collecting*. Specification is followed by verification- and validation iterations, which ensures the quality of the model before the FAT is performed.

Further, after the FAT, the process keeps the same flow as earlier when moving to site, illustrated in snap shot from workflow in Figure 4.11. In case of emulation the commissioning on site would be of lower extent.

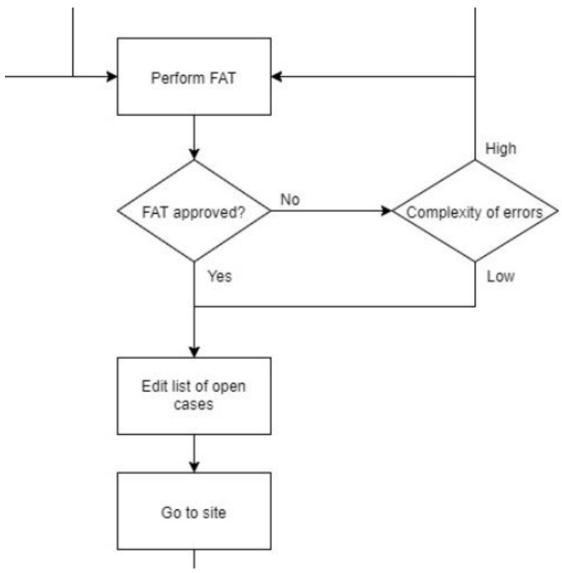
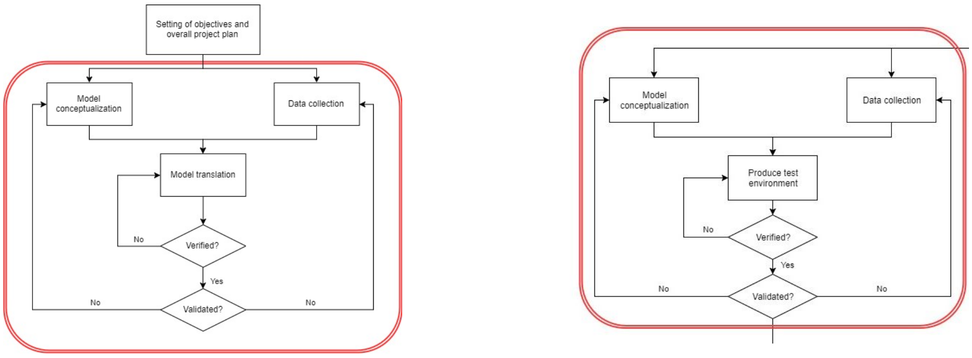


Figure 4.11: Snap of workflow: parallel activities modelling phase and development of code

4.3.3 Correlations of simulation and emulation

When designing the new work flow of controls process by adapting the work flow of simulation naturally similarities of the both work flows will be found. In Figure 4.12 the process for modelling the computer models used in simulation and emulation is compared, where one can see that the flow is almost identical. Conceptualization of the model will be a sufficient part of both processes together with the build of the computer model, followed by the iterations for verification and validation. The concept model will be software independent, but the computer model will in both cases be built in the Demo3D software.



(a) Simulation

(b) Emulation

Figure 4.12: Specification of modelling work flow.

Is it necessary to build the model twice?
A question raised during the case study is whether it is necessary to build both models independently, or if the controls engineers could reuse simulations model of the system. To answer that question one first need to understand what are the characteristics for the simulation model and what is known about the system at the time for simulation. As mentioned in section 4.3.1 it is sufficient to make the simulation model detailed enough but not fall under the waste category *Overproccessing* by working with more details than needed for the purpose of the simulation. If the same model should be used later in the project to be emulated on, it has to be verified with the specification of the emulation project and validated to have the characteristics of the real system. Any simplifications made by the simulation has to be redone.

Results from the interview study indicated that the rebuild of a computer model is more time consuming than building it from scratch, provided that there are a library of the current elements available. This points toward that it would not be beneficial for the emulation project to reuse the simulations computer model.

Can the model be done with the detail level required by emulation already in the simulation project?
Figure 4.13 shows an illustration on how the detail level of the drawings change over time in a customer project. The simulation- and emulation projects has been placed on the time axis based on where in the project they are initiated. By comparing the start time of the simulation project, and the start time for the emulation project the

change in detail level on the drawings becomes visible. This means that at the point for the simulation study, it exists no input to a model for the purpose of emulation, with sufficient detail level. This is due to the fact that the layouts in the sales phase are produced with a lower level of detail.

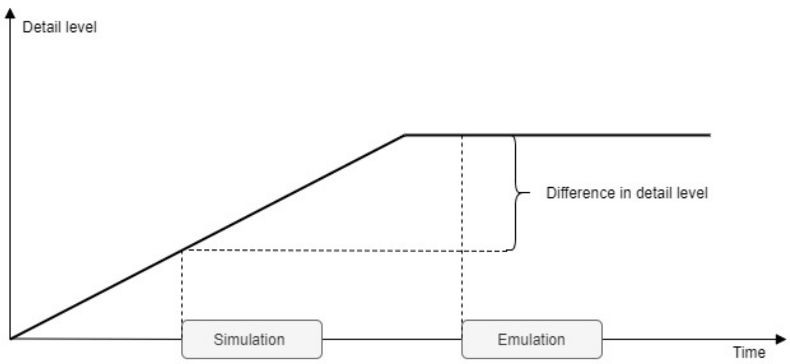
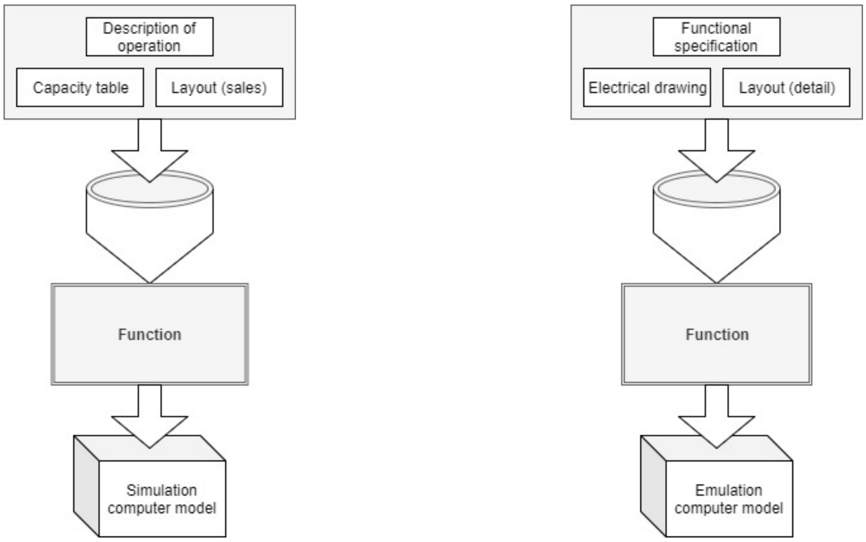


Figure 4.13: Graph over detail level increase over time

There is also a risk that the detail engineers work will result in deviations of the model due to changes in supplier drawings, building specific problems och interface correlations.

Moreover, the decision on emulate is taken later in the process. Therefore to make the simulation computer model detailed enough for emulation would be classified as *Overprocessing*, since it is not certain that the system will be emulated.

On the other hand, the fact remains that both models should be built and by finding a method to reduce the effort will benefit both processes. Simulation already works with a global library with elements, which reduces the effort to build the model. The Tech Center has an automatic generator for generating the emulating computer model out of I/O-lists and layouts. In other words, a function is needed to with low effort transform the inputs to each process to an output that meets the requirements of each process. Figure 4.14a and 4.14b illustrates this.



(a) Simulation **(b)** Emulation

Figure 4.14: Illustration of function of model generator.

By finding a standard way to perform the conceptualisation of the model, independent from the aim of the model and level of detail, a tool for translate the conceptual model to a software specific computer model could be developed. The point of this will be that the tool can be used for both simulation- and emulation models which will reduce the effort in both processes.

4.4 Summary of results

Firstly, the current processes of simulation and controls was mapped in a flowchart (Appendix A) and a VSM-inspired map (Appendix B). The non-value adding activities was identified in the current simulation process by categorising seven types of waste for simulation and emulation projects. A new workflow was suggested without the sources of waste, which resulted in a more streamlined workflow, this could be seen in Appendix C Figure C.1.

Further, an investigation on how the streamlined approach for simulation studies, can be applied to emulation projects within the same company, which resulted in a new workflow of controls projects. This new workflow is an adaption of the modelling phase of simulation projects to the current controls process, see Appendix C Figure C.2. Lastly, a suggestion on how the similarities of simulation and emulation should be handled was made in Section 4.3.3.

5

Discussion

In this chapter, the methodology and results of this thesis is discussed. First a Methodology review which is followed by Case specific. Lastly the Credibility of this research is discussed followed by a suggestion of Future research.

5.1 Methodology review

The strategy for this master thesis was to iterative collect data about the processes in the organisation, map them and together with the literature review find the most waste and redundant work in the process. This knowledge was then used to redesign the processes or at least suggest areas of improvements.

Initially the aim was to find correlations and tools for streamline the work and remove non-value adding activities. A few weeks in to the work, this was reviewed due to the fact that in order to remove non-value adding activities - also referred to as waste - the processes first has to be investigated and analysed. The risk is otherwise that the focus is put on the wrong parts and that the process is managed under a more "firefighting" approach than process improvement.

The study was selected to be a single-case study, which can be argued to not be preferred, as the generalisations made could be less credible when only investigating one real case (Yin 2014). This study required a deep investigation of the current state of the work process to present a credible map if its current state. Due to that fact this type of study would have been to time heavy due to the time window available, if performed on multiple cases.

The data in this study was collected thrpugh an interview study and a literature review. The data was analysed together with another review of the literature to find correlations between theory and the empirical findings. By investigate and map the work flow in a flow cart and a Value stream map the current state of the processes became visible. During the interviews the employees got the chance to express their own opinion about where the improvement potential could be found.

Furthermore, the results prove that a VSM-inspired map could be used as a tool to identify waste in engineering and design processes. It was supplemented with the flowchart during analyses and the result was a redesign of the processes. As the VSM tool is originally designed to map the product flow in a production process, some modifications had to be done, even if the approach from Keyte & Locher (2004) for information flow was used. The timeline of the simulation study or controls project was symbolizing the product flow and the support processes with information exchange symbolized the information flow. Due to the difference from a traditional VSM, the data bow with statistical information about the activities, such as cycle time, was neglected. A time line was added to overview the standard time for the process.

Internal benchmarking was used when improving the emulation process by transfer the methods of a simulation study. The simulation department is using a well proven workflow and as the controls department is lacking the workflow for emulation, which makes this a suitable case for internal benchmarking. When adapting an already existing workflow, the effort of developing a new workflow is reduced and one can expect some quality of the workflow. There is a risk though that despite the similarities, some characteristics of the other process makes the idea of benchmarking impossible due to the fact that the concepts are different. This seems not to be the case for this application, as only a small part of the simulation process has been adapted to emulation, where the needs are almost identical.

5.2 Problems within current work flow

The seven waste categories defined by Weiss (2013) was translated to the characteristics of simulation and emulation workflows in section 4.2.2. This can be used to discuss where the problems in the current process are located.

Transportation is an example of waste that in some cases could be categorized as necessary waste. Walking between offices explaining the output or asking where on the server to find certain material. This might contribute to the people relations and strengthen the team when people discuss and understand each others work. It should be considered though that an over exceeding of these activities might be considered as waste, since the output could have been more self explained in the first place. The transportation to move to somebody to ask where to find something should be considered as plain waste in the process.

What seems to be the largest issue in the simulation workflow seems to be the lack of frames and scope around the simulation studies. When working with external consultants the sales group is forced to plan and specify the scope and wanted outcome of the simulation. Once this function moved inside the building, the need for this type of inputs became more vague as the resources was already a part of the sales project. The simulation study executed parallel to the development of a project also opened up for the possibility of adding data and changes under an ongoing simulation project. As mentioned in Section 4.1, the workflow will follow a straight line if no new data is added during the ongoing study. Data added will be the cause of iterations in the simulation study, when the conceptual model is forced to be reviewed and thereby also the computer model. Since iterations is a driver of the cycle time of a project, the new data will be a driver of cycle time for simulation studies.

In current simulation studies the wastes are mostly identified as *Overproducing* when the simulation study is performed without a clear target and a correct specification initial to the study. This tend to happen when the simulation study is started parallel to the development of the solution, and there are no specification for it in the start of the study. As described in section 4.1.1, the appearance of a *Change order* in form of new data in to the study will force the simulation engineers to consider this new data and rework the computer model. The model existing before the *Change order* will now be considered as useless and the resources spent on in will be classified as *Overproduction*-waste. The waste could also be classified as *Defective output*, since the computer model will be considered as defective once the input data change and the model cannot be verified against the new input data.

Also the waste category *Overproduction* appears in the current simulation studies, when the specification is missing and the engineers is processing the computer model to a higher detail level than actually required for the study. This is not expressed as a problem in the process, but due to the utilization of resources this waste should be reduced. As making the simulation computer model too detailed for the purpose cannot be considered as a value adding activity, it should be controlled and eliminated.

In simulation studies, the value is produced when programming strategies in the computer model of the system and performing the experiments required to reach the target of the study. Indirect value is therefore created when building the computer model from its conceptualization as the computer model is sufficient for the later value adding activities.

Controls are struggling more with lack of strategy for implementing emulation as a virtual commissioning tool. The company has a vision on which criteria should decide on emulating of the system or not. The workflow now is to add emulation to the project as an extra activity which together with the PLC - simulation is clearly falling under the waste category *Overprocessing* as it adds double work to the process.

Controls has a workflow in new build projects which follows a logical order on developing, testing and implementing the controls software. By performing the emulation projects together with the TC's, the knowledge and experience is kept outside of the organisation and depends on the availability of the TC. The current strategy with adding extra work to the process and producing waste by overprocessing, the controls engineers lack motivation on performing the emulation project additional to the project. Emulation now results in building a model of the system in yet another test environment.

Also, waste categories as *Overproduction*, *Defective output* and *Unnecessary movement* could be identified in the current work flow.

Controls value adding activities can be considered as the development of the controls software, testing and validation of the function of the system. Set up of the test environment should therefore not be considered as an value adding activity, but will add indirect value to the process as the test environment is sufficient to the testing phases of the processes.

5.3 Similarities of simulation and emulation

Not only that simulation and emulation could be performed in the same software, there are other similarities. A simulation of the system is sometimes performed to validate the capacity of the system, this is usually done in a model which operated by built in logical strategies. There is also a possibility to perform this on an emulation model with the real controls software operating the system. In this scenario the differences between simulation and emulation becomes really vague. The same goes for the emulation model, where some parts of the models might be needed to simulate, as some functionality might not be operated by the external controller. Reinhart & Wünsch (2007) is mentioning *Full simulation of machinery* and *Hardware-In-the-Loop simulation* as the two approaches in Virtual commissioning, but one can also argue for if pure simulation could be considered as Virtual commissioning. One can on one hand say that it could be considered as commissioning in a really early stage of the project, but on the other hand the purpose of the simulation should be deciding if this could be the case or not. Especially as simulation could be used to visualise the process for a customer, which could never be considered as Virtual commissioning as it is more of a sales activity.

The workflows in simulation and emulation is chairing the same activity in building the computer model, but the inputs and aims of the models differ. This could be a motivation for wanting to use the same computer model for both activities, to avoid redundant work. However, the characteristics of the models are too different, which therefore is a motivation for focusing on a similar methodology for building the model instead.

5.4 Other case specifics

In the result of this thesis, some suggestions for future approach on simulation and emulation was formulated. As could be seen when comparing the work chart for future approach in simulation studies presented in Figure C.1 in Appendix C with Banks model (Section 2.1, Figure 2.1) for discrete event simulation, the both flowcharts are identical. As the model for future approach of simulations studies was developed by eliminating waste from the workflow, one can draw the conclusion that that the activities that deviated from Banks model is to be considered as waste.

The cause of the similarities with Banks model could be argued to exist due to the simulation engineers awareness of simulation theory and that there is a will to follow that methodology. However, the deviations from it could be explained by the fact that the simulation departments close relation to the sales project resulted in new data continuously being added to the simulation study. While this provided the sales project with a high flexibility during the development of the solutions, the simulation engineers also lost control over the scope of the simulation study.

The question of who should provide the resources for performing the foundation work for the simulation study is not proposed in this thesis. As this would have required a more extensive study of the processes prior the simulation study. Therefore, this decision is up to the case company to decide.

The result shows that new data is a driver of the cycle time for the simulation study. Norman & Banks (1998) mentioned *Possible updates or enhancements to the model* as a driver for cost in simulation studies. Reinhart & Wünsch (2007) was suggesting the three factors *Time*, *Quality* or *Cost* as drivers for virtual commissioning. Whereas, according to the result in this thesis, only the drivers *Cost* and *Quality* will motivate a simulation study, as *Time* is only a driver for more cost of a simulation study. One can include simulation in the concept of virtual commissioning by arguing about the fact that capacity testing on a simulation study could be considered as commissioning in a very early stage. With this reasoning, it could be explained that simulation shares the same driver as emulation. *Time* can not be included because of the simulation study representing such an early stage of virtual commissioning as it cannot replace traditional commissioning.

Even if the costs for a simulation project is calculated to be significant high, the simulation project can still be justified due to the high value created for the customer in respect of quality by performing the simulation project. That is to say, if the drivers and waste sources has been taken in to consideration the simulation project could be prepared accordingly.

Hvistendahl et al. (2019) came to the conclusion that since emulation would require parallel work in the commissioning phase, it is not possible to determine whether the total project cycle time can be reduced. By designing a workflow for controls which will decide on either emulation or PLC-simulation as in this thesis, it could be argued that hypothetically this could reduce the total project time. The reduction will be a cause of the emulation consuming same amount of time as PLC-simulation, but might reduce the time for commissioning on site due to the more possibilities in emulation. Probably, this will depend on each project and also the objectives for emulating that specific system.

5.5 Credibility of research

Preferably, the quality of the research has to be determined. This could according to Yin (2014) be done by four different tests; *Construct validity, Internal validity, External validity and Reliability.* By applying these four tests to the research, the trustworthiness and credibility of the results can be determined. Construct validity is basically designing the research and collecting the data credible. In this study the data was collected during interviews with different people with a variation of knowledge and experience. The data was also continuously checked with key people with an insight to the processes.

As the purpose of this single-case study is to reach a deeper understanding for a phenomenon inside the case, the validity is ensured by internal validity instead of external validity (Yin 2014). The internal validity is ensured by the quality of the analytic phase. Conclusions about some certain phenomenon was drawn due to some data collected during the interviews or literature review. The characteristics of the analytic part is determine whether or not this conclusion could be considered as correct or not.

The reliability of the research is conducted by making sure the results is reproducible, which means that another researcher should be able to follow the same methodology and achieve the same result and conclusion. The reliability is ensured by this report, which describes the procedure with a detail level such as the results should be achievable also by another researcher.

5.6 Future research

In Section 4.3.3 some of the similarities in simulation- and emulation projects is presented. The modelling iteration phase is pointed out as the largest common activity. If further resources could be put on finding a way to reduce the effort in building the computer model out of the conceptual model and input data, both simulation and emulation processes will be reduced in effort. The suggestion for future approach for the case company is to standardize a way to perform the conceptualisation of the model, independent from the aim of the model and level of detail. This development would be suitable to apply on the next stage of research within this area.

As the purpose of this thesis partly was to identify areas of improvement, the effort of developing a digital twin will be reduced, the digital twin aspect should be discussed. From the empirical findings it became evident that the possibility to create a digital twin of a plant existed. The effort is still considered to be quite high but mostly inflexible, as the current existing method is bound to a specific brand and equipment.

The general view of the status of workflow in emulation projects at the company in the case study can be compared to the general view of virtual commissioning discussed by Älegård & Knutsson (2017) and confirms their theory. Älegård & Knutsson (2017) is proposing that some of the issues with virtual commissioning is the lack of strategy for implementation. While the simulation studies has the model proposed by Banks (1998), emulation projects tend to be implemented without any strategy.

6
Conclusion

The purpose of this thesis was to provide efficiency in the processes of sales- and realisation phase to ensure fast and safe deliveries. By identifying areas of improvements and similarities in existing process the workflow can be streamlined in future model where waste is reduced. This will reduce the effort in developing a digital twin of any system, which provides the possibility to perform tests and analyses without access to the real system.

The result of this thesis was conducted by a case study, which resulted in modelling of the current processes in a flowchart and a VSM-inspired map. By analysing the data collected a suggestion of future approach for the case company was presented.

RQ1: How can the current simulation study workflow become more effective in a value adding activity approach?
The higher sources of waste was identified as the iterations caused by the appearance of new data during an ongoing simulation study. By removing this decision gate from the workflow and putting the *Model conceptualization* parallel to the *Data collecting* and iterate that until the conceptual model is validated against the designed solution. The scope of the study was also compared to the detail level of the simulation study, to support the time plan for the simulation.

The streamlined approach is suggested to be reached by put a high effort in the specification phase of the simulation study and to put a lot of weight on the conceptualization of the model. The scope should be specified and once the simulation study is started, no more data should be added to the simulation team.

RQ2: How can the methods of a traditional simulation study be applied to an emulation project?
Emulation project should adapt the same methodology as a simulation study when preparing and specifying the project. This will prevent the emulation projects to obtain the same waste sources as the earlier simulation studies.

To prevent redundant work and overprocessing in controls projects, the decision gate *Emulation or PLC-simulation?* was inserted in to the controls workflow. By taking objectives for emulations in consideration, the decision could be done before the development of controls software starts and therefore save resources in the project. By improving the translations from conceptual model to computer model, efficiency will be provided to both processes and there is also a suggestion to include emulation in to the already existing library of simulation components. Modelling inside the software with components available in a library and a conceptual model to start from, will streamline the process of an automated material handling system from sales to realisation.

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A
Flow cart of current process

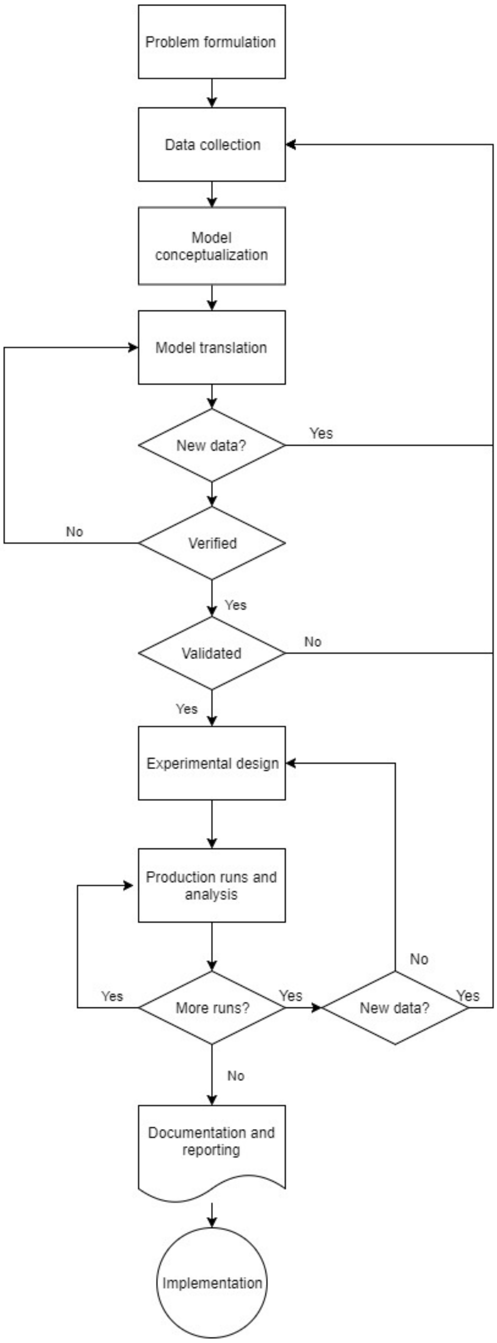

Figure A.1: Flow chart of current simulation process

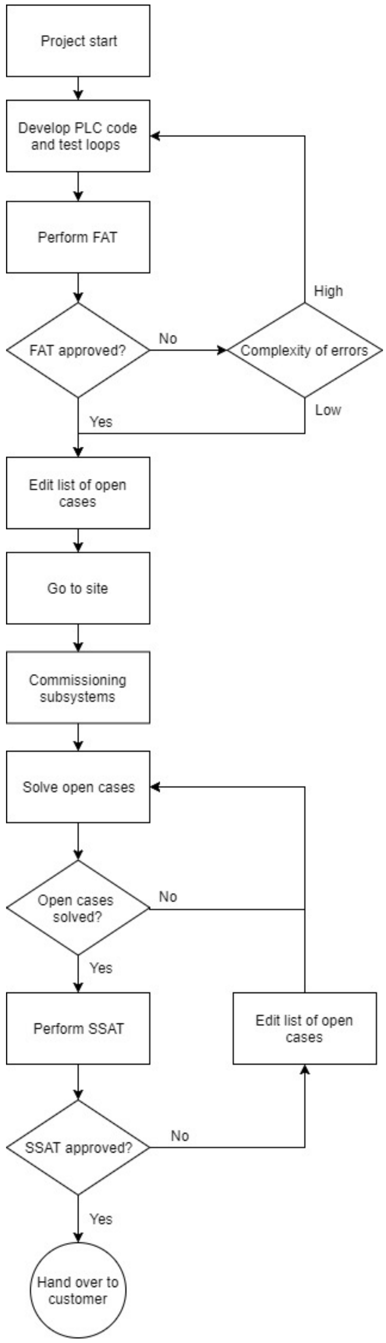

Figure A.2: Flow chart of current controls process.

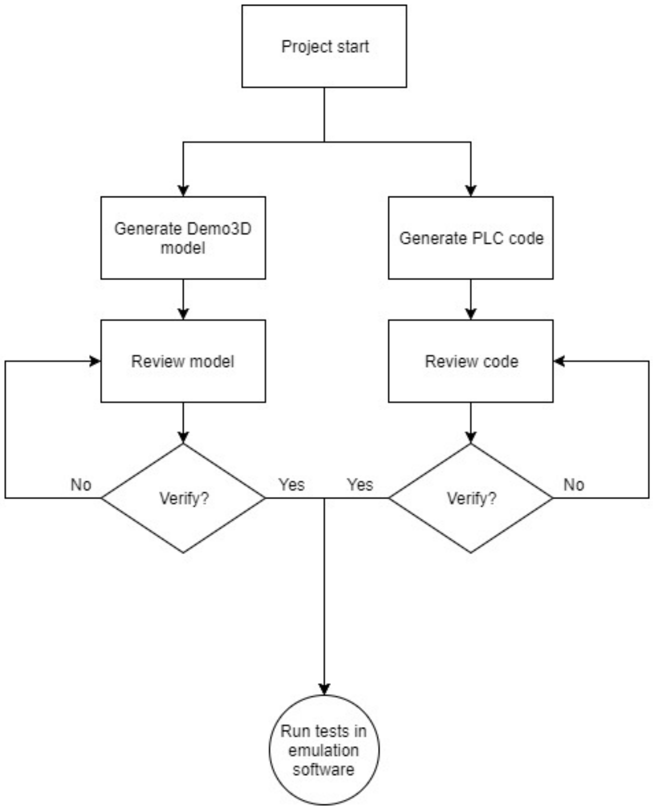

Figure A.3: Flow chart of current emualtion process at the Tech Center.

B

VSM of current processes

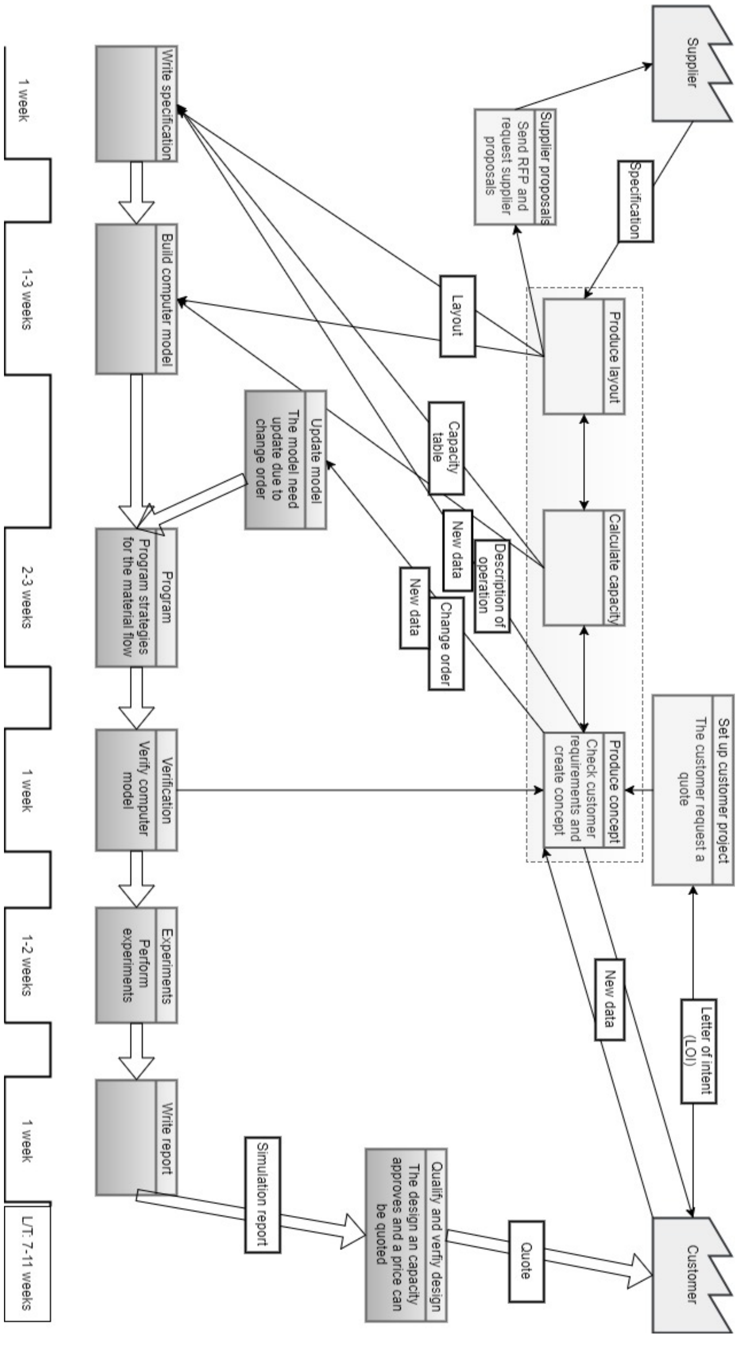

Figure B.1: VSM of current simulation process

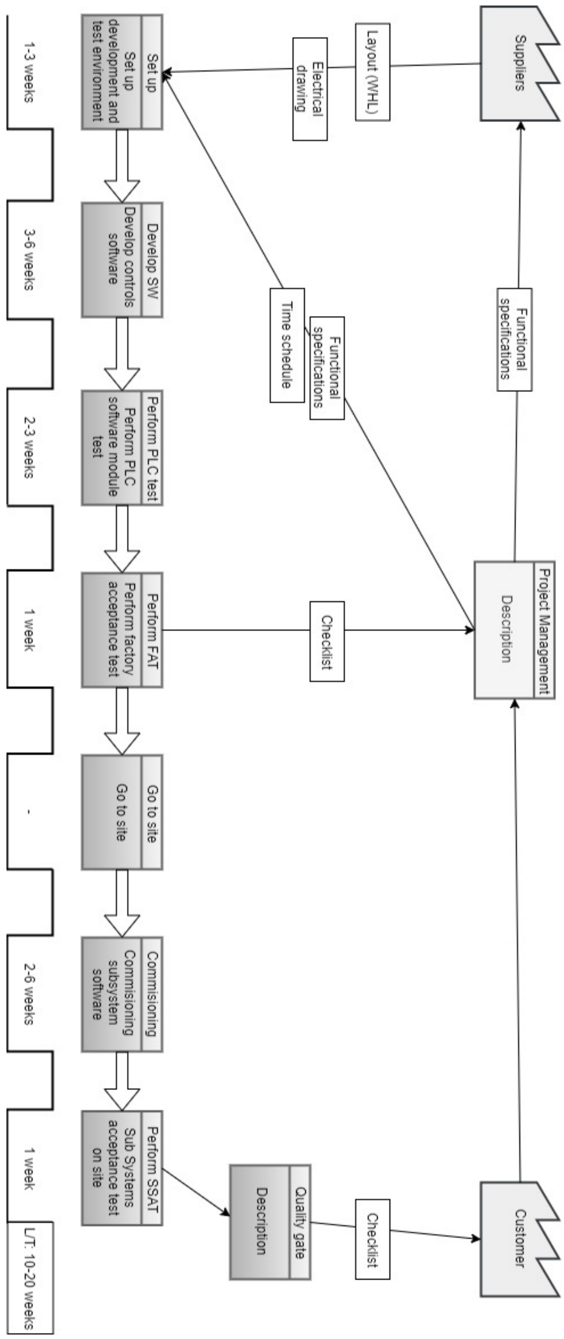

Figure B.2: VSM of current controls process

C
Flow chart future processes

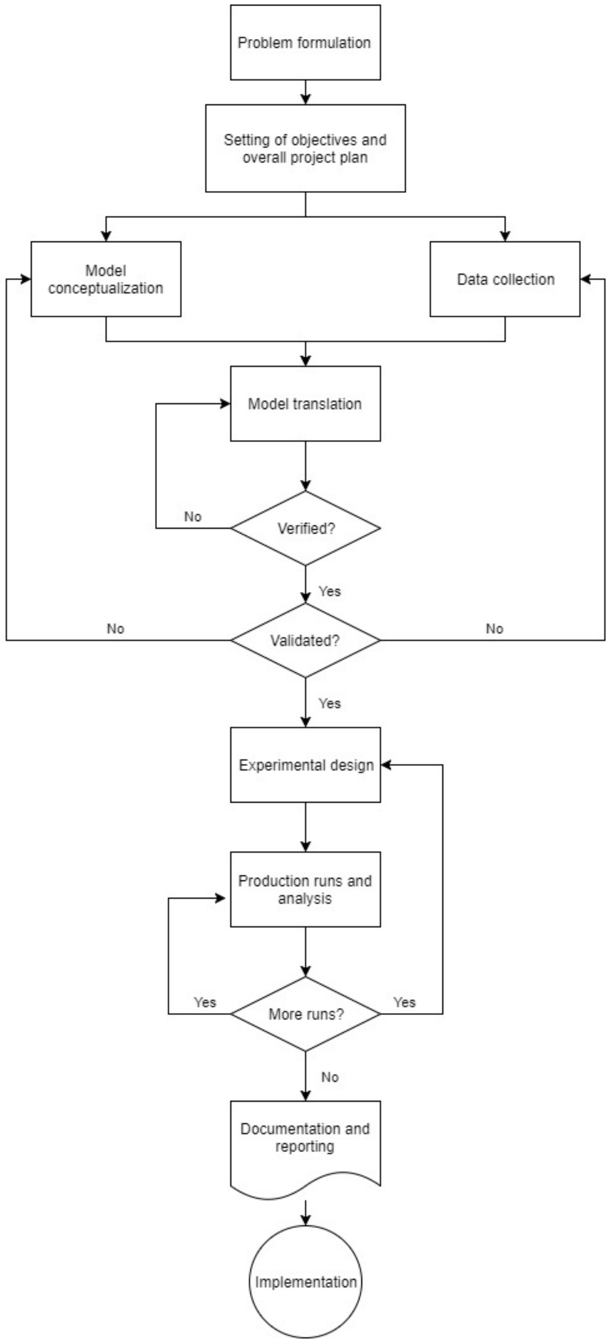

Figure C.1: Flow chart of future simulation process.

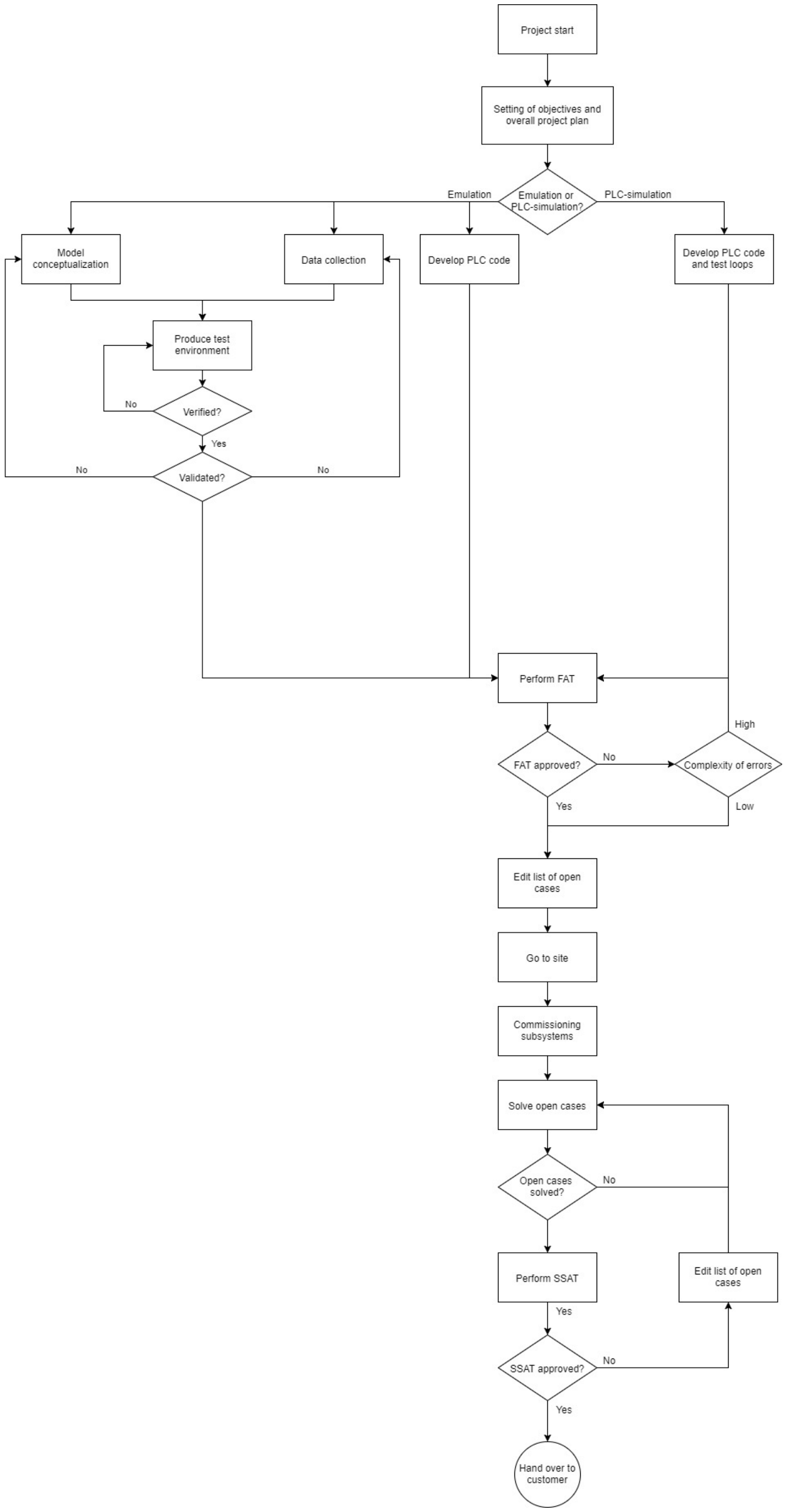

Figure C.2: Flow chart of future controls process

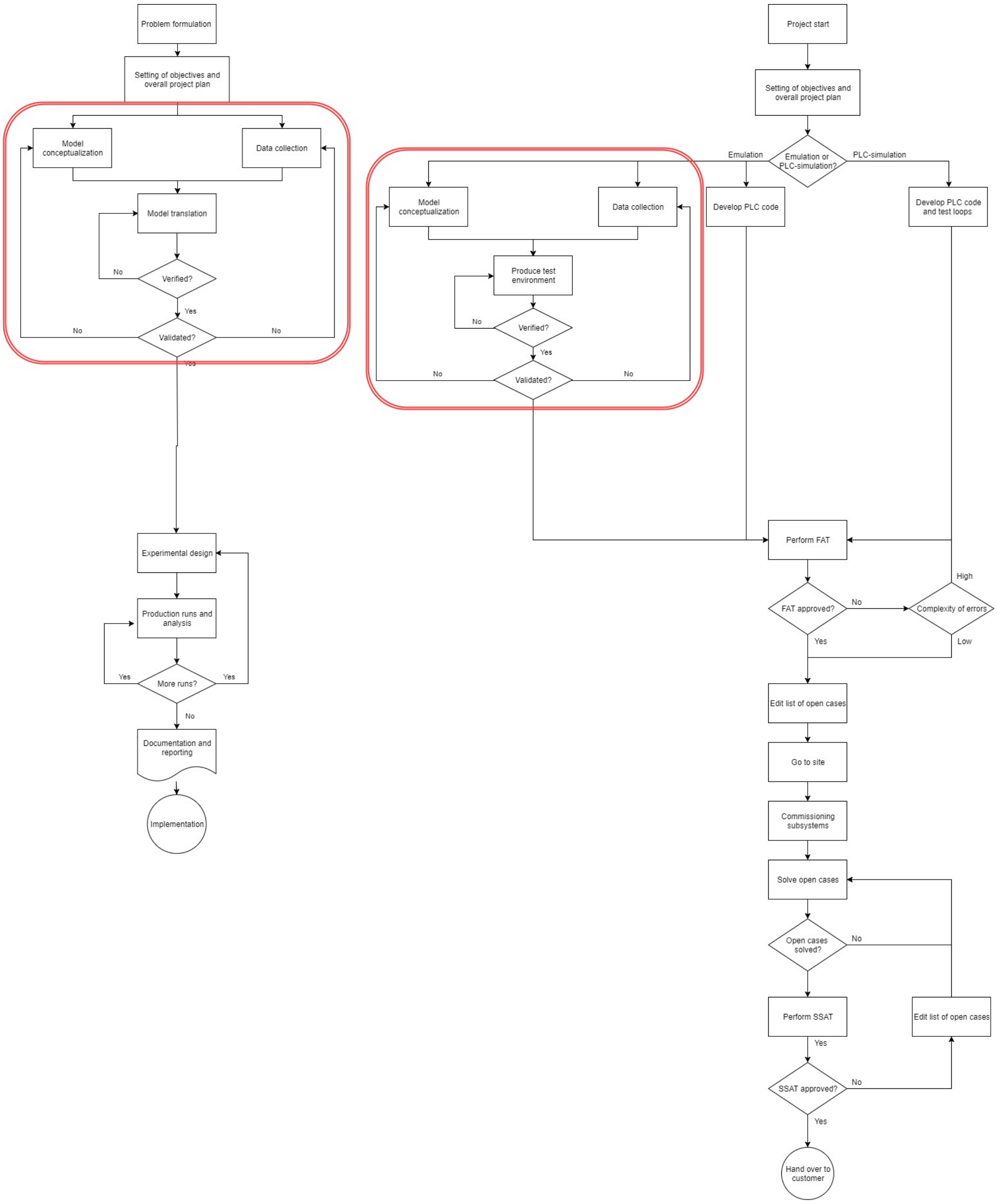

Figure C.3: Compare of simulation and controls processes