TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

IMPLEMENTATION OF PROCESS FLOW SIMULATION AS A CAPABILITY AT A MANUFACTURING COMPANY

PROTSESSIVOO SIMULATSIOONI KUI VÕIMEKUSE JUURUTAMINE TOOTMISETTEVÕTTES

MASTER THESIS

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Tallinn 2022

AUTHOR'S DECLARATION

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Thesis topic:

(in English) Implementation of process flow simulation as a capability at a manufacturing company

(in Estonian) Protsessivoo simulatsiooni kui võimekuse juurutamine tootmisettevõttes

Thesis main objectives:

1. To define the implementation process of simulation software at a manufacturing company
2. To analyse the benefits of the newly implemented tool
3. To assess the implementation strategy and workflow

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Identify the simulation needs of the company	01.03.22
2.	Compare available simulation software and select the most suitable one	06.03.22
3.	Plan the training process for the engineers	20.03.22
4.	Define new workflow	10.04.22
5.	Assess benefits of newly implemented tool and workflow	30.04.22

Language: English **Deadline for submission of thesis:** "23" May 2022 a

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CONTENTS

PREFACE

The thesis was written on the basis of the implementation project the author has been working on for the past 2 years in the manufacturing engineering team of her employer. The thesis work was done during the time the author has worked as a layouts and simulations engineer at the company, and chose the topic herself, for she believes the experience gained through the implementation journey was unique and would be of high value to the research community.

This thesis describes the implementation of process flow simulation as a capability at a manufacturing company. It includes the following steps: definition of simulations needs, selection of simulation software, creation of a business plan, training the engineers to use simulation, definition of new simulation ways-of-working, and the final assessment of the benefits of the new tool and workflow. As a result of the implementation project, 25 engineers have been trained to use process flow simulation, and 8 of them took over the responsibility of building simulation models for 3 defined use cases. Process flow simulation has shown potential to minimize production stops due to missing trolleys for product transfer, as well as to compare various process flow scenarios with common and unique fixtures for the products. The distribution of the simulation responsibilities among manufacturing engineers allows to save time on the data collection step of a typical simulation request cycle, as these roles own processes on the production lines, and can potentially build simulation models faster than the simulation engineer. Furthermore, a clear definition of the use cases that the manufacturing engineers handle according to the new workflow allows for the creation of simulation templates which can be easily reused for future requests, thus allowing for a shorter average processing time of a request over time.

The author would like to express her gratitude to her supervisors Aigar Hermaste and Maia Sinajeva, as well as thesis consultant Anna Dementjeva. Thank you for your great support. Also, big thanks to my colleagues in the Manufacturing Engineering and Automation Engineering teams, as well as Evo Kessler, Mait Soost, Elis Põld, Kristina Kudina, Marek Arru, and everyone else who worked with me on the realization of the simulation project – we created a beautiful thing that will move us forward into the future of manufacturing. Last but not least, a huge thank you to my family and friends for being there for me for the past 6 years of studying engineering.

Keywords: process flow simulation, implementation process, change management, Industry 4.0, master thesis.

List of abbreviations and symbols

ADKAR – Awareness-Desire-Knowledge-Ability-Reinforcement, a change management model

AGV – Automated Guided Vehicle

AE – Automation Engineer

BOM – Bill of Materials

CAD – Computer-Aided Design

CAP – Change Acceleration Process model

COVID-19 – Coronavirus Disease 2019

DES – Discrete-Event Simulation

ERP – Enterprise Resource Planning

GPU – Graphics Processing Unit

KPI – Key Performance Indicator

ME – Manufacturing Engineer

NPS – Net Promoter Score

OKR – Objective Key Results

PM – Production Manager

PO – Product Owner

RACI – Responsible-Accountable-Consulted-Informed, a responsibilities assignment matrix

SME – Subject Matter Expert

SWOT – Strengths-Weaknesses-Opportunities-Threats, a strategic management technique of company or process assessment

UI – User Interface

VoC – Voice of Customer

WoW – Ways of Working

1. INTRODUCTION

Industry 4.0 has defined the last decade of manufacturing, with companies making strides towards the realization of this concept within their production plants. Technological developments, such as big data, cloud computing and additive manufacturing, among others, promise increased production speed, higher flexibility, and improved product quality. The European Parliamentary Research Service stated in their 2015 analysis of the potential of Industry 4.0 that the transformations can help bring manufacturing back to Europe to remedy the loss of "one third of its industrial base over the past 40 years" [1]. The motivation to produce higher quantities of products faster, smarter and of better quality resulted in industries all around the world making great investments – over 900 billion USD per year - to introduce innovative technological solutions [2].

As the framework of the fourth industrial revolution includes a multitude of technologies, there is no one prescribed way of implementing the myriad of new solutions into a company. Each of the pillars requires a different set of resources (both tools and skills) and integration steps. Alongside the challenge of integrating new technology into existing setups and workflows, two of the biggest issues of implementing the Industry 4.0 framework were cited to be organizational change and change management [3] [4] [5]. The topic of implementing a new capability at a company is complex and cannot be captured into a three-step guide that would work for any kind of organization. In this thesis, one practical approach based on a real-life example will be described and analysed.

As part of her role as simulations engineer at a large manufacturing site in Estonia, the author has had the unique opportunity to introduce a new Industry 4.0 skill to the company – simulation. More specifically, it is process flow simulation or discrete-event simulation (DES) which serves to help perform line-balancing, analyse, and identify inefficiencies within a process flow, as well as test out multiple line scenarios. The author's job role included the tasks of comparing different simulation software, selecting the most suitable one, planning out and conducting the training for manufacturing engineers and automation engineers, and defining the new workflow for them. The author was assigned as the sole driver and executor of the simulation project, with her reporting to the managerial team and discussing certain aspects of the implementation plan with them.

This thesis touches upon the fields of operations research, change management, and business process management. The value of this work lies in the fact that companies rarely reveal the story of how an Industry 4.0 capability was integrated into their existing workflows, especially simulation. Some companies hire the simulation software provider to conduct the training to the engineers, yet, as it will be further described in the thesis, change management becomes easier when a colleague within the company, who is familiar with the existing processes, the products, and company, teaches the engineers, as opposed to some external entity. Also, it is not known how manufacturing companies divide the responsibilities of simulation modelling among their employees: Is there only one simulation engineer? Does a team of engineers use the software occasionally? Is there a special team dedicated to simulation projects? This work will recount the setup in which one simulation engineer will be the main user of the software at first and then slowly hand over parts of the responsibilities to the manufacturing and automation engineers.

With the introduction to the thesis (Chapter 1) coming to an end, the next sections of this written work will be described. Chapter 2 will cover the theoretical background required to fulfil the thesis tasks. The main body of the thesis – Chapter 3 – envelopes the practical work done for the thesis, including the definition of simulation needs, stakeholder analysis, engineers' simulation survey, the process of selecting the suitable simulation software, the business case created for the implementation project, the training conducted for the engineers, as well as the definition of the new simulation workflow. The assessed benefits of the simulation tool and the workflow can be found under Chapter 4. The summary of the main points from the written work will be provided in the Conclusions section.

2. THEORETICAL BACKGROUND

The implementation process of a new capability is a complex endeavour that includes multiple steps and facets to be accounted for – the technical setup of the new tool, cybersecurity, the change management process (including workflow definition), as well as the training of the new tool. The first two aspects are outside the scope of this thesis, as the IT department of the manufacturing company dealt with those. In the literature review, the definition for process flow simulation will be given, change management techniques used will be shortly discussed, and the decisions behind conducting the training will be explained. This will form the theoretical framework needed to move forward with the execution of the implementation project.

2.1 Process flow simulation

One of the ways to carry out process flow optimization is through the application of analytical models which involves the creation of a mathematical equation that would include all variables and constraints. Since real-world systems include a large set of variables to consider, with time they were replaced with simulation software that provided an easy-to-use user interface (GUI) that allowed people without a strong mathematical background to quickly develop models and test out their theories.

Process flow simulation refers to the simulation of a chain of processes for the purpose of identifying inefficiencies and bottlenecks. This type of simulation became an important part of operations research and supply chain management [6] [7]. Nowadays, the term is mostly associated with the simulation of chemical and semiconductor processes [8] [9], and instead the name 'discrete-event simulation' is used [10] [11] [12].

Discrete-event simulation (DES) uses following concepts for model-building:

- Entity – the product moving through the process flow;
- Activity/Event – a process within a process flow that takes a certain length of time to complete;
- Attribute – a property of an entity;
- Simulation clock – the mechanism of capturing the time a simulation run lasts;
- Statistics – numerical performance indicators of every building block of a simulation model that can be viewed during a simulation run or after its completion [13].

In 2D simulation software, the process flow is visualized as a flowchart-like structure through which units of work travel. In 3D software, such as Visual Components, the processes are tied to visually distinct CAD models of machines and human resources. Comparing the two types of DES tools, the 2D ones requires computational power (no GPU, for example) and the model-building process is arguably faster. On the other hand, 3D manufacturing simulation tools offer an additional function of modelling the production layout. Some popular simulation software providers are: Visual Components, SIMUL8, WITNESS, AnyLogic, Siemens Tecnomatix Plant Simulation, and Simio.

2.2 Change Management

The introduction of a new process or tool must be accompanied by a change management strategy to reduce the risk of a failed implementation. If the software was aimed to substitute an old program designed for an already existing workflow, change management may not be required. In the case study described in this thesis, however, the engineers have not had any prior experience or set procedures related to simulation, thus the introduction of the changes demanded some planning.

Change management can be defined as a set of activities that assist in the integration of changes into the workflows of the employees subjected to said changes. The goal of change management lies in the successful transition to the new process or state. The three domains of change management are organizations, people, and projects [14]. Depending on the change management model chosen, the focus can shift from one of the three domains to another. Multiple models exist, such as Kurt Lewin's theory, Kotter's eight-step change model, the ADKAR model, General Electric's Change Acceleration Process Model (CAP), and others [14].

Considering that the introduction of a simulation tool would not lead to organizational changes, and the change is not project-based, the "people"-domain of change management was of most importance. Thus, the people-centric ADKAR change management model, developed by Jeff Hiatt in 2003, was deemed most suitable [15].

The acronym ADKAR reveals the five phases of a change being introduced from the perspective of the employee whose workflow is to be renewed:

- A – Awareness,
- D – Desire,
- K – Knowledge,

- A – Ability,
- R – Reinforcement.

A graphical representation of the model can be found under *Figure 2.2.1*.

Figure 2.2.1. The ADKAR change management model. Source: Bandar Alqahtani [16].

The employees who will go through the changes of the process firstly become aware of the change from the communication of the management team. In order to integrate the changes, the employees must feel the desire or motivation to participate in the new process. New knowledge is delivered to the employees, and after some practice, knowledge turns into an ability. Lastly, reinforcement relies upon a framework which assures the continued application of the changes.
In a practical interpretation of the ADKAR model, Awareness and Desire are evoked through a presentation of the management's vision of the new workflow, Knowledge and Ability come from employee training, and the definition of a new workflow with all associated documentation allow for Reinforcement.

The ADKAR model does not mention one important aspect that occurs in the employees between the Awareness and Desire stages – the strong initial negative response to change. Oftentimes, the authors of the organizational or workflow changes does not take into account the emotional experience that the announcement of the change brings. A 'cold' introduction of the new processes without consideration of the employees' feedback can lead to high levels of frustration that in turn can end in turnover intention [16] [17]. As a result, the understanding of the emotional response of the team to change is vital when performing change management.

The Kübler-Ross change curve, initially designed on the basis of a study done of people coping with the grief of losing a loved one, has been recognized as a fundamental tool in the realm of organizational psychology [18] [19] [20]. The change curve, also known as the grief cycle, lays out the emotional journey that a person goes through when experiencing a big change in their life. *Figure 2.2.2* showcases the employees' morale go up and down over time as they try to cope with the changes [21]. The model reveals how the initial shock in regards to the news turns into depression, as the person feels that there is no hope for him or her to adjust to the new reality. At this stage, the employees can be expected to heavily voice their frustration, refuse to integrate the new workflow, or just ignore the issue. But then, the person makes some small trials and, after a certain time, decides that it is possible to change. Afterwards, the final stage of integration comes. The Kübler-Ross model helps the facilitator of the change navigate through the emotional response of the employees, and take suitable actions for the mitigation of conflicts.

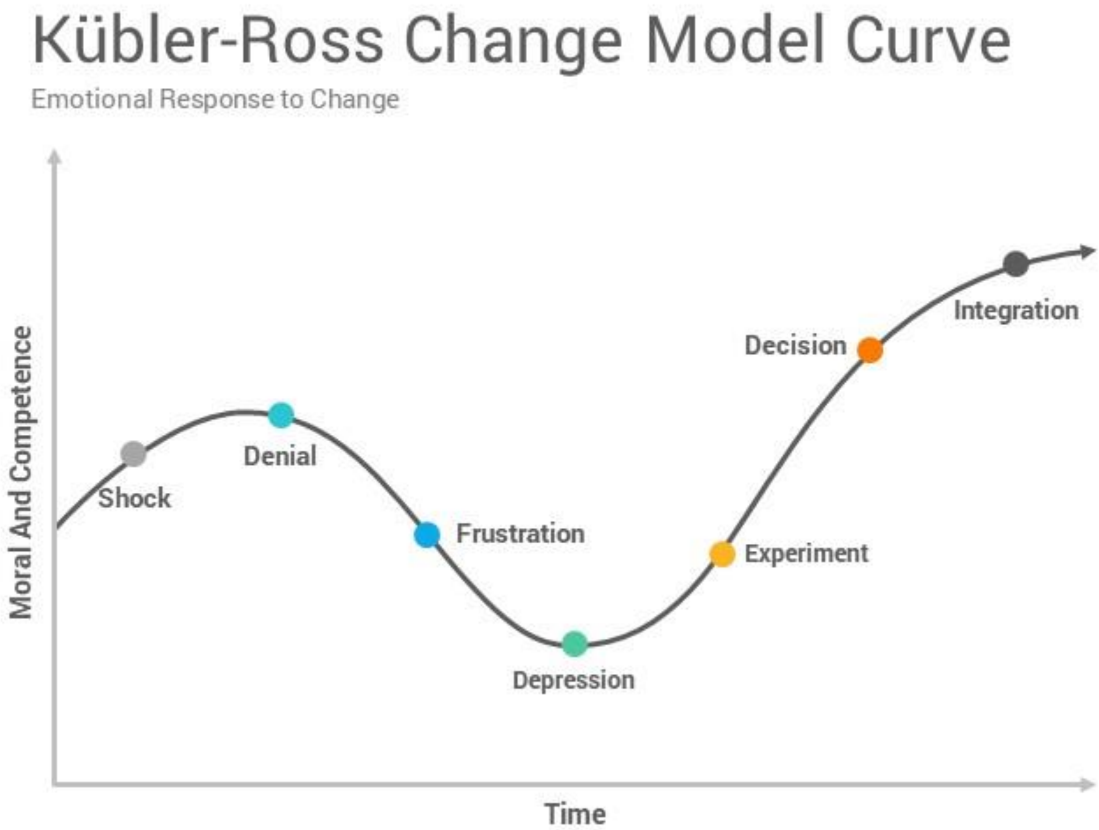


Figure 2.2.2. The Kübler-Ross change model curve. Source: Saxton Bampfylde [21].

Change management tools such as stakeholder analysis, change effectiveness assessment, and change readiness assessment support the implementation plan [23] [24]. Stakeholder analysis identifies the needs for a specific change and forms a foundation for the future workflow definition. The change effectiveness assessment

should be performed before and after the change has been implemented – at the beginning, the potential gains from the change should be brought out to make a cost-benefit analysis; later, the actual effectiveness of the change is to be measured to control the process [25]. Finally, change readiness assessment can be seen as a process resembling the stakeholder analysis, except that the employees who are to take over the new workflow are interviewed. The goal of this tool lies in the understanding of the employees' level of commitment to the change [24].
The change management journey results in the creation of a new workflow with clearly defined use cases. A RACI matrix, a popular framework for outlining the responsibilities of the different parties involved in the process, plays the role of a contract between the stakeholders on what actions can be expected from each side [27]. Progress check-in meetings with the team provide a platform for the employees to express their thoughts on the workflow and suggest changes.

2.3 Employee training

Not all organizational or workflow changes require employees to be trained, yet when a new software is added to their existing toolkit, the provision of these educational activities is vital. As software providers offer to conduct the training to the customer's employees, companies often choose this option, despite its often high price levels, disregarding the fact that the software support websites providing enough documentation and tutorials for a person to learn the tool individually. In the manufacturing company described in the thesis, the possibility of the simulations engineer to develop and conduct the training by herself was presented.

Several studies confirm that classroom or teacher-led teaching offers many significant benefits compared to self-learning, as real-life interactions allow for the teacher to engage with the students better using effective teaching practices and more interactions [28] [29] [30]. Also, the level of teacher familiarity with the students is positively correlated with knowledge test performance which leads to the assumption that training provided by a colleague in the team would constitute better results than hiring an external company to perform the training [31]. Thus, the author created the training material herself and performed the training as live-sessions with the engineers.

In order to achieve the highest degree of training efficacy, the personal learning styles of every engineer would ideally be taken into account. The VARK model lays out the four types – visual, auditory, reading/writing, and kinaesthetic [32]. To best address a group of people with different learning styles, a study format that includes a bit of everything would offer satisfactory results. As such, a Microsoft PowerPoint presentation with images, icons, and colourful annotations was created with the visual learners in mind; the explanation of the software functions was narrated by the author to the engineers to accommodate for the auditory learning style; the slides included short textual explanation of the functions and links to support articles for further reading for people who learn best by reading and writing; and, finally, practice assignments were given to all to work with the software and navigate it using a mouse and keyboard, thus supporting kinaesthetic studying.

Another element contributing to a higher level of training effectiveness is the inclusion or full integration of the concept of gamification. Gamification can be defined as the application of game mechanics into fields not related to gaming [33]. Most commonly, the introduction of a point- or badge-system is associated with this concept which invokes a desire to compete against other students in the classroom, and this transforms into the desire to study [34]. Two short quizzes to check the students' comprehension of the material were made using the quiz-creation platform Kahoot! [35]. The participant of the live quiz gets points not only for answering correctly, but also quickly, and this further increases the level of competitiveness among the students. Kahoot! has been analysed in several research case studies as an addition to the standard study format, and has proved to be quite successful [36] [37] [38].

3. IMPLEMENTATION PROCESS

Based on the theoretical knowledge gained in the previous chapter, the implementation of discrete-event simulation as a capability at the company could commence. Before choosing the software, the needs for simulation had to be identified (Chapter Section 3.1), and the stakeholders' view on the topic had to be captured (Section 3.2). The voice of the future users of the tool also had to be collected (Section 3.3). The process of selecting the appropriate simulation software is described in Chapter Section 3.4, and the planning of the project through the means of the creation of a business case was carried out as relayed in Section 3.5. The training was developed and conducted (Section 3.6), and the new simulation workflow created (Section 3.7).

3.1 Defining simulation needs

The vast majority of the companies in the manufacturing sector aim to pursue the implementation of Industry 4.0 technologies with the expectations these changes will benefit them in the long run. As a matter of fact, the annual Industry 4.0 survey run by McKinsey revealed that 90% of the respondents were "convinced of the technologies' value" [13]. The company at which the author works is following the same path, with every supply site pursuing to implement a different mix of new technologies and capabilities.

At the Tallinn factory, the managers of the automation engineering and manufacturing engineering teams have recognized a need in the use of process flow simulation in the existing workflows. The following perspectives on the topic of simulation were presented by the managers as well as through conversations with the team members.

Automation engineers are not heavily invested in the process of planning production lines and their layouts, yet when a new automation project is launched, they perform an analysis of the existing material or unit flow, and, based on estimated numbers, create to-be production systems. The engineers did not have specialized tools that would support them in this use case.

Manufacturing engineers, the de-facto process owners of the production lines, use line-balancing software when designing a new line. They also perform time-and-motion studies to generate process times for the different product variants. On a monthly basi.s, a global production plan is given to them on the basis of which the production setup is altered to help reach the targets. A common tool for analysing production scenarios is Microsoft Excel where the throughput is calculated based on the captured processing times, yields, and resource capacity. The use of spreadsheets with predetermined formulae constitutes a rather one-dimensional analysis, as best-case and worst-case scenarios are disregarded, and probability distributions of the unit arrivals and processing are not considered. Furthermore, the management has recognized the need to modernize the tools and capabilities of the engineers to match the company's road towards digital transformation.

On a global scale, an on-going large project in relation to manufacturing data integration and interoperability with other systems could potentially address the need that the Tallinn supply site has for new line-balancing and simulation capabilities, yet due to its massive scale and long testing time, the management has decided to pursue a local solution in the meantime. Some years ago, the Tallinn University of Technology assisted the company in finding a process flow simulation tool and teaching it to the engineers. Yet the trained engineers reported not having used the tool since the training, as no workflow change was planned out, and no dedicated person was assigned to assist the engineers in the simulation activities. The simulation software at that time was picked without conducting a comparison of all those available on the market. The engineers also commented on the tool having an old-fashioned and uncomfortable user interface. Judging by the lack of motivation from the employees to integrate that tool into their workflow, the training also seemed to have been too short and not catered to address the everyday problems that manufacturing engineers deal with. The same McKinsey article mentioned in the beginning of this sub-chapter confirms that the stalling of Industry 4.0 initiatives is a common problem – around 70% of projects of a similar kind do not achieve the previously set objectives [13].

A second attempt at implementing process flow simulation as a capability was launched in June of 2020. The author was hired to investigate the need for simulation and drive the implementation project.

3.2 Stakeholder analysis

Before commencing the search for simulation software on the market, the collection of the "voice of customer" (VoC) had to take place. The managers of the automation and manufacturing engineering teams were identified as stakeholders, as well as production managers, project managers, improvement managers, the factory design engineer, head of smart manufacturing, and the global process architect for smart manufacturing. A total of 21 people were selected. Whilst the primary users of the simulation tools would be the engineers, it was important to understand what the stakeholders understood under the term "simulation", what vision they had for the capability, and whether they could see themselves turning to the engineers with simulation requests. A survey made in Microsoft Forms was sent out to the customers.

The survey consisted of 6 questions. *Table 3.2.1* lists the questions and the type of response the stakeholders could choose from.

	Question	Possible answers
1	Do you see a need in simulating production/material flow in your team?	• Yes • No • Not sure
2	What kinds of problems should simulation software be able solve for you? Can you name any specific processes where you would apply it (components moving from warehouse, stock use within cell, counting how many pallets or test stations are required for a new or reconfigured line)?	Freeform
3	Is it sufficient for you to have a 2D interface or would you insist on visualising the simulations in 3D?	• 2D • 3D • I am unsure • I don't care
4	Which simulation programs relating to production/material flow (if any) have you used or would suggest?	Freeform
5	Would your team benefit more from a few trained specialists, or should everyone be able to run simulations?	Freeform
6	Please use the text bow below for any additional comments and remarks on this topic	Freeform

Table 3.2.1. Questions of the stakeholder analysis survey on the topic of simulation.

Out of the 21 respondents to whom the survey was sent, 15 have responded. Absolutely everyone saw a need in simulating production or material flow in their teams, as depicted in *Figure 3.2.1*. (question 1). They have highlighted that simulation would help solve problems such as preventing bottlenecks, optimizing processes, managing the material buffer, reducing cycle times, layout change consequences, and counting the need of production trollies (question 2). Figure 3.2.2 shows the word cloud of answers to this question, with outlier words removed.

Figure 3.2.1. Stakeholder analysis survey results for Question 1.

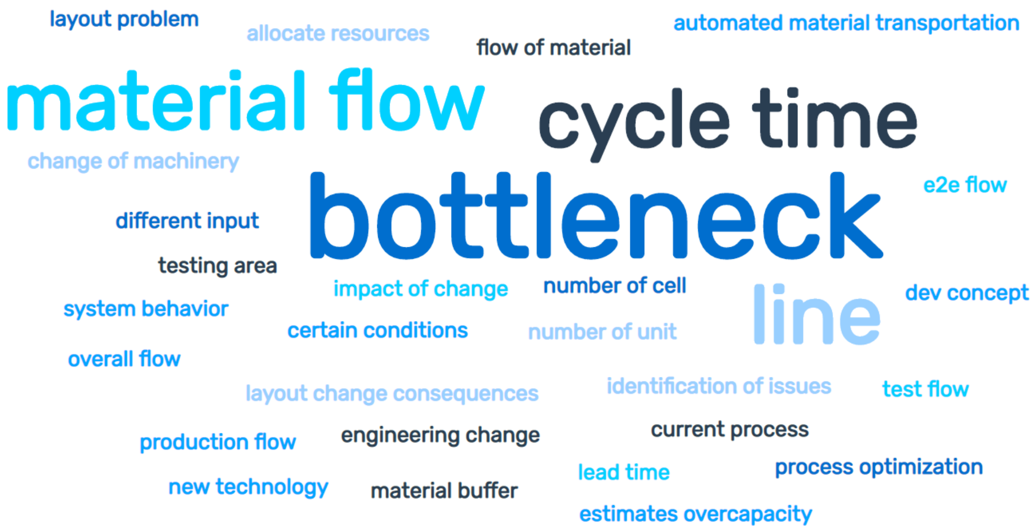


Figure 3.2.2. Stakeholder analysis survey results for Question 2.

Whilst the option to have 3D simulation was popular among the responders (with 33% of them preferring it over 3D), more than half saw 2D simulation as sufficient to fulfil their needs (question 3). *Figure 3.2.3* depicts the pie chart with all the replies to this question.

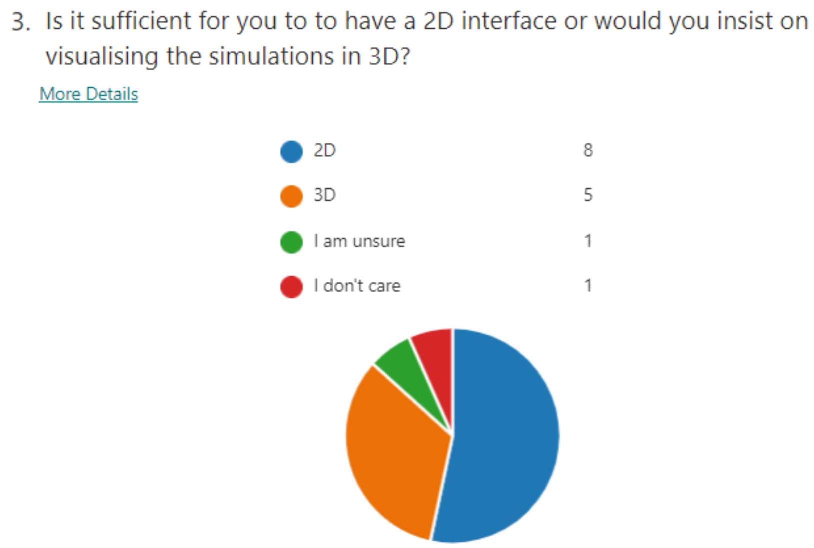


Figure 3.2.3. Stakeholder analysis survey results for Question 3.

Two thirds of the respondents answered to the question about the simulation software they have heard of or used, and 60% of them answered Arena Simulation, a tool provided by Rockwell Automation [14], which is taught in the course of Advanced Manufacturing Planning and Control at TalTech. Others have also mentioned Visual Components [15], Siemens Tecnomatix Plant Simulation [16], AnyLogic [17], SIMUL8 [18], and Enterprise Dynamics [19]. Unrelated to the topic of process flow simulation were the mentions of Pedestrian Dynamics [19] and MATLAB [20] (question 4). A myriad of answers was given to the question about what workforce setup would be most beneficial, i.e. whether everyone should have to simulate or only a few specialists, but the general view seems to be that a few trained specialists should be lead simulation engineers, yet everyone who wishes can get access to the tool and run simulations in it. Three respondents emphasized that manufacturing engineers in particular seem like the most plausible group of people to be associated with process flow simulation activities (question 5). The final question served as a place for the survey respondents to express any other opinions they had about the topic at hand. The importance of the management dedicating itself to the simulation implementation project was highlighted, since otherwise the initiative would fail. Also, visualizing the work done in simulation software was deemed as a desired feature. The tool should be easy to use if one is to consider buying a license for it. Some people shared examples of tools they want to be implemented or that have been used before. Also, one stakeholder wished for a high level of interoperability between existing tools and the potential new simulation software, so that no more work is created due to the need to input data into the simulation model (question 6).

From the survey it can be concluded that the interest in process flow simulation among managerial roles is very high, and the simulation implementation plan should be further developed. *Table 3.2.2* sums up the conclusions from the survey.

	Question	Most popular response
1	Do you see a need in simulating production/material flow in your team?	Yes
2	What kinds of problems should simulation software be able solve for you? Can you name any specific processes where you would apply it (components moving from warehouse, stock use within cell, counting how many pallets or test stations are required for a new or reconfigured line)?	• Bottleneck identification • Material flow analysis • Cycle time reduction
3	Is it sufficient for you to have a 2D interface or would you insist on visualising the simulations in 3D?	2D
4	Which simulation programs relating to production/material flow (if any) have you used or would suggest?	Arena
5	Would your team benefit more from a few trained specialists, or should everyone be able to run simulations?	Few specialists + access for all to use the tool if desired
6	Please use the text bow below for any additional comments and remarks on this topic	• Tool should be easy to learn • Think of interoperability • Dedication from management to the implementation is important

Table 3.2.2. Summary of the stakeholder analysis survey on the topic of simulation.

3.3 Engineers' simulation survey

In the next step, the engineers were called on to participate in a separate survey where they could not only voice their opinions on the possibility of introducing simulation as a tool, but also to check how they understand the topic in general. A total of 23 engineers

(6 automation engineers and 17 manufacturing engineers) were expected to participate in the quiz/survey.

The survey was composed of 9 questions divided into 3 sections. Questions 1-4 were geared at gaining the engineers' insights and knowledge on simulation. Questions 5-8 asked the respondents of their simulation experience and opinions on the topic. The last section included only one question – Question 9 – the purpose of which was to understand what other skills the engineers could be interested in in learning. Table 3.3.1 lists the questions and possible answers for the engineers' survey.

		Question	Possible answers
Section 1: Knowledge check	1	What do you associate the term "simulation" with the most?	• 3D models • Excel sheets • BPMN diagrams • Animation • Other
	2	Select the basic building blocks of a typical simulation model:	• Queue/Buffer • Process/Activity • Start • End • Resource • AGVs • PowerPoint slides
	3	What is considered a Resource in the context of a simulation model?	• MCR • Dispensing robot type #1 • Dispensing robot type #2 • Line Operator • AGV • Product • Internal production system
	4	Put the steps to building a simulation model in the right order (multiple correct sequences possible):	• Define Start point • Define the Activities • Define Resources • Define processing times • Add resource availability, machine failure rates, activity

			efficiency, changeover times, etc. • Define the Queues • Connect the elements with one another (define product routing • Define End point • Run the simulation • Review the simulation report
Section 2: Prior experience & opinions	5	Have you ever simulated before?	• Yes • No • Only through simulation video games
	6	Which of the following simulation software have you heard of?	• AnyLogic • Arena • Visual Components • SIMUL8 • Siemens Tecnomatix Plant Simulation • Other
	7	On a scale from 1-5 (1 - min, 5 - max), how big of an impact could the usage of process flow simulation tools have on your productivity, in your opinion?	Scale 1-5
	8	What do you believe to be the biggest issues with simulation?	• The simulation results are not precise/cannot be trusted • Building a model takes too much time and effort, and the end result is not worth it • The simulation model will not provide me with any new insight on the layout/process • Other

Section 3: Future outlook	9	Which of the following skills would you be interested in learning or improving for your work?	• Statistics • Machine Learning • Programming • Data Visualization • Microsoft Office Suite • SAP • Project Management tools • Other

Table 3.3.1. Questions of the engineers' simulation survey.

22 of the 23 engineers responded to the quiz. The majority of the respondents associated simulation with animation (19 votes) and 3D models (12 votes). Simulating production line scenarios with Excel was not a popular answer, and 2 respondents added that simulation was related to "a numerical approximation of a process of interest" and "process characteristics" (question 1). The pie chart with the answers can be viewed in *Figure 3.3.1*. The replies to the next question revealed that the engineers had a good understanding of the main components that belong to a typical simulation model, them being Queue/Buffer, Process/Activity, Start, End, and Resource. All 22 respondents selected Process/Activity, 19 out of 22 selected Start and End, and 17 out of 22 chose Queue/Buffer and Resource (question 2). *Figure 3.3.2* shows the distribution of answers.

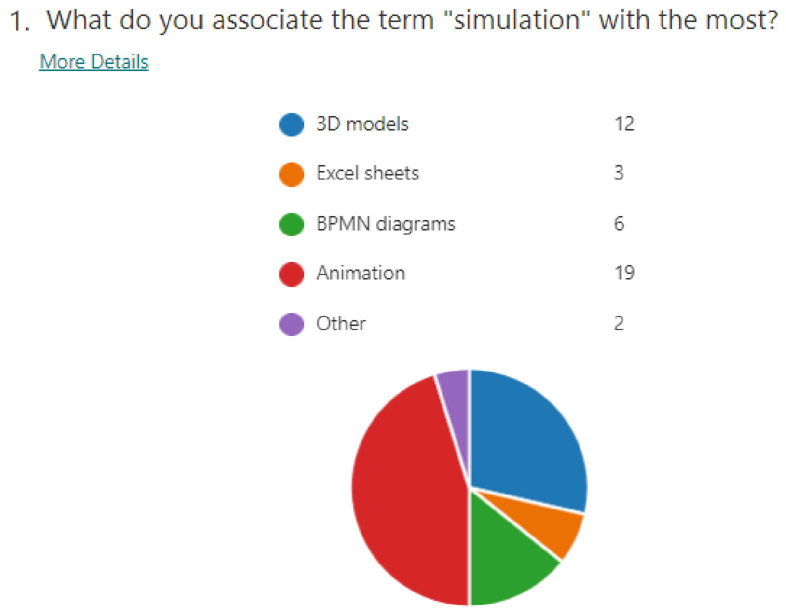


Figure 3.3.1. Engineers' simulation survey results for Question 1.

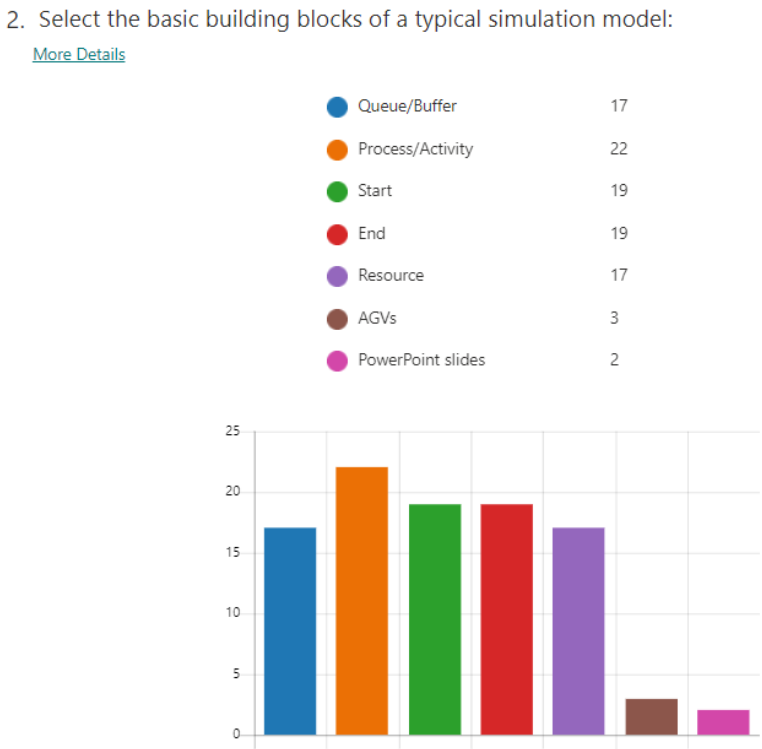


Figure 3.3.2. Engineers' simulation survey results for Question 2.

In discrete-event simulation, human workers assigned to stations are commonly regarded as resources, yet simulation software is inherently flexible, so setting up industrial robots, AGVs, and machinery as resources is also possible. The vast majority of the respondents have correctly chosen line operators (20 votes) as resources, as well as dispensing robots and AGVs (question 3). When it came to the quiz question about the sequence of steps to building a simulation model, then the engineers showcased that they intuitively knew the workflow for simulation, as they thought systematically (question 4). The first and the last two steps in this question were obvious - first, a Start point is defined, and at the very end, the simulation is run, and the report is reviewed - and all other steps in between could have been mixed. But the purpose of this question was to give the respondents the opportunity to think like a simulations engineer and get a general idea of the steps required to build a model. Only 8 out of 22 engineers have simulated before, meaning that training will be required in the next phase of the project (question 5). In the question about the software that they have heard of before, the most popular answer was Visual Components. That is a surprising answer, as it contrasts with the replies given by the managerial roles. Perhaps the automation engineers knew of the tool, as it provides with robotic offline programming, and they may have used it before as a replacement of or in conjunction with software of the likes of ABB RobotStudio. Besides Visual Components, the engineers have heard of SIMUL8 and Arena (question 6). Figure 3.3.3 shows the distribution of replies to this question.

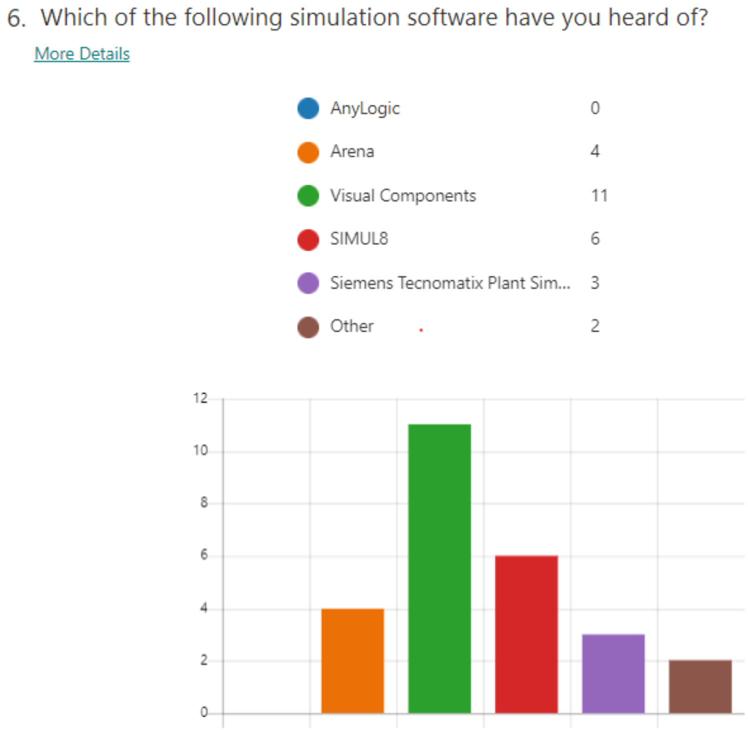


Figure 3.3.3. Engineers' simulation survey results for Question 6.

The engineers have assessed the impact of process flow simulation on their productivity with an average score of 3.64, with 4 being the mode. The rating is neutral leaning towards positive (question 7). Asking the respondents about the biggest issues they see with simulation, the replies were almost evenly distributed, with the most common occurring answer being that building a model takes too much time and effort. Those who have voted "Other" specified that creating exact replicas of a system or line is the biggest challenge, that finding information suitable for the simulation input is very difficult, and representing the actual process is a simulation tool can be tricky (question 8). *Figure 3.3.4* showcases the pie chart for this survey question.

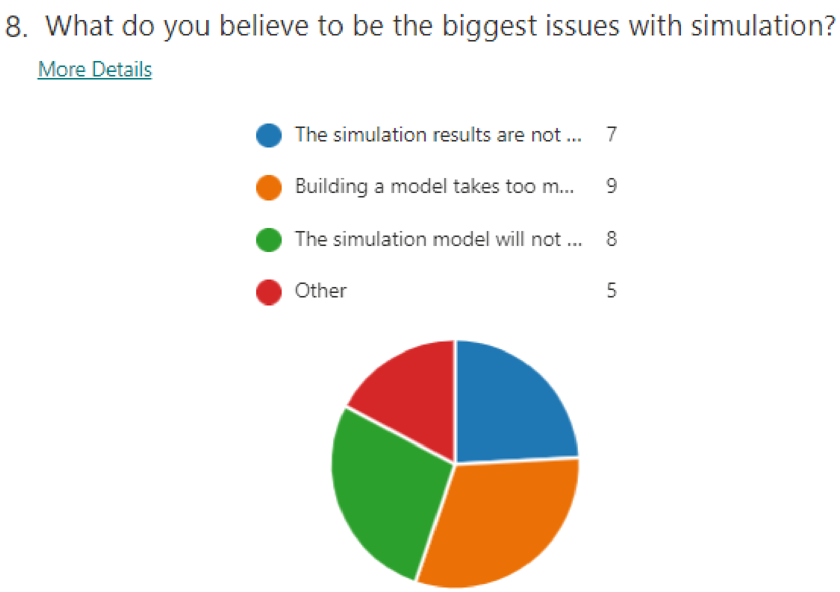


Figure 3.3.4. Engineers' simulation survey results for Question 8. Refer to Table 3.3.1 for full text of given options as answers.

The final question of the survey gathered information on which skills the engineers would like to learn or improve in the future. The top 3 answers included data visualization, machine learning, and programming. *Figure 3.3.5* shows all answers that the engineers have given to the last question.

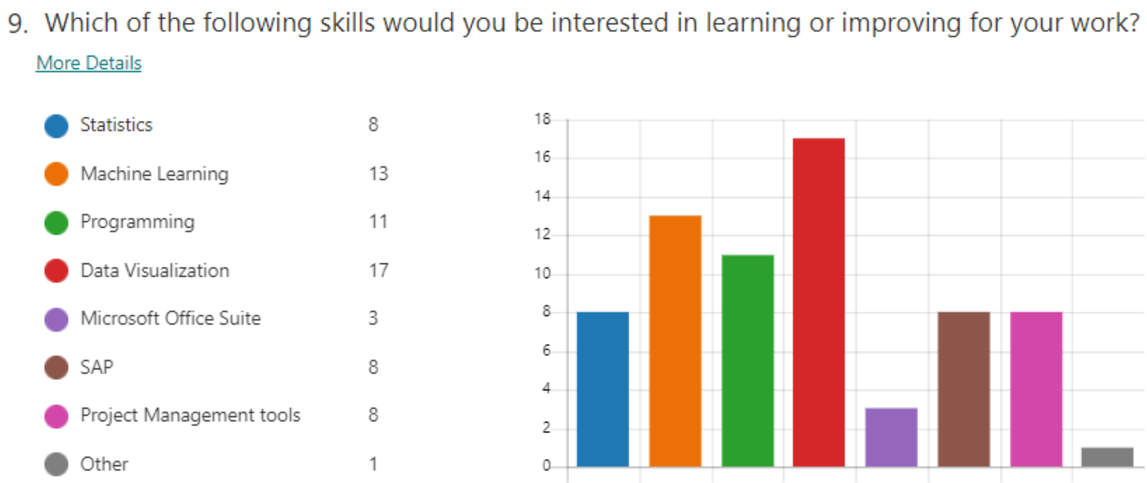


Figure 3.3.5. Engineers' simulation survey results for Question 9.

To summarize the results of the simulation survey conducted for the group of automation and manufacturing engineers, the engineers have a pretty good understanding of what process flow simulation is, and what is important when building models there. The attitude towards simulation as an extra tool in their skillset is seen as neutral-to-positive, with concern being expressed about the time and effort it would take to create the models. The engineers are aware of the existence of some process flow simulation tools like Visual Components and SIMUL8, and the word “simulation” makes the employees think primarily of animation and 3D models. The latter could be explained by their reoccurring exposure to CAD models of new products which may lead them to the assumption that 3D visualization is necessary to simulate processes. *Table 3.3.2* displays the summary of all results of the questionnaire, with the most popular responses provided in the right-most column.

		Question	Possible answers
Section 1: Knowledge check	1	What do you associate the term "simulation" with the most?	• 3D models • Animation
	2	Select the basic building blocks of a typical simulation model:	• Queue/Buffer • Process/Activity • Start • End • Resource
	3	What is considered a Resource in the context of a simulation model?	• Dispensing robot type #1 • Dispensing robot type #2 • Line Operator • AGV
	4	Put the steps to building a simulation model in the right order (multiple correct sequences possible):	• Define Start point • Define the Activities • Define Resources • Define processing times • Add resource availability, machine failure rates, activity efficiency, changeover times, etc. • Define the Queues • Connect the elements with one another (define product routing • Define End point • Run the simulation • Review the simulation report

Section 2: Prior experience & opinions	5	Have you ever simulated before?	No
	6	Which of the following simulation software have you heard of?	Visual Components
	7	On a scale from 1-5 (1 - min, 5 - max), how big of an impact could the usage of process flow simulation tools have on your productivity, in your opinion?	3.64
	8	What do you believe to be the biggest issues with simulation?	Building a model takes too much time and effort, and the end result is not worth it
Section 3: Future outlook	9	Which of the following skills would you be interested in learning or improving for your work?	• Machine Learning • Programming • Data Visualization

Table 3.3.2. Summary of the engineers' simulation survey.

Looking at the responses from the roles that were surveyed – managers, automation engineers, and manufacturing engineers – we notice the differences in their attitudes towards the topic. Managers unanimously expressed how much process flow simulation should be set up as a capability at the supply site, whilst the engineering team was more modest with their response, most likely due to their negative past experience with the implementation attempt. Additionally, since the manufacturing engineers are the main designers of the production flows within the supply site, they would use the tool more heavily, and thus they must have viewed the addition of simulation as an extra layer of complexity to their jobs.

At this stage of the implementation plan, the exact use cases and workflows for the simulation tool were not defined yet. The general understanding of what process flow simulation can bring to the table and the motivation of the managers to introduce this capability to the engineers' toolset has nevertheless allowed this project to move forward, with the next step being the search for and selection of a process flow simulation tool that would meet the company's needs.

3.4 Selection of the simulation software

When a company embarks on a project in which a new software tool for long-term usage is set up to be acquired, the engineering team becomes responsible for the comparison of the technical capabilities of the different options on the market, whilst the management concerns itself with the financial and possibly strategic aspects of purchasing a product from one or another software provider. The current use case followed the same pattern.

As process flow simulation has not been established as a tool at the company prior to this initiative, there were no Subject Matter Experts (SMEs) locally or globally within the firm to consult with; the framework for the software selection, as well as the entire implementation process, had to be newly defined. The author was paired with one automation engineer who has worked at the company for more than half a year, whose task was to assist the author in performing the project steps according to the company's ways of working.

The first step was to get a grasp of how many simulation software options were available on the market. An initial list of 24 options was made, out of them 9 supported only 2D simulation, 6 – only 3D, whilst the rest offered both options. Information on the price, availability of a demo or trial version of the software, as well as the existence of trained experts and/or sales representatives in Estonia was collected. Around 30% of the tools came from smaller providers and did not have any local support. Some of the options also required other software in order to operate, i.e. some were just plugins and not standalone programs. Taking the aforementioned factors into account, the list went down to 16 software options.

Deeper research started with the goal to understand the pros and cons of the 16 tools, based on the assessment of various online reviews and comments. Websites such as Capterra [21] proved to be very useful at this stage. A summary of comments was made for every software option. On the basis of the pre-testing analysis, a top 10 list was made. The remaining 6 were discarded.

Whilst reviews written by users and independent evaluators were considered, it was decided to acquire a trial of every software and test it out in-house based on a basic, made-up production line. The process diagram in *Figure 3.4.1* showcases the test scenario. The ability to route out units based on a percentage (e.g. 5% of the units go to repair), as well as to define the processing time in the form of a range of possibilities (in 90% of the cases, the test time is 120 s, whilst in 10% - 500 s), was a vital requirement for the software.

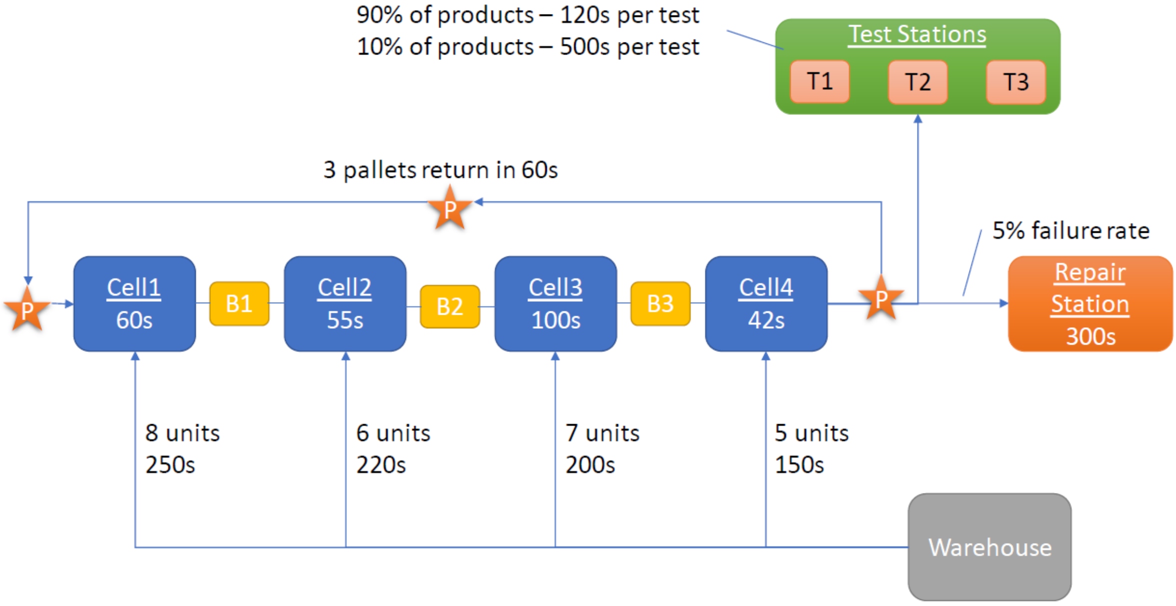


Figure 3.4.1. Diagram of the simulation test scenario.

Aside from testing the process steps of different software to get to the goal of creating the model shown in *Figure 3.4.1,* a set of comparison criteria was established. The parameters, together with the explanations, are brought out in *Table 3.4.1.*

Criteria	Description
Computational overhead	Can you smoothly run a simulation of the size you need?
UI (User Interface)	Is the program well-structured? Can you find all needed components easily?
Reports	Are the reports easy to read? Do you get all the information you need?
Functionality & configurability	Does the software offer all the functions that you need to make an appropriate simulation model? Can you configure the model exactly to your liking?
Easy to learn	How easy is it to build a working model with little to no training?
Support material	Is it easy to find support material (instructions, tutorials, user forums, etc.) in case you get stuck?
Visual appeal	Is the created model visually appealing to you? Do you like the animation, icons, etc.?
Interoperability	Does the software work with other systems within the company?

Table 3.4.1. Testing assessment criteria.

It was decided not to use a weighted factor model, as all parameters were deemed equally important. A scale of 1-5 (1 – poor, 5 – excellent) was used to assess the programs.

The software was tested keeping in mind that the future users of the software – the manufacturing and automation Engineers – may have never used a discrete-event simulation tool before, and that a long, in-depth training of the tool would not be possible, as the tool was aimed to only assist engineers in their decision-making, not become one of the primary job tasks. So, the author did not go through training and did not follow any tutorials when testing the tools, with the main goal of checking how easy it was to get around the interface for a first-time user. The easier to use the tool is perceived by the engineers, the more motivated will the engineers be to learn it. And, considering the reserved outlook of the engineers on simulation, it was of high importance to accommodate the tool to them. For the same reason, the user interface was also assessed by its similarity with other software commonly used by them, like Microsoft Office.

From the 10 simulation software contenders in the list, for 2 of them a trial could not be acquired during the time of the testing. So, in the end, only 8 programs were tested. By the end of the end of this phase, the test model could not be fully made in some software. As the test scenario included basic functions that every discrete-event simulation tool is able to handle, there was no doubt that it was possible to finish constructing the model in this "failed" group of tools. Yet if other tools allowed for a faster, more comprehensive model creation with no training, then these latter options would be preferred.

The final evaluation of the tools can be found in *Table 3.4.2*. Options F & G were the software tools for which a trial could not be acquired on time. Option H received the highest score out of all – 35 points from the maximum 40 points. Option C came in close second with 33 points, and the 3rd best software got 3 points less – 30 points. Option A fared the worst with 21 points on 8th place.

ID	Software name	Computational overheads	UI	Reports	Functionality & configurability	Easy to learn	Support material	Visual appeal	Interoperability	SUM	Ranking
1	Option A	3	3	2	4	2	3	2	2	21	**8.**
2	Option B	4	3	3	4	2	2	5	2	25	**6.**
3	Option C	5	5	5	5	5	4	3	1	33	**2.**
4	Option D	2	3	3	5	2	4	5	4	28	**5.**
5	Option E	5	4	3	5	5	5	2	1	30	**3.**
6	Option F										
7	Option G										
8	Option H	5	4	4	5	5	5	3	4	35	**1.**
9	Option I	5	4	4	5	3	5	2	1	29	**4.**
10	Option J	5	4	2	3	4	3	2	1	24	**7.**

Table 3.4.2. Software testing results. Names of software tools hidden, signified instead with Options A-J.

Option H came from a large software and manufacturing solutions provider and included the possibility to simulate both in 2D and 3D. Its weakness lied in medium visual appeal, despite the feature of constructing 3D layouts. The documentation for the software was exhaustive, and it also scored high on the interoperability criterium, as it could be connected with some crucial production programs at the company. Some of its controls were not intuitive, whilst some UI elements were well-made, such as the tabs in the menus being color-coded or a specialized button that automatically created a utilization chart and highlighted the bottleneck process.

Option C, the 2nd best software, included a simple 60-second introduction to the user-interface during the first start-up which meant that the tool was user-friendly, easy to learn, and the provider emphasized the value a lot within the tool. The UI is clean in the sense that only the essential building blocks are shown which would motivate a first-time user to explore the tool right away. Custom report capabilities, easy definition of routing logic, and the naming convention of processes is not programmatic, which, surprisingly, differs from a select number of other tools on the list. The only weakness of Option C lies in the lack of 3D simulation.

Finally, Option E is a popular process flow simulation tool used in academia with lots of support material online. It uses little computational resources and is a stable tool with little to no bugs. The visualizations in the software are outdated, yet the UI is relatively simple enough for first-time users to use.

Accompanying the simulation testing results was the feature comparison table shown in *Table 3.4.3*.

	A	B	C	D	E	H	I	J
Comprehensive library of process blocks	✓	✓	✓	✗	✓	✓	✓	✓
Support for multiple types of entities	✓	✓	✓	✓	✓	✓	✓	✓
In-built separation of materials and products	✗	✗	✗	✓	✗	✓	✗	✗
Simultaneous run of multiple experiments	✓	✓	✓	✗	✓	✓	✓	✓
Reporting (with charts)	✗	✓	✓	✓	✓	✓	✓	✓
Build KPI dashboard	✓	✓	✓	✓	✓	✗	✓	✓
Automatic suggestion of efficiency improvements (e.g. OptQuest)	✗	✗	✓	✗	✓	✗	✓	✓
Most commonly used probability distributions	✓	✓	✓	✓	✓	✓	✓	✓
Custom probability distributions	✓	✓	✓	✓	✓	✓	✗	✗
In-built machine setup time & downtime definition	✗	✓	✗	✓	✗	✓	✗	✓
Shifts definition	✓	✓	✓	✗	✓	✓	✓	✓
Cost calculation	✗	✓	✓	✗	✓	✓	✓	✗
"Buffer"/"Queue" block	✓	✓	✓	✓	✓	✓	✗	✓
2D visualization	✓	✓	✓	✗	✓	✓	✓	✓
3D visualization	✓	✓	✗	✓	✓	✓	✓	✓
Upload of prod. area data for analysis (via Excel)	✓	✓	✓	✗	✓	✓	✓	✓
Animation of unit transfer	✓	✓	✓	✓	✓	✓	✓	✓
Import of Creo files	✓	✓	✗	✓	✗	✓	✓	✓
Import of SolidWorks files	✓	✓	✗	✓	✗	✓	✓	✓
Interoperability with ABB RobotStudio	✗	✗	✗	✓	✗	✗	✗	✗
Import of SAP data	✗	✗	✗	✗	✗	✓	✓	✓
Import of 2D factory layouts	✓	✓	✓	✓	✗	✓	✓	✓

Table 3.4.3. Feature comparison of simulation tools. Options F & G, not tested, were omitted from the table.

The evaluation table was presented to the management involved in this project, and they have made an internal assessment of the strategic and financial aspects of the simulation tools. In the end, Option C that took second place in the tests was selected. Although Option H offered extra features, it was 3-4 times more expensive than Option C. Selecting a less expensive new tool also minimized the risk of big financial losses in case the implementation project would end up crashing. At this point it can be revealed that the 2D discrete-event simulation tool named SIMUL8 was hidden under Option C. The subsequent steps of the implementation plan were carried out with and based on SIMUL8.

In retrospect, after having have used the tool for more than 1.5 years and receiving feedback from other engineers, SIMUL8 ended up being the better option anyway. The author happened to have taken a university course where Option H was taught and where one of the course tasks was to create a full production line in it, and a number of parameters required more mouse clicks and more background knowledge of the internal functioning principles of the software to be set up, compared to SIMUL8. This fact proves that only long-term usage of a tool can give the full picture of it. In a later chapter, the implemented software will be assessed after 1 year of usage in detail, but already here it can be mentioned that the software ended up serving the needs well.

3.5 Business case for the simulation implementation project

With the simulation software now chosen, a business case could be written for the project. The main points from document are presented in *Table 3.5.1*.

Business case topic	Content
Aim of the project	To introduce process flow simulation as part of the standard workflow at the supply site
Current situation	• Excel + line-balancing tool used for line analysis • No simulation tool available
Other software	Not available; global solution will be implemented several years later
Work already done	• Simulation software comparison • Best selected (SIMUL8)
Strategic impact of the initiative	• Expected result: better decision-making • Connection to organization's strategies: Industry 4.0 ambitions • Efficacy objectives: increased competence, an example to other supply sites, optimized production lines and processes
Scope of included work	• Acquire license for SIMUL8 • Simulations Engineer builds simulation models for various lines and systems • Interim assessment of the tool • Train automation and manufacturing engineers to use the tool • Define new workflow
Roles involved	Manufacturing engineers, automation engineers
Complexity level	• Medium • Complexity factors: initiative will require monetary and human resources; during

	training, reduced productivity of the manufacturing engineers and automation engineers
Cost-benefit analysis	• Cost: SIMUL8 license between 3000-5000 EUR [22], potential training costs • Benefits: better insight into the processes of the factory, better decision-making leading to cost savings, reduced cycle times, and higher utilization
Project deliverables	Automation and manufacturing engineers trained to use a simulation tool
Change management	• Preparatory info sessions for automation and manufacturing engineers before training commences • Bi-weekly check-in to gain feedback and solve issues • 2x 2 h training sessions
Status & progress monitoring	Bi-weekly meetings of simulations engineer with management team

Table 3.5.1. Overview of business plan in tabular form.

As for any project, a SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis should be made (see *Figure 3.5.1*).

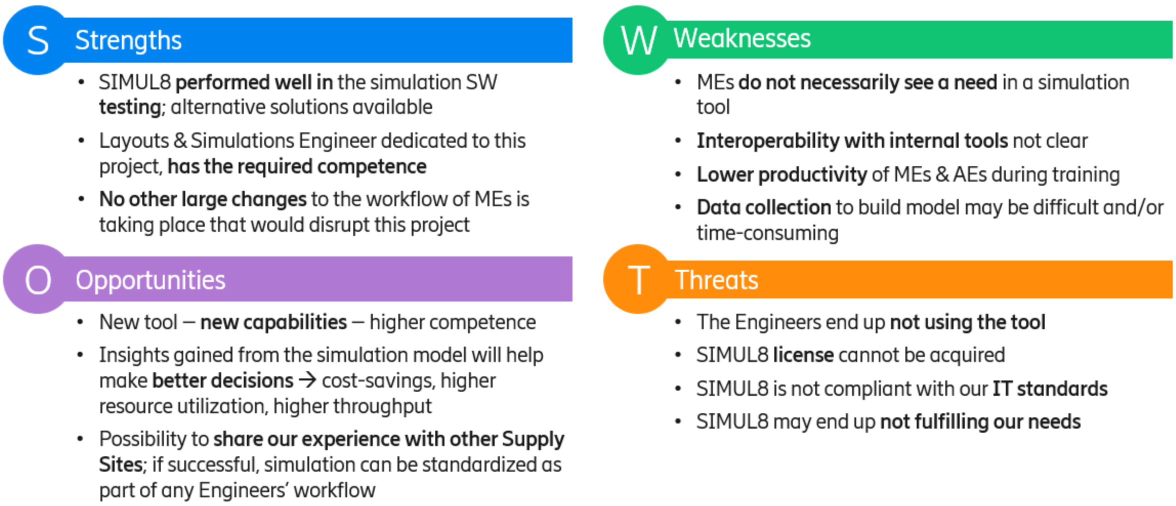


Figure 3.5.1. SWOT analysis of project.

The threats listed in the SWOT analysis are to be assessed through the use of a risk matrix (see *Figure 3.5.2*).

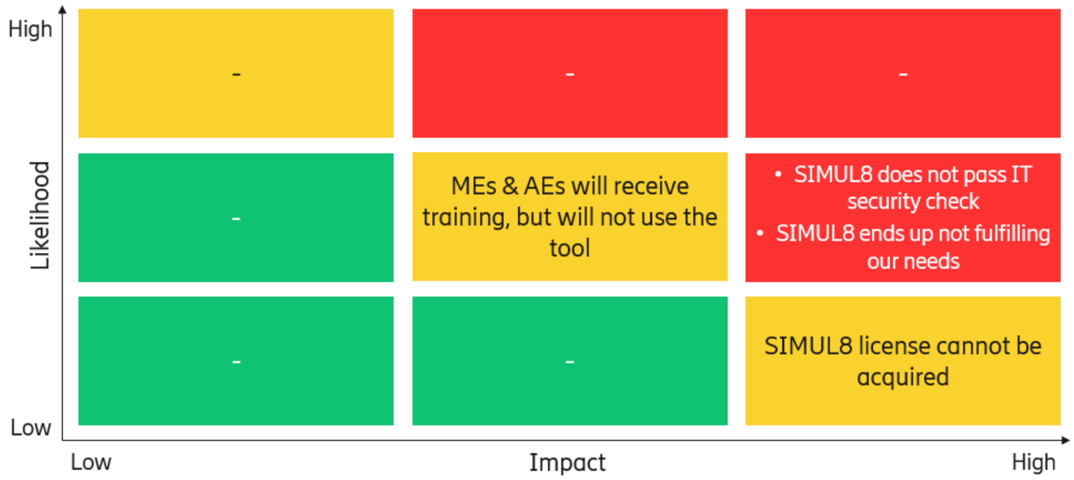


Figure 3.5.2. Risk matrix.

Risk mitigation measures for all 4 cases are written in *Table 3.5.2*.

Risk	Category	Solutions
SIMUL8 license cannot be acquired due to limited budget	High impact, low likelihood	• Request for budget replenishment from Head of Supply Site if possible • Wait for start of new fiscal year • Seek for less expensive simulation software options
SIMUL8 does not pass IT security check	High impact, medium likelihood	Seek for other simulation software option
SIMUL8 ends up not fulfilling our needs	High impact, medium likelihood	• Contact vendor to seek for solutions (clarify workflow, ask if the software can be customized, etc.) • Seek for other simulation software option

The manufacturing engineers and/or automation engineers will be trained but will not use the tool	Medium impact, medium likelihood	• Find reason for aversion • Provide additional training if needed • Implement certain management strategies (for example, small rewards to those who build the most simulation models in a week or month) to motivate the team

Table 3.5.2. Risk mitigation plan.

Finally, an action plan was created for the simulation implementation initiative (see *Table 3.5.3*).

Action step	Duration	Resources required	Desired outcome
Acquire SIMUL8 license + IT compliance check	2 weeks	- Budget for purchase - Approval of Manager of Production Technology - IT compliance test by local and global IT teams	Ready-to-use SIMUL8 license, approved by IT
Learn SIMUL8	1 week	- Human resource: layouts & simulations engineer - Technical resource: SIMUL8	Layouts & simulations engineer is accustomed to the tool and can build simulation models
Create simulation models	4 weeks	- Data about structure and processing times for production lines, given by manufacturing engineers - Human resource: layouts & simulations engineer - Technical resource: SIMUL8	Built simulation models of several production lines and systems, with results report
Process feedback about tool and workflow	0.5 weeks	- Human resource: layouts & simulations Engineer	Decision about next steps (proceed with SIMUL8 or choose another tool)

Compose training material and define workflow for MEs and AEs	1-2 weeks	- Human resource: layouts & simulations engineer	Workflow and training material ready
Train MEs and AEs to use SIMUL8	4 weeks	- Human resources: layouts & simulations engineer, manufacturing engineers, automation engineers	All manufacturing engineers and automation engineers ready to use SIMUL8
Define new ways of working for MEs	2-3 weeks	- Human resource: layouts & simulations engineer, manufacturing engineers - Technical resource: SIMUL8	Select manufacturing engineers take in simulation requests within a specified scope

Table 3.5.3. Action plan.

The business case ended with the simulations engineer recommending moving forward with the project due to the potential gains that the implementation of simulation software can bring. Simulation software is a helpful tool that can analyse as-is systems and test out what-if scenarios. It is designed to aid in decision-making yet is not capable of automatically suggesting solutions to existing problems. For example, bottlenecks in the production line or process flow will be highlighted, but it is up to the respective employee, team or department to come up with a solution and make the final decision.

3.6 Training of the new tool

After the acceptance of the business case, it was the task of the management and the indirect purchaser to negotiate the price for the licenses and sign the contract for the software usage. The software provider offered a paid training where a team of up to 10 people would be introduced to the tool. The total number of automation and manufacturing engineers was 23 people, and their use cases for the simulation tool differed. As such, it would have been inevitable to purchase 3 trainings packages (2 to cover the manufacturing engineering team, and 1 – for the automation engineers). The total cost for the training alone would constitute more than 20 000 EUR, according to the prices that SIMUL8 has shared with the company via email. After performing a cost-benefit analysis on the training cost, the offer was deemed not worth the price, considering that the company has a dedicated resource – the simulation engineer – to drive the implementation and create the needed training for her colleagues. As a matter of fact, a custom-made training, designed after the use cases of each engineering role, from a person who grasps the ways of working of the company would produce better results, as a trainer's relatability was identified as a critical aspect of an effective training [23].

Before teaching others to use the tool, the simulation engineer learned the software through the means of a free-of-charge online training provided by SIMUL8 [24], as well as by applying the tool for real-life use cases. The licenses for the software were set up in January 2021, and the author spent 4-5 months using the tool for simulating production lines, automated systems, and even AGV movement routings. After the tool has been tested on these examples, a comprehensive beginners' training could be constructed.

Whilst the official support website of SIMUL8 includes articles and examples files that would help first-time users make a model, a "cold referral" to the website would send a negative message to the engineers, and they would not be motivated to pursue learning the tool. Studies show that adult learners are more independent and responsible compared to children [25] [26], so providing material for self-learning would have been a viable option. Nevertheless, students tend to show a higher level of engagement in an active-learning group environment as compared to passive, individual learning [27]. The company acquired 3 floating licenses, so a live practice lesson in which the engineers would follow the author's instructions step-by-step was not possible. The acquisition of more licenses was not deemed as an appropriate solution, considering that it was hard to assess how often the engineers would use the tool after the training. As such, the training was structured as two lectures, and after each the engineers received a homework assignment through which they could test out the showcased features and try out the software. After the training and homework submission the engineers had to go through an exam developed as a multiple-choice test via Microsoft Forms. One of the assignments in the test was the task of building a model based on a given process flow diagram. The SIMUL8 file had to be sent to the simulation engineer, and the in the test there were 2 questions related to the built model. The training structure can be found in *Table 3.6.1*.

Study item	Content	Time required for item
SIMUL8 Training – Session 1	• General introduction to simulation (definition, competitors using simulations, benefits of simulation, common difficulties when building a model, formula of simulation)	2h

	• Kahoot quiz game for general introduction to simulation • SIMUL8 Basics I (interface, basic Building Blocks, entry of processing times, Reports)	
Homework 1	• SIMUL8 Basics I	0.5-1h
SIMUL8 Training – Session 2	• SIMUL8 Basics II (change simulation run time, process efficiency, process utilization) • SIMUL8 Routing & Label use cases (conditional routing, Routing Out property, Labels, conditional processing timings) • SIMUL8 Tips & tricks (Replicate capacity, Segregate End Results, High Level Analytics Panel, Duplication Wizard, Travel Time Matrix) • Kahoot quiz game for SIMUL8 Basics II, Routing & Label use cases	2h
Homework 2	• SIMUL8 Basics II • SIMUL8 Routing & Label use cases	0.5-1h
Exam	• 12 multiple-choice simulation theory questions • 1 practical assignment (covering SIMUL8 Basics I, II, and Routing & Label use cases) • 2 questions relating to the results of the practical assignment	1h

Table 3.6.1. Structure of Simulation Basics training.

It was decided to teach the engineers not all functions that SIMUL8 supports, but the essential parts that would allow them to build the models required. These include: definition of process flow simulation, basic model building (e.g. the exploration of simulation objects such as Start Points, Activities, Queues, and Ends), simulation run time setup, results analysis (via the Results Manager and process utilization charts), routing logic (e.g. Routing Out disciplines from Activities), and Labels. SIMUL8's scripting language Visual Logic, the simulation optimization engine OptQuest [28], and the connection setup to external data sources such as Excel and SQL were not covered by the training.

The trainings were carried out using PowerPoint slides, with the simulation engineer acting as a trainer, explaining the topics, showing live demos in SIMUL8, sharing her experience working the tool and handling simulation requests from project managers and other roles. The trainings were held in the summer of 2021, when the COVID-19 pandemic was still active. In-person meetings and trainings were possible, but in smaller groups. Also, some engineers worked at home. Thus, a hybrid model of teaching was performed – through Microsoft Teams and in-person in a meeting room. The slides were made not only for the purpose of visual aids of the speaker, but to also serve partially as instructions on how to access certain capabilities of the software. *Figure 3.6.1* and *3.6.2* showcase slides from Session 1 of the SIMUL8 Training. The design of the slides is simple, colourful, and highlights the most important parts of the user interface.

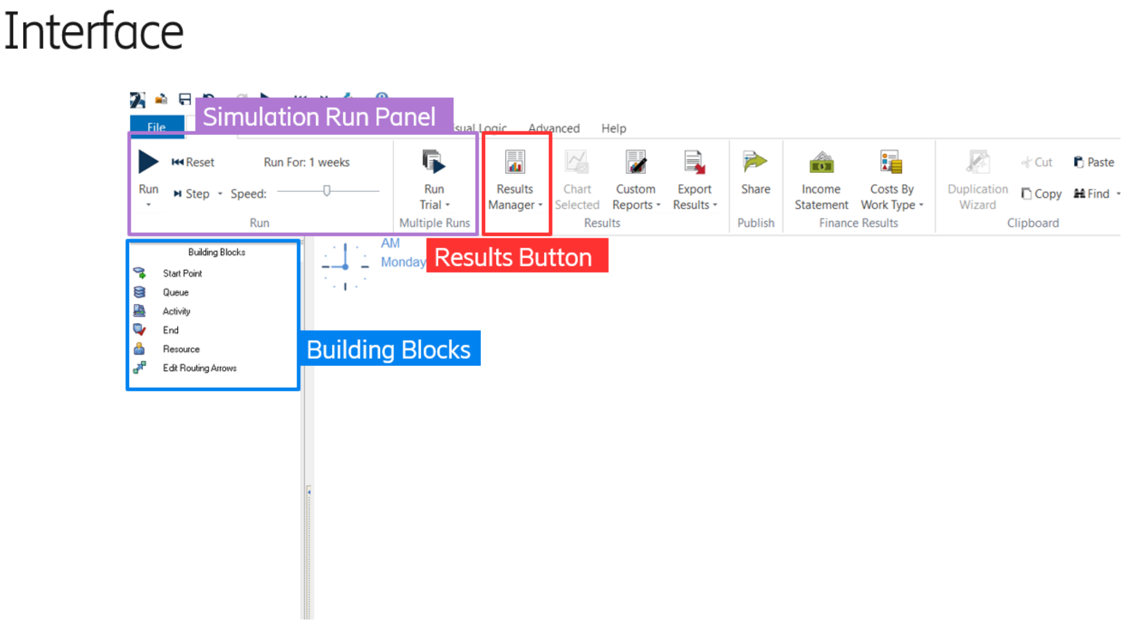


Figure 3.6.1. Slide showing SIMUL8's user interface from Session 1 of the training.

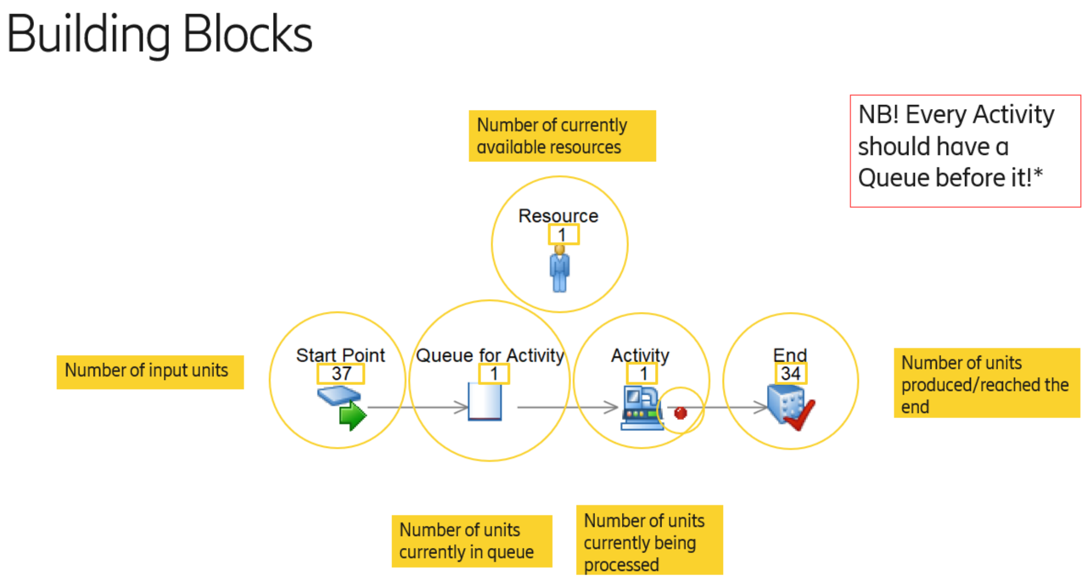


Figure 3.6.2. Slide showing SIMUL8's building blocks from Session 1 of the training.

For more complex concepts, such as product routing, flowchart-like images were made for better understanding (see *Figure 3.6.3*).

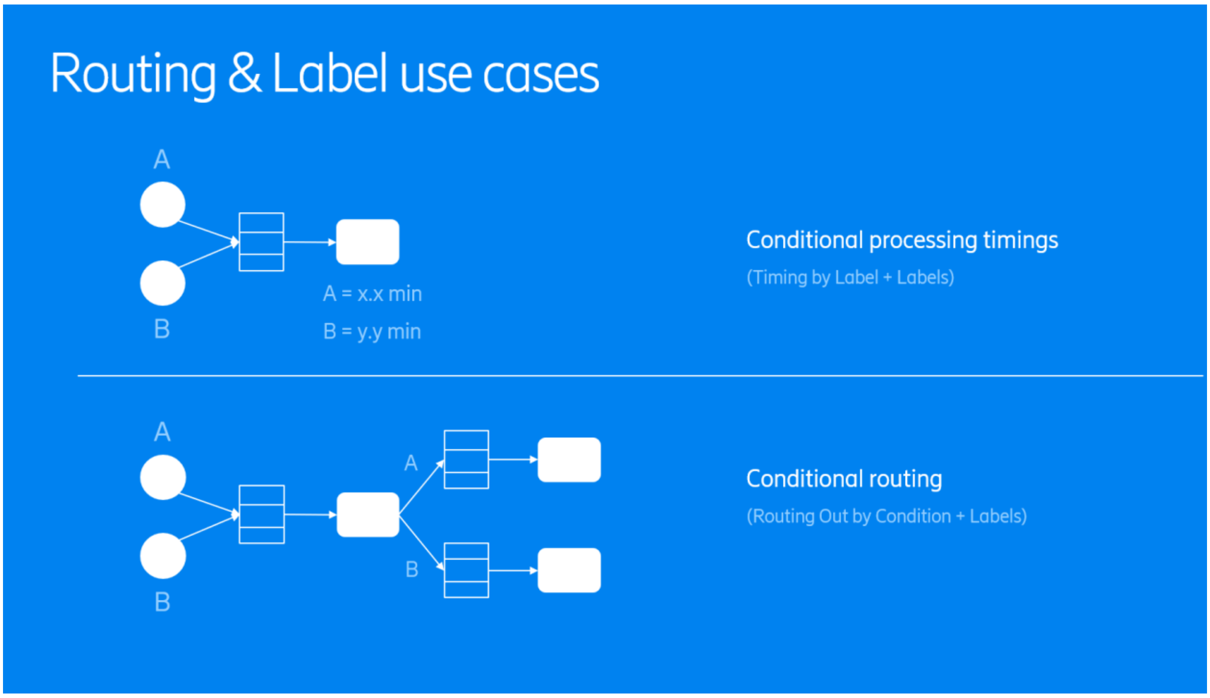


Figure 3.6.3. Slide showing Routing & Label use cases from Session 2 of the training.

Some slides resembled instructional user guides for software, as shown in *Figure 3.6.4*.

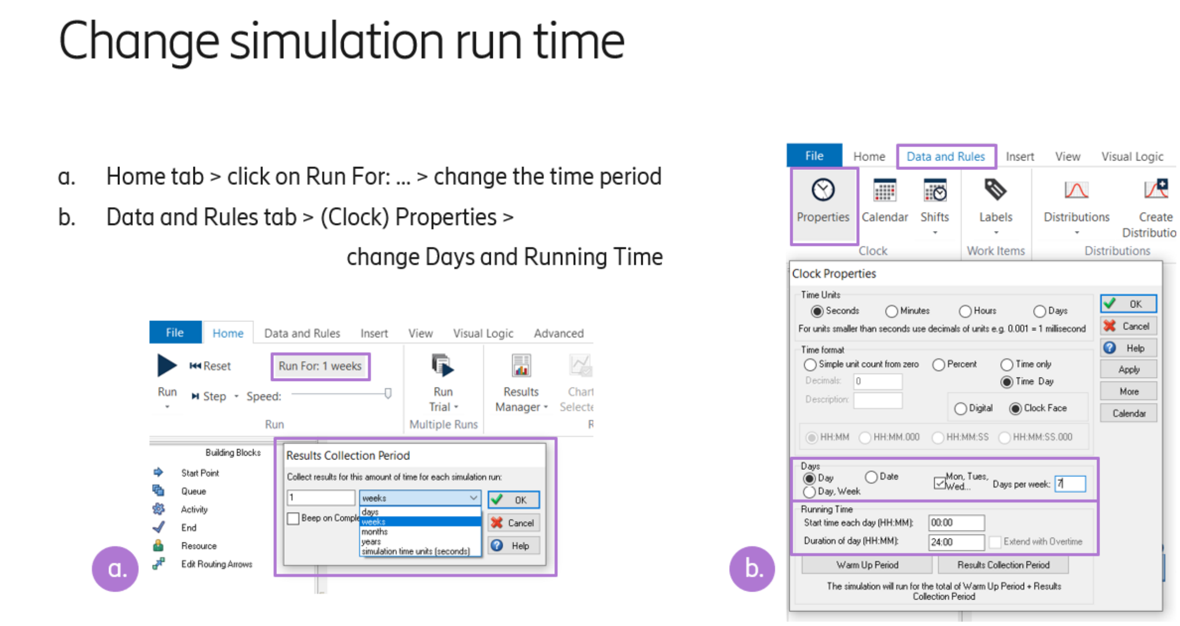


Figure 3.6.4. Slide showing the steps to change the simulation run time from Session 2 of the training.

Kahoot [29], a quiz-based learning platform, was used during training sessions for a short test of the engineers' knowledge gathered so far. Once a quiz is developed by the trainer, the live game starts with the players logging into the game through the web browser or the mobile app. Every question is presented with multiple answer possibilities and had a time limit. The faster one answers a question correctly, the more points the player gets. *Figure 3.6.5* displays a Kahoot game for Session 1 in preview mode from the quiz editor's side. On the left is the view that the player gets on their phone during gameplay where they must choose one of the answers. On the right is the common view projected from the quiz developer where the players can see the question and the possible answers.

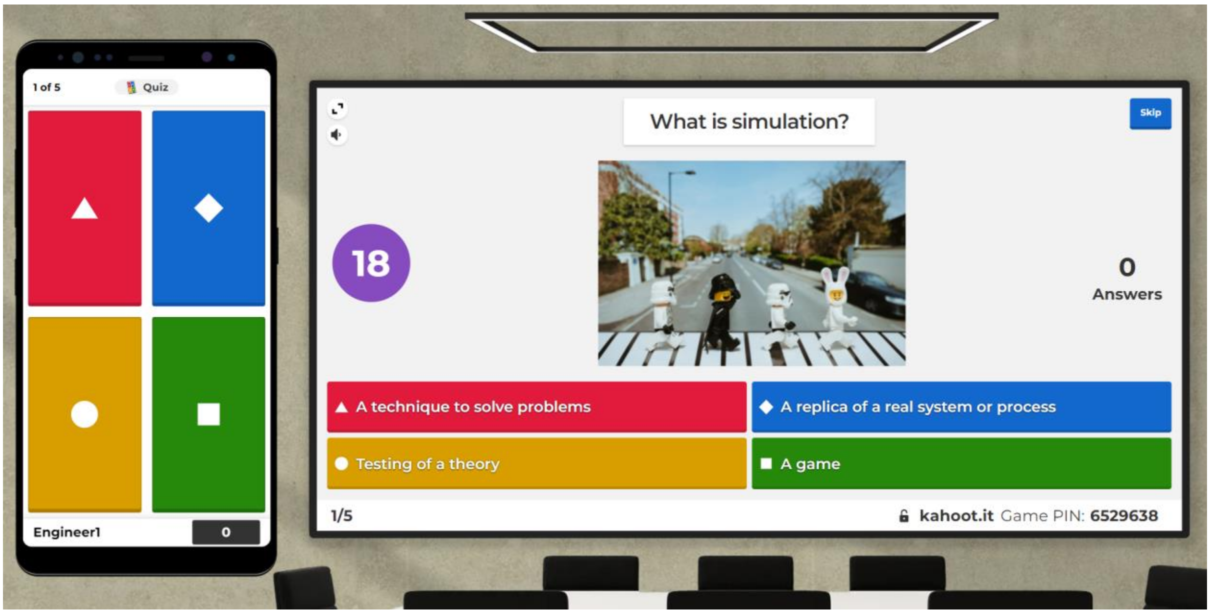
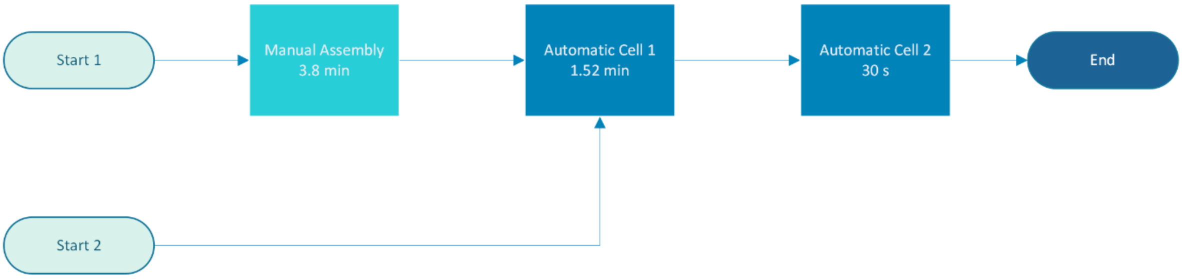


Figure 3.6.5. Kahoot quiz game in preview mode.

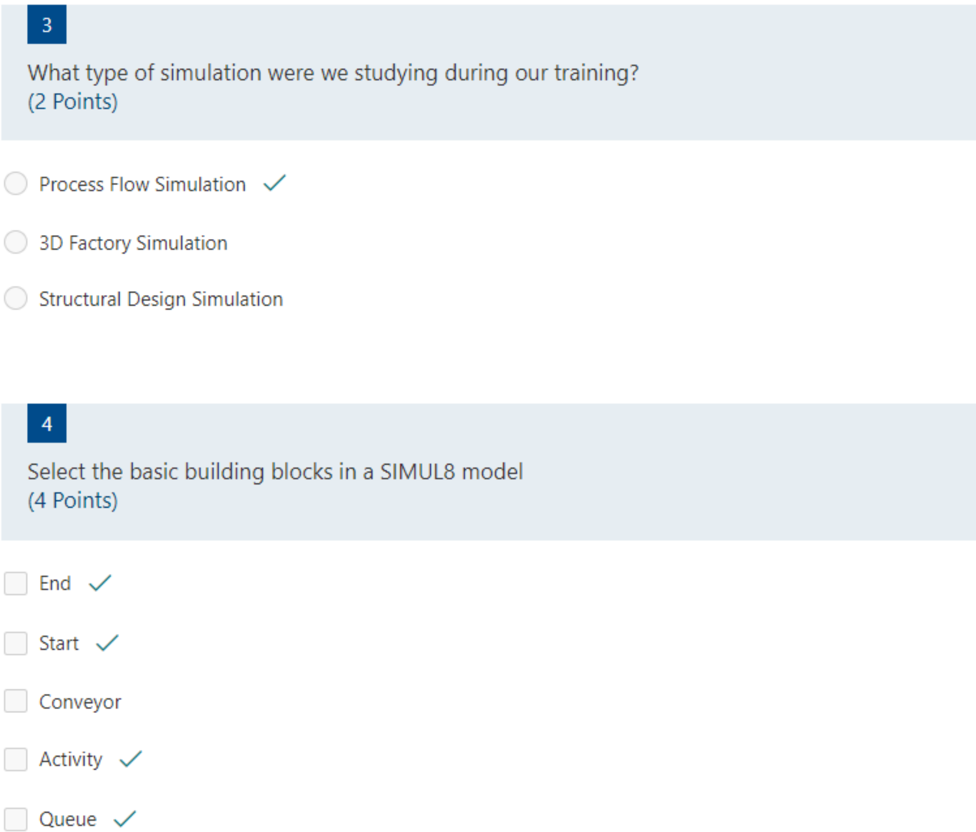
After each training session, the engineers received homework for the completion of which 1 week was given. The homework consisted of a process flowchart and a list of conditions. An example of a homework from Session 1 of the training is shown in *Figure 3.6.6*.

After submitting both practical assignments, the engineers had to take a test to check their knowledge. Some examples of the test questions can be found below (see *Figure 3.6.7*). The theory questions covered both the general topic of simulation, as well as SIMUL8-specific features.



1) Arrival time of units at Start 1: 180 seconds, Exponential distribution
2) Arrival time of units at Start 2: 2 min, Exponential distribution
3) Buffer size between Start 1 and Manual Assembly: 4 units
4) Buffer size between all other Start points and between all Activities: 2 units
5) Average distribution in Manual Assembly station
6) Fixed distribution in both Automatic Cells
7) **2 human resources allocated to Manual Assembly

Figure 3.6.6. Homework example.


3

What type of simulation were we studying during our training?
(2 Points)

Process Flow Simulation ✓

3D Factory Simulation

Structural Design Simulation

4

Select the basic building blocks in a SIMUL8 model
(4 Points)

End ✓

Start ✓

Conveyor

Activity ✓

Queue ✓

Figure 3.6.7. Exam questions examples, with the correct answers marked.

The practical assignment in the exam was built similarly to the homework – a process flow diagram was given with some conditions, and questions relating to the simulation results were asked.

The average score that the engineers received for the exam was 60 points out of the maximum of 70 points. This includes the results of both the automation and the manufacturing engineers. Out of 25 engineers who took the test, 3 of them had to correct their models in order to successfully complete the exam. Overall, the exam went predominantly well for the engineers, judging by the scores.

To get a better understanding of the engineers' experience during the training, an anonymous feedback survey was sent out to them. For this survey, separate results were collected from the automation and the manufacturing engineering teams. 5 automation engineers and 10 manufacturing engineers responded to the survey. *Table 3.6.2* shows the 5 questions from which the survey was composed.

	Question	Possible answers
1	How satisfied were you with the SIMUL8 training?	1-10
2	Name 1 thing that you liked about the training	Freeform
3	Name 1 thing that you disliked about the training	Freeform
4	Assess your SIMUL8 skills after the training	1-10
5	Any comments, suggestions, requests?	Freeform

Table 3.6.2. Questions asked in the feedback survey for the simulation training.

The automation engineers held a high opinion of the training, with 4 out of 5 people being promoters, whilst 1 person remained neutral (see *Figure 4.8*).

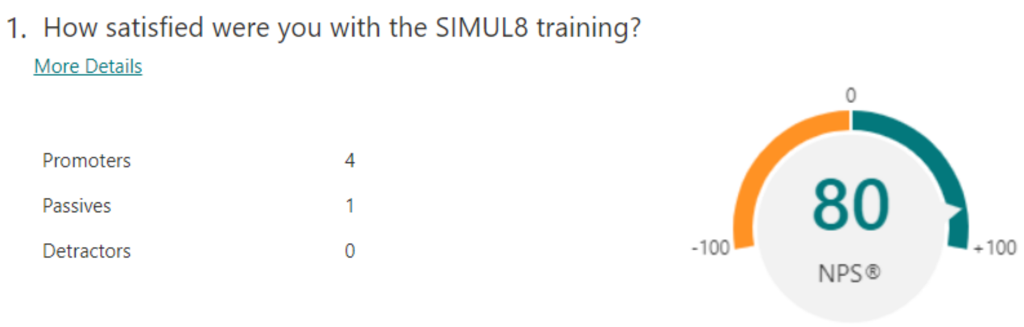


Figure 3.6.8. Net promoter score (NPS) question from the training feedback survey for the Automation Engineers.

The manufacturing engineers voted even higher – with 9 out of 10 people being promoters of the training (see *Figure 3.6.9*).

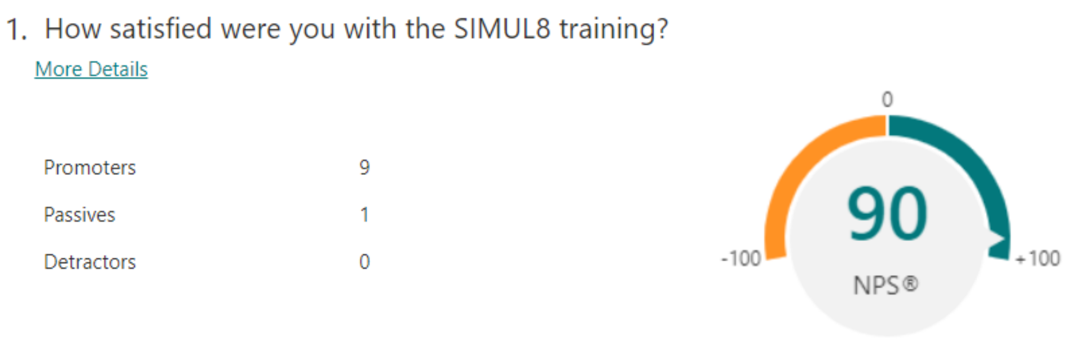


Figure 3.6.9. Net promoter score (NPS) question from the training feedback survey for the Manufacturing Engineers.

Both engineering roles praised that the presentations were well-structured and that the material was very understandable; positive attitude of the trainer as well as the interactiveness of the training was also highlighted. Many of the engineers did not point out any negative sides, but some commented on the unavailability of the SIMUL8 license at some point (since all 3 licenses were occupied at that time), the high speed of the presentation which required a rewatch of the recording, and difficulties with scheduling the training as some roles in that particular time period were very busy with other projects.

When it came to the self-assessment of the engineers' skills after the training, then the scores were modest compared to their satisfaction with the training material. Both groups showed an NPS of -20 points, with *Figures 3.6.10* and *3.6.11* displaying the individual answers.

4. Assess your SIMUL8 skills after the training

5 Responses

ID↑	Name	Score	Category
1	anonymous	7	Passives
2	anonymous	8	Passives
3	anonymous	7	Passives
4	anonymous	7	Passives
5	anonymous	5	Detractors

Figure 3.6.10. Responses to the self-assessment question from the Automation Engineers.

4. Assess your SIMUL8 skills after the training

10 Responses

ID↑	Name	Score	Category
1	anonymous	4	Detractors
2	anonymous	7	Passives
3	anonymous	6	Detractors
4	anonymous	7	Passives
5	anonymous	6	Detractors
6	anonymous	10	Promoters
7	anonymous	7	Passives
8	anonymous	7	Passives
9	anonymous	8	Passives
10	anonymous	7	Passives

Figure 3.6.11. Responses to the self-assessment question from the Manufacturing Engineers.

The mode answer is 7 out of 10 points, which according to the NPS scale belongs to the passive category but can be deemed as a "healthy" medium score. It is important to note that, at the time of conducting the survey, the engineers have not built a simulation model of their own lines; only the training exercises were done by them.
To the last question, the engineers noted that the training was good, and that they would be interested in an advanced course.
About 5-6 months after the completion of the training, the engineers received a check-up test consisting of 8 questions. 2 of the questions showed a model, and the engineers had to type in what mistakes they see in them, and the rest were multiple-choice questions. A total of 12 respondents participated in the quiz, and they collected an average score of 33.1 out of 35 points. This shows that, despite the engineers' modest self-assessment score, they retained the study material well, and showed critical thinking in the simulation domain by analysing existing models.

3.7 New workflow definition

With the completion of the simulation basics training, a plan was set with the management to create a workflow in which the manufacturing engineers and the automation engineers would include SIMUL8 as part of their toolset. Considering the differences in use cases for the two types of engineers, it was decided to create separate workflows, with the manufacturing engineers put as a priority. At the time of writing the thesis, the new Way of Working (WoW) for the automation engineers has not been composed, so the subsequent text will pertain only the manufacturing engineering team.

The main purpose of the training lied in the desire to hand over a portion of the simulation responsibilities onto the manufacturing engineers. The management's vision of discrete-event simulation replacing Excel-based analytical methods provided the motivation for this step. Although the layouts & simulations engineer's performance was not assessed as lacking, the distribution of work tasks among multiple people would offload her for other activities. Furthermore, as manufacturing engineer own the processes on the production lines, they have an innate deeper understanding of the production flow, as well as a quicker grasp of the data set required to make a model. These reasons lead to the formation of the assumption that the team would create simulation models faster, and potentially with a higher level of accuracy. The time that goes into collecting and understanding the input data by the layouts & simulations engineer can be seen as a waste. *Figure 3.7.1* visualizes the three benefits and two risks of the new setup.

Figure 3.7.1. Benefits and risks of the new Ways of Working (WoW).

Despite the fact that all manufacturing engineers (MEs) received the initial training, it was decided not to involve absolutely all team members. First of all, 4 Engineers have been allocated to the long-lasting bill of materials project, so extending their list of responsibilities would slow down their progress in that project. Secondly, although the average level of knowledge obtained from the training was on a relatively high level, not all engineers shared an excitement for the tool, or were quick in building models. Whilst it is still under discussion what the future plans regarding simulation for them would be, the author decided to engage people on voluntary basis, yet with the requirement that each product segment would have 2-3 people. The author set up a meeting with the MEs, explained the way forward, and made a list of candidates for the "Simulation MEs" role. A total of 8 manufacturing engineers agreed to take part in simulation activities.

The separation of tasks between the simulations engineer and the manufacturing engineers was expressed through assigning the latter with three specific use cases for simulation:

1. Layout change,
2. Trolley needs,
3. New product/data.

By defining the exact type of requests that the MEs would cover, less confusion would arise as the new workflow takes place, and the frustration in regard to who does what is spared.

As SIMUL8 does not offer 3D simulation and relies on the analytical representation of process chains as opposed to the physical location of workstations like in AutoCAD, the layout change use case is represented through a production line model where relevant transfer times (between stations, assembly halls, etc.) and workstation capacities are added or modified. For example, the new layout pushes the repair area to another hall which will introduce a significant transportation time from the test equipment to repair and back. The increase in the transfer time will affect the buffer size, throughput, and needed capacity of certain operations.

The trolley needs use cases means the calculation or estimation of trolleys needed to service the line. Here, the simulation model will be changed from the one where Start Points push products onto the line, to one where a Queue with the input number of trolleys feeds the line, and the trolleys return to the start and go again in cyclical fashion. Later in the statistics of the last process before the trolley queue the number of completed jobs, so, the number of units that the line has serviced, is shown. Provided this number meets the demand, the number of trolleys defined in the simulation will be enough.

Finally, the third use case covers the situation when a new product is added to the line, or the process timings change after a time-and-motion study, or the testing yields have improved. No new model has to be built here; existing models are updated and saved as new files. All other use cases outside of the aforementioned scope are to be handled by the simulations engineer.

To better communicate the workflow on the technical side and explain to the engineers how to handle different use cases, an advanced simulation training was composed. Although a number of new SIMUL8 features were showcased in the training, its main focus lied on the strategic thinking of solving simulation problems and requests. Before introducing new concepts, a warm-up exercise was conducted as well. The full scope of the advanced training can be found in *Table 3.7.1*.

Study Item	Content
Recap	• Simulation Basics I and II topics • Warm-up exercise
Use case: Layout change	• Main idea • Input data • General structure of SIMUL8 model • Demo
Use case: Trolley calculation	• Main idea • Input data • General structure of SIMUL8 model • Demo

Use case: Model update	• Main idea • Input data
Extra functions	• Queue Start-Up • Batching • Constraints • Scenario Manager • Groups • Custom Reports
New WoW	• Diagram • Simulation Wiki-Page • Progress assessment • Next steps

Table 3.7.1. Structure of Advanced SIMUL8 training.

Initially, 2 hours were allocated for the training, but due to more time being spent on the warm-up task than expected, a total of 3 hours (with breaks) were required.
The training did not include tests or homework assignments, as the basic technical knowledge has already been obtained and tested many times in the Simulation Basics training.
Below are some example slides from the advanced training. *Figure 3.7.2* shows how the "Main idea" slide for every use case was structured.

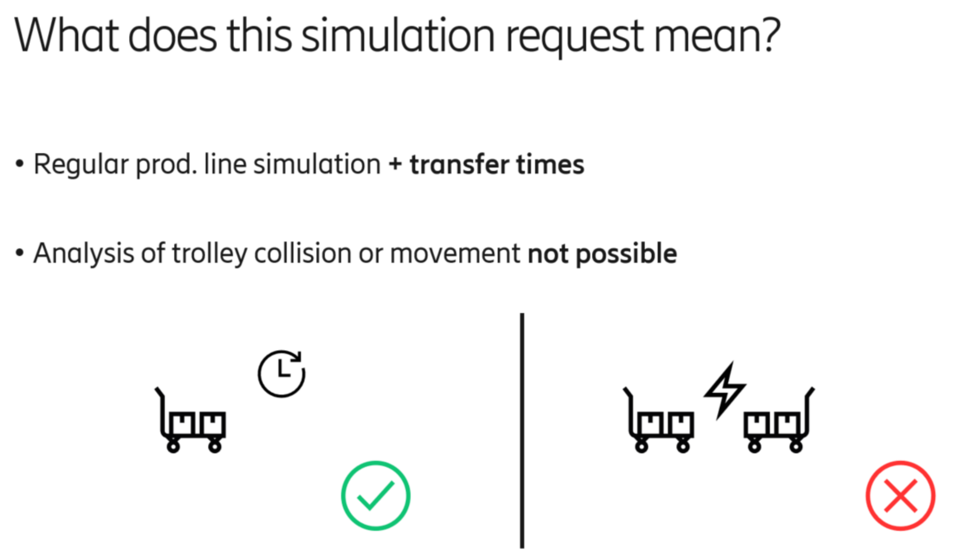


Figure 3.7.2. Slide explaining the general idea behind the layout change use case.

An example of a cyclical model required to test the set number of trolleys can be found in *Figure 3.7.3*.

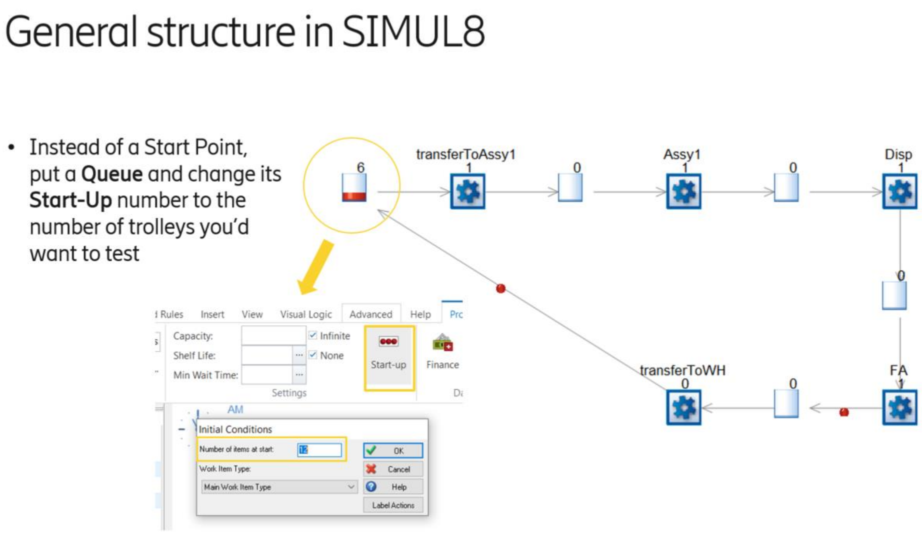


Figure 3.7.3. Slide explaining the method of setting up a trolley needs simulation.

When explaining the extra functions, the menu pathway was included on the slide, as well as a screenshot with marked buttons and input fields. Articles from the SIMUL8 Support website were linked too, for further reading (see *Figure 3.7.4*).

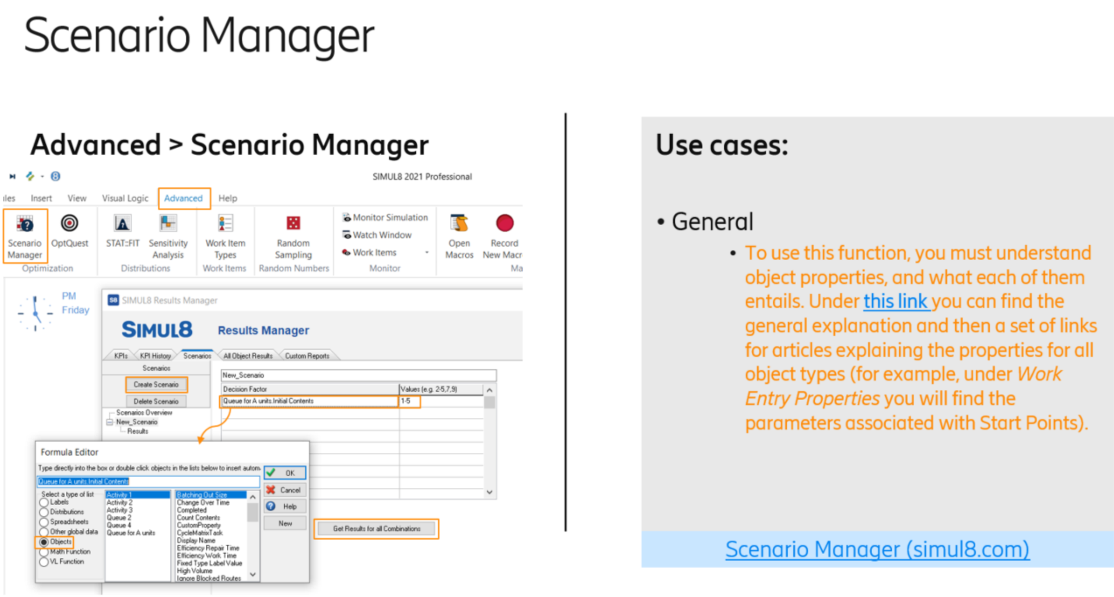


Figure 3.7.3. Slide with information about the Scenario Manager function in SIMUL8.

In the same training, the new way of working was explained. The select number of simulation manufacturing engineers would receive simulation requests from product owners and production managers, instead of turning to the simulations engineer. The MEs check if the request is covered by the three use cases that were agreed upon, and then either start simulating or send the outlier to the simulations engineer. The step of data collection is included in the new process flow, yet as MEs deal with this kind of information on the daily, it can be safely assumed that the time spent on this activity is rather small. After the model is built, the file is sent to the simulations engineer for verification. If the model does not require any rework, the MEs can present the results to the product owners and/or production managers. By the end of the simulation request, the file is uploaded to an internal simulation wiki-page where all done models are stored. The diagram for the new workflow is shown in *Figure 3.7.4*.

Other activities in relation to the new WoW introduction include the discussion and confirmation of the simulation RACI matrix with the manufacturing engineers, as well as a workshop with the product owners (POs) and production managers (PMs) on the new workflow, what simulation tool is used, and what can be expected of the engineers when they send it their requests.

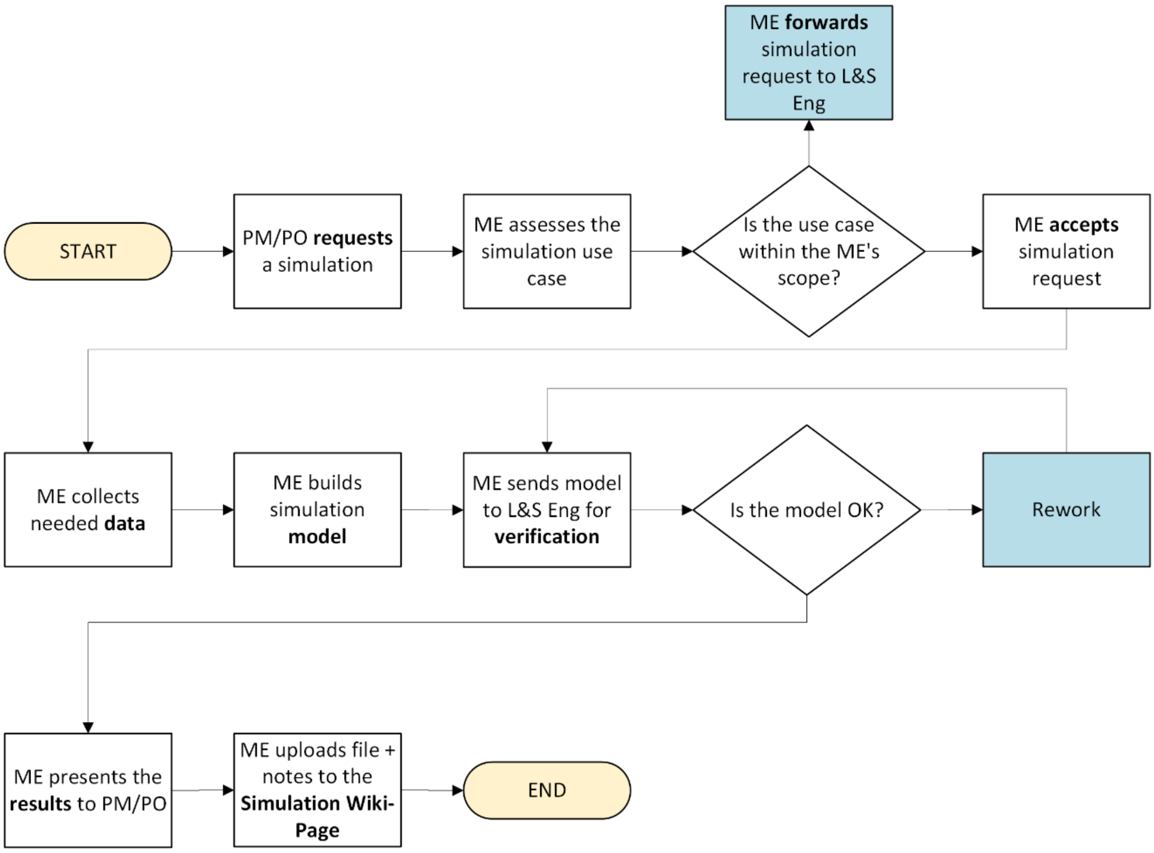


Figure 3.7.4. Process diagram explaining new workflow.

The manufacturing engineers were asked to track the time spent on simulation tasks. It is estimated that 8-10 hours or 5% of their worktime in a month will be dedicated to simulation. This was also communicated to the POs and PMs, so that they would have realistic expectations of the engineers. The MEs estimated a handling time of up to 2

weeks for each simulation request. It is important to note here, though, that while in the beginning the creation of a full model will certainly take a lot of time, the subsequent updating of the models with new information will be quick and will result in a lower occupancy of the engineers with simulation.
One month after go-live a progress check-in with the both the MEs as well as the POs and PMs was planned to take place with the goal of receiving feedback on the efficacy of the workflow.

4. IMPACT ASSESSMENT

By the time of writing this thesis, one month has passed since the new simulation workflow for the manufacturing engineering team has been implemented. This short timeframe does not allow to make a thorough analysis of the impact that the changes have brought. Nevertheless, two successful use cases for using process flow simulation will be brought out, one benefit from the workflow perspective will be described, and some observations of the negative kind in relation to the project can be found in the end of this chapter to provide a balanced outlook of the implementation process.

4.1 Success stories of using simulation software

The first story revolves around the application of discrete-even simulation for the estimation of trolley needs. Before parts of the simulation responsibilities were handed over to the manufacturing engineers, one employee recognized that the tool can be used to assist him in his issue: the number of trolleys needed, initially calculated in Microsoft Excel, did not match the requirements of the production line as expected, as there were several instances of production stop due to the warehouse not being able to supply the line with additional trolleys.

To determine the number of trolleys needed, the production line was to be simulated with the inclusion of data such as the processing times of the workstations, testing yields, and the capacity or number of machines or workstations serving at every process step. The breaks of the line operators were taken into consideration, lowering the station availability for work from 100% to 87%, and the weekly demand determined how many units were expected to be manufactured, with the shift times specified accordingly. The number of trolleys to test out in the system can also be seen as an input for the model. As a result of the simulation model, the throughput, so the number of units produced by the end of one week, indicated whether the demand was met or not with the set number of available trolleys. The overview of the simulation model inputs and outputs is visualized in *Figure 4.1.1*.

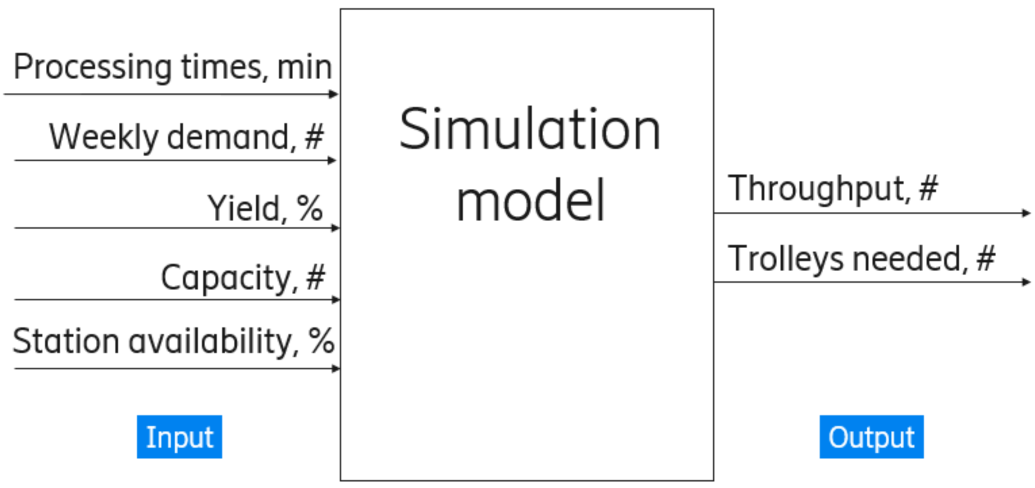


Figure 4.1.1. The inputs and outputs of the trolley calculation use case.

The next image, *Figure 4.1.2*, shows the redacted SIMUL8 model, including the indication of the initial number of trolleys being 9 pieces (see filled up Queue before Station 1). The closed-loop construction emulates the process of the trolleys being released after the successful completion of the second test, and the unloading time is taken into account.

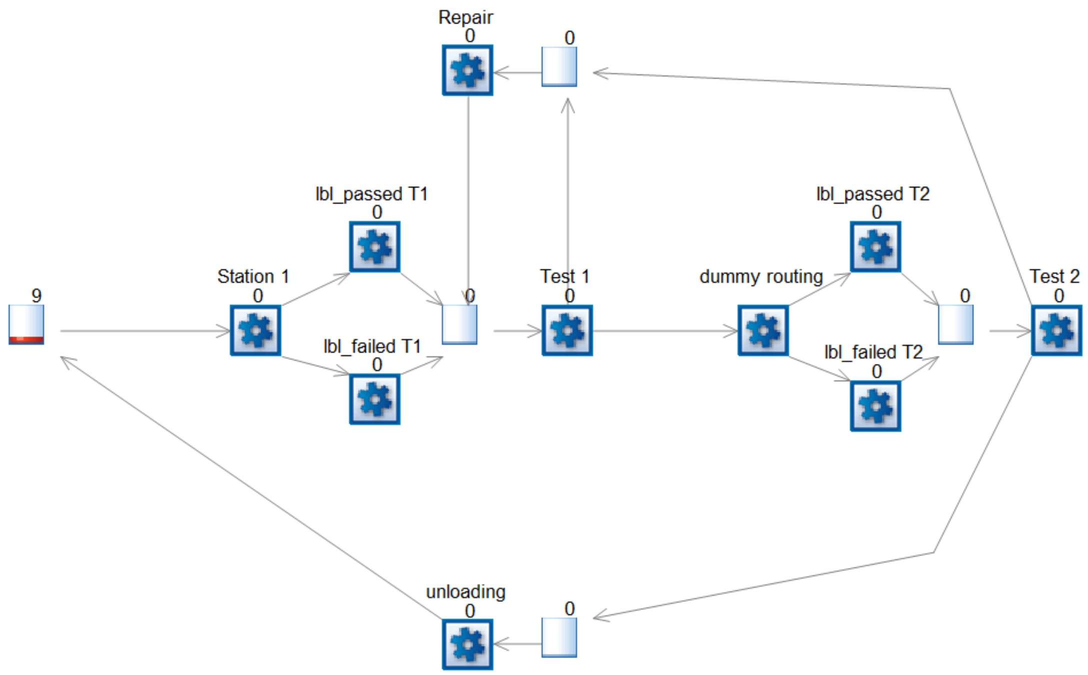


Figure 4.1.2. Redacted SIMUL8 model used for trolley calculation.

Some dummy processes were added to the structure to model specific routing logic using Labels and with the account of yields.

For a statistically accurate result, the Run Trial feature was used. This option automatically chooses the optimal number of runs that would cover the whole range of possible values of the selected KPIs. With multiple trolleys inputs being tested, the number of trials spanned from 4 to 10. The selected KPI – throughput per week – was expressed as the minimum, maximum, and average numbers. For the sake of simplicity, the results of the simulated scenarios will be displayed as the difference between the SIMUL8 result and the demand, shown in percent. The results are brought out in *Table 4.1.1*.

Number of trolleys	Difference between simulated throughput and the expected demand
9	-1,43%
10	-0,71%
11	1,43%
16	7,86%
21	14,29%

Table 4.1.1. Trolley needs simulation results.

The 9 trolleys initially set up for the line do not meet the demand. We observe a trend that the higher the number of trolleys in the system, the higher is the throughput. The most economical decision would be to deploy 11 trolleys, as that number would match the demand requirements ideally, and provide a small buffer for unexpected spikes.

Production stops are costly wastes and should be avoided whenever possible. The constructed simulation model provided a dynamic analysis of the issue at hand, with the inclusion of more variables compared to the simple Excel calculation based on cycle times. This proves the efficacy of the process flow simulation in detecting optimization capabilities that lead to cost savings.

The second success story revolved around using SIMUL8 to compare two fixture scenarios. One assembly line is handling a product mix where different products use different fixtures. The units are routed to testing machines according to the fixtures that are used on them. Recent developments in the product design would allow for the use of the same type of fixtures, and the impact of the changes on the throughput needed to be analysed.

The input data of the simulation is similar to that shown on *Figure 4.1.1*, except that the model is far more complex and includes also the thorough simulation of the repair flow. The changes needed to analyse the fixture impact, however, was simple – the

routing of the units from the buffer to the testers had to be changed in a way that all types of units could go into all testers, without any need for classification.
The throughput was once again chosen as the primary metric for the comparison of the simulation scenarios, yet the averaged-out utilization of the testers has also shown a drastic change with the implementation of a common fixture. *Table 4.1.2* shows the increase in throughput and utilization in the common fixture model as opposed to the AS-IS situation.

Product	Difference in throughput, %	Difference in tester utilization, %
Product A	11,54%	4%
Product B	66,67%	45%

Table 4.1.2. Changes in throughput and tester utilization in the case of a common fixture introduction.

The table reveals the drastic improvement of the selected metrics for Product B. The big jumps hint at the fact that with the existing setup with two different fixtures does not benefit Product B which is blocked from being tested by a nearby underutilized machine due to the fixture incompatibility. The increase in tester utilization at Product B furthermore leads to a balanced distribution of incoming products and, thus, a better production flow.
With the assessment of such a what-if scenario, fact-based decisions can be made for future changes in production flows, and the simulation results become the foundation for cost-benefit analysis.

4.2 Workflow assessment

Over the course of her employment, the author kept track of the time spent on building simulation models for the projects she was involved in. The assignments vary in complexity, so a one-to-one comparison between the author's lead time and that of the manufacturing engineers is not possible. Nevertheless, one of the reasons backing the workflow in which manufacturing engineers simulate process flows instead of the simulation engineer lied in the potential reduction of model building time. As manufacturing engineers own their processes and generate the data commonly needed as the simulation model inputs, the time required for the data collection step decreases.

Table 4.2.1 outlines the time spent in minutes for every simulation task for 4 different projects, as well as the percentage of the total time one or the other task required.

Project	Data collection	Model building	Report creation	Meetings (progress check-in, flow comprehension, etc.)	TOTAL (min)
Project AA	45	90	60	60	255
	18%	35%	24%	24%	
Project TP	255	780	330	180	1545
	17%	50%	21%	12%	
Project AM	50	1125	120	160	1455
	3%	77%	8%	11%	
Project BB	100	870	90	240	1300
	8%	67%	7%	18%	
AVERAGE (%)	**11%**	**58%**	**15%**	**16%**	100%

Table 4.2.1. Time spent by the simulations engineer on every type of simulation task (in minutes), based on the example of 4 projects.

The data shows a high level of variability of the time allocation for the tasks. For example, the simulations engineer spent somewhere between 35% and 77% of her time building the model, with the average being 58% of the time. We can conclude that the engineer spends most of the time working on the simulation, whilst the accompanying tasks, such as data collection, report creation, and attendance of meetings with the stakeholders take up roughly 1/6 of the time each. Figure 4.2.1 shows the average time distribution for the tasks, according to the data of the simulations engineer, in form of a pie chart.

The table and the diagram do not cover the time that simulations engineer has to wait until she receives the data after requesting for it. At times, a reply with the data would be given 1 week after first contact. Thus, it creates a significant delay in the continuation of the project.

Likewise, some of the meetings with the stakeholders included time spent on understanding both the problem statement as well as the data. A process owner would omit such meetings which would in turn contribute to the quick completion of the simulation request.

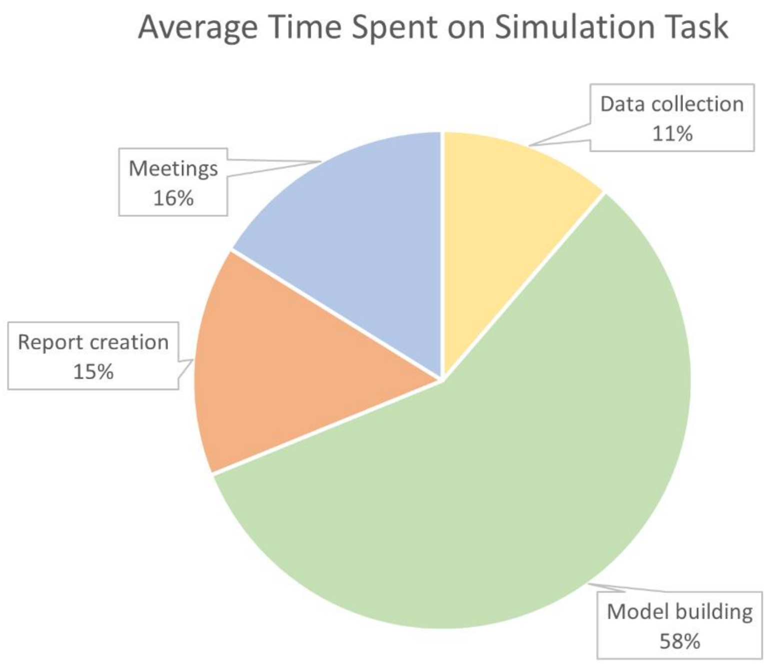


Figure 4.2.1. Average distribution of time allocated to different simulation tasks by the simulations engineer.

After conversing with the manufacturing engineers, rough estimations on the time spent on the aforementioned activities were made. They are presented in *Figure 4.2.2*, together with the comparison of the simulations engineer's data. We notice a significant drop on time spent on meetings, going down by 8.5 points. On the other hand, the model building time increases by 4.5%. This remark is especially relevant at the beginning, as the manufacturing engineers are still getting accustomed to the new simulation workflow and tool. At first glance, it seems that the data collection portion went up, yet the time reported for it by the manufacturing engineers was highly variable. If the data was already available in some previous time analysis, the data collection time was minimum. On the other hand, if, for example, potential transfer times from one station to another had to measured, the engineers would need to visit the factory floor, and this would increase the time spent on this activity dramatically. One final note about the graph – the engineers have estimated zero time spent on report creation. They explained it so that they present the results during regular meetings with the product owners and production managers, so there is no need to write any documentation. The author advised the engineers to at least make some notes in the simulation files themselves of the technical aspects of the model (for example, what Labels were used for the products).

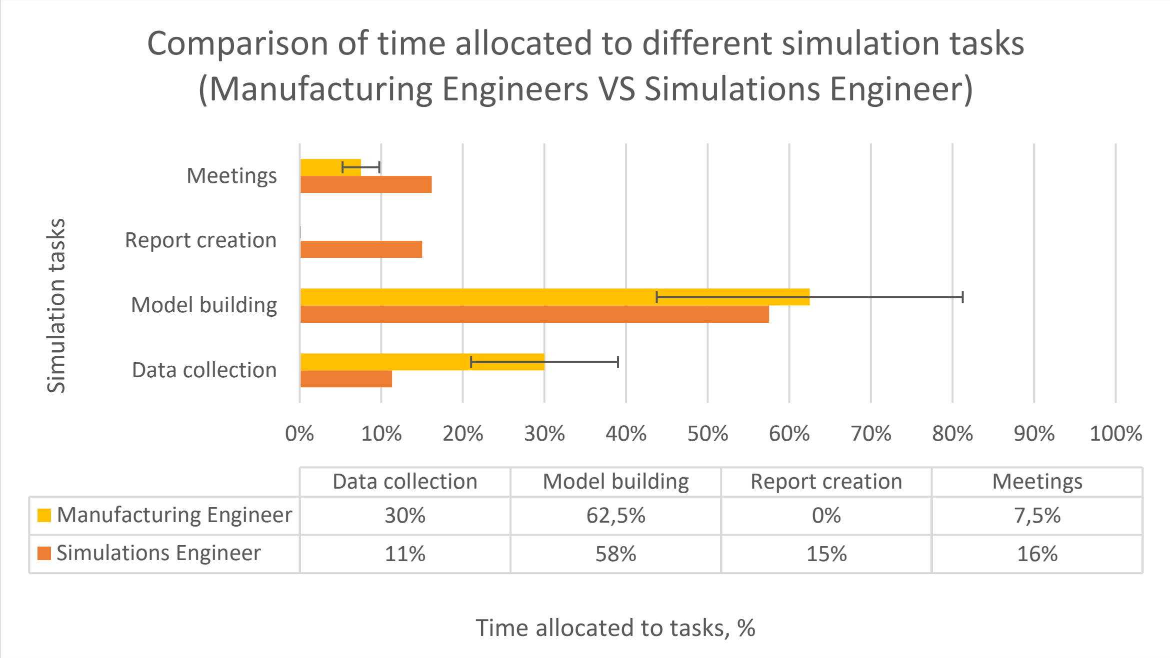


Figure 4.2.2. Comparison of simulations engineer's time allocation with that of manufacturing engineers', based on rough estimates.

A more thorough analysis of the workflow effectiveness is required to make conclusive statements. For now, the manufacturing engineers agree that the model building stage will become shorter, as times goes by, considering that the production line models will have already been made by them, and layout and/or flow changes do not happen often, making old models reusable for new simulation requests. The data collection process has the potential to be improved.

The manufacturing engineers were requested to track the time spent on simulation tasks for future analysis.

4.3 Critique of the tool and workflow

The process of implementing new software and workflows proved to be difficult mostly due to the initially lukewarm reaction to the upcoming change. The team of manufacturing engineers showed disinterest in the tool, with the argument being that existing solutions cover their needs. This experience highlighted the importance of the knowledge of change management theory and techniques, as otherwise an ill-planned implementation strategy would have further aggravated the team members.

Another issue turned out to be related to the timeline laid out in the business case (see action plan under *Table 3.5.3*). A total duration of 16.5 weeks or a little over 4 months was planned for the implementation. In reality, around a year was required to get to the final stage. Various reasons can be named to explain the delay – re-prioritization of other assignments by the management, no motivation to "hurry" to finish the implementation compared to other burning issues, and so on. On the other hand, a quick, sudden change would not bear sustainable results.

SIMUL8 proved to be a user-friendly, feature-rich tool, yet it shows lacks in minor cases, such as no support for split-screen mode on Windows, buggy animation when changing the simulation run speed, relatively poor quality of exported PDF file of the simulation results, work items self-destructing if the queue is full (as opposed to just stopping movement), and others. A few simulation requests at the manufacturing site would benefit from a better integration with AutoCAD files to simulate layouts, in addition to an extended feature set for work item transporters (like trolleys or AGVs).

Whilst process flow simulation does cover the need for a tool that enables the creation of what-if scenarios, it does not substitute the existing line-balancing software and does not operate with any other BOM or ERP programs used at the company.

SUMMARY

With the world of manufacturing consistently working more and more towards the realization of Industry 4.0, the exploration and implementation of different enabling technologies is taking places in production companies. One of the domains of this industrial revolution relates to simulation software, including but not limited to process flow simulation. In this thesis, the implementation process of this type of simulation at a manufacturing company is described.

First, the simulation needs via a stakeholder analysis and a survey of the future users of the software, i.e. the manufacturing and automation engineers, are identified. The stakeholders have deemed the possibility to simulate as useful, brought out bottleneck identification, material flow analysis, and cycle time reduction as the main problems that the simulation tool can help solve, decided that 2D simulation would be enough (as opposed to 3D simulation), and envisioned the team setup having a few specialists in simulation, but everyone else having access to use the tool if desired. In the simulation survey, the engineers showed a good understanding of the overall workings of process flow simulation, yet the majority of the people has never simulated before. They also assessed the impact that the new tool would bring as average – 3.64 points out of 5.

Based on the initial assessment, the search for the suitable simulation software could begin. A list of comparison criteria was made, as well as the potential software candidates were identified. The developed test scenario helped in evaluating the user-friendliness of the different tools, together with other criteria. The evaluation report was sent to the management team, and after the analysis of the costs, the most suitable program was selected.

For the implementation project, a business case was composed which included the action plan, SWAT analysis, risk management details, and other details. With the project greenlit, the author learned the tool, used it in several projects as a proof-of-concept, and then created the training material for the manufacturing and automation engineers in order to hand over the knowledge of using the simulation tool to them. A workflow with three defined use cases that the engineers would cover was established.

Currently, the new simulation way-of-working is still under assessment at the company, as at the time of writing the thesis, the changes have been active for only 1 month. Nevertheless, a preliminary analysis indicates that the use of simulation software can help negate the costs of production stops due to insufficient trolleys assigned to the production line, as well as assess the business case of using one and the same fixtures as opposed to separate ones. Furthermore, speaking of the new workflow, the manufacturing engineers estimate a slight increase of time spent on model building, yet

the data collection time is highly variable, depending on the simulation request. Further analysis of this question is required to make the final conclusion.

Overall, the implementation plan is at its final stage, as the new workflow must be controlled and maintained, with the possibilities of additional changes occurring remaining open. In the future, a more thorough cost-benefit analysis has to be made, with now the manufacturing engineers handling simulation requests. Also, the introduction of a workflow for 3D simulation, in combination with existing layout management software, would further integrate simulation as a capability at the manufacturing company.

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