Vaasan yliopisto
UNIVERSITY OF VAASA

Tommi Luoma

New factory layout simulation and immersive VR-experience preview – case Logset Oy

School of Technology and Innovations
Master’s thesis in Industrial Management
Master’s programme in Industrial Management

Vaasa 2020

UNIVERSITY OF VAASA
School of Technology and Innovations
Author: Tommi Luoma
Title of the Thesis: New factory layout simulation and immersive VR-experience preview – case Logset Oy
Degree: Master of Science in Economics and Business Administration
Programme: Master's Programme in Industrial Management
Supervisor: Rayko Toshev
Year: 2020 **Pages:** 69

ABSTRACT:

The decision to build new manufacturing facility is one of the most important decisions for company as it requires a lot of resources. Uncertainty of the future will make the decision even harder for the management board. However, development in technology, regarding 3D-simulation software, Virtual reality applications and accessible computing power have made 3D modeling and simulation viable solution for factory planning. Therefore, 3D-simulation and Virtual reality are used in this research as methods to give valuable data and insight for the forest machines manufacturing case company’s decision makers.

Visual Components 4.2-software is used in this research to model 3D-simulations. Results contain one assembly line simulation for harvester, one assembly line simulation for forwarder and two layouts to test partially combined assembly line performance. Assembly line simulations are made to build 3D-model of harvester and forwarder and assembly line simulation layouts are given to project researcher as a reference model as this thesis is part of a bigger research project. Harvester and forwarder are built from 3D-models provided by the case company following current assembly process steps. Two partially combined assembly line layouts are made to estimate performance metrics of the new factory, focusing on output volumes, cycle times and lead times of harvester and forwarder.

3D-simulation model for partially combined layout is run to estimate yearly production, showing output volume, mean cycle time and mean lead time for both machines in a different manufacturing scenarios. Results show basic performance metrics of the new factory and simulation can be viewed using Virtual reality-glasses by using Visual experience software, developed by Visual Components. First 3D-simulation model for partially combined assembly line revealed the problem areas and bottlenecks of the assembly lines. Second model is used to show how balancing assembly line and improvements in the manufacturing process can improve the performance of the factory.

Results demonstrate that 3D modeling and simulation are advantageous methods for factory planning and Virtual reality can be used as a complementary method for visualization creating more immersive experience.

KEYWORDS: 3D modeling and simulation, Facilities planning, Visual Components, Virtual factory, Virtual reality

Contents

Figures

Tables

Abbreviations

3D	Three Dimensional
CAD	Computer Aided Design
CTL	Cut-To-Length
JIT	Just-In-Time
ROI	Return on Investment
UI	User interface
VC	Visual Components-software
VR	Virtual Reality
WIP	Work in progress

Acknowledgement

I like to thank my supervisor Dr. Rayko Toshev for his guidance and giving me the possibility to work and be a part of the research project with this thesis. I also want to thank Professor Petri Helo for giving me the opportunity to contribute to the research project.

I like to thank Logset Oy for giving this interesting research problem and especially Mika Oinas for providing the necessary information and data used in this research.

I like to thank my friends and family, especially my parents for their support.

In Vaasa, September 2020
Tommi Luoma

1 Introduction

Finland is traditionally known for its forestry. Forest industry accounts more than 20% of Finland’s export revenue (maa-ja metsätalousministeriö, 2019). Big forestry sector needs forest machines for procurement of raw materials. This has developed a new growing industry. Finland is currently number one in manufacturing Cut-to-Length (later CTL) forest machines and third biggest market for CTL-forest machines (Johnsen, 2019). Demand for CTL- forest machines have been growing in the past few years and companies like John Deere and Ponsse have heavily invested in their production facilities and expanded their capacity; John Deere with 15 million euros and Ponsse with 38 million euros. (Tikkanen, 2018; Metsätrans, 2019; Sorsa, 2019). In 2017 Ponsse, John Deere and Komatsu were leading the market in Finland with 97% of the market share regarding harvesters and 92% of the forwarders, whereas this research’s case company Logset having only 0,4% of the harvester market and 4,6% of the forwarder market. (Johnsen, 2018).

As planning, developing and building a new manufacturing facility is an expensive process and often one of the most important decision for a company, it is however even more crucial for smaller manufacturer, since room for error can be smaller if a company does not have so much capital compared to its competitors. Since companies are competing in a global market, a new manufacturing facility should provide competitive edge to an investing company. Competitive edge can be achieved by providing better quality, being more cost-effective, reducing lead time and being innovative. Factory layouts, manufacturing systems and material flows all play roles when companies try to achieve competitive edge. (Stephens, 2019: 361–362.)

Use of computer simulation, more precisely three dimensional (later 3D)-simulation and utilization of Virtual Reality (later VR) can help companies design a new factory and predict its performance before any physical structures are built. (Stephens, 2019: 362.) This research focuses how Finnish forest machine manufacturer Logset Oy can use 3D-simulation in planning, conceptualizing and developing a new factory.

1.1 The Logset Oy new factory simulation project

This research is a part of a bigger project where the focus of this research is on 3D-modelling of assembly lines for harvester and forwarder and simulating the assembly process as well developing a concept for partially combined line. Conceptualization of the factory and visual representation is done by using Visual Components 4.2 software.

Logset Oy is a forest machine manufacturer founded in 1992 by Gustav Frantzén, Seppo Koskinen and Kristian Stén. Logset Oy location is near Vaasa, at Koivulahti. Its main products are forwarders, harvesters and harvester heads for CTL-logging and it offers after-sales service, spare parts, training and customer support. Currently, Logset Oy has seven models for harvesters, forwarders and harvester heads. The main difference between their seven models in harvesters and forwarders are engine power and load capacity. For software part, Logset has developed control systems for forwarders and harvesters and measuring systems for harvesters' heads. Logset employs around 100 workers and its distribution network covers 25 countries and Logset's machines are working more than 25 countries. (Logset, 2020a.) In 2019, Logset had a turnover of 48.0 million euros with 2,5 million profit representing the best year in Logset's history (Logset, 2020b).

1.2 Research justification and contribution

This research gives valuable information for Logset's board members to help decision making process for new factory. 3D modelling and simulation visualize production, assembly process, area and resource allocations as well flow of work, which can help detecting bottlenecks among other possible concerns. In addition to help visualize possible problems, simulation can provide innovations and show new factory in a new point of view, especially when simulation is done by outside of the company or industry external, as this research is.

VR provides more detailed insight for new factory. For example, VR can help identify potential hazards and illustrate ergonomics. Statistics derived from the simulation are essential when making decisions for future factory. Since simulation is much faster and cheaper to change than a real factory, different version and modifications can be made and tested to find most suitable one.

One of the main contribution for the case company is to show how current assembly process, where harvester and forwarder are assembled in a separate lines, can be assembled in partially combined lines.

1.3 Research objectives and questions

The fields of study related to this research are machines manufacturing, production and industrial management.

Since this research is a part of a Logset's new factory production simulation- project, the research objectives are supportive to the project. The primary objective of the research is to create a 3D- model of the layout, which can be used to simulate the production process of harvester and forwarder. Target number for manufactured machines per year is assigned from the company. Target number includes harvesters and forwarders manufactured on a balanced line with a possibility to increase volume in the future. Also, company provided some pre-defined space allocations for warehouse, pre-assemblies, service and office. Size of the factory and the number of assembly stations are roughly pre-defined by the company. Research questions are derived from this scope, in order to get beneficial data from the simulation.

There are two detailed research questions for the research:

1. How can 3D-simulation help develop a new factory?
2. What benefits can virtual reality bring to a new factory layout planning?

1.4 Research limitations

This research is limited to building 3D harvester and forwarder on a 3D factory assembly line simulation and building simplified model focusing on work times of different task and phases in order to create concept of balanced assembly line and reach demands related to capacity of the new factory. The research is limited to case company's forest machine manufacturing process with no access to other forest machine manufacturers' data.

Timeline of the research focus on present production and how it can be done in the future. The data from the assembly process is very limited, having only the sequences and the work times of the main assembly work tasks which are required in order to build a harvester and a forwarder. These assembly work times are provided from the company and are in some cases vague predictions.

Due to nature of the research being a case study with focus on production, some details are generalized and some parameters are not published in full details in order to respect case company's confidential information.

1.5 Structure of the thesis

This research is structured into 5 chapters. In chapter one overall introduction, research background, questions and objectives are presented. Chapter two is for literature review where relevant theories and key definitions are explained. This includes concepts such as 3D-simulation and manufacturing facilities design. Methodologies used in this study are discussed and presented in chapter three with the use of Saunder's research onion. In chapter four, the simulation software is briefly descripted and the results of the research are presented in the next chapter. Chapter six is for conclusions and suggestions for future studies.

2 Literature review

This chapter goes through theoretical aspect of this research and gives insight to valuable terms and keywords used in this research topic. In the next paragraph, most important subjects relating the research are introduced starting from basic definitions, continuing then to manufacturing facilities design and layout. After this, facilities performance metrics, lean principles, industry 4.0 and VR are briefly introduced. Software Visual Components 4.2 with some definitions and concepts regarding 3D-simulation and modelling are introduced in its own chapter four after methodology chapter.

2.1 Basic definitions

This section briefly introduces some basic terms used in this research relating to forest machines.

2.1.1 Harvester

“A harvester is a type of heavy forestry vehicle employed in CTL-logging operations for felling, delimbing and bucking trees.” (Rong-feng, Xiaozhen & Chengjun, 2017). Case company Logset has seven different harvester models which variates from smaller and lighter six-wheel harvesters to more powerful and heavier eight-wheel harvesters. Heavier machines are used in clear cutting and smaller machines are just in thinning operations. (Logset, 2020c.)

2.1.2 Harvester head

Harvester head is a tool for CTL-logging. It is used for cutting, delimbing and bucking trees and it has a measurement system, which produces real time data helping operator. Logset has seven models starting from smaller ones designed for thinning operations all the way to the bigger ones designed large clear fells and the biggest one made for track-based harvesters. (Logset, 2020f.)

Figure 1. Logset 12H GTE Hybrid harvester and harvester head Logset TH85 in 2017 (Logset 2020d).

2.1.3 Forwarder

A forwarder hauls logs to a roadside landing area after harvester has operated (Rongfeng et al. 2017). Case company Logset has seven different forwarder models which variates from smaller and lighter forwarders to more powerful and heavier forwarders. Main difference with heavier forwarders is their bigger loading capacity compared to smaller and lighter forwarders. (Logset, 2020g.)

Figure 2. Logset 5FP GT forwarder hauling logs (Logset 2020g).

2.2 Simulation

Stephens (2019: 362 – 363) defines simulation as follows:

> *"Simulation is an experimental technique, usually performed on a computer, to analyze the behavior of any real-world operating system. Simulation involves the modeling of a process or a system where the model produces the response of the actual system to events that occur in the system over a given period of time."*

Moreover, Kikolski (2017) adds that simulation can be seen as an approximate imitation of a studied phenomenon or behavior of a given system in the virtual space with the use of its simulation model where the simulation model is based on a mathematical model often recorded in the form of a computer programme.

There are various commercial software available which provide solutions for facility lay-out planning and simulation. In general, facility layout planning software are based on the discrete-event simulation concept, in which the operation of the system corresponds accordingly to the chronological order of events (Yap, Taha, Dawal & Chang, 2014). In this research, the software used is Visual Components 4.2 and it enables discrete-event simulation in a 3D-virtual environment (Yap et al. 2014; Solidworks, 2020).

Other two common simulation methods in addition to aforementioned discrete-event simulation (DES) are system dynamics (SD) method and agent-based modeling (ABM) method. These methods are suitable for complex system like manufacturing facility, which is adaptive to changes in its local environment and is composed of other complex systems (Marshall et al. 2015).

In **DES,** the core concepts are resources, events, attributes and entities. *Resources* are objects that provide a service to an *entity*, which are objects with attributes and require resources when experiencing events. An *event* is something that happens at a certain time point in the environment that can affect resources and/or entities. *Attributes* are features or characteristics unique to an entity, which can change over time or stay same. Outputs of DES are system performance indicators such as throughput of services or products, resource utilization, number of entities in queues and wait times. (Marshall et al. 2015.)

ABM simulation method uses autonomous and interacting objects called *agents*. Agents sense their environment and behave on the basis of their defined decision rules. How-ever, their next actions are based on the current state of the environment. Agents may learn and adapt and they may have assigned goals to maximize or minimize their objec-tive. (Marshall et al. 2015.)

SD simulation method is used for representing the structure of complex systems and understanding their behavior over time. The core elements are accumulations (stocks), feedback, rates (flows) and time delays. Its core assumption is that behavior of the system is due to its structure and not due to external forces or factors. SD is often used to produce patterns and trends, as well as mean values as outputs from the model. (Marshall et al. 2015.)

Regarding facilities design and layout, simulation can be used to optimize layout, improve capacity, compare different logistic solutions with different material handling systems and test how just-in-time (later JIT) can be utilized in the facility (Stephens 2019:16).

Nowadays, virtual models and simulation can be used to make an inexpensive factory design since instead of building real expensive systems, designer can build factory layouts and define resource configurations in virtual environment without any physical prototypes. This way, by utilizing dynamic simulation and virtual modeling potential problems caused by the layout can be visualized for different stakeholders. (Bogdan, Lewis, Kovačić & Mireles 2006.)

Simulation scope varies in facilities planning; it can cover the entire factory, one department or one manufacturing cell. In a typical simulation, built model of the system is experimented in different conditions to learn how system reacts in different situations. As a descriptive model, simulation does not give optimum solution but it provides a tool for understanding and predicting the behavior of the system. (Tompkins, Bozer, Tanchoco & White 2010: 702.)

Simulation software used in this research generates statistics describing the performance of the system. This is also true with many other simulation software. As simulation software generates statistics and it is possible to make stochastic processes and input random failures into simulation model, simulation can be used in many ways to test what-if scenarios and find bottlenecks and how use of different production batches can change production volumes. (Stephens 2019: 16.)

For building a simulation model Stephens (2019: 365–366) suggests systematic approach:

1. **Problem definition** – define the problem and state the goals.
2. **System definition** – Define the boundaries and restrictions in terms of resources.
3. **Conceptual model** – Develop a graphical model to define components, variables and interactions between them.
4. **Preliminary design** – decide and select factors that are critical for the system performance.
5. **Input data preparation** – identify and collect the required data by the model.
6. **Model translation** – develop and formulate model in appropriate simulation language.
7. **Verification and validation** – confirm that model and the output represent wanted system.
8. **Experimentation** – Manipulate and test the model in different scenarios.
9. **Analysis and interpretation** – analyze the data generated by the simulation model and realize to what extend the validity of the *output* is dependent on the validity of the *input* data.
10. **Implementation and documentation** – record and document the results and use the results remembering its limitations.

There are various reasons for simulation modeling. Stephens (2019: 366) lists six potential reasons for simulation: **evaluation** of how proposed system performs, **comparison** of different design alternatives, **prediction** of system performance, **sensitivity analysis** of different variables, **optimization** of plant performance and **bottleneck analysis** for discovering bottlenecks of the system. These aforementioned reasons were present and tested when building the simulation model or after running built simulation model and analyzing results.

2.3 Manufacturing facilities design

Facilities planning is extensive process including countless of different variables and factors starting from site location decision and strategy going all the way more detailed subjects such as material handling and *layout*, which contains physical location of equipment, materials, people and workstations. (Stephens 2019: 1–2.) Tompkins et al. (2010: 14 – 16) have presented systematic way for planning facilities as follows:

1. **Define the problem** – the objective of the facility should be clear. Volumes of products must be defined. Primary and support activities and their requirements should be specified regarding material flows, equipment, personnel must be specified in order to enable uninterrupted manufacturing.
2. **Analyze the problem** – Find interrelationship between all activities. Relationships of quantitative and qualitative actions within the facility boundaries should be defined.
3. **Determine the space requirements for all activities** – when calculating space requirements, it is important to have all material, equipment and personnel requirements considered. In this phase it is important to generate different alternative layout designs.
4. **Evaluate alternatives** – Facility plans and layout should be ranked in order respecting previously selected criteria.
5. **Select preferred design** – The most suitable design fulfilling company’s goals and objectives should be selected. If there is no acceptable design, the planning process should be started again from previous steps.
6. **Implement the design** – Implementing the best design will take time since there is need for more detailed planning when the actual construction starts. This phase also requires maintaining and adapting the design plan regarding chances in products, demand or improvements in technology.

This systematic way for facilities planning resembles Stephens (2019) aforementioned framework for building a simulation model and it is no surprise since simulation model can be also viewed as a **virtual factory**, which as a term can refer high fidelity simulation, a virtual organization or a virtual reality representation and an emulation facility (Jain, Shao & Shin, 2017). Hopp & Spearman (2011: 660–661) introduces more customer focused view to the facility design process called factory physics approach as following:

1. The customer determines the product, so that volumes, mixes and cycle times are forecast.
2. The product(s) determine(s) the processes, since most products have a basic recipe of steps that must be followed to produce a unit.
3. The processes determine needed machines and requirements will get more detailed during the planning process.
4. The machines determine the facilities needed to support them.
5. The facilities determine the overall size and structure of the plant.

Especially the second guideline is good addition compared to aforementioned guidelines regarding to this research, since there are certain basic steps that needed to be followed when simulating assembly of harvester and forwarder.

2.4 Layout

Tompkins et al. (2010: 6–7) defines *layou*t as term which consists all equipment, machinery and furnishings within the building envelope and more specifically for manufacturing facility the term layout consists production areas, production-related or support areas and personnel areas withing the building.

One of the main goals in layout planning is efficient planning regarding material flows. Material transport times and distances, as well how many times material have to be moved, are trying to be minimized in layout planning. It is also important to design layout in a way that it is flexible, so that potential extension or alteration would be possible. (Haverila, Uusi-Rauva, Kouri & Miettinen, 2009: 482.)

Literature divides layouts usually to three different main types. Nicholas (2010) uses fixed-position, process and product layouts. Haverila et al. (2009: 477–478) as for use different terms such as production line, cellular layout and functional layout. However, Tompkins et al. (2010: 110–111) presents four different layout types such as production line product layout, fixed product layout, product family layout and process layout and present volume-variety layout classification, which can be used as guide when selecting and planning layout for new factory (see figure 3). Case company position in this volume-variety layout figure is fixed location layout by its low manufacturing volume and variety.

Fixed-position layout means that the end item remains in one place while it is being produced. These kind of products are usually large and hard to move and are common in a project work e.g. ships and aircraft. However, even larger objects can be mass produced by using different staging areas, in other words multiple fixed-position shops. (Nicholas 2010). This use of multiple different fixed-position shops is similar with case company's current manufacturing system and represent quite well layout in the built simulation model.

Process layout utilizes similar process and operations and clusters them into functional work areas or departments (Nicholas, 2010). This is also known as *functional layout*, where workstations are clustered into groups based on their similarity. It is typical to use functional layout if there is lot of material movement in the factory. (Haverila et al. 2009: 477– 478.) Process layout, as Nicholas (2010) refers it, is flexible and can be used to manufacture variety of products even if products have differences in demand and process steps. Downside of process layout is its wastefulness regarding time, inventory, defects and material handling. (Nicholas, 2010.)

Product layout is used when facility has repetitive or continuous processes and the layout is made to support producing the product on a production line, flow line or assembly line. This kind of layout is often used when there are only few end products. Production line requires usually large capital investment as equipment and transfer system can be costly if high efficiency and flow rates are wanted. Product layouts are usually very inflexible, though minor variations are possible. (Haverila et al. 2009: 477–478; Nicholas, 2010.)

Most of facility layouts can be presented in two ways: as a *block layout*, which represents macro flows of the facility and shows location and shape of different departments and as a *detailed layout*, which is more concerned with micro flows of the factory and shows exact location of equipment, work cells and storage areas in every department. (Tompkins et al. 2010: 292.) Simulation layout made in this research resembles block layout, as more detailed simulation would require more resources.

Mass production and *job shop* are a two basic layout orientations. Assembly line illustrates best mass production since it is product orientated and follows a fixed path through the facility. Job shop layout is more process orientated and it is more suitable for manufacturing and fabrication departments compared to assembly work. (Stephens, 2019: 91.) The case company utilizes both orientations in their current setup since low volume prevents mass production. However, in the new factory simulation, the benefits of assembly line and characteristics of mass production are taken account. One way to develop job shop orientation closer to mass production is utilization of group technology, which is used in the simulation model. *Group technology* means classifying parts into groups with similar process sequences (Stephens, 2019: 91). This method is applied into combined assembly line of harvester and forwarder, where similar work tasks with similar parts are assembled in the same assembly cell.

There are two main types of work cells: *assembly cells* and *machining cells*. Whereas machining cells are usually more easily automated, assembly cells are harder or too costly to automate. (Nicholas, 2010.) Assembly cells are the main type of the work cells in the case company as it assembles its products in a line of assembly cells, or in other words in multiple fixed-position shops. As work contains a lot of human work and volumes are low, there are no easily findable spots for cost-effective automation. However, effects of automation for performance of the assembly line could be easily tested in simulation if there is a reasonable estimation how much automation could reduce assembly process time. By running the simulation, the long-term effects could be tested and return on investment could be estimated.

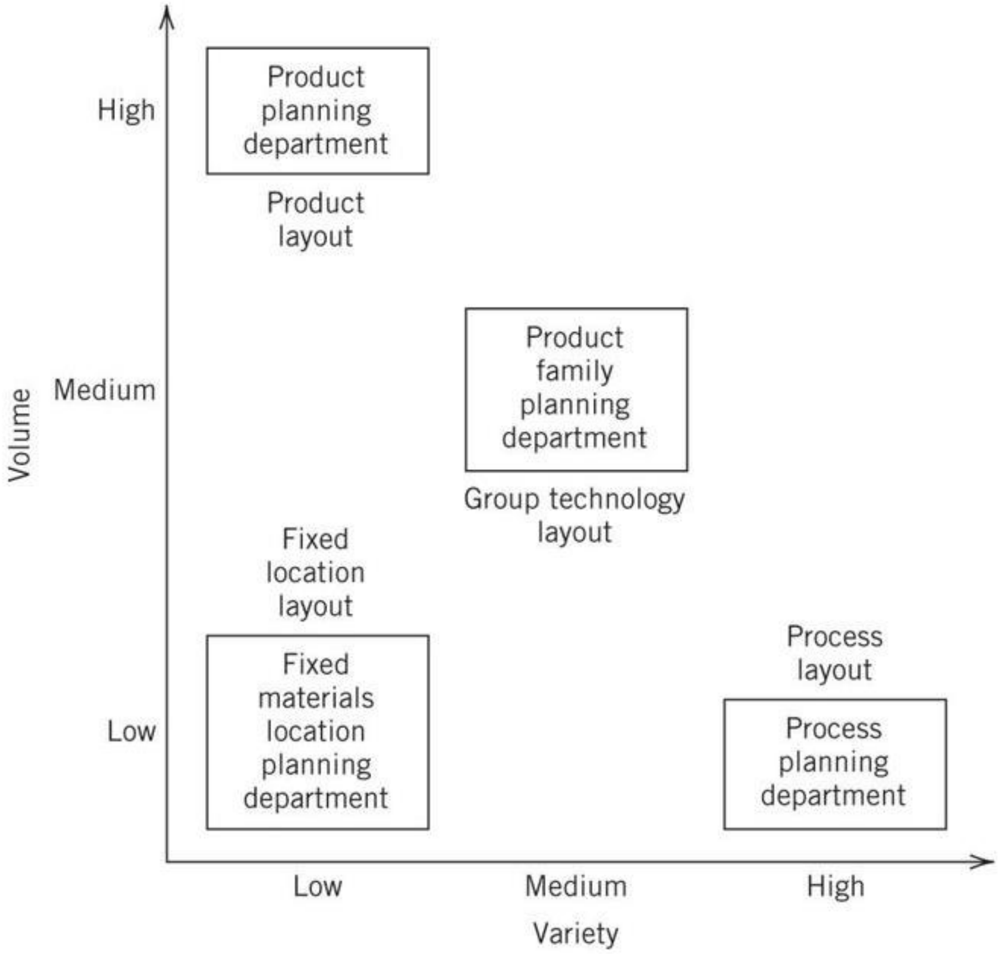

Figure 3. Volume-variety layout classification (Tompkins et al. 2010: 98).

2.5 Assembly line balancing

An assembly line as a set of distinct tasks which are assigned to a set of workstations linked by a transport mechanism respecting assembling sequences which define the assembly process flows from one workstation to another (Bahadir, 2011). The transport system moving workpieces between stations can be e.g. an automated guided vehicle (later AGV) or conveyor (Naderi, Azab & Borooshan, 2019). Balancing refers to adjusting workstations to conform to required takt time. This can involve increasing bottleneck workstation's capacity or lowering capacity on nonbottleneck stations. Process is said to be balanced when the cycle times are equal in every workstations. Conversely, process is unbalanced if the times to performs jobs are different at different workstations. (Nicholas, 2010.)

Haverila et al. (2009: 485) simplifies the purpose of assembly line balancing as a way to get the best possible productivity. In the assembly process the balanced line can be achieved by moving and changing different stage of works in a different workstations (Haverila et al. 2009: 486).

More precisely, assembly line balancing includes decisions about required resources regarding the number of workers, stations and station equipment. Scheduling is also a part of assembly line balancing as sequencing and the way how tasks and workers are assigned have an impact on the performance of the line. The goals of the assembly line balancing are often cycle time minimizing or reducing the number of assembly stations. (Naderi et al. 2019.) Bahadir (2011) adds that in assembly line balancing allocation of jobs are based on the objective of minimizing the workflow among the workers, reducing the throughput time as well as the work in progress and thus increasing the productivity. As assembly line balancing requires information about work tasks and their durations, a time study should be concluded to calculate the approximate real process times of a tasks (Bahadir, 2011).

One of the main goals of manufacturing facility is to have balanced assembly line.
Stephens (2019: 78) lists purposes of assembly line balancing as:

1. To equalize the workload among the assemblers
2. To identify the bottleneck operation
3. To establish the speed of the assembly line

4. To determine the number of workstations
5. To determine the labor cost of assembly and packout
6. To establish the percentage workload of each operator
7. To assist in plant layout
8. To reduce production cost

Regarding assembly line balancing, the simulation model is used to identify bottlenecks, determine number of workstations and establish the speed of the assembly line. Due to nature of the case company's products and manufacturing volumes, the assembly line differs from traditionally viewed assembly line, where products are moved in high volumes from workstation to another e.g. via conveyer. However, methods of assembly line balancing can be applied also in the case company's manufacturing process.

As assembly line balancing problem is different in different industries and varies even inside the same industry, companies require tailored methods for assembly line balancing problems as companies have different requirements and limitations in their production. There can even be different assembly lines inside the same facility, which each require customized procedure for assembly line balancing. (Naderi et al. 2019).

It is common for companies to assemble more than one product on a single assembly line as developing, building and maintaining an assembly line is very costly. In cases like this, the assembly line balancing problem is called as mixed-model assembly line balancing problem. There are several methods for formulating assembly line balancing problems into mathematical formulas starting from integer programming models going all the way to heuristic, genetic and logic-based Benders' decomposition algorithms. The assembly line balancing problem is an NP-hard combinatorial optimization problem that has been investigated by many researchers starting from the 1950's (Gansterer & Hartl, 2018; Naderi et al. 2019.)

Facility performance metrics are important part of assembly line balancing as balancing cannot be done without knowing the performance of different stations. These performance metrics are presented in the next chapter.

2.6 Facility performance metrics

One of the goals of simulation is to see how new facility performs. In this case the main focus is on assembly line and its performance. Following chapters explain some basic facility performance metrics.

2.6.1 Throughput

Hopp and Spearman (2011: 229) defines throughput as “the average output of a production process per unit time.” This is sometimes referred as throughput rate. A typical way to define throughput of a plant is to calculate average quantity of manufactured good (defect-free) parts or assembled products per unit time (Hopp & Spearman, 2011: 229).

2.6.2 Capacity

“An upper limit on the throughput of a production process is its capacity.” (Hopp & Spearman 2011: 229). Haverila et al. (2009: 399) simplifies capacity as maximum production volume within a given time. Usually, most systems working above or even at its capacity will cause system to become unstable causing for example work-in-process (Hopp & Spearman 2011: 229). The pace for the assembly process is determined by the slowest workstation or work task, which is called as *bottleneck.* By focusing bottlenecks and improving the capacity of bottleneck, it is possible to increase overall capacity of the factory. (Nicholas, 2010.) Haverila et al. (2009: 400) reminds, that real capacity is often only 50 - 90 % of theoretical capacity because of interruptions, defects, maintenance and machine breakdowns for example. However, Haverila et al. (2009: 369) notes that when cumulative production volume duplicates, the time required to assemble one product can decrease as much as 20% due to employees learning and getting better and faster in their job. This phenomenon is called *learning curve*.

2.6.3 Cycle time

Hopp and Spearman (2011: 230) defines the cycle time as a "average time from release of a job at the beginning of the routing until it reaches an inventory point at the end of the routing." Nicholas (2010) simplifies definition for cycle time as a time between when units are completed in a process. Cycle time as a concept is a crucial when implementing pull production since it implies repetitive and steady material flow during manufacturing process. Cycle time should not be mistaken with production rate as for example 6 products per hour does not mean steady flow compared to cycle time with 10 minutes. (Nicholas, 2010.)

2.6.4 Takt time

Takt is a German word used in describing a Japanese system that indicates a precise interval of time (Hopp and Spearman, 2011: 161). Takt time refers to required cycle time which in other words is the production target and it is based on demand (Nicholas, 2010). Setting takt time for every process is crucial part for ensuring that all the necessary parts are on right time on right place on the assembly line. Every workstation should keep up with the takt time so that required production will be matched in the final assembly process. (Stephens, 2019: 20). Takt time is important metric for sub-assemblies. Even though this simulation does not focus on sub-assemblies, it possible to calculate required takt times in future studies for different sub-assemblies from the simulation model as the speed and the need of the final assembly line is known.

2.6.5 Lead time

Hopp and Spearman (2011: 331) specifies lead time into two types: **customer lead time**, which means the time allowed to fill a customer order from start to finish and **manufacturing lead time**, which means the time allowed on a particular routing. Simulation model and thesis uses manufacturing lead time as main definition. Production planning and layout planning is used to keep lead times as short as possible, as it reduces capital invested in WIP, improves delivery reliability and quality as well makes capacity planning easier. Productivity and quality improve when lead time is shortened as defects are easier and faster to detect. Plain and clear material flow and compact layout are one of the enablers for shortened lead time. (Haverila et al. 2009: 402–407.)

2.7 Lean manufacturing & lean six sigma

Lean manufacturing is developed from lean thinking where value added is the guiding philosophy, meaning that all elements of cost which do not add value to the end product are eliminated (Stephens, 2019: 18). Bicheno & Holweg (2016: 1) simplifies lean as "doing more with less." Hopp and Spearman (2011: 334) uses following definition for lean manufacturing "a manufacturing supply chain is lean if it accomplishes its fundamental objective with minimal buffering cost."

Lean manufacturing is one of the guiding principles in this research. Its influences can be seen in the simulation. For example, *andon*, which means line stop method indicator where different colors indicate current situation in the assembly line, is used in the simulation. (Stephens, 2019: 20.)

Six sigma is term which originates from Motorola's quality control practices from the 1980s. It is originally a statistical method to drive defects very low in the manufacturing processes. From there is has developed to comprehensive management system emphasizing data-driven and customer-focused decisions. (Hopp & Spearman 2011: 410–413.)

Benefits of six sigma regarding simulation comes from its framework and tools. Since building and developing a simulation is iterative, it suitable to use Six sigma framework which is often used for processes that do not exist yet or need redesign. This Framework is called DMADV, which is a variant of original Six sigma framework called DMAIC. DMADV is abbreviation from:

- **Define** the goals for the project.
- **Measure** and determine customer needs and specifications.
- **Analyze** the process options to meet the customer needs.
- **Design** the process to meet customer needs.
- **Verify** the design performance in term of its ability to meet customer needs.

(Hopp & Spearman 2011:413.)

Since simulation software enables inserting failures in the manufacturing process with many different types of distributions, six sigma statistical tools could be used in the simulation. However, since simulation is used only in conceptualization of new factory there is no meaningful reason for detailed statistical analysis regarding errors in simulated production as there are no detailed data of how often failures happen in the current system. Yet, failures can be inserted in the simulation to test what-if scenarios.

2.8 Industry 4.0

Developments in technology or other breakthroughs have always caused changes in manufacturing systems and often these breakthroughs have so huge effect on manufacturing and social lives of human being that literature uses term “industrial revolution” when referring them. Currently, world is going through the fourth industrial revolution which is characterized by artificial intelligence, cyber-physical systems, digital twins and internet of things to name a few. (Kumar, 2019.)

The term “Industry 4.0” or the fourth industrial revolution originates from Germany. The term was first used in a presentation at the 2011 Hannover Fair by Professor Wolfgang Wahlster. The term Industry 4.0 is widely used and it has a vast number of meanings but in a nutshell, it refers to the “intelligent networking of machines and processes for industry with the help of information and communication technology.” (Visual Components, 2019.)

One of its key components, as mentioned before, is Cyber-Physical Systems (CPS). The function of CPS has been defined as monitoring physical processes and creating a virtual copy of the physical world. (Jain et al. 2017.) As simulation is one of the main components when discussing about industry 4.0, it is reasonable to take it and its possibilities into account when building and developing a simulation model of the factory.

Characteristics of industry 4.0 can be seen for example in use of AGVs in the simulation model. Also, if properly developed, simulation model can be seen as a *digital twin* as it tries to mirror real life performance and can be used in predicting future states of the system (Padovano, Longo, Nicoletti & Mirabelli, 2018). Digital twin can be defined as a "dynamic, virtual software-generated representation of corresponding physical assets and processes." (Visual Components, 2019).

Developing a full virtual twin factory takes a lot of resources but simulation model build in this research could be a good starting point, since assembly line is conceptualized. However, digital twin factories are more suitable when the real factory is more automated compared to case company current factory or potential new factory. (Volvo, 2017.) Also, at this point, there are no exchange of data between the real factory or its production and simulation model which limits the use of simulation model as a digital twin.

2.9 Virtual Reality

Fuchs, Guitton & Moreau (2011) defines virtual reality goes as follows:

> *"Virtual reality is a scientific and technical domain that uses computer science and behavioral interfaces to simulate in a virtual world the behavior of 3D entities, which interact in real time with each other and with one or more users in pseudo-natural immersion via sensorimotor channels. "*

Virtual reality is only way to allow people "walk through" facilities before it even exists. Even though simulation is a great way to test what-if scenarios and model new facilities, virtual reality is currently only way to "test drive" facility in first person perspective. As technology advances, VR in facilities planning will probably be even more utilized (Stephens: 347– 350).

The VR equipment required typically consists of a head mounted display (HMD) and a position and orientation tracking system. This hardware had long been very expensive but recently, VR technology has started to become available in the consumer gaming market enabling better utilization also in the research, development and simulation purposes. (Niehorster, Li & Lappe, 2017.)

Several simulation programs use VR as a tool for visualization. Some programs like Visual Components utilize VR in commissioning of robotic cell. This is done by creating a digital twin and then testing and verifying the model in a simulated virtual environment. (Pérez, Rodríguez-Jiménez, Rodríguez, Usamentiaga & García 2020.) This is similar as virtual manufacturing, where virtual reality technology is used in real-time manufacturing-based simulations in order to optimize product design and processes for a specific manufacturing goal. One of the goals of virtual manufacturing is to generate 3D models and real-time simulations of manufacturing processes to aid the design and production of products. (Yap et al. 2014.)

Updates and development in VR and VC software are enabling more interactive experience as newest version of VC can have pickable objects so that user can select objects and move them around in the layout (Visual Components, 2020g).

In this research, VR is mainly used in visualization purposes and analyzing the simulation model in a more detailed way.

3 Methodology

This chapter introduces the methodologies and data used in this research and the reasoning behind them. Even though computer simulation can be seen as a unique research method and approach (Helo, Tuomi, Kantola & Sivula 2019) it is still suitable to present the research process by using research onion developed by Saunders, Lewis & Thornhill (2007) to get deeper understanding of the research process.

3.1 Research onion

Research onion is introduced for readers to help understand philosophies and approaches used in this research. Following paragraphs show how research onion is applied in this research from outer shell to inner layers.

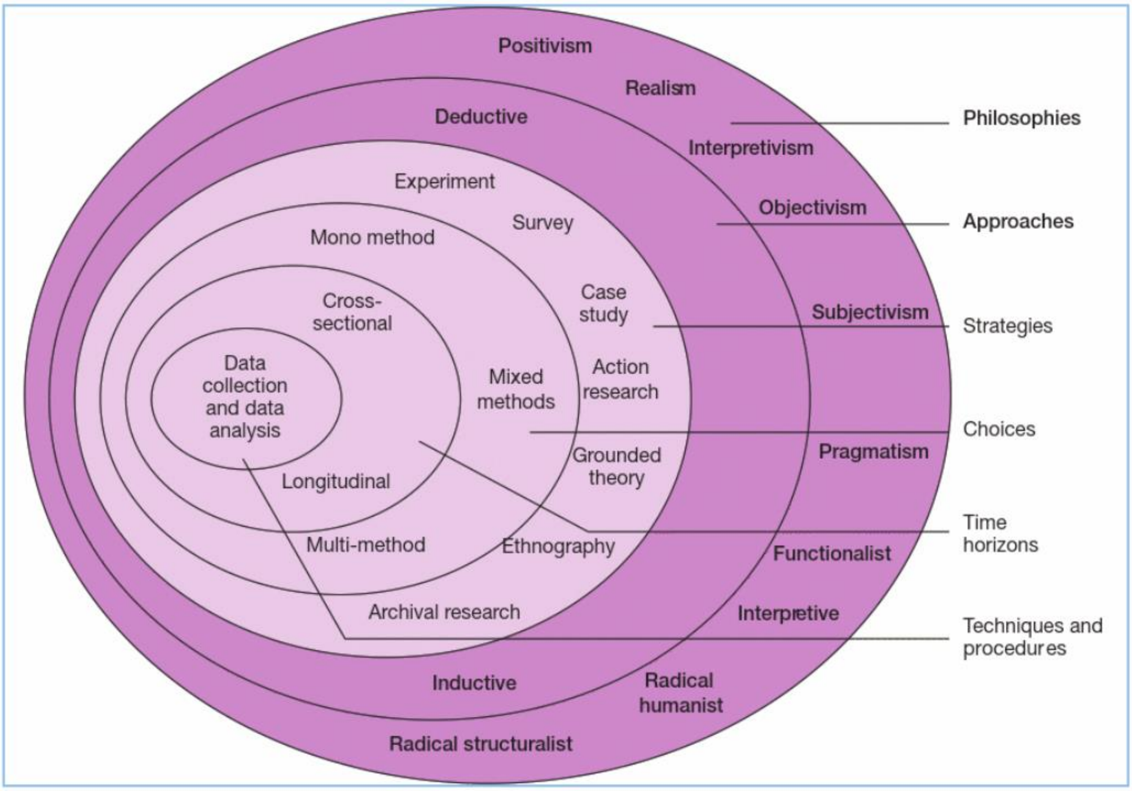

Figure 4. Research onion (Saunders et al. 2006).

3.1.1 Research philosophy

The term research philosophy relates to development of knowledge and the nature of that knowledge. The main influence of the researcher's research philosophy is his view of the relationship between knowledge and the process how it is developed. There are three major branches in research philosophy: epistemology, ontology and axiology. Research philosophy used in this research is **pragmatism**, which major branch is epistemology. In pragmatism, the research question plays the most important role. (Saunders et al. 2007; Wilson 2014: 8 – 11). Tashakkori and Teddlie (1998: 30) mentions, that in pragmatism research results can be used to bring positive consequences within researcher's value system. Since this research is a case-study and one of the main results is a built 3D-simulation, which is used to find ways to improve the system, it is appropriate to use pragmatism as a research philosophy in this research. Wilson (2014: 10–11, 335) states that "what" and "how" are the focus for pragmatist researchers regarding the research problem and adds that pragmatism is suitable paradigm if research philosophy has characteristics from both positivism and interpretivism but does not fully align with either philosophies.

3.1.2 Research approach

Deductive approach and inductive approach are the main approaches associated with research methods (Saunders et al. 2007). Inductive approach is a theory building process, where observations of specific instance are established as generalizations about the phenomenon under investigation. Deductive approach is a theory testing process, where established theory is tested to see if it applies to specific instance. (Hyde, 2000.) The research approach used in this research is **inductive** since data and constraints were given from company and then used as a foundation for the simulation model. This approach is similar to Wilson's (2014: 12–13) view of inductive approach, where observations and findings are used in contributing a new theory. In this research, the "new theory" is built 3D-simulation.

3.1.3 Research strategy

Research questions and objectives mainly guides which research strategy is the most suitable one for research (Saunders et al. 2007). There are many different strategies, such as survey, experiment, case study, action research, grounded theory, ethnography and archival research (Saunders et al. 2007). In this research the research strategy can be seen as a combination of case study and experiment. Since the whole project is made for company with end goal being a functional 3D-simulation, this implies that right choice for strategy is **case study**. However, since interactions with case company resulted in changes within the simulation to accomplish better results, such as better total of manufactured harvesters and forwarders, there is an argument for this research belonging to experiment-category of research strategies. Wilson (2014: 124) states that purpose of experiment is studying how change in independent variable produces a change in another dependent variable. This can be tested within the simulation. Traditionally experimental research strategy uses control group and experimental group (Wilson, 2014: 124). This also applies in simulation since it is possible to see how changes in simulation models compares with former simulation models.

3.1.4 Research choice

The data used in a research contributes whether the research choice is mono-method, mixed-methods or multi-method (Saunders et a. 2007). In addition of 3D-models of the assembled parts, the data used in simulation are mostly about work times of different jobs and assembly tasks. These are quantitative data. However, building a 3D-simulation is not only based on raw quantitative data. It is reasonable for case company to have some qualitative opinions and wishes for 3D-simulation. Mixed methods refer to a research where both qualitative and quantitative data have been used (Saunders et al. 2007). Therefore, the used method in this research is **mixed method**. This works well with selected research philosophy since pragmatism is usually viewed as most suitable and popular paradigm for mixed methods (Wilson 2014: 11).

3.1.5 Time horizon

Saunders et al. (2007) use two different classes for time horizon used in a research: cross-sectional and longitudinal. Longitudinal design typically involves several years of research and it is a study of particular case over long period of time compared to cross-sectional design where data is collected at a single point in time (Wilson, 2014: 124). This research is **cross-sectiona**l since simulation is built to describe system at particular time and there is no change or development in the simulation after the simulation is built.

3.1.6 Techniques and procedures

Saunders et al. (2007) classifies data to primary and secondary regarding their origin. Primary data is collected specially for research project which is being underwork and secondary data is data which is used in a research project but were originally collected for some other purpose (Lee Abbott & McKinney 2013). By these definitions, most of the used data in this research is **secondary data** since the case company already had the data before this research. In addition to data given from the case company, the data used in literature review is also secondary.

Data analysis aligns heavily on research philosophy used in the research – pragmatism. By the nature of the research, it being a case study and a simulation, the data is analyzed between iterations of simulations and then used to improve the next iteration of simulation's performance in order to reach the demands of the case company within its constraints.

Reliability is a measure of consistency. In research it means that results of the study should be possible to replicate by another researcher following data collection techniques and analysis procedures used in the research (Saunders et al. (2007); Lee Abbot & McKinney (2013.) In this case, where the result of the study is a simulation model, more specifically a model focused in a flow and the output of the assembly line with only two main products, it very easy to replicate the results of the study especially when simulation shows how different variables and constraints are defined and used. The biggest threat for reliability in this research is subject bias, which means that information from the research subject are not reliable (Saunders et al. 2007). In this research, the data and comments from the case company are used as they were given. This is also result of pragmatism. It is out of scope of the research to challenge given assembly times from the case company since the goal is to create 3D-simulation model and simulate production with given constraints.

Validity refers measuring the accuracy of measure. It is concerned whether outcome of the research really measures what it is supposed to measure (Saunders et al. (2007); Lee Abbot & McKinney (2013.) To increase validity of the research and the simulation, two factory visits were made to get familiar with the current production. Before building final simulation model for calculating yearly output, two separate simulations for assembly of harvester and forwarder were made in order to learn and get familiar with the assembly process, 3D-parts and software. The validity of the simulation is tested by running simulation first with current assembly times making sure that output of the factory is close to real life performance.

4 Visual Components software

This chapter introduces simulation program Visual Components 4.2 which is used in this thesis to build a 3D-simulation. Most used features are described more precisely. The results of the study and simulation are presented after introduction of the software.

4.1 Visual Components 3D-simulation software

Visual components is 3D manufacturing simulation software founded in 1999, headquartered in Espoo. Software can be used to plan, design and validate new production solutions and concepts. Visual Components has three software products: essentials, professional and premium. Essentials is the plain version, where user can build, design and simulate factories with ready-made components. Professional has additionally component modelling feature and premium is the most extensive version, which has interactive VR among other more advanced features. (Visual Components 2020a.)

Visual Components have released different versions of simulation software and they have been updating their products among the years. In this research, VC 4.0 premium was used in the beginning but it was later updated to newest release VC 4.2 premium to get the benefits and functionalities of the newest release.

Visual Components Experience- software is an application to view layouts and 3D-simulations with VR glasses and mobile phones (Visual Components 2020b). This free application created by Visual components was used in this research to watch developed 3D-simulation animations in a virtual reality.

The features of different VC 4.2 products are presented in the table 1. The software features and user interface are introduced in the next paragraphs.

Table 1. VC software products and features (adapted from Visual Components 2020c).

Essentials	Professional	Premium
Layout configuration	Component modeling	Paint process visualization
Process modelling	Geometry simplification	Virtual topology
eCatalog	Wizards	Curve teaching tool
CAD compatibility	Basic CAD	Create path statement
Project ready deliverables	+ All essentials features	VRC connectivity for UR and Stäubli
Simple robotics		Siemens S7 PLC connectivity
Point cloud support		Interactive VR
2D drawing		+ All essentials features
PLC connectivity		+ All professional features
Statistics and reporting		
VC experience		

4.1.1 User interface

Overview of the VC 4.2 user interface (later UI) can be seen in figure 5. The left panel is for **eCatalog**, where user can search components and drag and drop them in to **3D world** where the layout is built. 3D world is in the middle of the picture. **Output** panel shows info from the simulation down low. **Properties** panel on the right show component properties. Top of the UI is reserved for tabs, which contains different functionalities and features. The basic tabs without add-ons are **File**, **Home**, **Process**, **Modelling**, **Program**, **Drawing** and **Help.** Home and modelling tabs and their most relevant features are briefly introduced in their own paragraphs.

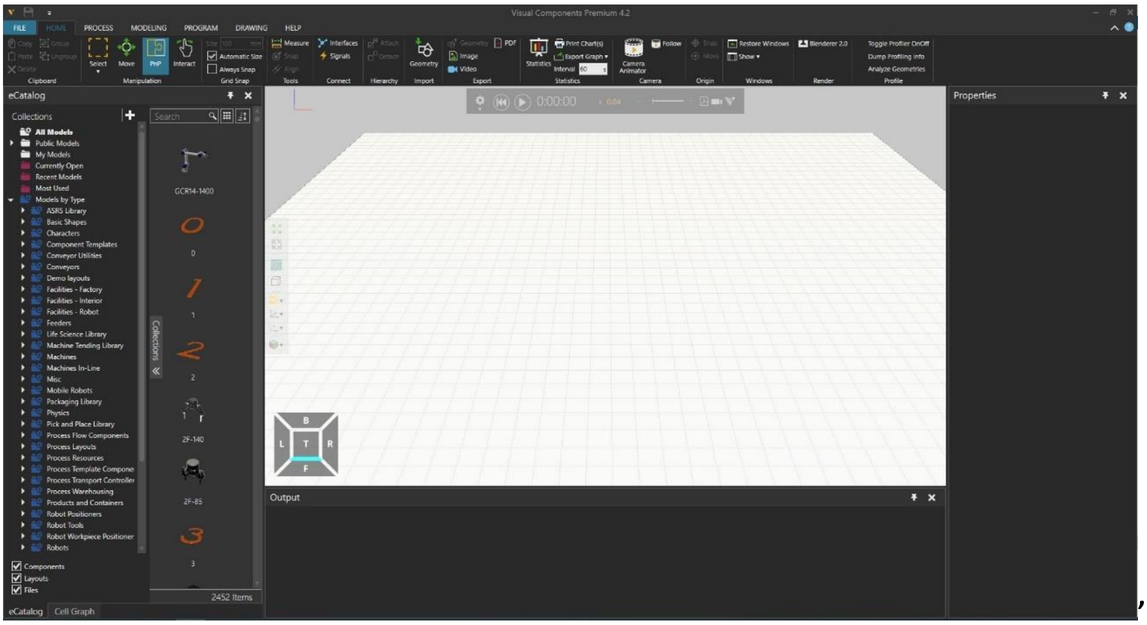

Figure 5. Home screen of the VC 4.2.

Left panel has also **Cell graph**, which shows used components and gives possibility to user to hide components (see figure 6.). Figure also shows view selector in the 3D world.

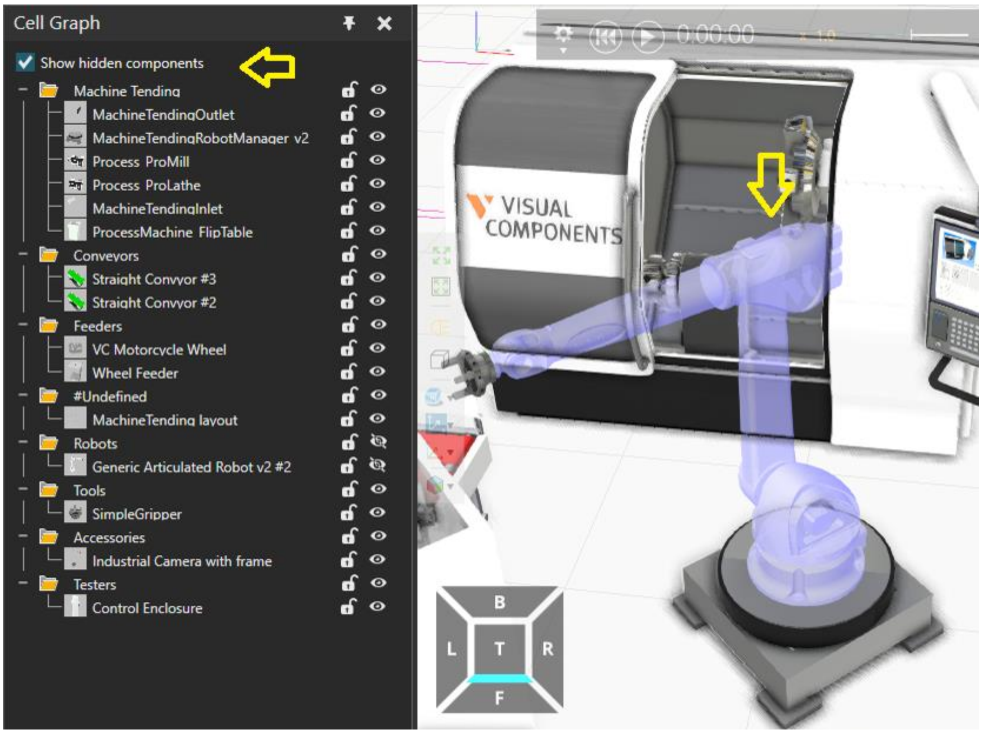

Figure 6. Cell graph (Visual Components 2020d).

In the top of the UI are the tabs which opens different screen views and shows more functionalities (see figure 7).

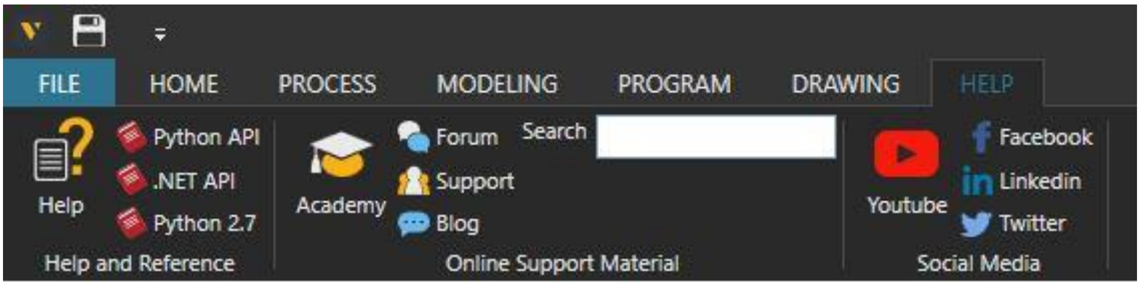

Figure 7. Tabs in the Visual Components user interface.

4.1.2 Home screen

Home screen tab (see figure 8) has all the basic functions and tools to build simple layouts. It has *manipulation* tools: select, move, PnP and interact. *Tools* section include measure, snap and align. Home screen has feature for *importing* geometry and *exporting* simulation in a different forms such as video, animation, pdf or picture. Home screen tab has section for *statistics*, which opens new screen for creating and showing detailed statistics. *Camera* section opens tool for recoding video or animation. *Origin* section has two tools for changing and moving the origin of the 3D-component. *Windows* section enables user to hide or show different tabs. *Render* and *Profile* sections are add-ons downloaded from Visual Components forum as well *Follow*-mode in Camera section.

Render add-on utilizes free rendering software *Blender* as it converts simulation scene into blender scene, which can be then rendered (Visual Components 2020e). This add-on is used to make more realistic pictures and animations.

Profile add-on shows simulation performance related indicators and it can be used to find critical components which need attention when trying to improve performance of the simulation (Visual Components 2020f).

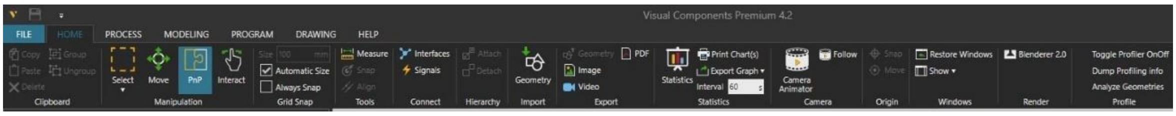

Figure 8. Home tab functionalities, tools and features.

4.1.3 Modeling

Modeling tab was the second most used tab after home tab in this study. Under this tab user has basic CAD tools for creating and modeling components. *Geometry* section which has *features* and *tools* were often used in this research. Since most of the 3D-models where given by the case company, modeling focused more on to adapting 3D-models by assigning more realistic materials, decimating models for better performance and overall building 3D-model of harvester and forwarder with moveable links from 3D-components.

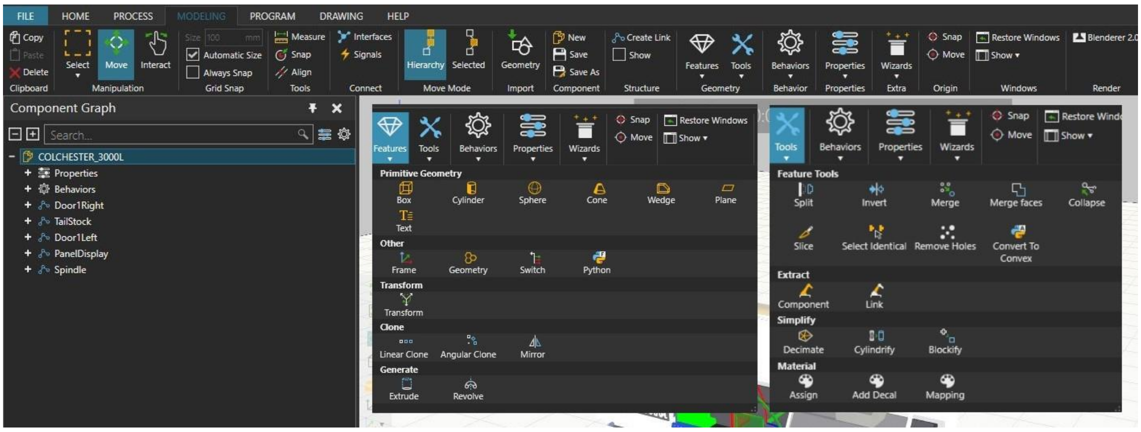

Figure 9. Edited screenshot of modelling tab with Features and Tools section open.

Figure 10 shows how modeling features and tools were utilized to make cabin doors and bonnet interactive. Figure also shows the effect of edited components as different materials where assigned to different components and parts when modeling components. This enables more realistic results and e.g. plain 3D-model of cabin is edited so that doors have windows enabling user to see through the cabin. Bonnet is made so that it is possible to lift in order to see the inside better. This is a good example how VR can also help and improve design as different stakeholders can open and test if the bonnet can be lifted enough for certain operations.

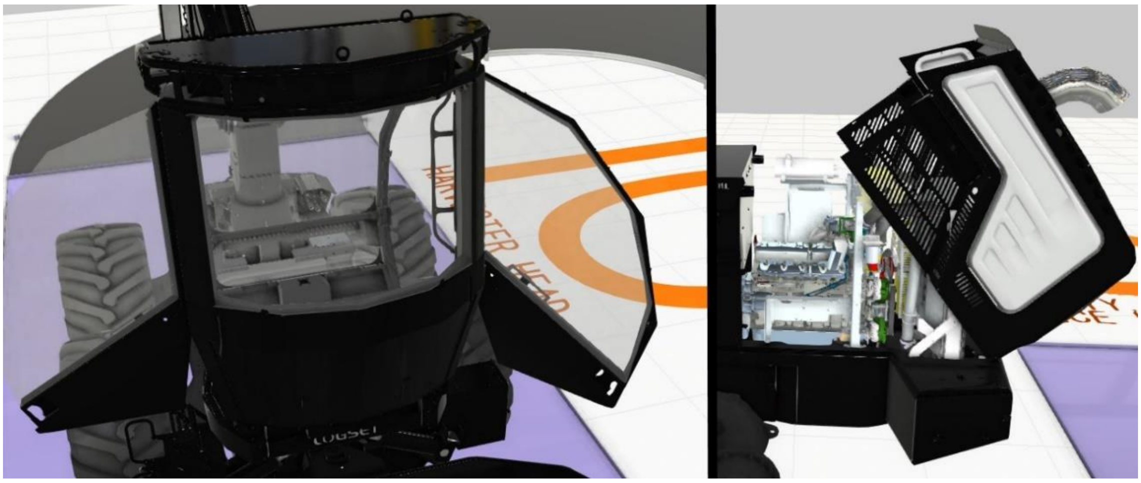

Figure 10. User can interact cabin doors and bonnet in VC and in VR.

5 Results

In this section the results of the research are presented. This research produced four simulation layouts: one assembly line for harvester, one assembly line for forwarder and two capacity models, where the main focus is on work times. Assembly line models were given forward in this research project for project researcher to build one combined assembly line layout. Capacity models are used to estimate yearly production volumes and as a tool for analyzing the production flow and its performance. Capacity models and the video of it are present in the research project's PowerPoint which is presented to Logset's management board.

Before the final simulation models designed for capacity calculations are presented, the process of simulating manufacturing of harvester and forwarder is briefly introduced.

5.1 Assembly line simulations

Since built 3D-models of harvester and forwarder were used in capacity models and these lines highly contributed to the bigger combined assembly line layout, this process and the results are introduced in this chapter.

The harvester and forwarder were both assembled from plain 3D-models of components as seen in the figure 11. These models were given by the case company and they were edited with VC modeling tools to assign realistic materials and colors as discussed in previous chapter. Harvester and forwarder lines were assembled respecting the current assembly work in the case company. Major work tasks and sequences can be found in the appendices. However, there are minor changes since work tasks in appendices are made for the first capacity simulation model.

Harvester line was built first before forwarder and with VC 4.0 but then remade with VC 4.2 as it was published during this research project. This was done to ensure that there would be no problems due to different software version when combining two layouts.

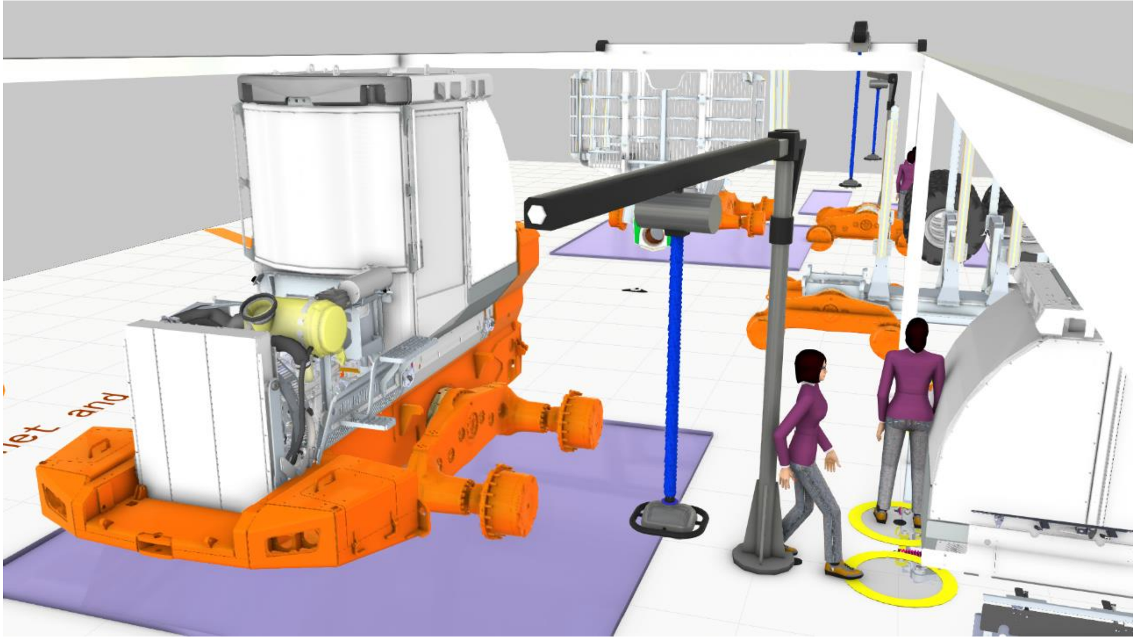

Figure 11. Harvester and forwarder were built from plain 3D-components.

Comparing figure 11 to 12 it is easy to see the difference of plain 3D-models versus edited 3D-models. Figures 12 and 13 were also rendered with Blender add-on. In the figure 11, assembly stations can be seen in purple color with components placed next to their respective stations. Also, cranes and lift assists for human workers are visible.

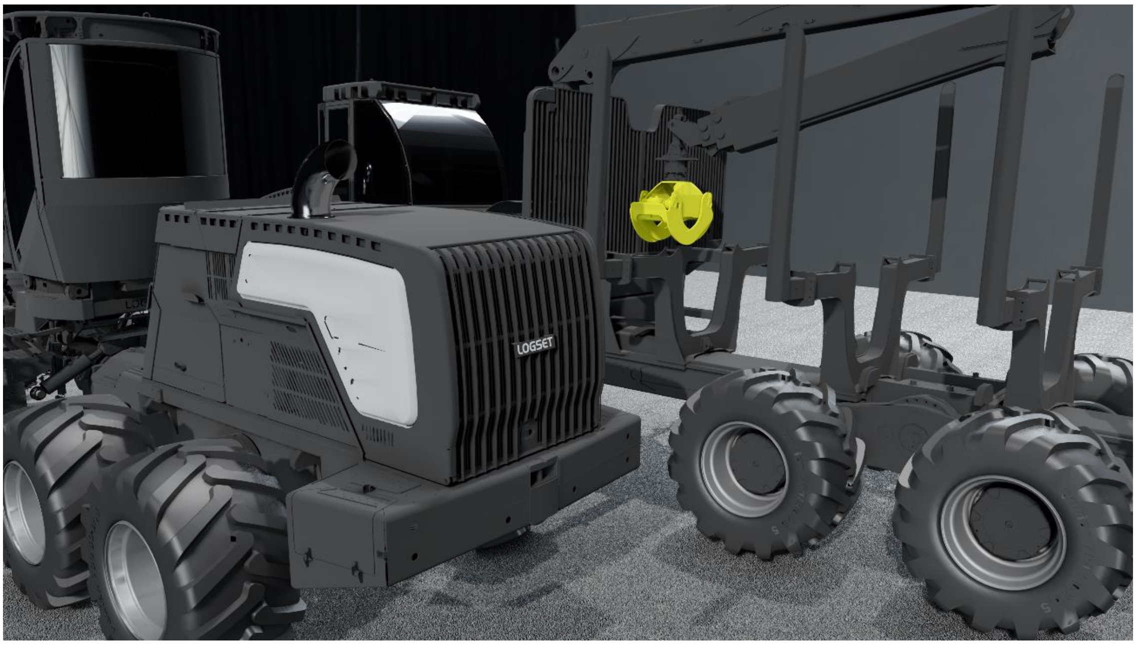

Figure 12. Rendered harvester and forwarder.

Figure 13. Assembled harvester and forwarder.

As seen from the above figures, the built harvester and forwarder look approximately as their real-life versions. However, models are missing some details and components. For example, lights and hydraulic hoses are missing. Also, the quality of the 3D-models had to be compressed in some cases due to lack of processing power, as rendering one scene (layout) for first time took sometimes more than 72 hours.

Process of building harvester and forwarder lines are discussed separately in the next chapters.

5.1.1 Harvester line

This chapter briefly describes the simulation process of harvester assembly. Figure 14 shows the overview of the built line for harvester. The harvester is assembled from 22 different components respecting the current work order of assembly in the case company. Harvester is assembled by using human workers in assembly process and automated guided vehicles (see figure 15) moving assembled harvesters from phase to phase until the built harvester has wheels and it can be driven to the next station. Heavier components are lifted using cranes and lift assists, otherwise humans will move and assemble parts by hand.

Assembly process is simulated focusing on bigger and larger components, meaning that smaller details are left out. However, some bigger components were divided into smaller pieces in order to simulate assembly process in a more detailed way. Outcome of this simulation was looping assembly process building full harvester. The built harvester is later used in the capacity model and the harvester assembly line simulation model is given to the project researcher as a reference model for his work with combined assembly line.

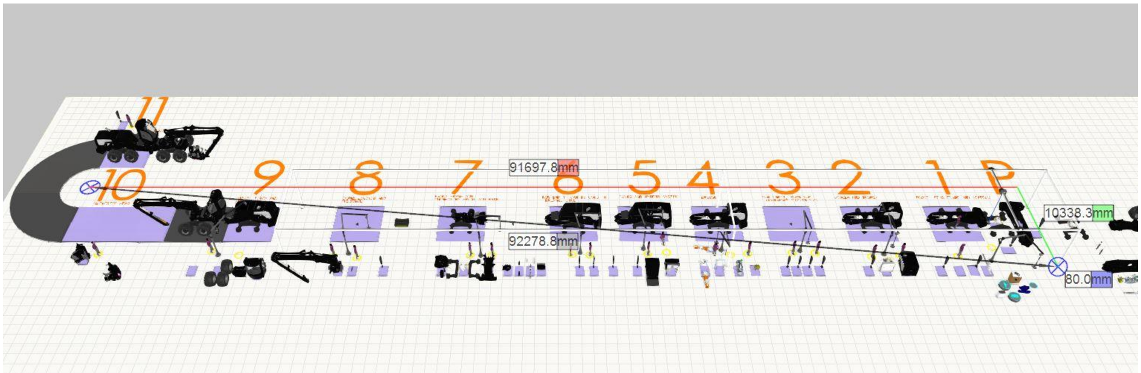

Figure 14. Built assembly line for harvester.

Components are located next to their respective assembly station as seen in the figure 14. This however is not their long-term storing area, as these places are reserved for logistics workers moving components from sub-assemblies when needed in the assembly stations. Sub-assemblies and the simulation of sub-assembly are out of scope in this research as assembly line determine the needed speed for the sub-assemblies. Therefore, it is more important to have assembly line simulated and designed first, as more detailed simulation including sub-assemblies can be made after the assembly line is conceptualized and desired output have been reached.

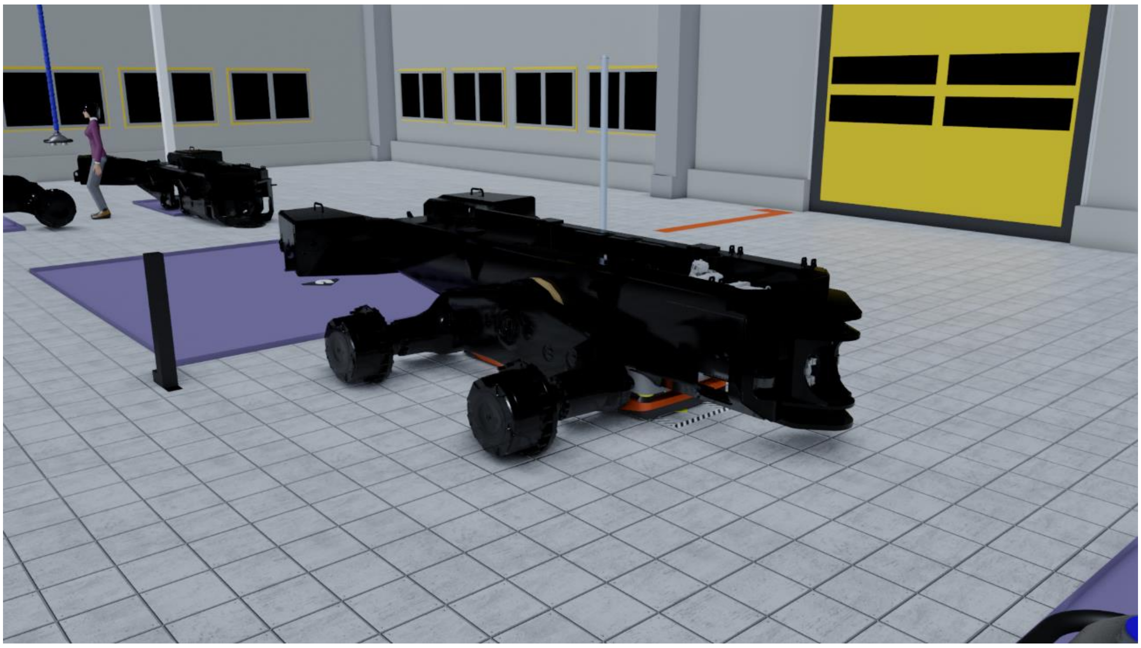

Figure 15. AGV moving WIP from workstation to another.

5.1.2 Forwarder line

This chapter briefly describes the assembly process of forwarder. Assembly line for forwarder is built in similar way as line for harvester. Of course, the line is adapted for forwarder dimensions and respecting its working steps and sequences. Forwarder is built from 27 different components. Like harvester, the forwarder was built concentrating bigger components and some components were divided in smaller pieces for more accurate simulation experience. Simulation model of the forwarder line was then given forward to project researcher like the harvester line. The built forwarder is also later used in the capacity model. In the figure 16 the first six assembly stations can be seen, with components placed next to their respective assembly stations. The last two stations including work tasks such as testing, finishing the delivery content and washing are out of the figure.

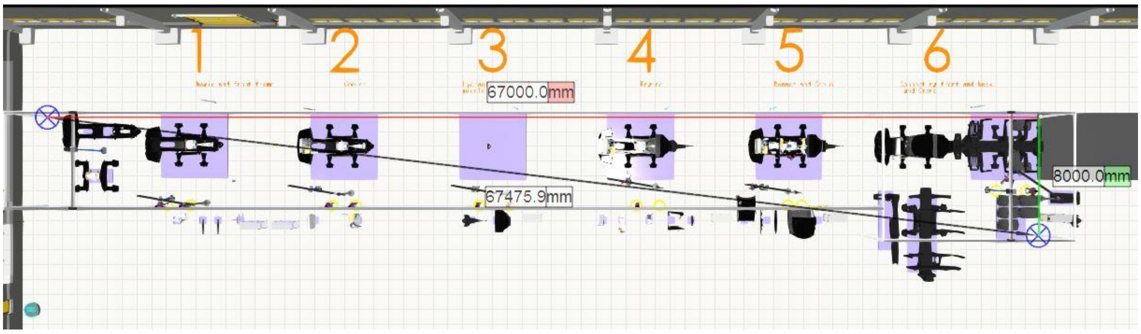

Figure 16. Built assembly line for forwarder.

5.2 Capacity models

One of the main objectives of the whole research is to estimate yearly output and conceptualize assembly process so that it is possible to reach target number of manufactured machines per year. Initial plan was, that another project researcher would combine aforementioned lines and then the simulation model could be run to get beneficial data. However, combining harvester and forwarder assembly lines proved to be a difficult and time-consuming task.

Also, detailed 3D-simulation is very heavy computing process so there was need for more simpler and faster model. Therefore, I built simplified combined layout simulating harvester and forwarder assembly process, concentrating only assembly line work times and flow of the line and used that to estimate yearly production, find bottlenecks and visualize the flow of the line. A vision from the company was to have partially combined line, where line would separate after few combined assembly stations. Therefore, first six assembly stations are combined and after that forwarder and harvester goes to their own assembly stations as seen in the figure 17 and 18.

Even though case company makes seven different harvester models and seven different forwarder models, these simulation models only use one type of harvester and forwarder as differences between different models are not so significant compared to different machines. It is however well known that production system's performance degrades if variability increases (Hopp & Spearman, 2011: 309). In this study scope comparing differences between harvester and forwarder is the main focus, even though adding different models to simulation could be done rather easily if exact assembly times for different models are known. This would require company to do time study of their production in a more detailed way.

Two capacity models were built. In the first model, the assembly process is built respecting the current assembly times of harvester and forwarder. This model concentrated purely work times of different workstations and it was used mainly just to get the estimation of the yearly production and get the first glimpse of the partially combined assembly line.

In the first capacity model, the simulation run time was set to 2000 hours to simulate 250 workdays in a one shift work. For comparison, another run time was 4000 hours which was made to test the outcome of two-shift work in 250 workdays. 250 workdays were chosen as it represents well normal working days during a year in Finland (Teknologiateollisuus, 2019). 8 hours working days were used as full-time working hours in this simulation due to vague precision of working times data given by the case company. Both capacity models use 25 min time when WIP is moved from assembly station to the next assembly station. However, moving is faster in last assembly stations when both machines can be driven forward to the station or work task, usually being test drive or washing.

The first capacity model uses work sequences and work times as presented in the appendices 1 and 2. The order of different works and their times were given by the case company and it resembles current assembly times in the company. Some assembly tasks were moved from different assembly phase to another during simulation process in order to get better performance and more balanced assembly line to see if it is possible to reach the target number for yearly production with current assembly times.

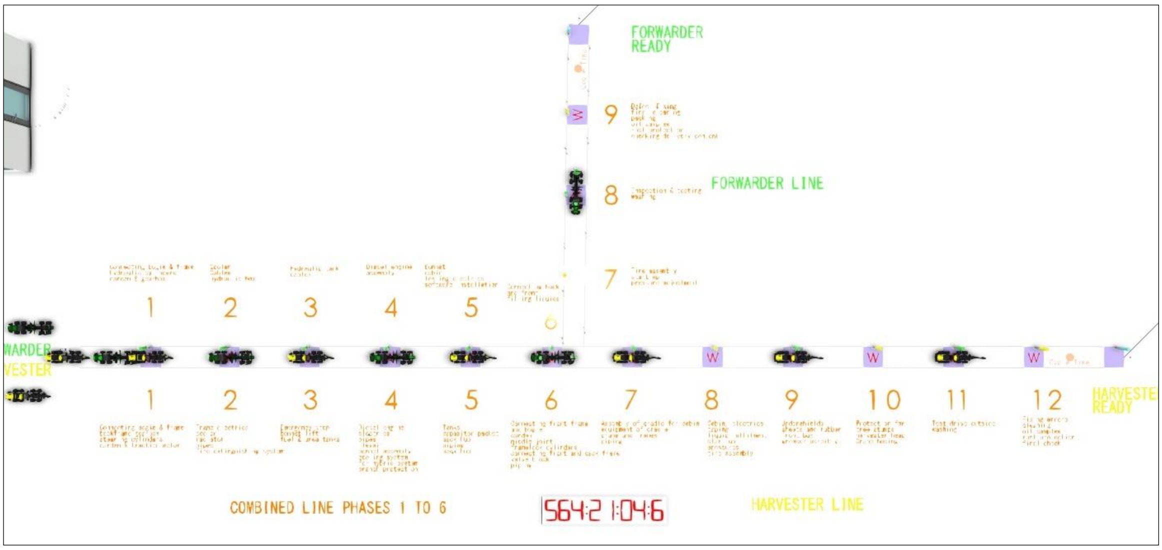

Figure 17. Overview of the layout.

The figure 17 shows the overview of the created layout. Numbers indicate assembly stations, except number 8 in the forwarder line and number 11 in the harvester line represents test drive, which happens outside and does not therefore require assembly stations. Last stations in both lines are reserved for finishing and checking the delivery content, which do not require assembly work or specified assembly stations containing heavy tools. However, these station are included in the simulations to take account these time-consuming tasks and as a reminder to have area allocation for these last steps.

As stated before, this first capacity model uses only *active* working time. For that reason, it is only used to find and identify bottlenecks and get first glimpse of the partially combined assembly line. Second model is made in order to get cycle time and lead time, as it contains also *non-active* working time giving more realistic results.

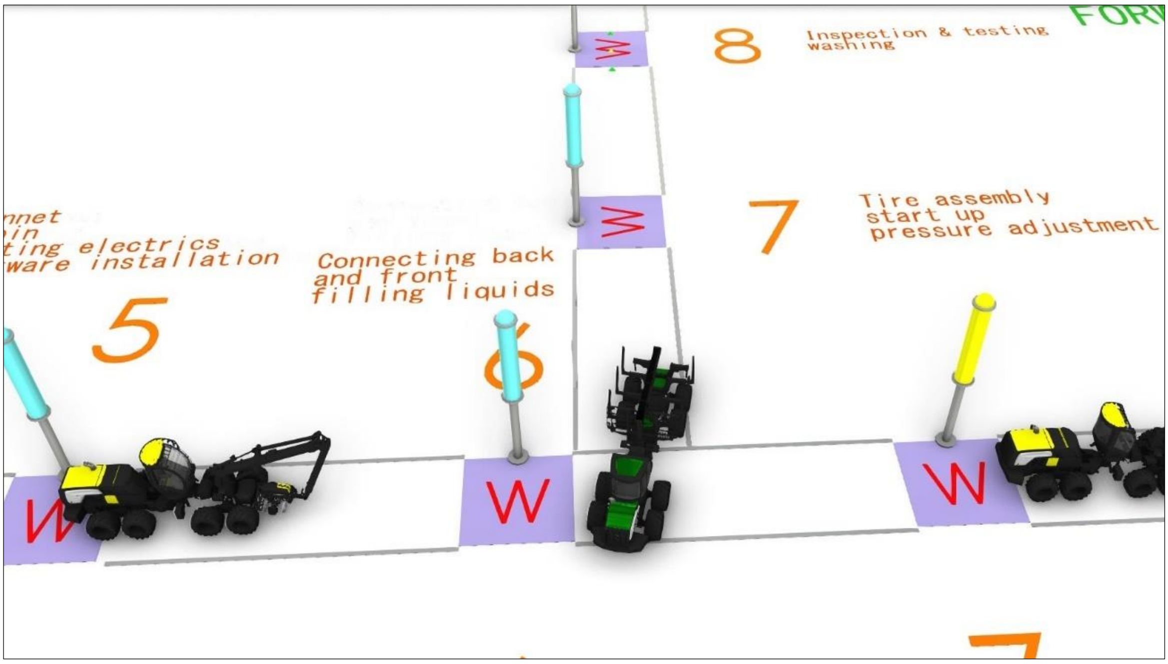

Figure 18. Line separates after six combined phases.

Figure 18 is a screenshot from the first capacity simulation model. In the figure, forwarder being assembled is moved to its own assembly line. Beacons with different colors indicate assembly station status, whether the station is busy or empty and waiting for work. Text above or next to numbers indicate the main work tasks in the workstations.

As it can be seen from figures 17, 18 and 19, the line is very simplified having no simulated assembly work, workers or components next to stations as the purpose of the capacity models is to visualize the movement of the WIP, flow of the line and estimate yearly production and derive other informative data. This way the simulation model is faster to run with computers and the performance of the line is easy to see and analyze. Also, changes are much faster to do in the layout as there are no detailed assembly work simulated. This is an important factor as there is no detailed layout plan for the factory. The capacity models do not take part in the discussion of the shape of the line, whether it reminds letters U, P, L or S, it is another discussion and needs to be designed with logistics, sub-assemblies and area allocations in mind. However, the concept of partially combined line will have an effect when designing the assembly line.

Figure 19. Capacity model can be used to find utilization rates for different phases.

3D-world view and the pseudocode generated by VC 4.2 with descripting comments of the same situation can be seen in figures 19 and 20. User made comments are separated from the code with character “#” in the beginning of the comment line.

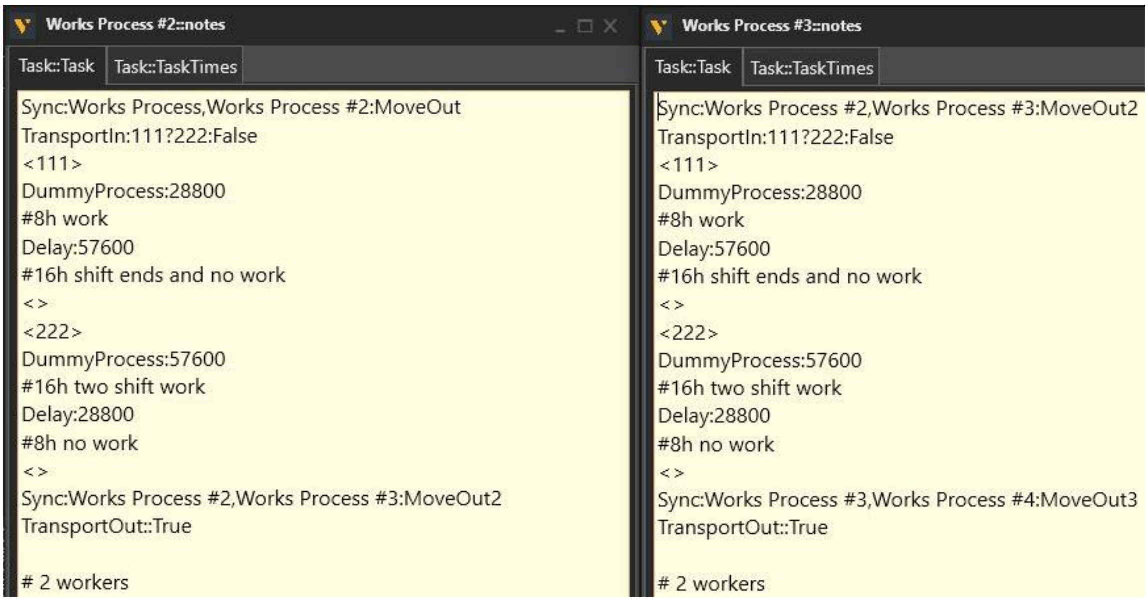

Figure 20. Screenshot of the pseudocode from the situation seen in the figure 19.

In the next two chapters, the results of the capacity model simulations are presented.

5.2.1 First capacity model results

The first capacity model shows clearly that the target number for yearly production is unachievable with current assembly times (see appendix 3).

Harvester's assembly process and assembly times are so unbalanced compare to forwarder's work task times, that it jams the assembly line. In several workstations, harvester's work times require more time than forwarders. Even when the line produces three times more forwarders than harvesters, the performance is still bad and volumes are low.

However, it seems that forwarder can very well being assembled in this line, as its work times are very balanced. This can be due to company's current manufacturing system, where forwarders are assembled already in a more developed way utilizing several assembly cells compared to harvester's assembly process, which are assembled in one place from start to finish. Also, the volume of the manufactured forwarders is bigger compared to harvesters, which can result faster work times in forwarder manufacturing, as employees are more experienced with forwarder assembly process.

This simulation was run multiple times with small different modifications i.e. moving works to next assembly station or station before compared to its current station. However, there were no good solutions as some tasks in the harvester assembly process can take alone 16 hours and many station needed almost 30 hours to finish their work. For example, when harvester requires 27 hours work time in a bottleneck station phase 4, it causes next stations to starve and previous station cannot put their work forward on to next station as station 4 is still working. As there are several workstations, which require almost as much time as bottleneck station, improving bottleneck station would not improve performance significantly as harvester's work times in the workstations are often more than double compared with forwarder's work times.

5.2.2 Second capacity model results

Second model is made to show how improvements in the assembly of harvester effect the output of the factory. In this simulation, forwarders are made in one shift and harvesters in two shift, just to show what the volume could be if harvester assembly process could be improved so that every station could do their work in 16 hours with the exception of harvester's test drive, which takes 24 hours. However, test drive is not problem as it can be done outside and capacity could be improved by assigning more employees to the testing. In this model, forwarder assembly process was also improved in one assembly station from 10 hours to 8 hours to show the effect of balanced workflow.

Simulation run time is 6000 hours in second capacity model as it simulates production during 250 workdays in a year and takes account *non-active* working time in order to get more realistic results. Results of the second simulation show that improvements in the assembly times regarding harvester would have enormous effect on the output of the factory (see appendix 4). Estimations of assembly workers are presented also in the table, were the assumption is that there is always two worker in every assembly phase except for the few last phases in both lines, which are inspection, washing and testing.

Results shows the importance of balanced assembly times and how important it is to reduce work task times. Even though volume is still under the target number for manufactured machines per year, it would be much easier to increase, for example working more than 250 days in a year by using summer workers, working weekends and building forwarders also in two-shift.

As second capacity model takes account also non-active working time, the simulation software can calculate mean cycle time and mean lead time for both machines in different scenarios (see appendix 5).

As mean cycle time is around 24 hour, it implicates that the main goal should be to reduce current assembly phases at least under 24 hours in every phase with the exception being test drive as machines can be buffered outside. However, when designing assembly line and developing assembly process, active working times and work shifts should be taken account and 24-hour goal should be aimed even lower at 16 hours in order to avoid expensive nights shifts. This means that if development in assembly processes do not produce wanted results regarding reduced assembly times, there is a need for additional assembly stations enabling possibility to divide work from one station to two stations. For example, if bottleneck station 4 having 27 hours of work is divided in to two stations, there would be two stations with 13,5 hours of working time.

Dividing works to two stations is not however only a matter of work times as it is a development process which needs discussion and cooperation with company employees as some work tasks are complex installations which can be hard to divide in to smaller work tasks.

6 Summary and conclusions

This chapter summarizes key findings of the research and presents managerial implications and suggestions for future studies.

6.1 Summary

This thesis covers the use of 3D-simulation in conceptualizing a new factory. In this section, the result regarding research questions are briefly presented.

How can 3D-simulation help develop a new factory?

As shown above, 3D-simulation can be used in development of new factory. It is a fast and cheap method for developing different layout alternatives, which can also be tested and compared by using simulation, helping companies to select the most suitable layout. Simulation can help identify possible problems and find suggestions for improvement in the new factory and its production before any physical structures are built. Even the process of developing 3D-simulation can produce valuable information, as there is a need to gather data regarding manufacturing process and this step can produce positive insight of the process. The built 3D-simulation can be run to produce estimations of performance metrics of the new factory. This data can be utilized e.g. in calculating ROI. Different batches and manufacturing scenarios can be tested in 3D-simulation to find most profitable and suitable system for production.

The possibilities and functionalities of 3D-simulation software are vast. Even though 3D-simulation software is used in this research project to build 3D and 2D layout of the factory, simulate production and assembly work, modeling 3D harvester and forwarder and calculate predictions of future factory metrics, there are still a lot of possible applications were 3D-simulation and the 3D-simulation software could be used and applied to. Even after the layout for the new factory is decided, 3D-simulation model can be used to test adjustments in the building phase and develop the model to be used as a digital twin.

What benefits can virtual reality bring to a new factory layout planning?

3D-simulation software can save developed layouts as animation which are viewable with VR-glasses. In addition to visualization, it is possible to make components interactive, so that person using VR-glasses and touch controllers can for example open cabin doors and test if area allocation is big enough for that. During COVID-19, VR can be seen even more important tool to give insight of the factory for different stakeholders due to travelling restrictions. It is worth mentioning, that VR can be used as a powerful marketing tool. Whether it is for company employees, investors or customers, it is the only way to “made a walk” in the new factory before any physical structures are built.

6.2 Managerial implications

By the nature of the research being a case study, it is understandable that the company managers and the management board hope to get useful data or managerial implications to improve company’s performance.

In addition to conceptualized layout of the new factory, this research highlighted the importance balanced assembly times, especially this study showed the need for improvement regarding harvester assembly process. Also, results show that 3D-simulation and virtual reality are valuable tools for manufacturing company since possibilities are vast. For example, 3D-simulation can be used to find competitive edge. As stated in the introduction, forest machines manufacturers in Finland have invested a lot in their production and facilities recently. By benchmarking competitors` production as much as possible and then using 3D-simulation as a tool to show weaknesses and strengths in competitors` production processes could lead to competitive edge as case company could avoid competitors mistakes and cherry pick their success factors.

Even if managers do not find this research results useful, it should be noted that in Gartner’s top 10 strategic technology trends for 2020, hyperautomation and multiexperience are trends number one and two. In both trends, virtual reality and digital twins play major roles as visualization of functions and process are important. (Panetta, 2019.) For this reason, it is advisable to get familiar with 3D-simulation and VR and the possibilities of the current technology.

6.3 Further research

Building 3D-simulation can take a lot of resources in matter of computing power and work time, especially if responsive persons are inexperienced as learning and familiarizing new software can take a while. In addition to that, 3D-simulation developers need to learn and understood case company's products and processes, which also require time and attention. In order to reduce time required developing 3D-simulation, an automated import of layout data into 3D-simulation environment should be studied more as Laemmle and Gust (2019) already have shown promising development under this subject. However, this aforementioned method requires predetermined layouts, so in a matter of developing a completely new layout this method is not appropriate and probably not easily applied if manufacturing process contains mainly manual work.

As 3D-simulation layout can be very complex and built in a very detailed way, there is always possibility to rework developed layout into more precise version and make adjustments. For example, sub-assembly production processes and material flow can be simulated to make more precise 3D-simulation. Stochastic processes, failures and more variability can also be added into simulation to test different scenarios. Also, in order to get more precise simulation, work time observation should be performed in the current assembly process to get more realistic results.

The target number for yearly production was not reached with this simulation. Therefore, a new layout design with added stations should be considered after more precise work time study. This new layout should be made in cooperation with manufacturing experts and simulation developers in order to ensure that simulation model would reflect reality as well as possible, especially making sure that different work tasks are in right order manufacturing wise and work tasks times are precise.

This research and simulation models demonstrated that balancing the assembly line would produce notable improvement regarding yearly output. With more precise data and developing a simulation model with company's expert, a new simulation model could be utilized better in regards of production development.

Visualization is one of the key selling points for 3D-simulation and VR. As components in the 3D-simulation world can have different materials, it would be interesting if software could utilize this data combined to 3D-layout of the factory and give some estimation of the noise level in the factory as there are already acoustics software where build 3D model can be exported and further analyzed. This would also make VR-experience more immersive as audio experience would also be simulated. This would also be beneficial when developing layouts, as noise level could be monitored and kept low and safe.

VR gives also new opportunities. While writing this thesis, new updates in VC enables more possibilities in VR. It is now possible to move pick and move components in VR if those components are made pickable. This make VR more interactive and it is possible to make changes in layout while using VR-headset and controller. (Visual Components, 2020g.) In the future simulation models, objects should be made pickable so that different stakeholders can make changes in the layout while in VR and suggest and test improvements in the layout.

References

Bicheno, J. & Holweg, M. (2016). *The Lean toolbox: A handbook for lean transformation* (5th edition.). Buckingham: PICSIE Books.

Bogdan, S., Lewis, F. L., Kovačić, Z. & Mireles Jr, J. (2006). *Virtual Factory Modeling and Simulation*. Retrieved July 13, 2020 from https://doi-org.proxy.uwasa.fi/10.1007/1-84628-334-5_7

De Carlo, Filippo, Maria Antonietta Arleo, Orlando Borgia & Mario Tucci. (2013). Layout Design for a Low Capacity Manufacturing Line: A Case Study. *International Journal of Engineering Business Management,* 5. Retrieved July 10, 2020 from https://doi.org/10.5772/56883

Fuchs, P., Guitton, P. & Moreau, G. (2011). *Virtual Reality: Concepts and Technologies*. Retrieved July 10, 2020 from https://ebookcentral-proquest-com.proxy.uwasa.fi/lib/tritonia-ebooks/detail.action?docID=2010050

Gansterer, M. & Hartl, R. F. (2018). One- and two-sided assembly line balancing problems with real-world constraints. *International Journal of Production Research, 56*(8), p. 3025. Retrieved September 7, 2020 from https://doi.org/10.1080/00207543.2017.1394599

Hakim, Catherine. (2000). *Research design: Successful designs for social and economic research*.

Haverila, M., Uusi-Rauva, E., Kouri, I. & Miettinen, A. (2009). *Teollisuustalous* (6th edition). Tampere: Hämeen Kirjapaino.

Helo, P., Tuomi, V., Kantola, J. & Sivula, A. (2019). *Quick guide for Industrial Management thesis works*. Vaasan yliopisto. Retrieved June 9, 2020 from http://urn.fi/URN:ISBN:978-952-476-871-9

Hopp, Wallace J. & Spearman, Mark L. (2011). *Factory physics.* (3rd edition). Waveland.

Hyde, K. F. (2000). Recognising deductive processes in qualitative research. *Qualitative Market Research: An International Journal, 3*(2), 82–90. https://doi.org/10.1108/13522750010322089

Jain, S., Shao, G. & Shin, S. (2017). Manufacturing data analytics using a virtual factory representation. *International Journal of Production Research, 55*(18), pp. 5450–5464. Retrieved July 8, 2020 from doi:10.1080/00207543.2017.1321799

Johnsen, Torbjörn. (2018). Finnish forest machine market 2017 compared to the Swedish. *Forestry.com.* Retrieved July 6, 2020 from https://www.forestry.com/editorial/finnish-forest-machine-market/

Johnsen, Torbjörn. (2019). Forest machine sales in Finland 2018. *Forestry.com.* Retrieved July 3, 2020 from https://www.forestry.com/deep/forest-machine-sales-finland-2018/

Kikolski, M. (2017). Study of Production Scenarios with the Use of Simulation Models. *Procedia engineering, 182*, pp. 321–328. Retrieved September 14, 2020 from https://doi.org/10.1016/j.proeng.2017.03.102

Kumar, K. (2019). *Digital Manufacturing and Assembly Systems in Industry 4.0*. Retrieved July 10, 2020 from https://doi-org.proxy.uwasa.fi/10.1201/9780429464768

Laemmle, Arik & Gust Stefan. (2019). Automatic layout generation of robotic production cells in a 3D manufacturing simulation environment. Retrieved June 3, 2020, from https://doi.org/10.1016/j.procir.2019.04.207

Lee Abbott, M. & Mckinney, J. (2013). *Understanding and Applying Research Design.* Retrieved June 9, 2020, from https://ebookcentral-proquest-com.proxy.uwasa.fi/lib/tritonia-ebooks/detail.action?docID=1120726.

Logset. (2020a). Logset. Retrieved January 31, 2020, from https://www.logset.com/logset

Logset. (2020b). Logsetin vuosi 2019 oli ennätyksellinen. Retrieved July 6, from https://www.logset.com/fi/uutiset/logsetin-vuosi-2019-oli-ennatyksellinen

Logset. (2020c). Harvesterit. Retrieved July 7, 2020 from https://www.logset.com/fi/harvesterit

Logset. (2020d). Logset 12H GTE Hybrid. Retrieved July 6, 2020 from https://www.logset.com/fi/harvesterit/logset-12h-gte-hybrid

Logset. (2020e). Harvesteripäät. Retireved July 7, 2020 from https://www.logset.com/fi/harvesteripaat

Logset. (2020f). Kuormatraktorit. Retrieved July 7, 2020 from https://www.logset.com/fi/kuormatraktorit

Logset. (2020g). Logset 5FP GT. Retrieved July 6, 2020 from https://www.logset.com/fi/kuormatraktorit/logset-5fp-gt

Maa-ja metsätalousministeriö. (2019). Metsäteollisuus Suomessa. Retrieved July 3, 2020 from https://mmm.fi/metsat/puun-kaytto/metsateollisuus-suomessa

Marshall, D. A., Burgos-Liz, L., Ijzerman, M. J., Osgood, N. D., Padula, W. V., Higashi, M. K., . . . Crown, W. (2015). Applying Dynamic Simulation Modeling Methods in Health Care Delivery Research—The SIMULATE Checklist: Report of the ISPOR Simulation Modeling Emerging Good Practices Task Force. *Value in health, 18*(1), pp. 5–16. Retrieved September 17, 2020 from https://doi.org/10.1016/j.jval.2014.12.001

Metsätrans. (2019). 2018 oli kaikkien aikojen ennätysvuosi harvestereiden rekisteröinnissä. Retrieved July 3,2020, from https://metsatrans.com/2018-oli-kaikkien-aikojen-ennatysvuosi-harvestereiden-rekisteroinnissa/

Naderi, B., Azab, A. & Borooshan, K. (2019). A realistic multi-manned five-sided mixed-model assembly line balancing and scheduling problem with moving workers and limited workspace. *International Journal of Production Research, 57*(3), pp. 643–661. Retrieved September 2, 2020, from doi:10.1080/00207543.2018.1476786

Nicholas, John. (2010). *Lean Production for Competitive Advantage: A Comprehensive Guide to Lean Methodologies and Management Practices.* Retrieved April, 9, 2020, from https://ebookcentral-proquest-com.proxy.uwasa.fi/lib/tritonia-ebooks/detail.action?docID=5338532

Niehorster, D. C., Li, L. & Lappe, M. (2017). The Accuracy and Precision of Position and Orientation Tracking in the HTC Vive Virtual Reality System for Scientific Research. *i-Perception, 8*(3). Retrieved September 17, 2020 from https://doi.org/10.1177/2041669517708205

Padovano, A., Longo, F., Nicoletti, L. & Mirabelli, G. (2018). A Digital Twin based Service Oriented Application for a 4.0 Knowledge Navigation in the Smart Factory. Retrieved July 10, 2020 from https://doi.org/10.1016/j.ifacol.2018.08.389

Panetta, Kasey. (2019). Gartner Top 10 Strategic Technology Trends for 2020. Retrieved July 23, 2020 from: https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2020/

Pérez, L., Rodríguez-Jiménez, S., Rodríguez, N., Usamentiaga, R. & García, D. F. (2020). Digital Twin and Virtual Reality Based Methodology for Multi-Robot Manufacturing Cell Commissioning. Retrieved July 10, 2020 from https://doi.org/10.3390/app10103633

Rong-feng, S., Xiaozhen, Z. & Chengjun C. (2017). Study on Drive System of Hybrid Tree Harvester. Retrieved July 6, 2020 from https://doi.org/10.1155/2017/8636204

Saunders, M., Lewis, P. & Thornhill, A. (2007). *Research methods for business students.* (4th ed.). Retrieved June 3, 2020, from https://ebookcentral-proquest-com.proxy.uwasa.fi/lib/tritonia-ebooks/detail.action?docID=5139642

Senem Kursun Bahadir. (2011). Assembly Line Balancing in Garment Production by Simulation. *Assembly Line - Theory and Practice*. Retrieved September 5, 2020 from https://doi.org/10.5772/22712

Solidworks (2020). 3Dcreate/Visual Components Oy. Retrieved September 17, 2020 from https://www.solidworks.com/partner-product/3dcreate

Sorsa, Vilja. (2019). Metsäkoneiden tuotanto pyörii ennätystahtiin ja osaavista käsistä on pulaa – John Deere investoi voimakkaasti. *Op.media*. Retrieved July 3, 2020 from https://op.media/teemat/metsa/metsakoneiden-tuotanto-pyorii-ennatystahtiin-ja-osaavista-kasista-on-pulaa-john-deere-investoi-voimakkaasti-349d0ee9d4dc494e8b90be8af3d648c5

Stephens, Matthew P. (2019). *Manufacturing facilities design & material handling.* (6th edition). Purdue University Press.

Tashakkori, A. & Teddlie, C. (1998). *Mixed methodology: Combining qualitative and quantitative approaches*. Thousand Oaks, CA. Sage.

Teknologiatellisuus. (2019). Työntekijöiden työaika 2019–2021. Retrieved July 15, 2020 from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjM7OfO083qAhWQyKYKHfvqAmIQFjAAegQIBBAB&url=https%3A%2F%2Fteknologiateollisuus.fi%2Fsites%2Fdefault%2Ffiles%2F2020-01%2FVuosity%25C3%25B6aika_2019-2021_2.pdf&usg=AOvVaw3xSTeLj0mzQEmqsq-0sA4n

Tikkanen, Seppo. (2018). Ponssen jättilaajennus valmis Vieremällä: "Nyt ollaan niissä tehdasmitoissa, missä pitää ollakin". *Yle*. Retrieved July 3, 2020 from https://yle.fi/uutiset/3-10369231

Tompkins, J. A., Bozer, Y. A., Tanchoco, J. M. A. & White, J. A. (2010). *Facilities planning* (4th ed.). Hoboken, NJ: Wiley.

Wilson, J. (2014). *Essentials of business research: A guide to doing your research project* (2nd ed.). Los Angeles, CA. SAGE.

Visual Components. (2019). Digital Twins and Virtual Commissioning in Industry 4.0. Retrieved July 10, 2020 from https://www.robotics.org/content-detail.cfm/content_id/8173

Visual Components. (2020a). About us. Retrieved February 5, 2020, from https://www.visualcomponents.com/about-us/

Visual Components. (2020b). Visual Components Experience- software. Retrieved June 22, 2020, from https://www.visualcomponents.com/visual-components-experience/

Visual Components. (2020c). Home page. Retrieved June 22, 2020, from https://www.visualcomponents.com/

Visual Components. (2020d). Introducing visual components 4.04. Retrieved June 22, 2020, from https://www.visualcomponents.com/insights/blog/introducing-visual-components-4-0-4/

Visual Components. (2020e). Take your images and animation to the next level with the Blender Add-On. Retrieved June 22, 2020, from https://www.visualcomponents.com/insights/blog/take-your-images-and-animation-to-the-next-level-with-the-blender-add-on/

Visual Components. (2020f). Profiler. Retrieved June 22, 2020, from https://forum.visualcomponents.com/t/profiler/950

Visual Components. (2020g). Introduction to Interactive VR. Retrieved September 2, 2020, from https://academy.visualcomponents.com/lessons/introduction-to-interactive-vr/

Volvo. (2017). Virtual twin plant shorten lead times. Retrieved July 10, 2020 from https://www.volvogroup.com/en-en/news/2017/mar/virtual-twin-plant-shorten-lead-times.html

Yap, H. J., Taha, Z., Dawal, S. Z. M. & Chang, S. (2014). Virtual reality based support system for layout planning and programming of an industrial robotic work cell. PloS one, 9(10). Retrieved September 17, 2020 from https://doi.org/10.1371/journal.pone.0109692

Appendices

Appendix 1. Forwarder phase times

Confidential

Appendix 2. Harvester phase times

Confidential

Appendix 3. Results of first simulation model in different scenarios when used case company's current assembly times.

Confidential

Appendix 4. Results of simulation in different scenarios with balanced work times.

Confidential

Appendix 5. Mean cycle time and lead time with different scenarios.

Confidential