DEGREE PROJECT

Application of discrete event simulation for assembly process optimization

Buffer and takt time management

Tim Snell
Pontus Persson

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Luleå University of Technology
Department of Engineering Sciences and Mathematics

Preface

This master thesis have been challenging and perceptive over its course from January to June 2020. The assistance from supervisors and working alongside colleagues has played a key role in the outcome of this project. We are proud of our efforts and satisfied with the results, hoping that Scania will proceed with our recommendations and incorporate them in their daily work.

Firstly we want to thank Scania for the opportunity to perform our master thesis in Oskarshamn and providing us with good care. A special thanks goes out to our Scania supervisor Erik Karlsson and head of department Tomas Hallenberg for guidance and feedback. Torbjörn Ilar from Luleå tekniska universitet has continuously provided us with valid input regarding simulation technicalities and overall project managing. Thanks to Imagine That Inc for granting us licenses for their latest version of ExtendSim Pro and for the support throughout this project. Working with Scania and its employees in Oskarshamn has been educative and of great joy.

Pontus Persson

Tim Snell

Abstract

A master thesis within mechanical engineering performed by two student has been conducted at Scania in Oskarshamn. The purpose has been to investigate if *Discrete Event Simulation* using ExtendSim can be applied to increase Scanias assembly productivity. The projectiles was to investigate how the buffer systems could be managed by vary the amount of buffers and their transport speed. The assembly line takt times with regard of their availability was also investigated. The method of approach was to build a simulation model to gaining valid decision making information regarding these aspects. Process stop data was extracted and imported to ExtendSim where the reliability library was used to generate shutdowns.

Comparing 24 sets over 100 runs to each other a median standard deviation of 0,91 % was achieved. Comparing the total amount of assembled cabs over a time period of five weeks with the real time data a difference of 4,77 % was achieved. A difference of 1,85 % in total amount of shutdown time was also achieved for the same conditions.

The biggest effect of varying buffer spaces was for system 6A. An increasement of up to 20 more assembled cabs over a time period of five weeks could then be achieved. By increasing all the buffer transports speeds by 40 % up to 20 more assembled cabs over a time period of five weeks could be achieved. A push and pull system was also investigated where the push generated the best results. A 22 hour decreasement of total shutdown time and an increasement of 113 more assembled cabs over a time period of five weeks could be achieved.

Keywords: assembly optimization, buffer management, takt time management, discrete event simulation, production, scenario simulation and ExtendSim

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1 Introduction

In corporation with Scania, a master thesis project within mechanical engineering has been conducted. The work has been performed in Oskarshamn by two students from Luleå technical university where the assembly process was the focus area. The purpose has been to investigate if *Discrete Event Simulation* (DES) using ExtendSim can be applied to increase Scanias assembly productivity. The goal of the project was to create a simulation model to be incorporated in Scanias daily work as a tool to optimize their assembly process.

1.1 Company description

Together with its suppliers Scania is a world leading company, delivering transport solutions all over the world. The research and development are concentrated to Sweden while the manufacturing department is located in Europe, Latina America with regional production facilities in both Africa, Asia and Eurasia. This work will be focusing on the truck cab assembly process in Oskarshamn. The cab manufacturing process is divided into four different sub-processes consisting of press shop, body manufacturing, base- and cover painting and last and final the assembly process. There is also a logistics department acting as a support process to the entire factory [1].

1.2 Problem formulation

The Assembly process is divided into eight different assembly lines with buffers in-between the lines. The supply of assembly parts are regulated and continuously monitored by the logistic department. The assembly lines are continuously driven, meaning that they are moving at a constant speed. If one assembly station stops, the entire line stops and the upcoming assembly lines are therefore affected. See Figure 1 below for a visual representation of how the buffers interact with assembly line one and two. The buffers hold a certain amount of cabs which are transported between the lines.

Figure 1: A visualisation of how the buffers interact with assembly line one and two.

Since different cab models requires different resources and have various assembly times a combination in which order they are assembled needs to be made. This to ensure to always be within in the takt time and keep up with the rest of the production. The order are determined by balance calculations where the cab models and their correlating assembly times are combined to find the most optimal order. An *Overall Production Effectiveness* (OPE) is also incorporated to ensure that the assembly workers are to manage the work without rushing. This to ensure a good working condition and establishing quality trough out the assembly process.

As always, theory and the practical application does not go exactly hand in hand due to different types of reasons. For instance the human factor and machine malfunctions. If these stops are too long the buffers in-between the assembly lines are drained and eventually the next line stops. When the problem then are resolved and the assembly line is back operating, problems with achieving a stable production rate are occurring. The production rate gets unstable since all the lines are dependent on each other and with empty buffers in-between there are no margins to be reliable on. Today, Scania does not poses any good method to overcome these production stops and get back to a stable production rate in a reasonable time. Lots of the decisions are made by gut-feeling and therefore the evaluation whether it is good or not gets difficult. Scania wants to gain deeper understanding in how this method can be updated and also to be incorporate in their daily work of production planning. Scania wants to investigate the following problem formulations stated below:

- How does the amount of cab buffers affect the production productivity?
- How is the production productivity affected by vary the speed for cab buffer transports?
- What is the optimal assembly line takt times with regards of each OPE?

1.3 Aim and scope

To build a simulation model that resembles the assembly process in an accurate way. The simulation model should have the capability to run different scenarios to analyse and evaluate of the problem formulations stated above.

1.4 Limitations

The limitations of this project is stated below. These were set to manage the project within the given time frame.

- The logistical flow is not included. The buffers of assembly parts was assumed to be continuously refiled during the simulation.
- Pre-assemblies were not included in the simulation model.
- There are no wait in shutdowns for line 1 since it is the start point of the simulation where cabs are continuously created.
- There are no wait out shutdowns for line 9 since this is the end point of the simulation where the cabs exits without regard to the costumer delivery.

2 Background study

In this background study DES and its applications are presented, as well as a motivation for the chosen methods and tools of this project.

2.1 Discrete event simulation

Since costumer demand continuous changes a flexible, high performance and cost effective production system is of the essence. Both to meet costumer needs but also to gain competitive advantages. DES modelling is one of the tools used to meet these demands [2]. The strength of a good DES model is its capability to replicate the performance of a system in detail and therefore provide valid decision-making insights. Both in the perspective to upgrade your present system or to incorporate a brand new one [3].

Never the less, a simulation model provides a pointer and is therefore not to be blindly trusted, leading to the need of virtual confidence. Meaning to link process data and incorporate it in the simulation model [4]. To achieve a realistic simulation model the accuracy of the process data needs to be as high possible. This data can be extracted from how the system operated in the past, present or what you it to reach [3]. The process data is in other words what defines the simulation model and if that data is invalid, the model becomes that as well. Due to its need of this process data it opens the method for criticism that it can result in not being innovative enough and therefore being trapped in the past [3]. This criticisms is something that need to be taken into consideration when using this method to ensure that the outcome of the simulation model is valid for the time to come.

2.2 Simulation applications

DES can be incorporated in many different applications. The benefits of building DES models makes it widely applied in various industries and areas. Areas where DES is commonly used in are manufacturing, education, healthcare, economics, logistics and not the least within the autonomous industry [5]. In a case study, evaluating lean manufacturing principles in an existing assembly operation, the benefits of DES was investigated. By simulating a model of an existing production system different variables could be modified. By simulating different scenarios with lean manufacturing principles a comparison with the actual production system could be done. Some of the scenarios simulated were different warehousing and in-process inventory levels, transport and conveyance requirements and the effectiveness of production control and scheduling systems. The results showed great benefits of the lean system. By analysing the lean system relative the existing system they saw great results. Some of the results presented were the reduction of the average time parts spend in the system by 55 percent, changeover times reduced in the assembly cell from 11 to 3 minutes and 10 percent reduction in finished goods inventory [6]. In another case study, a DES model was made to studying the waste incineration process sustainable development. Their simulation model was used for evaluating and testing extreme case scenarios over a one year period, which would not be possible for testing in reality considering safety issues and regulations [7]. Multiple DES projects and case studies have been conducted with similar effects and organisation improvements [8][9].

2.3 Project managing

The level of execution in a full scale simulation project is a directly connected to its use of project managing. Everything from determining the aim and scope to how the time and resources should be prioritised sets the foundation to a successful project. Within DES projects there are a few phases that are essential before successfully building a simulation model. [7][5] These are:

- Building a process map (also called formalised scheme) of the system.
- Building a conceptual model.
- Manage data gathering.

Building a process map

Creating a process map is a great method for understanding, enable representation and analysis of how the processes operate. Direct observation of a process is not enough to see the full relationship among work items in different parts of the production, this can be understood by creating a process map. When having a process map it can be used for analysing future improvements and optimizations in the organisation, or as for this project it can be used as a basis for building the simulation model. In this way, a third party reader can better understand how the different processes operate as well as how the simulation model work. [10][11]

Building a conceptual model

Conceptual modelling is a widely used method within simulation related work. Conceptual modelling is the phase where a model is being abstracted from the real world system. This is over all agreed to be most difficult, least understood and of highest significance during the entire simulation project [12]. The importance of a conceptual modelling phase is that the abstraction is conducted at the correct level of detail. This is also the step where the decisions regarding what to be simulated or not, this to reach the desired level of complexity in an as short time frame as possible. A common mistake is to build a too complex model where its purpose had been fulfilled already [12]. This then allocates resources, resulting in a higher economical cost. See Figure 2 below for a graph describing how the models accuracy changes during its scope and level of detail.

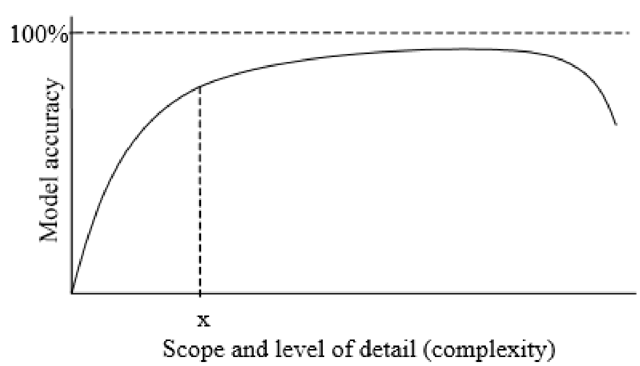


Figure 2: How the models accuracy changes during its scope and level of detail [13].

Managing data gathering

DES project often rely heavily on high input data and data management to be able to build a model that replicates the reality. Therefore the data gathering phase is essential and time consuming. A general eruption is how time consuming the data gathering phase often gets. Empirical studies has shown this phase to be approximately one third of the entire project time. [2][14] A study of managing DES project presents a method for managing input data. The aim of the study was to make DES projects more time-efficient by presenting a structured model for handling input data. The model consists of different phases which can be seen in Figure 3 below.

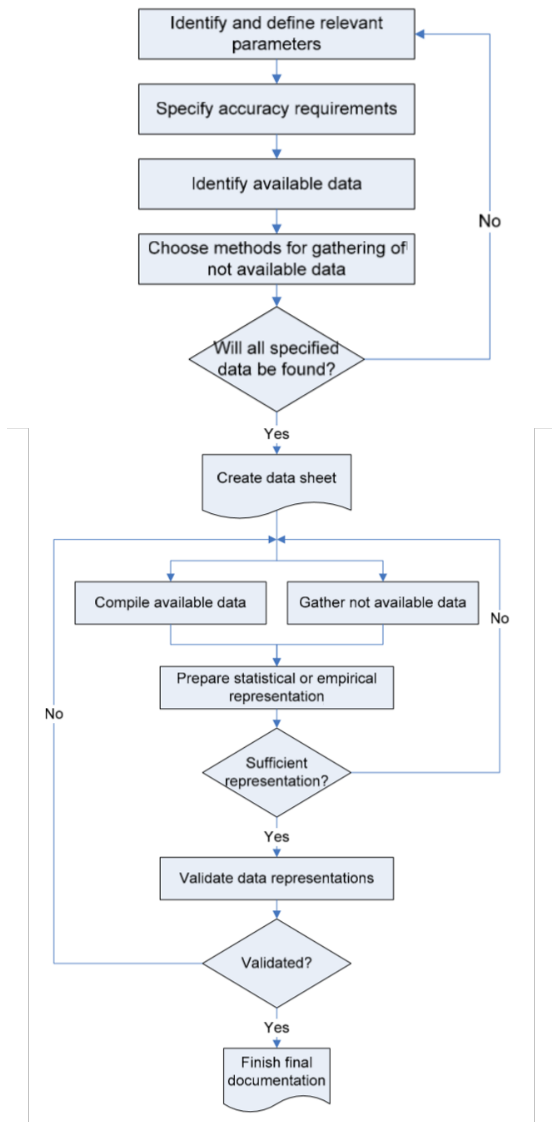


Figure 3: Model for handling input data in DES projects consisting of 12 stages [15].

The model consist of stages for gathering data, handling and processing data and finally validating and documenting the data. When gathering data, a rule of thumb is to gather as much data as possible, this to get good quality and valid representation of the different parameters. It is important to identify if data is available or not, thereafter deciding the correct method for gathering unavailable data can be chosen. Detailed time studies is the preferred method for accurate results, but this entails more time spent during the data gathering phase. One of the most common input data is breakdown data to analyse the *Time Between Failures* (TBF) and *Time To Repair* (TTR). For this type of data it is recommended to gather atleast 230 samples to get a good statistic representation. When gathering data it is recommended to store all the data in the same database or spreadsheet to easily manage the data later in the project. When handling and processing data some kind of filtering process is usually needed to eliminate extreme data points which will interfere with the stochastic or empirical representation. Data describing variation in a process often requires additional calculations to be converted into a suitable form compatible with the simulation software. Statistical distribution preferably requires some sort of statistical calculation tool for easier and faster calculations, otherwise this can be calculated manually. Data documentation and validation is a continuous process throughout building a model. This is important to get a fair representation of the actual process and an easy handling process when applying the data into the simulation model. [15]

2.4 Findings and conclusions

DES is a commonly used method among many areas and organisations, not the least for the manufacturing and autonomous industry. The applications of DES are often to simulate different scenarios to be able to validate and optimize different processes and production improvements. Although it is a great method, it is important not to blindly trust the model since it does not represent the reality in full detail. To achieve a realistic simulation model it is therefore important to have as accurate process data as possible. Many case studies show great results when analysing different production parameters and variables by running different scenarios using a DES model. Therefore DES is a great method for this project.

A common denominator within in the research regarding project managing and over all execution of a simulation project is the importance of all the steps included. There are no shortcuts to be made if you want to produce a result to be trustworthy. Every step of the work process needs too be thoroughly planned and well executed. This to gain a as good representation of the system and also to evaluate what needs to be included in the model to reach its purpose, on time and in full.

3 Theory

This section includes the theoretical framework for the project.

3.1 Simulation methods

Some of the most common simulation methods are discrete event, continuous and agent based [16][17]. Systems can be described either as discrete or continuous where the method to simulate with the agent based approach has the capability to be applied in both of the systems. DES is an event-driven simulation method, meaning that changes in the system are initiated by events and not by a global time as for the continuous systems [17]. A simply way to separate these two systems is that the discrete systems can be described as a bank. The costumer arrives at the bank, waits for their turn, gets processed and then leaves the bank. This system is determined by the costumer and initiates a change when the costumer changes state in the bank. A continuous system can be described as the motion of water from a dam, the water pours with an continues motion dependent of time. Agent Based Simulation (ABS) is as it sounds, depending on the models so called agents. The agents interact with each other to be evaluated how that effects the rest of the system. An agent is determined by a set of rules to be executed in that order. Never the less, there is still a level of autonomy that model dynamics can not pre-define. This since the agents have a sense of intelligence, awareness, memories and contextual awareness. [17] The background study concluded that the DES was the most suitable method for this project and therefore of big interest. The key features of DES simulation are stated below.

- Predefined start and end points.
- An event-driven simulation method.
- Events occur instantaneously and therefore the time step in between processes are zero.
- The sequence of events are stored in an event-queue to be executed in the correct order that is determined by the user.

3.2 Process mapping

A common and well known method to gain deeper understanding and visually represent of a system is process mapping. The level of information containing in the process map is determined by the level of scope of the project itself. This to gain valid information to the project at hand and not to be focused on the wrong type of details. As seen in Table 1 below three different types of maps and their correlating level of scope are described.

Table 1: What map to be used depending on the level of scope [18].

Level of scope	**Map to be used**	**Key features**
Organisation	Relationship map	• Supplier-Organisation-costumer interactions. • Key sections of the organisation. • Supplier-costumer supply chain.
Process	Cross-functional process map	• Swimlane of the process. • Workflow of the process. • Supplier-costumer interactions.
Job/Performer	Process map	• Value adding time of the system. • Non value adding time of the system.

It is essential to clarify the level of scope as early as possible. This to be able to set up a plan of action to be executed in the shortest amount of time. It is difficult to determine which map to use if the level of scope is wrongly declared, this emphasises the importance of being thorough. [18]

3.3 Conceptual model

A conceptual model is a simplified representation of a real or proposed system. The goal of a conceptual model is to define and illustrate what to be modeled by moving from problem situation through model requirements. It can be defined as "The conceptual model is a non-software-specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions, and simplifications of the model."[[19], p.13] The conceptual model is non software specific because the focus is about building the correct model for the problem, not how a software should be applied.

The key benefits of having a well executed conceptual model are listed below. [19]

- Minimises the likelihood of incomplete, unclear, inconsistent, and wrong requirements of the simulation model.
- Helps build the credibility of the simulation model.

Before creating a conceptual model there are a few key activities that are essential. A framework of the key activities can be seen in Figure 4 below.

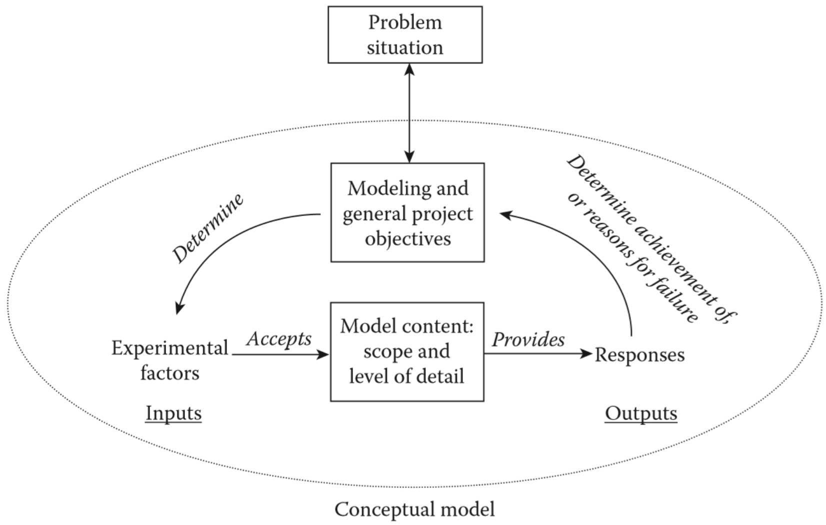


Figure 4: A framework of key activities and their relations before creating a conceptual model [20].

Problem situation

The first activity in the conceptual modeling framework is understanding the problem situation. The modeler needs to get a good understanding of the problem situation in order to develop a model that describes the real world in an accurate way. This activity is therefore essential and the first part before building a conceptual model of a DES project. [19]

Determining modeling objectives

The second activity is determining modeling objectives. The objective of a DES project should never be to build a simulation model, but rather to identify the aim of the organisation, and later determine how and in what way a simulation model can contribute to that aim. The objectives should be expressed in terms of what can be achieved by use of the simulation model, these objectives are direct linked with the time frame of the project. Once the objectives are determined, the modeler can define which input and output parameters the model should be able to handle. These parameters depend on which responses and experimental factors the model should include, therefore this can preferably be done with the client in some extend. The client might also have opinions on how the information should be extracted from the model, if it should be represented as numerical data or graphical reports. [19]

Input and output data

There are two purposes of identifying output responses. These are to identify and validate if the model objectives have been fulfilled, but also to indicate and point out model errors and why they occur.

Identifying the model inputs can be seen as determining the experimental factors. These are used to investigate different scenarios in order to achieve the modeling objectives. The inputs can be quantitative data, which can be controlled by changing numbers in the model. There are different methods of data entry which should be evaluated. The inputs can also be qualitative data like changing simulation logic which requires model structural changes. It is important to identify which category the inputs belong to. This is because they affects how the simulation model is built. It is also important to identify the range of which the experimental factors should be varied. By doing this, unnecessary model complexity is avoided.

Once outputs and inputs are determined the model scope and level of detail can be set. When doing this all model components (entities, activities, queues and resources) should be identified which are to be determined if they should be included or excluded from the model. The level of detail each component should hold and how they are controlled is preferably defined to facilitate the construction of the simulation model. Assumptions and simplifications are also determined at this stage. [19]

When evaluating a conceptual model it is important to fulfil certain criteria in order to go from a conceptual model to a computer simulation model. The four main criteria of a effective conceptual model are validity, credibility, utility and feasibility. The different criteria are described in Table 2 below. [19]

Table 2: The four main criteria for conceptual model evaluation.

Criteria	**Description**
Validity	A modelers perception that the conceptual model can be converted into an computer model accurate enough for the purpose at hand
Credability	The clients perception that the conceptual model can be converted into a computer model accurate enough for the purpose at hand
Utility	The conceptual model can be developed into a computer model that can be used as decision making in the specific context
Feasibility	The conceptual model can be converted into a computer model with the time, resources and data available

3.4 Validation of simulation model

A definition of validation is as following "Validation of a computational model is the process of formulating and substantiating explicit claims about the applicability and accuracy of computational results, with reference to the intended purposes of the model as well as to the natural system it represents" [[21], p.4]. A challenge within validation is to declare a general method, this due to the reason that simulation models often are based on a system. Since these systems vary, a general method gets difficult to declare. There is also the aspect that the definition does not state when the validation is good enough and therefore this phase can be infinite without a proper way to specify when the model is applicable for its purpose [22]. Despite these problems some key validation features has been determined as following [22].

Intended purpose

Since all projects have different goals, the purpose of the simulation models vary. It is crucial to have a clear purpose of the simulation model before reaching this phase [22]. This since the evaluation of this phase is concerning whether the model is full-filling its purpose or not. With a non existing or vague purpose this phase gets impossible to execute.

Mathematical character

To validate the results, mathematical character of the simulation model needs to be further investigated [22]. There are four different phases the simulation model can be characterised as, these are listed below [23].

1. Exact models with exact solutions.
2. Exact models with approximate solutions.
3. Approximate models with exact solutions.
4. Approximate models with approximate solutions.

With these four phases an evaluation of the simulation model can be made. An important aspect to keep in mind is that all models involves some sort of simplifications which makes it impossible to reach an exact model with exact results. [23]

Time

An aspect that goes a bit "hand in hand" with the intended purpose is the time dimension the model is to be used within. If the simulation model is to give information for years to come or to be used within a far more narrow time frame. Since the time frame declare if a possible validation with observation is possible or not the validation process vary. [22]

Validation categories

From the three validation features described earlier, these three validation categories have been developed, these are listed below [22].

- Confirmation validation.
- Sub validation.
- Reference validation.

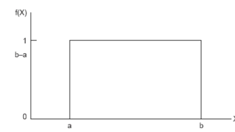
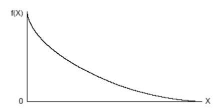
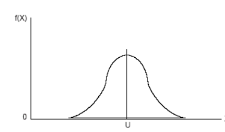
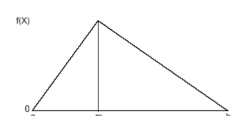
These categories are a combination of the three validation features described earlier. Further validation within the categories can be conducted from the perspective of external and internal validation. The external validation is to evaluate how well the model resembles the real system. The internal validation is to further investigate the mathematical functionality of the model. [22]

3.5 Data management

Data managing play a key role in the success of any DES project. This involves gathering of input data, analysis of the input data and the implementation of the analysed input data into the simulation model. There are two ways of gathering data, either by collecting data from historical records or to collect current time data. The selection depends on the availability of the data and what the data is used for [24]. There are several methods for collecting unavailable process data. The easiest way is to use a stopwatch and time the activities along the production flow, timing every step and process needed. Although this method is easy it does not always perform accurate data and it requires many iterations to represent variation in a truthful way. Another easy method is to conduct interviews with operators and supervisors who works with the processes daily. Operators and supervisors often have great knowledge and a truthful representation of the processes, although this is not to be blindly trusted. Other methods for gathering data of manual and automatic operations are frequency studies, video analysis, MTM (Methods-Time Measurement) and SAM (Sequence-based Activity and Method analysis) [14].

Data can also be extracted from PLC systems triggered by sensors which entails large amount of data stored in databases. Large amount of data often requires some sort of filter to eliminate extreme data points, but also some sort of statistical software to generate an accurate statistical distribution for processes with variation [14]. Data can be categorised in two categories, these are discrete and continuous data. Discrete data has a certain value while continuous data can be any value in an defined range. Continuous data is usually represented as a statistical distribution. A statistical distribution is used to approximate what happens in the real world when a process has variations. A statistical distribution is a set of random values that specify the frequency which an event is likely to occur and how often it is likely to occur [17]. It is important to find the right statistical distribution for the specific process in order to get a correct representation. In Table 3 some of the most common statistical distributions used in DES models are presented. These distribution are available in ExtendSim. [17][14][24]

Table 3: Some of the most common statistical distributions used in DES models and what they are used for.

Distribution	**Description**	**Distribution form**
Uniform	A range of possible values which are equally likely to be observed. Often used to represent an activity with minimal information of its task.	 [25]
Exponential	Often used to describe interarrival processes in simulation models, meaning a random number of arrivals distributed around an average value will occur within a specific unit of time. This distribution can preferably be used to describe TBF and TTR for a process.	 [26]
Normal	The normal distribution consist of two parameters, the mean value and the standard deviation. It is symmetric, meaning that there are equally many numbers lesser than or greater than the mean value. It is often used to represent a process consisting of many sub-processes.	 [27]
Triangular	The triangular distribution only has three parameters, the mean value, the maximum possible value and the minimum possible value. The distribution does not have to be symmetric around the mean value since both the maximum and minimum possible values are defined. This distribution is used to describe activity times in situations where the practitioner does not have full knowledge of the system but suspects that it is not uniformly distributed.	 [28]
Weibull	The weibull distribution consist of two parameters, a shape parameter and a scale parameter which describe the mean and the variance. It is commonly used to represent product life cycles and reliability issues for mechanical equipment that wear out.	 [29]

Validation to ensure the distribution generates values correlating to the sampled data and gives a good representation of the observed system is crucial. Two well known and tested methods for this is the *Kolmogorov-Smirnov* (KS) test and *Anderson-Darling* (AD) test. Both of these tests are based on cumulative probability distributions of sampled data, by calculating the distance between the distributions their validity is calculated. The formula to calculate the KS-statistic for a given theoretical cumulative distribution can be seen i Equation (1) below [30],

$$KS_n = \sqrt{n} sup_x |F_n(x) - F_n(x)|. \tag{1}$$

$F(x)$ is the theoretical value for the distribution at x. $F_n(x)$ is the empirical value of the distribution for a sample size of n. The null hypothesis that $F_n(x)$ calculates from the underlying distribution $F(x)$ evaluates if it should be rejected or not. The null hypothesis is rejected if KS_n is larger than a critical value of KS_α for given value of α. [30]

The formula to calculate the one-sample AD-statistic can be seen i Equation (2) below,

$$AD = -n - \frac{1}{n} \sum_{n=1}^{n} (2i-1)(\ln(x_i) + \ln(1 - (x_{n+1-i}))). \tag{2}$$

$[x_1 < .... < x_n]$ is the order of samples from lowest to highest from a sample size of n. $F(x)$ is the theoretical distribution that the sample is compared to (not included in the formula, just used as a comparison). The null hypothesis that $[x_1 < .... < x_n]$ calculates from the underlying distribution $F(x)$ evaluates if it should be rejected or not. The null hypothesis is rejected if AD is larger than a critical value of AD_α for a given value of α. [30]

3.6 ExtendSim

ExtendSim has the capability to simulate discrete event, continuously, agent-based and mixed-mode processes which gives the program a wide area of application. ExtendSim version 10.0.6 consists of ten different libraries to be able to model all these types of system. The libraries are stated in Table 4 below with a description of its purpose.

Table 4: Libraries that can be used within ExtendSim.

Library name	**Purpose**
Item	Used to model discrete event processes.
Value	Used for mathematical calculations, statistics and data gathering.
Rate	Used to model discrete rate processes.
Reliability	Used to simulate the reliability of a process.
Chart	Used to display charts and plots.
Report	Used to gain results from the simulation.
Animation	Used to create a 3D environment of the model.
Utilities	Used to set up the user interface, debugging and information extraction.
Electronics	Used to model electrical systems.
Templates	Compilation of predefined systems.

Each library consist of different blocks that can be used for different applications. In the version 10.0.5 the reliability library was introduced where the Reliability Block Diagramming (RBD) modeling is enabled. By building Reliability Block Diagrams (RBDs) their availability can be determined and be used either as stand alone RBD tool or be combined within ExtendSims other capabilities. The RBD is determined by a start node followed by the amount of components (processes that affects the RDB) and an end node. The components can either be in series or parallel depending on how they affect each other. The components are then determined by the distribution builder where the distributions are imported and the event builder where events are created. The events can occur either by distribution or by reading a signal connected to the component. [31]

The blocks within the libraries are placed by a ”drag and place function” into a file sheet. Logic within the model is either build by linking pre-defined blocks in combinations or by programming individual blocks. See Figure 5 below for a detailed representation of the connections between three blocks.

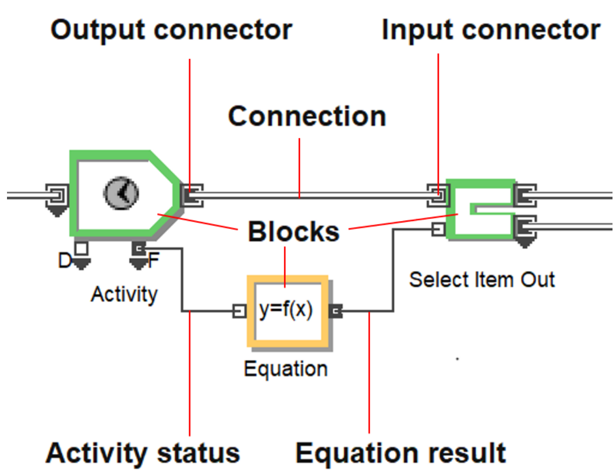


Figure 5: Different connections between three blocks within ExtendSim.

Each block is uniquely programmed and has its own predefined settings to choose from where the user can enter dialog parameters. If the programmer wishes to exceed from the pre-defined blocks, it is possible to change block structure code or program individual blocks from scratch. This way the programmer can build a model that acts exactly as wanted in any complexity. When programming within ExtendSim, a programming language called ModL is used. ModL is a C++ based programming language with certain extensions and enhancements to make it more suitable for simulation modeling. [17][32]

ExtendSim have a direct link to Stat::fit, a tool to determine which distribution that is most suitable [17]. It can handle up to 50 000 data points to be evaluating which distribution that has the best resemblance, if any do exists [33]. There is also the possibility to import these data points directly in a spread sheet from Excel. Stat::fit is incorporated from *Geer Mountain* and is therefore used as an ad in ExtendSim.

4 Method

In this section the chosen methods for this project is further described.

4.1 Status analysis

To gain sufficient amount of information of the assembly process, lots of different departments within Scania needed to be contacted. A discussion with Scania supervisors became a natural first step in the information seeking process. The gathered information gave an overall understanding of the layout and functionality of the assembly process. The logistic department was also contacted to gain information regarding material supply to the assembly lines. A few CAD files of the assembly line layouts was exchanged from another group of master thesis students. These CAD files were used as a foundation for understanding when visiting the assembly lines and talking with the operators. The assembly line responsible from each section of the assembly lines were interviewed to get an accurate understanding for the assembly processes. With this information, multiple process maps were constructed. One for the entire assembly process to get a perspective of how the assembly lines and buffers interact with each other but also one for each assembly line to get detailed information of how every line operates. To gather information regarding data for failure rate and stop times the quality department was contacted. A meeting was set to get better understanding of how the data logging systems worked and how the data could be extracted in the most efficient way. By talking to these different departments, expert knowledge could be gathered to get a full picture of the assembly process which this master thesis project was reliable on.

4.2 Conceptual modelling

The method of conceptual modelling consisted of three phases. The first phase was to implement the conceptual model framework followed by building the conceptual models and lastly evaluating conceptual models. These phases are further described below.

Conceptual model framework

Early on in the project the problem situation and the project description was analysed and broken down to get an uniform understanding. This was done by further studying the master thesis description in combination with visiting the assembly processes to get a more practical view. As the problem got more and more understandable, further discussion with supervisors was held to make sure nothing was to be left out when moving further on with the project. Along with discussing the problem situation with supervisors, aim and scope for the model as well as problem formulations was set. When these were set, the experimental factors and output responses for the model was determined. After the discussion with the supervisors a good understanding of the model requirements was gained. With this understanding the conceptual modelling could be initialised.

Building conceptual models

The conceptual models were generated in workshops, much like a brainstorming activity where ideas of conceptual models were sketched for different parts of the assembly process. The sketches were drawn on a whiteboard including different blocks, their interactions, what happens at each interaction and their conditions. The sketches did not include any software specific definitions, but was rather defined as neutral as possible. All the ideas were discussed and combined into three different conceptual models with different level of detail. Once the conceptual models were generated they were presented and built with computational tool for better representation and understanding.

Evaluating conceptual models

The final concepts were evaluated and later presented for the supervisors. All of the concepts were evaluated and discussed regarding validity, credibility, utility and feasibility. At the end, the concept that was best suited for the project was chosen.

4.3 Data management

After contacting the quality department a meeting was held with one of the workers who analysed different process data, gaining information regarding historical process data and how it was stored. Access to a database called Power BI was given where process stop data was sampled and stored by a PLC system. In this database filters for position, time interval and reasons for stoppage could be used. Once the process data availability was understood, the conceptual models were evaluated.

When gathering process data for the simulation model, process stop data was in focus. Data was gathered separately for the different reasons of shutdown, this to eliminate the risk of getting false distributions. The thoughts behind this was to individually investigate the reasons of shutdown to verify that the distributions do not get wrongly represented as all reasons of shutdowns behaves in their own way.

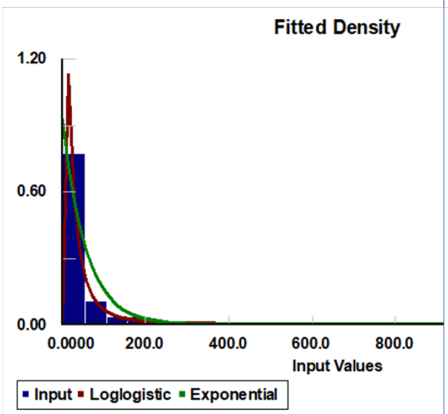
Process stop data was gathered and filtered to fit the desired use and later exported into Microsoft Excel. For each distribution the aim was to gather 300 data points. For some processes the amount of data points exceeded 300 data points and for some processes the amount of data points was lesser than 300. A macro within Excel was created to remove unnecessary information so the data only consisted of duration time, the timestamp for when the stops occurred and the time between each stop. See Appendix A for a representation of the raw data from Power BI before and after the macro has been used. The data was transferred to a separate Excel document where all process data was stored and calculated into TBF and TTR in the unit of time seconds. The TBF and TTR data was further processed to remove data that was false represented. Different filters were used to manage different data. This was done to eliminate time for non working hours. Depending on how frequent the stops occur for different data, different filters were used. The filter conditions and when they were used can be seen in Table 5. A colour scale was also used to highlight and manually eliminate extreme value data points. These values were either too large or too small to occur in reality and therefore removed to fit a realistic distribution.

Table 5: Filters for process stop data and when they are applied.

When	Filter conditions
High frequent data that occurs multiple time every work day. Data consisting of 100 data point or more over the time period 2020/01/01-2020/03/09.	0s > data > 25920s
Medium frequent data that occurs at least once every second work day. Data consisting of less than 100 data points over the time period 2020/01/01-2020/03/09.	0s > data > 198000s
Low frequent data that occur at least once every second week where data can be logged multiple times for the same stoppage over the time period 2019/11/01-2020/03/09.	100-3600s > data > 1209600s

The filtered data was later inserted into Stat::Fit, see Appendix E for a representation of the data before extracted to Stat::Fit. The Stat::Fit software was used to calculate the best fitting empirical distribution function. Different empirical functions were compared to each other and the data density plot to get the best representation for the associated data. The distributions generated in Stat::Fit is ranked based on the *Kolmogorov Smirnov test* and the *Anderson Darling test* which was also taken into consideration when choosing a distribution. The chosen distribution was saved in Excel and later exported into ExtendSim, see Appendix C for the distributions and Appendix D for event cycles for the associated distributions. In Figure 6, ranked distributions, calculated distribution tests and a distribution plot generated in Stat:Fit is shown.

distribution	rank	acceptance	aicc prob
Loglogistic(2, 1.3, 20.6)	100	do not reject	0.328
Lognormal(2, 3.05, 1.36)	69.9	do not reject	1
Pearson 6(2, 19.1, 1.62, 1.55)	61.7	do not reject	0.21
Inverse Weibull(2, 0.775, 0.0926)	2.42	do not reject	0
Inverse Gaussian(2, 10.8, 56)	2.25	do not reject	0.00173
Pearson 5(2, 0.713, 6.46)	0.225	do not reject	0
Weibull(2, 0.699, 42.1)	0.014	reject	0
Gamma(2, 0.628, 89.2)	2.71e-006	reject	0
Exponential(2, 56)	0	reject	0
Power Function(2, 1.28e+003, 0.244)	0	reject	0
Triangular(1, 1.25e+003, 1)	0	reject	0



distribution	Kolmogorov Smirnov	Anderson Darling
Beta	0.193	9.53
Chi Squared	0.336	190
Erlang	no fit	no fit
Exponential	0.256	17.9
Gamma	0.172	6.44
Inverse Gaussian	0.0839	2.23
Inverse Weibull	0.0833	2.2
Johnson SB	no fit	no fit
Loglogistic	0.0627	0.307
Lognormal	0.0671	0.43
Pareto	0.259	25.3
Pearson 5	0.0932	3.63
Pearson 6	0.0696	0.42
Power Function	0.35	38.1
Rayleigh	0.673	334
Triangular	0.729	333
Uniform	0.814	441
Weibull	0.123	3.86

Figure 6: Distributions generated by Stat:Fit based on input data. The generated distributions and their corresponding rank can be seen at the top. In the bottom left the data density plot compared with two distributions can be seen. In the bottom right the generated distributions with their corresponding distribution test results can be seen.

For processes where historical data was not available manually timing was the method of approach. The transports within the cab buffers were analysed by using a stopwatch. A start and end was determined to measure a constant time for the cab to move from one buffer space to another. The same method was applied when measuring the tilt cab positions and elevators.

4.4 Building the simulation model

Since the assembly process as an entire system quickly got difficult to understand and comprehend a decision to build the model in sub parts was made. The different assembly lines and buffer systems were modeled one by one until the whole assembly process was built. For each assembly line, a separate RBD model was build to control the different shutdowns. The RBD models were built to generate three different kinds of shutdowns, shutdowns caused by distributions, wait in shutdowns and wait out shutdowns. The wait in and out shutdowns are dependent on the status of the buffer systems and the assembly lines. When the conditions for a wait in or out shutdowns are true a signal is sent to the RBD model to generate a shutdown.

Since the RBD library was first introduced in the update for ExtendSim version 10.0.5 it consisted of some technical issues and errors, the students therefor had a close contact with the ExtendSim development department for assistance when dealing with technical issues and ExtendSim related problems. This gave the students insight and a deeper understanding of the program.

With all the assembly lines and buffer systems connected to each other the model quickly got too large and extensive to navigate effectively through. The assembly lines and buffer systems were therefor made into hierarchical blocks, representing multiple blocks as one. This gave a good user interface and made it easier to navigate through the model. The hierarchical blocks were also modified to imitate the looks of the assembly process map.

To easily manage and adjust the simulation settings all the essential model parameters has been dynamically linked to a database. This makes it so that the user can change a parameter by only adjusting one value without the need of changing every block setting. To further optimize the simulation settings interface a control panel was built. In the control panel all the parameters from the database have been copied and linked. The control panel also consist of result windows where all necessary graphs and values are displayed. To gain better understanding of the flow trough out the simulation model animations where added to keep track of line shutdowns and buffer levels.

4.4.1 Removed and added buffer spaces

Table 6 and 7 below describes how buffer spaces are added and removed when running different scenarios in the model.

Table 6 below describes how buffer positions are removed. Removing a buffer position in the model means that the specific space is physically removed. This is equivalent with rebuilding the actual buffer system and adjusting its transportation length. It is also equivalent with removing position sensors and increasing the transportation speed so it matches the transportation time removed.

Table 6: Definition of which and how buffer spaces are removed in the model.

Buffer system	**Buffer positions**	Description
1	1.0, 1.1 and 1.2	The three first buffer positions were removed in the written order order.
3	3.11, 3.10 and 3.9	The three last buffer positions were removed in the written order.
4	4.2 and 4.1	The two last buffer positions were removed in the written order.
5	5.1	The last buffer position was removed.
6A	6A.1	The last buffer position was removed and 20 seconds was added to 6A.0.
6C	6C.3 and 6C.4	The last two buffer positions were removed in the written order.
7	7.2 and 7.1	The last two buffer positions were removed in the written order. 20 seconds was added to 7.0 when 7.1 were removed.
8	8.1	The last buffer position were removed and 20 seconds was added to 8.0.

Table 7 below describes how buffer positions are added. Adding a buffer position in the model means that the specific space is physically added. Adding a position is equivalent with either rebuilding the actual buffer system and increasing the transportation length or by adding position sensors and decrease the transportation speed to match the new buffer position.

Table 7: Definition of which and how buffer spaces are added in the model.

Buffer system	**Buffer positions**
1	Three buffer positions were added at the end with the same process transportation time as 1.9.
3	Three buffer positions were added at the end with the same process transportation time as 3.11.
4	Three buffer positions were added at the end with the same process transportation time as 4.2.
5	Three buffer positions were added at the end with the same process transportation time as 5.1.
6A	Three buffer positions were added at the beginning with the same transportation time as 6A.0.
6C	Three buffer positions were added in front of 6C.4 with the same transportation time as 6C.4.
7	Three buffer positions were added at the end with the same process transportation time as 7.2.
8	Three buffer positions were added in front of 8.1 with 20 seconds in transportation time.

4.5 Validation simulation model

When validating the simulation model the following steps for evaluation were completed.

Intended purpose

When the model was built the students evaluated the model together with the supervisors from Scania and the university whether the simulation model fulfilled the purposes stated in the problem formulation.

Mathematical character

To determine the mathematical character of the model the simulation results from 24 sets of 100 runs over a 5 weeks time period were statistically compared to each other to validate the uniformity of the result. A staple diagram was made to display the standard deviation between the 24 sets for all the result parameters. The mean values of shutdown times and cabs assembled were compared with real data from Power BI and weekly statistical reports. The cabs assembled was gathered from weekly statistical reports over 9 weeks between the time period of 2020/01/06 - 2020/03/16 where a mean value of five weeks was calculated. The shutdown times was gathered from Power BI over the time period of 20 weeks and divided by four to calculate a mean value over five weeks. Values greater than 30 minutes were extracted from the gathered data to match the simulation settings for maximum shutdown time.

Time

As the simulation model where to be used within an as narrow time frame as possible, both for this master thesis project and within Scanias daily work, validation through observations became reality.

5 Conducting tests

As the project had three main problem formulations to investigate the series of tests where divided regarding to these with an initial run to gain decision making information. This to tailor the test and by that ensure validity and credibility. A few key settings where the same for all three tests to ensure an equality and uniformity. The key settings are stated below:

- Simulation run-time: 5 weeks of production (5 days/week with 14,2 working hours/day).
- Amount of runs: 100.
- Amount of buffer initialised: Two for all buffer systems except one and two which had five.
- The time to repair for andon, safety and technical shutdowns was set to be maximum of 30 minutes.

5.1 Initial run

To gain information about how the initial state of the production an initial run was simulated where no changes of parameters where set. The run time was one years of production where the goal was to gain deeper understanding of the buffer systems and assembly lines and to tailor specific test runs.

5.2 Amount of buffers

To investigate the optimal amount of buffers and how they affected the production rate the test included both varying the amount of buffers individually and together for the buffer systems. Complementary tailored tests were also simulated where the parameters where based of the results from the initial run. Depending on the buffer system levels either a buffer space was added or removed. A buffer space was added when the mean value of the buffer level was larger then half of the buffer system capacity. A buffer space was removed when the mean value of the buffer level was smaller then half of the buffer system capacity. The specifications for the different scenarios that were tested can be seen in Table 8 below. To be able to run all these scenarios at the same time the scenario manager in ExtendSim was used.

Table 8: Scenarios that was tested for evaluating the amount of buffers.

Scenario	BS1	BS3	BS4	BS5	BS6A	BS6C	BS7	BS8	Change
1	11	13	3	2	2	5	3	2	Current state
2	12	13	3	2	2	5	3	2	BS1 + 1
3	13	13	3	2	2	5	3	2	BS1 + 2
4	14	13	3	2	2	5	3	2	BS1 + 3
5	10	13	3	2	2	5	3	2	BS1 - 1
6	9	13	3	2	2	5	3	2	BS1 - 2
7	8	13	3	2	2	5	3	2	BS1 - 3
8	11	14	3	2	2	5	3	2	BS3 + 1
9	11	15	3	2	2	5	3	2	BS3 + 2
10	11	16	3	2	2	5	3	2	BS3 + 3
11	11	12	3	2	2	5	3	2	BS3 - 1
12	11	11	3	2	2	5	3	2	BS3 - 2
13	11	10	3	2	2	5	3	2	BS3 - 3
14	11	13	4	2	2	5	3	2	BS4 + 1
15	11	13	5	2	2	5	3	2	BS4 + 2
16	11	13	6	2	2	5	3	2	BS4 + 3
17	11	13	2	2	2	5	3	2	BS4 - 1
18	11	13	1	2	2	5	3	2	BS4 - 2
19	11	13	3	3	2	5	3	2	BS5 + 1
20	11	13	3	4	2	5	3	2	BS5 + 2
21	11	13	3	5	2	5	3	2	BS5 + 3
22	11	13	3	1	2	5	3	2	BS5 - 1
23	11	13	3	2	3	5	3	2	BS6A + 1
24	11	13	3	2	4	5	3	2	BS6A + 2
25	11	13	3	2	5	5	3	2	BS6A + 3
26	11	13	3	2	1	5	3	2	BS6A - 1
27	11	13	3	2	2	6	3	2	BS6C + 1
28	11	13	3	2	2	7	3	2	BS6C + 2
29	11	13	3	2	2	8	3	2	BS6C + 3
30	11	13	3	2	2	4	3	2	BS6C - 1
31	11	13	3	2	2	3	3	2	BS6C - 1
32	11	13	3	2	2	5	4	2	BS7 + 1
33	11	13	3	2	2	5	5	2	BS7 + 2
34	11	13	3	2	2	5	6	2	BS7 + 3
35	11	13	3	2	2	5	2	2	BS7 - 1
36	11	13	3	2	2	5	1	2	BS7 - 2
37	11	13	3	2	2	5	3	3	BS8 + 1
38	11	13	3	2	2	5	3	4	BS8 + 2
39	11	13	3	2	2	5	3	5	BS8 + 3
40	11	13	3	2	2	5	3	1	BS8 - 1
41	12	14	4	3	3	6	4	3	All + 1
42	13	15	5	4	4	7	5	4	All + 2
43	14	16	6	5	5	8	6	5	All + 3
44	10	12	2	1	1	4	2	1	All - 1
45	9	11	1	1	1	3	1	1	All - 2 (BS>1)
46	8	10	1	1	1	3	1	1	All -3 (BS<1)
47	12	14	3	1	1	6	2	2	Tailor 1
48	13	15	3	1	1	7	2	1	Tailor 2

5.3 Buffer speed

To investigate how the buffer speed affected the production rate the test included both varying the buffers speed individually and together. Complementary tailored test where also simulated where the parameters where based from the initial run. Depending on the amount of wait in shutdown on the upcoming assembly line the speed was either increased or kept the same. The specifications for the different scenarios that was tested can be seen in Table 9 below. To be able to run all these scenarios at the same time the scenario manager in ExtendSim was used.

Table 9: Scenarios that was tested for evaluating the buffer speed.

Scenario	BS1	BS3	BS4	BS5	BS6A	BS6C	BS7	BS8	Change
1	1	1	1	1	1	1	1	1	Current state
2	0,8	1	1	1	1	1	1	1	BS1 - 20%
3	0,6	1	1	1	1	1	1	1	BS1 - 40%
4	0,4	1	1	1	1	1	1	1	BS1 - 60%
5	0,2	1	1	1	1	1	1	1	BS1 - 80%
6	1	0,8	1	1	1	1	1	1	BS3 - 20%
7	1	0,6	1	1	1	1	1	1	BS3 - 40%
8	1	0,4	1	1	1	1	1	1	BS3 - 60%
9	1	0,2	1	1	1	1	1	1	BS3 - 80%
10	1	1	0,8	1	1	1	1	1	BS4 - 20%
11	1	1	0,6	1	1	1	1	1	BS4 - 40%
12	1	1	0,4	1	1	1	1	1	BS4 - 60%
13	1	1	0,2	1	1	1	1	1	BS4 - 80%
14	1	1	1	0,8	1	1	1	1	BS5 - 20%
15	1	1	1	0,6	1	1	1	1	BS5 - 40%
16	1	1	1	0,4	1	1	1	1	BS5 - 60%
17	1	1	1	0,2	1	1	1	1	BS5 - 80%
18	1	1	1	1	0,8	1	1	1	BS6A - 20%
19	1	1	1	1	0,6	1	1	1	BS6A - 40%
20	1	1	1	1	0,4	1	1	1	BS6A - 60%
21	1	1	1	1	0,2	1	1	1	BS6A - 80%
22	1	1	1	1	1	0,8	1	1	BS6C - 20%
23	1	1	1	1	1	0,6	1	1	BS6C - 40%
24	1	1	1	1	1	0,4	1	1	BS6C - 60%
25	1	1	1	1	1	0,2	1	1	BS6C - 80%
26	1	1	1	1	1	1	0,8	1	BS7 - 20%
27	1	1	1	1	1	1	0,6	1	BS7 - 40%
28	1	1	1	1	1	1	0,4	1	BS7 - 60%
29	1	1	1	1	1	1	0,2	1	BS7 - 80%
30	1	1	1	1	1	1	1	0,8	BS8 - 20%
31	1	1	1	1	1	1	1	0,6	BS8 - 40%
32	1	1	1	1	1	1	1	0,4	BS8 - 60%
33	1	1	1	1	1	1	1	0,2	BS8 - 80%
34	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	All - 20%
35	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	All - 40%
36	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	All - 60%
37	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	All - 80%
38	1	1	0,9	0,8	0,6	0,7	0,8	0,8	Tailor

5.4 Takt time

To compensate for the difference in availability between the assembly lines the takt time for each assembly line was adjusted. For the tailored tests the takt times were set based on the RBD availability results from the initial run. The availability from assembly line 9 was used as a reference when adjusting the rest. If the availability of one assembly line was higher than the reference, the takt time for that assembly line was decreased and vice versa. For each availability percent that differ from the reference the takt time was changed by five seconds. Two more tests were also tested where the takt times were set to resemble pull and push systems. For the push system the takt time for assembly line 9 was kept the same while the other takt times were gradually decreased. For the pull system assembly line 1 was kept the same while the other takt times were gradually decreased. The specifications for the different scenarios that were tested can be seen in Table 10 below. To be able to run all scenarios at the same time the scenario manager in ExtendSim was used.

Table 10: Scenarios that was tested for evaluating the takt times.

Scenario	Line 1	Line3	Line 4	Line 5	Line 6A	Line 6C	Line 7	Line 8	Line 9	Change
1	167	167	167	167	167	137	167	167	167	Current state
2	160,5	172	165,5	173	172,5	137	172,5	174,5	167	Tailor
3	159	160	161	162	163	134	165	166	167	Push
4	167	166	165	164	163	132	161	160	159	Pull

6 Status analysis

This section describes the assembly process of its current state.

6.1 Assembly lines

The assembly process begins when cabs enter the first assembly line after painting is finished. The current takt time were 167 seconds for all assembly lines except for line 6C where it was 137 seconds. There are 24 different cab models that are determined by three size attributes, these are depth, height and structure. Apart from the different cab models, the customer has the options to customise their cab with different equipment and colours. There are two working shifts Monday to Friday. Their working hours are:

- 06:24 - 15:12
- 15:12 - 23:12

The assembly process consist of eight different main assembly lines, an overview of the full assembly process can be seen in Figure 7. Each assembly line has its fixed stations where different predefined assembly processes are carried out. In Figure 7 the main assembly lines are represented in yellow, the pre-assembly lines are represented in brown and are connecting into the main assembly lines. The cab buffers are represented as green and the tilt cab processes are represented in red.

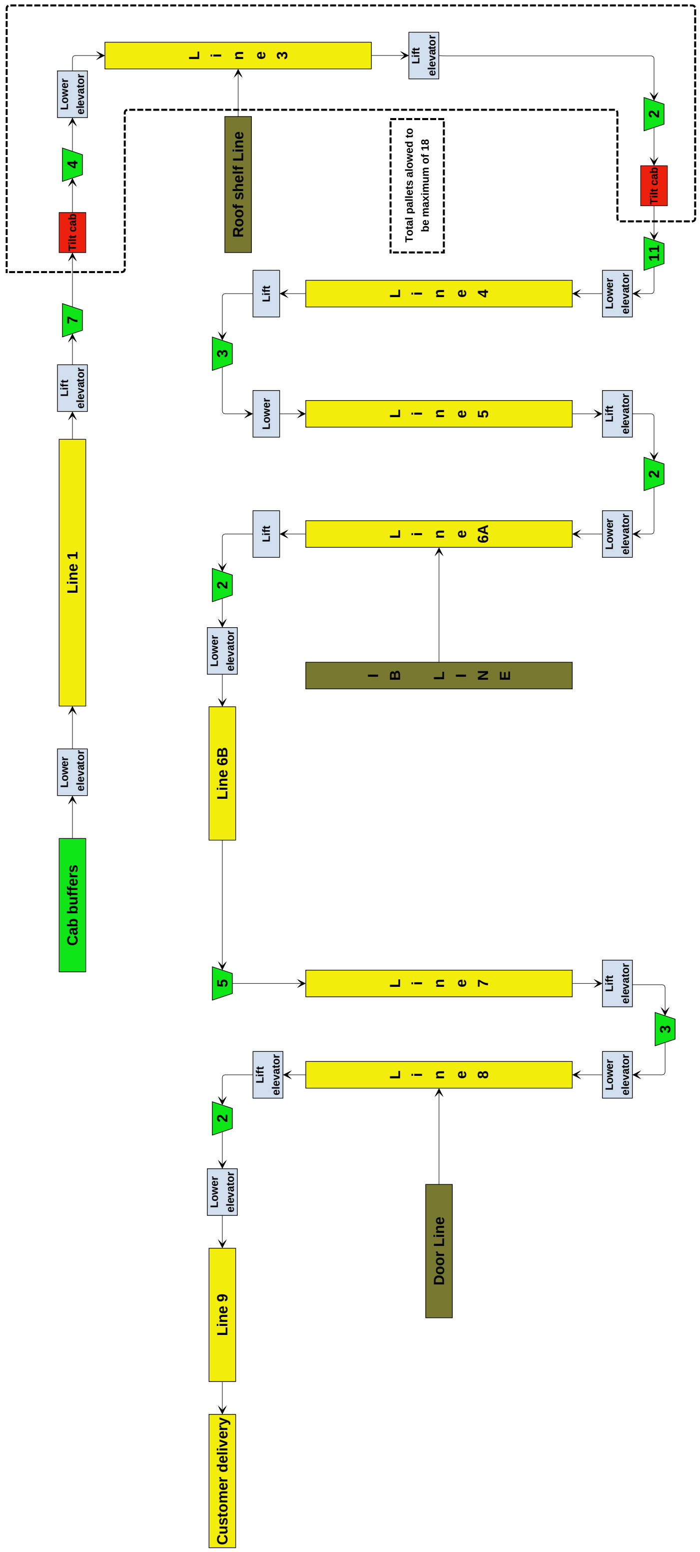


Figure 7: Overview on the full assembly process.

In Figure 8-15 a more detailed representation of the assembly lines are shown. The orange boxes indicates activities with process times equals to one takt time. The blue boxes are *quality gates* that also take one takt time. The *move cab* is an extra station where the cab is transported from the elevator onto the assembly conveyor band where no work is conducted. There is a *move cab* in the end of the assembly lines where the cab leaves the assembly conveyor and enters the elevator. There are two types of assembly positions, *Stop and go positions* and *Continuous positions*. The *Continuous positions* move on a conveyor with a constant speed to match the takt time. The distance between two cabs is always constant to match the takt time with the conveyor speed. The *Stop and go positions* are indicated with a red arrow and the *Continuous positions* with a blue arrow. The *Slide position* is an extra position that workers use when longer takt time is required, often occurring for bigger cab models. This then gives an extra takt time to complete the montage and there is therefore no need to stop the assembly line. The grey boxes indicates where pre assembly stations are interacting with the main assembly lines and also where their buffers are located. The black lines, shaped as a square indicates where workers are allowed to execute their work. As seen for example in Figure 8 the *Rotate cab* is outside the square and therefore indicates that this station is executed without any workers. The worker animation in the top left corner of the stations indicates the amount of workers needed to execute the work. In Figure 8 below a detailed representation of assembly line 1 is shown.

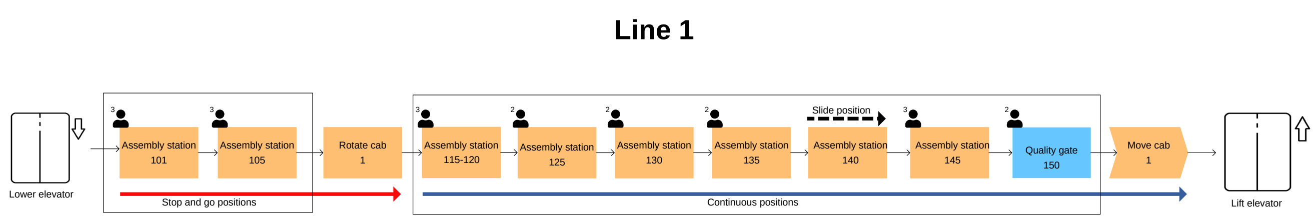


Figure 8: A detailed representation of line 1. There is no move cab in the beginning of this line since the elevator goes directly into assembly station 101.

In Figure 9 below a detailed representation of assembly line 3 (assembly line 2 does not exist.) is shown.

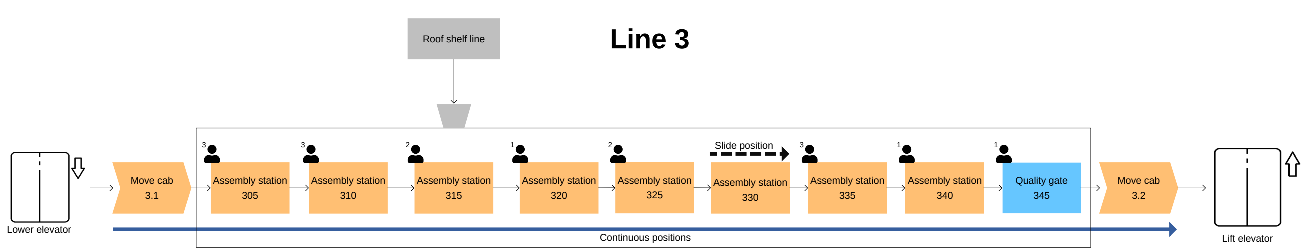


Figure 9: A detailed representation of assembly line 3.

In Figure 10 below a detailed representation of assembly line 4 is shown.

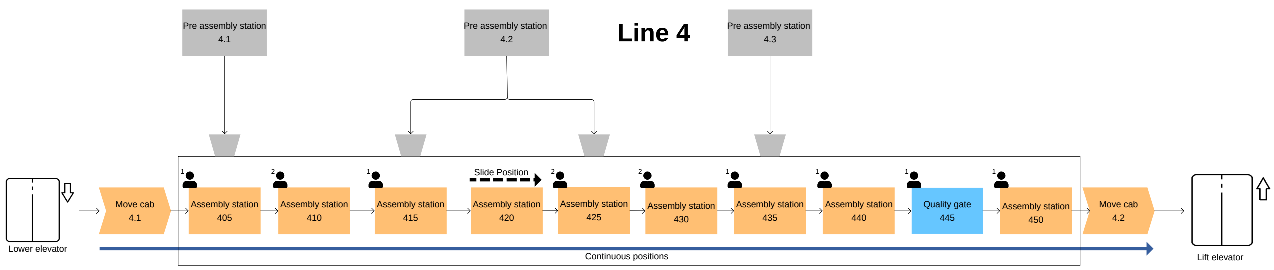


Figure 10: A detailed representation of assembly line 4.

In Figure 11 below a detailed representation of assembly line 5 is shown.

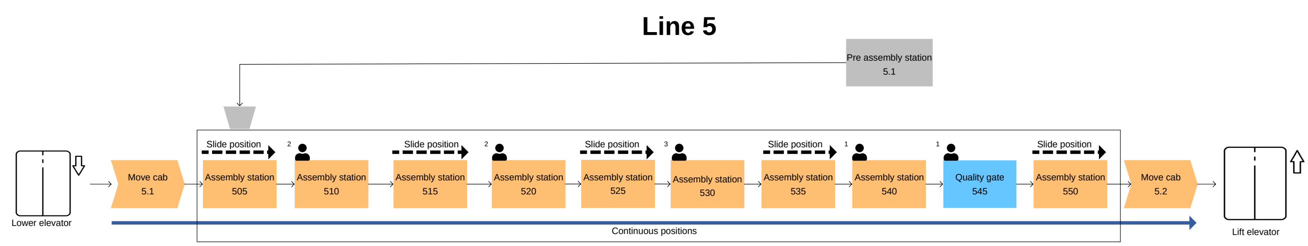


Figure 11: A detailed representation of assembly line 5. The pre assembly 5.1 station is placed were it is due to its physical location in the assembly process.

In Figure 12 below a detailed representation of assembly line 6A is shown.

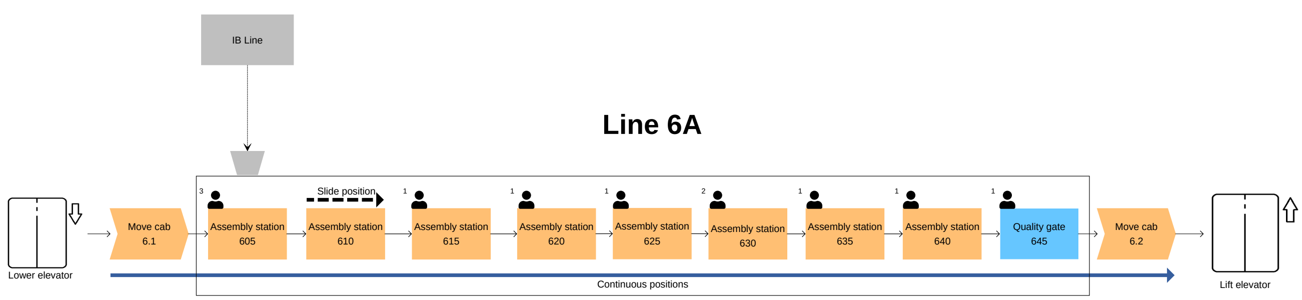


Figure 12: A detailed representation of assembly line 6A.

In Figure 13 below a detailed representation of assembly line 6C and 7 is shown.

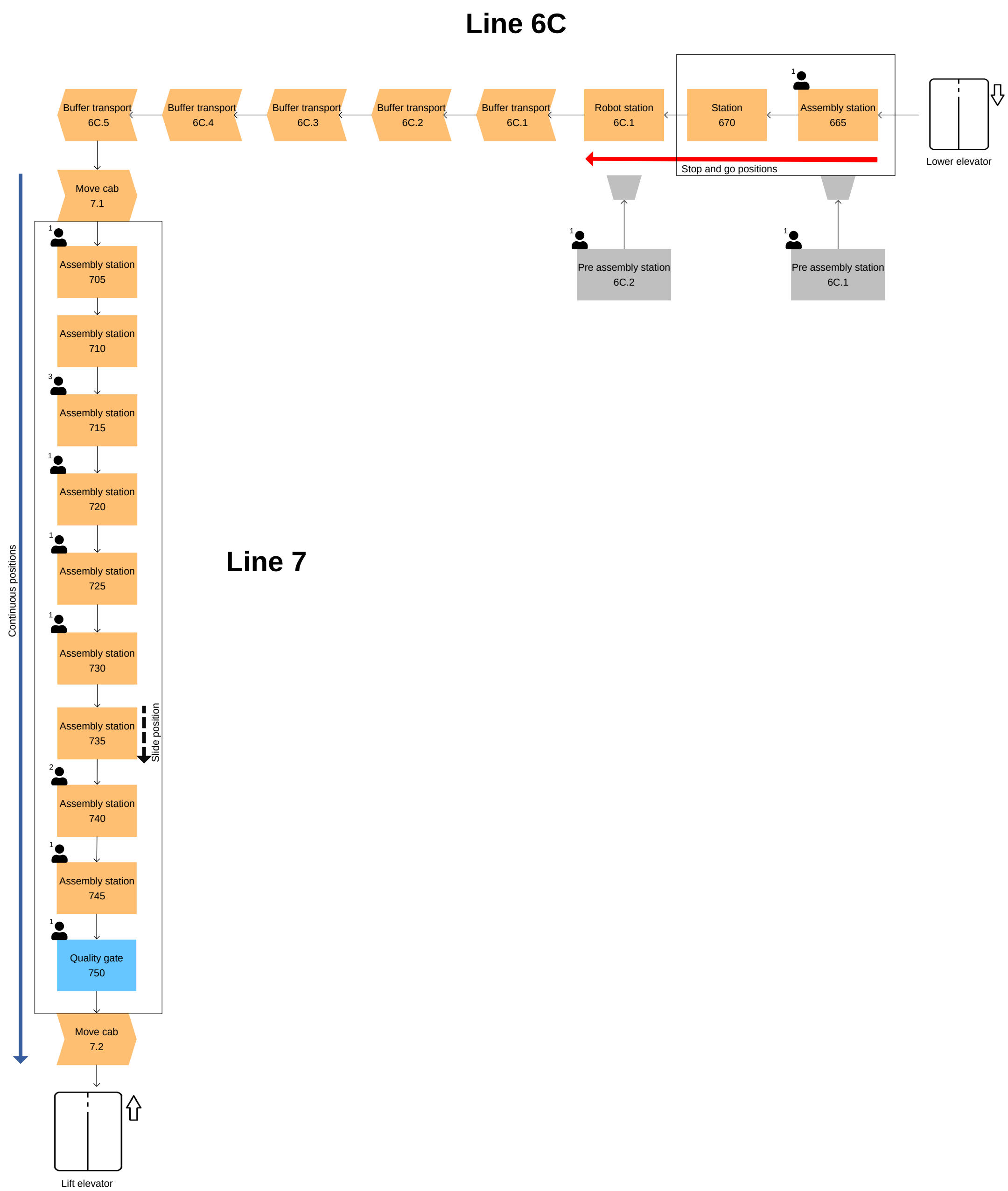


Figure 13: A detailed representation of assembly line 6C and 7.

In Figure 14 below a detailed representation of assembly line 8 is shown.

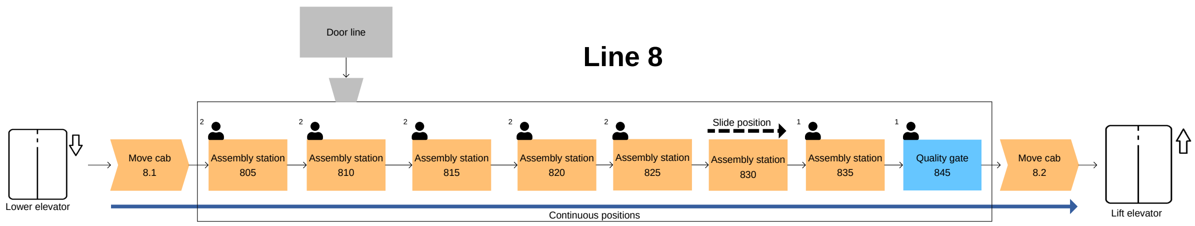


Figure 14: A detailed representation of assembly line 8.

In Figure 15 below a detailed representation of assembly line 9 is shown.

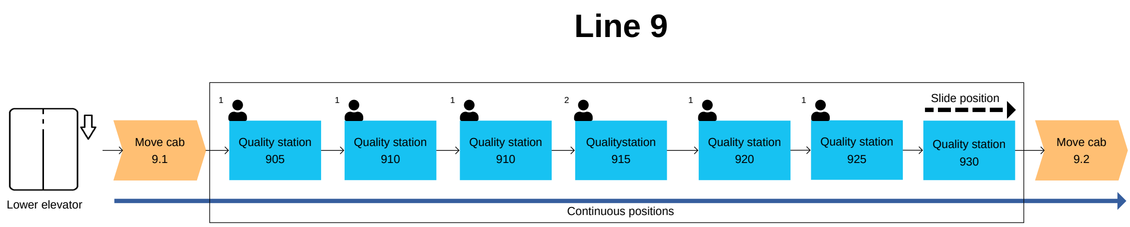


Figure 15: A detailed representation of assembly line 9, consisting of only quality inspection stations where final inspection is done.

6.2 Cab buffer management

Between each assembly line there are buffers where the cabs are transported to the next assembly line. The buffers are there to prevent interference on the following assembly lines if there occur any stoppages. The cabs are lifted by an elevator at the end of an assembly line. The cabs are later transported through the buffer and later lowered onto the next assembly line. The buffer system makes it possible for forklifts to operate on ground floor while the cabs are transported above. At the buffers between assembly line 1 and assembly line 3 the cabs are tilted onto custom made pallets. This makes it more ergonomic for the workers on the assembly line. At the buffers between assembly line 3 and assembly line 4 the cabs are tilted back to its original position on a stand. Within these buffers there are only allowed a total of 18 pallets. See Figure 16 below for a detailed representation of the buffer system for assembly line 1-4.

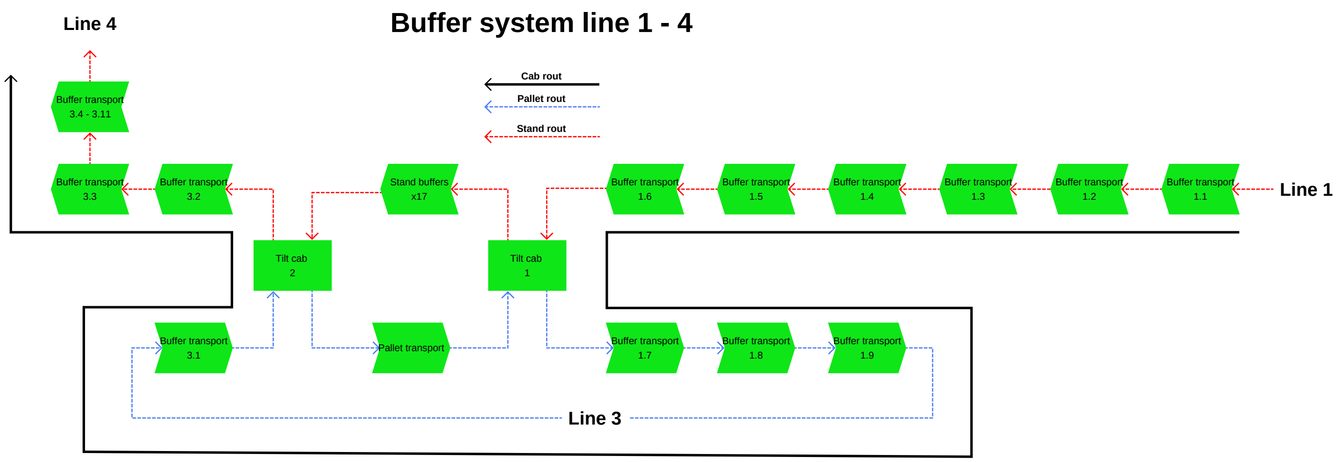


Figure 16: A detailed representation of the buffer system for assembly line 1-4.

6.3 Production stop

All positions along the assembly lines work with an andon system. If the operator suspects that there is not enough time to finish the task at hand within the takt time, the operator will push an andon alarm button. When this happens the operator will get assistance to help finishing the task. If the task is finished within the takt time the andon alarm button is pushed again and the line continues as normal. If the button is not pushed a second time within the takt time the whole assembly line stops, this is called an andon stop.

Other reasons for production stops are wait in and wait out stops. These types of stops are due to empty or full cab buffers. Wait out stops occur when the cab buffer is full and the wait in stops occur when the cab buffers are empty. Safety stops and technical stops occur when there is a risk of danger or the technical equipment malfunction. Planned stops can also occur, these stops are often planned for when the timing is right. The result of all these stops is an unstable production rate throughout all the assembly lines. All production stop data is stored in a database logged by sensors along the assembly lines. The operators are also obligated to document production stop data with a comment of reason which is stored in a separate database.

7 Results

This section includes the results for this project.

7.1 Conceptual model

Three conceptual models were produced, they can be seen in Figure 17-19.The input experimental factors are assembly line takt times, buffer transport speed and amount of buffers. The output responses are the amount of cabs assembled, shutdown times and throughput time. The conceptual models represents one assembly line and how they are interacting with the buffers. The level of detail is lowest for concept one and highest for concept three. The chosen concept was concept two. In Figure 17 below a representation of concept one is shown.

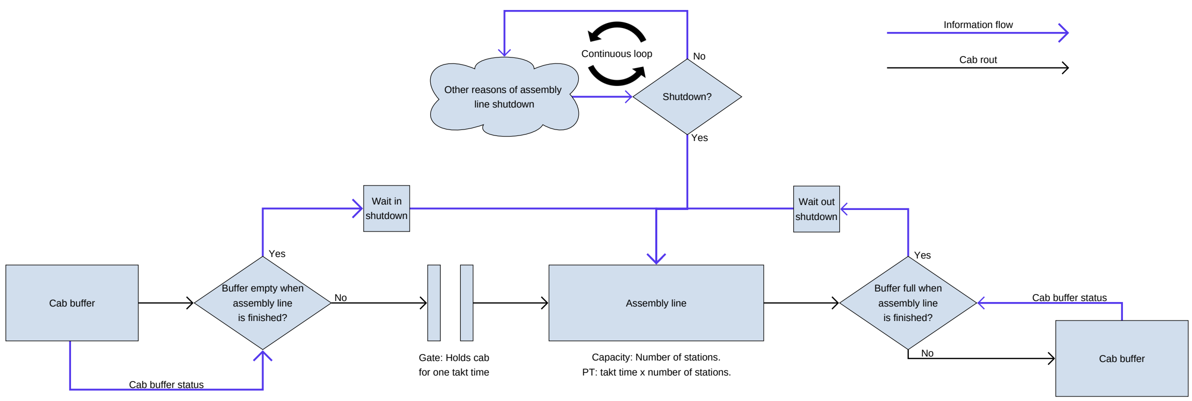


Figure 17: Representation of concept one.

In concept one cabs entering the buffer, waiting to be processed. As the assembly line is active the first assembly station eventually gets empty. The decision block is connected to the buffer, reading if there is a cab to be processed. If not, a wait in shutdown is initiated and the line stops. The cab then enters the gate where it holds the cab until there is an empty station, this to control that the amount of cabs being processed is correct. The assembly line can be seen as an activity where the capacity is set to the amount of stations. The cabs are then getting processed and leaves the assembly line. The decision block is connected to the buffer, reading if there is an empty buffers space. If not, a wait out shutdown is initiated. Above the assembly line a cloud of reasons for shutdown is connected, these are reasons except for the wait in and out shutdowns. This runs continuously while the assembly line is active, signalling a shutdown to the assembly line when a problem has occurred.

In Figure 18 below a representation of concept two is shown.

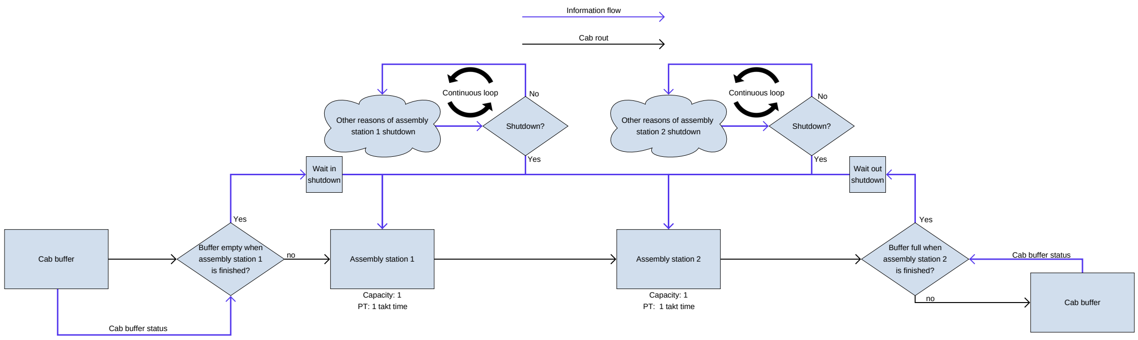


Figure 18: Representation of concept two.

The functionality of wait in- and out shutdown is the same as for the first concept seen in Figure 17. There is no need for a gate in this concept since the capacity within the assembly stations is set to one. This is the main difference between the concepts, how the activity is defined. In this concept the activity is defined as assembly stations that together form the assembly line. Since the activity now is defined as a station, each station has its own reasons for shutdown.

In Figure 19 below a representation of concept three is shown.

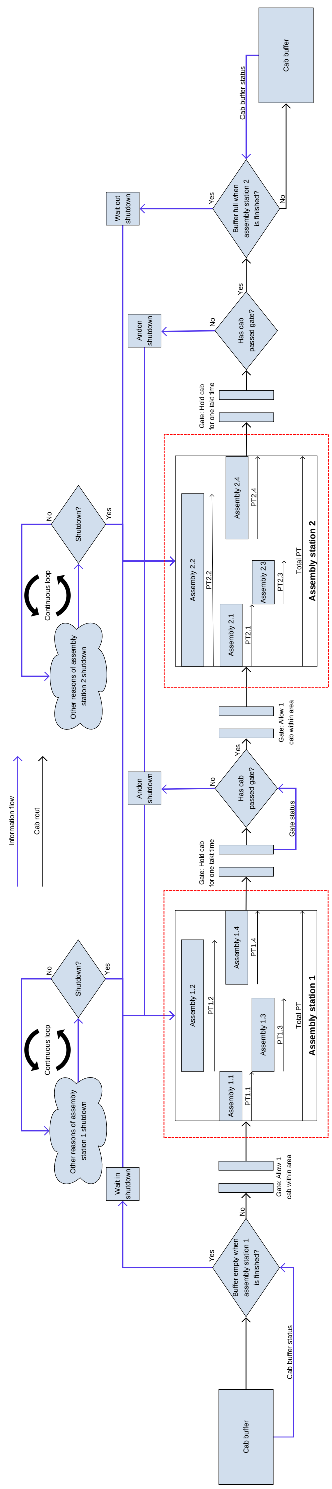


Figure 19: Representation of concept three.

The functionality of wait in and out shutdown as well as the cloud of reasons for shutdown are the same as in concept two seen in Figure 18. The difference is that a further breakdown of the activity block is made. In this concept the activity is defined as a multiple assembly processes that together form an assembly station. There is a gate before the cab enters the station making sure that only one cab can enter since there now are multiple processes and only one assembly station this gate is needed. Since the assembly processes combined time defines the assembly station a variation of process time can be applied. The gate after the assembly station then holds the cab for one takt time, this to represent that if operators are finished with the assembly process in advance the cab cannot be move on to the next station until the takt time has passed. There is also the possibility that the operator does not manage in time and a shutdown is initiated, this is called an andon shutdown. When the first assembly station is complete the cab moves on to the next assembly station.

7.2 Simulation model

In this section, screen shots of the simulation model interface are shown. In Figure 20 below the simulation model is shown.

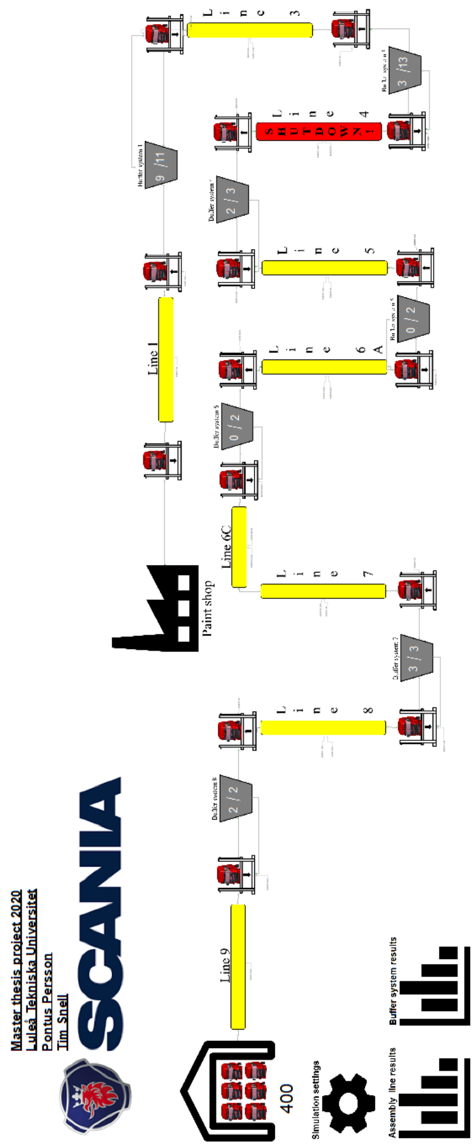


Figure 20: A screen shot of the simulation model interface. Assembly line four is red due to shutdown. The buffer systems displays the current buffer level over the buffer system capacity.

A screen shot from the simulation settings window within the control panel can be seen in Figure 21 below. The user can easily change the simulation settings without needing to change the actual model.

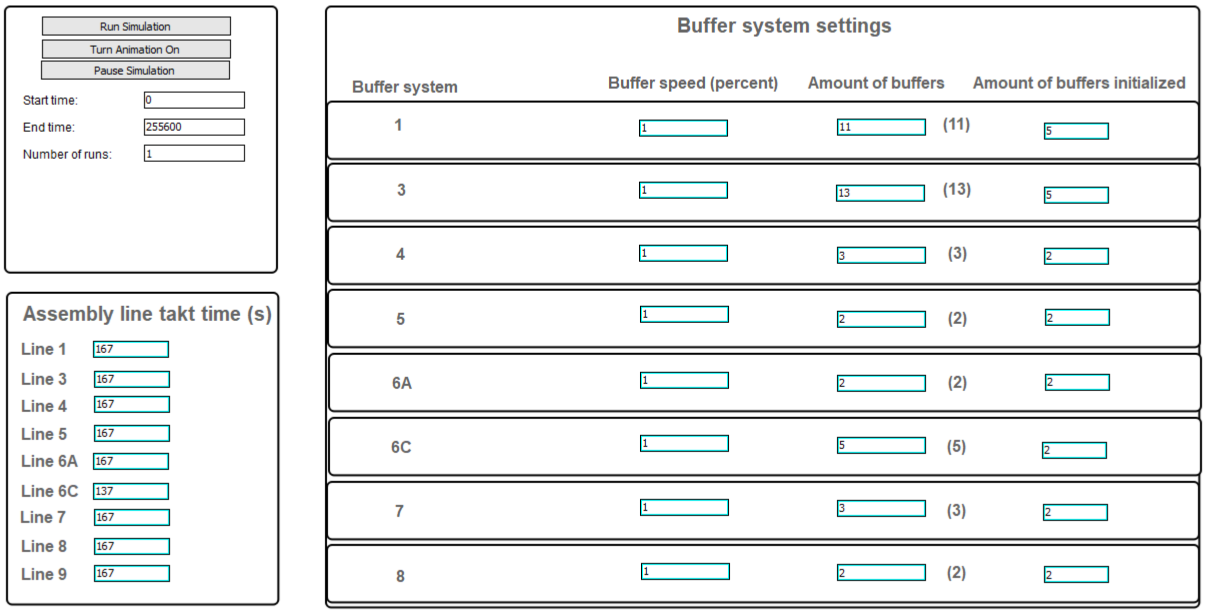


Figure 21: A screen shot of the simulation settings window.

A screen shot from the assembly lines result window within in the control panel can be seen in Figure 22 below.

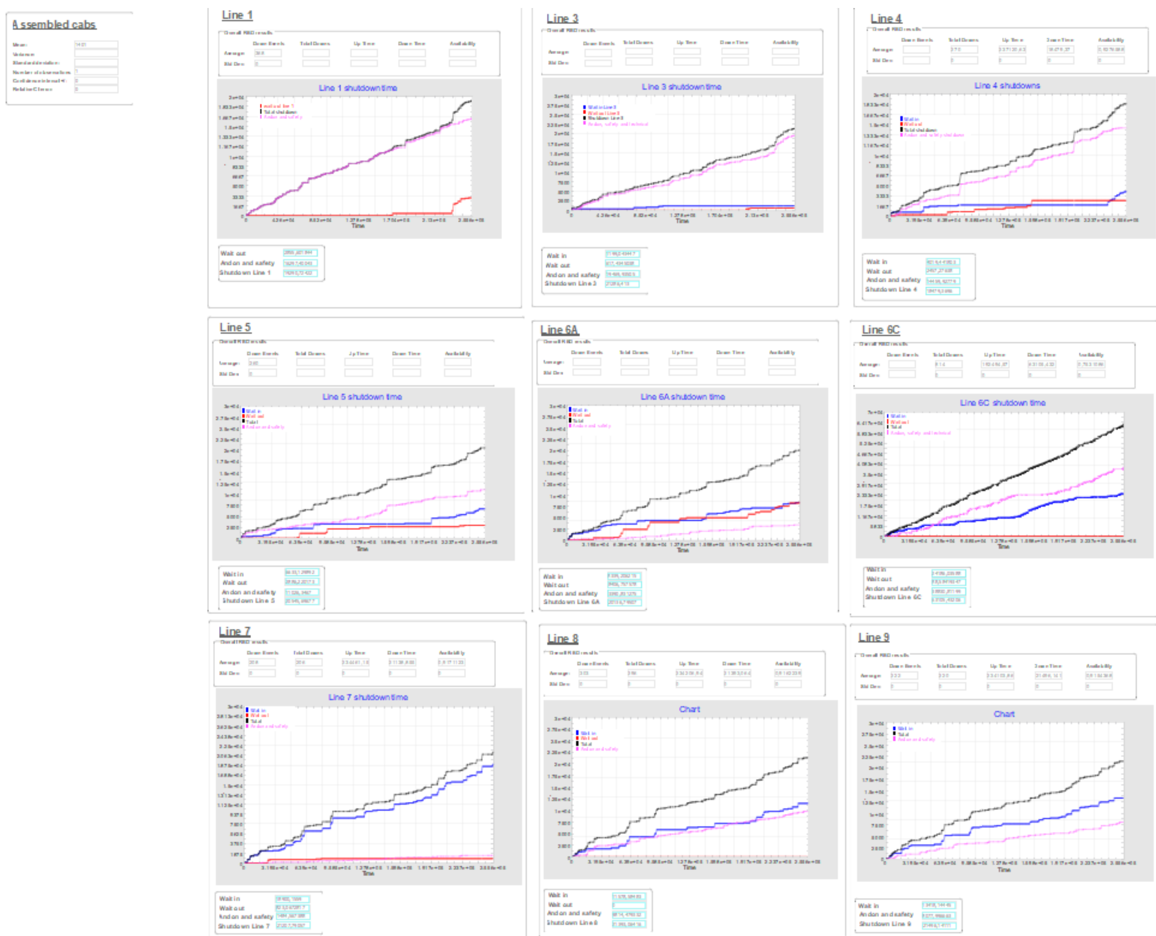


Figure 22: A screen shot from the assembly line result window. A graphical display of all the shutdowns for each assembly line can be seen. The lines indicates different kind of shutdowns.

A screen shot from the buffer system result window within in the control panel can be seen in Figure 23 below.

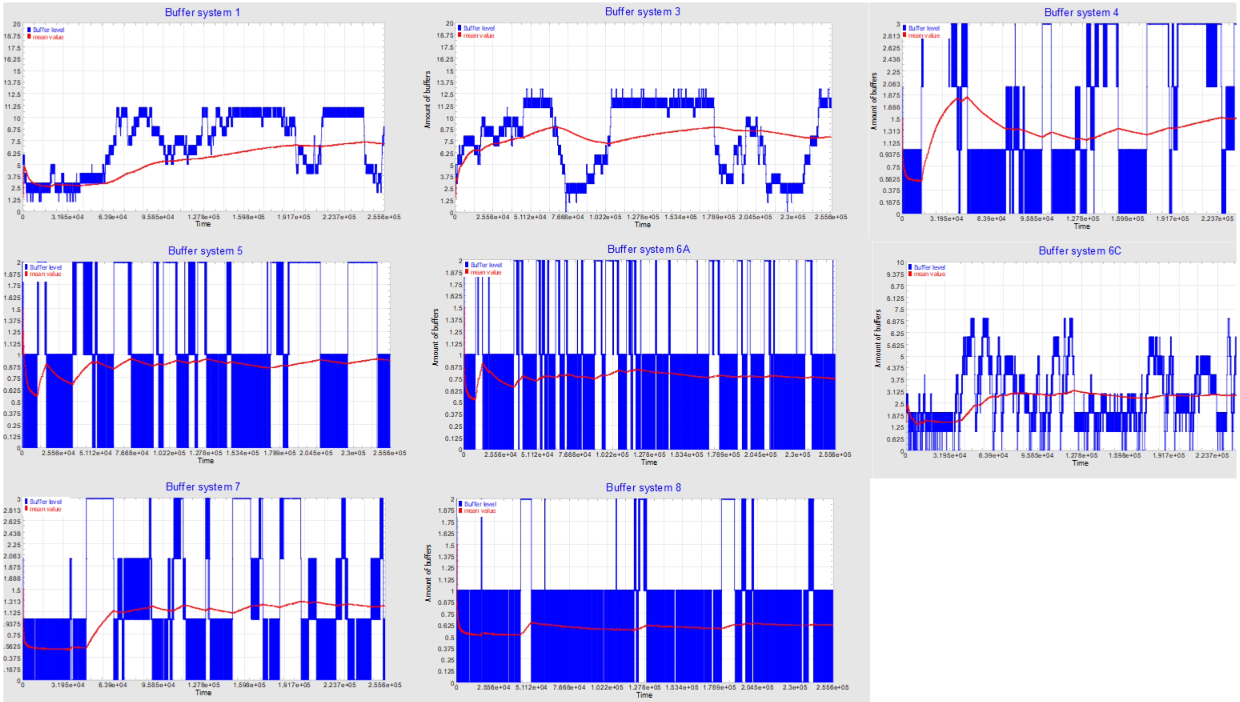


Figure 23: Buffer level graphs of the different buffer systems. The blue line indicates the buffer level over time and the red line indicates the mean buffer level over time.

7.3 Validation

The simulation model has the mathematical character of phase 4 corresponding to an approximate model with approximate results. In Table 11 below the mean value of assembled cabs from the simulation model and Scanias weekly statistical reports are tabulated.

Table 11: Amount of cabs assembled according to the simulation model compared with the weekly statistical reports.

Mean cabs assembled (model)	**Mean cabs assembled (weekly statistical reports)**	**Difference (%)**
7002,0	6683,0	4,77

In Table 12 below the mean values of total shutdown times from 24 simulation sets and Power BI with their percentage difference are tabulated.

Table 12: Shutdown times from the simulation model compared with Power BI.

	Total wait in shutdown time (h)	**Total wait out shutdown time (h)**	**Total andon, safety and technical shutdown time (h)**	**Total shutdown time (h)**
Simulation model	122,46	37,66	156,88	317,01
Power BI	114,49	46,97	161,52	322,99
Difference (%)	6,96	19,82	2,87	1,85

In Figure 24 the standard deviation for 24 sets of all the simulation result parameters are displayed. The median percentage standard deviation is 0,91%. See appendix F for the complete result.

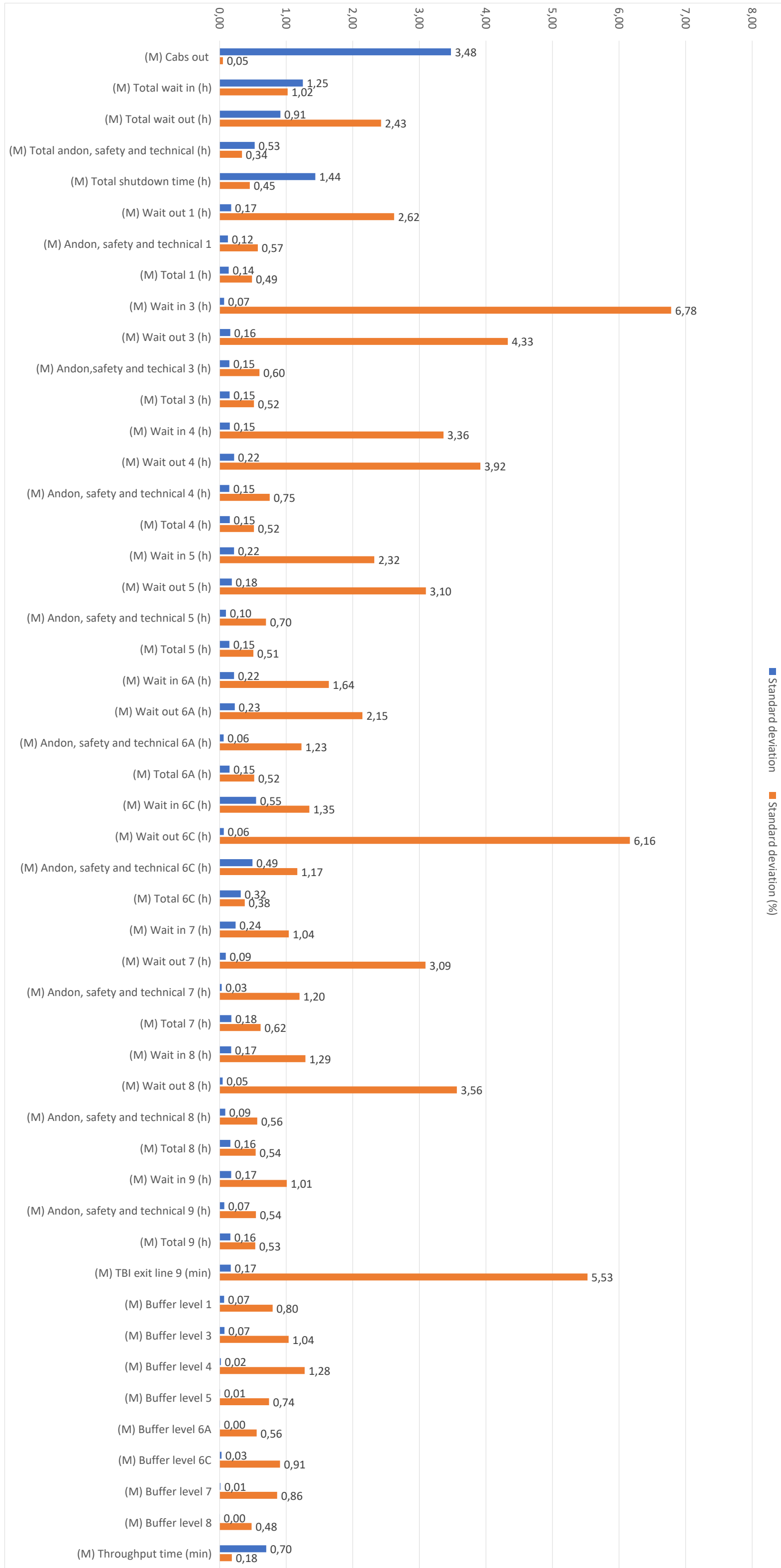


Figure 24: The standard deviation of simulation result parameters with the confidence interval 95%. The blue staples represents the standard deviation and the orange staple represent its corresponding percentage.

7.4 Simulation model results

In this section the simulation model results are shown.

Initial run

In Table 13 below the mean buffer level for the different assembly lines are tabulated. There is also a comment for every buffer system whether the buffer level is above or below half the initial buffer level capacity.

Table 13: Generated results for the buffer levels from the initial run.

Buffer system	Mean value buffer level	Comments
1	8,6	> half buffer capacity.
3	7,2	> half buffer capacity.
4	1,5	= half buffer capacity.
5	0,9	< half buffer capacity.
6A	0,8	< half buffer capacity.
6C	3,2	> half buffer capacity.
7	1,4	< half buffer capacity.
8	0,8	< half buffer capacity.

In Table 14 below the resulting wait in shutdown times for the assembly lines are tabulated. There is also a comment regarding their size in correlation to each other.

Table 14: Generated results of the wait in shutdown times from the initial run.

Buffer system	Wait in shutdown time for upcoming assembly line	Comments
1	9,68 h	Lowest.
3	44,23 h	Low.
4	91,99 h	High.
5	136,36 h	High.
6A	401,32 h	Highest.
6C	245,94 h	High.
7	145,01 h	High.
8	186,44 h	High.

In Table 15 below the availability for the assembly lines are tabulated. There is also a comment of their availability in comparison to assembly line 9.

Table 15: Generated results of the assembly lines total availability of the RBD from the initial run.

Assembly line	**RBD availability(%)**	**Comments**
1	94,2	Highest.
3	91,5	Low.
4	93,2	High.
5	91,7	Low.
6A	91,8	Low.
6C	76,3	Lowest.
7	91,8	Low.
8	91,4	Low.
9	92,9	Reference.

Amount of buffers

In Table 16 below the mean result for 48 scenarios over 100 simulation runs are presented. The values have been selected from the full scenario manager result. See Appendix G for the complete result from the scenario manager.

Table 16: The mean results for 48 scenarios over 100 simulation runs. The colour coding for the cabs out are green for high values and red for low. The rest are green for low values and red for high.

Scenario name	(M) Cabs out (h)	(M) Total wait in (h)	(M) Total wait out (h)	(M) Total andon, safety and technical (h)	(M) Total shutdown time (h)	(M) Throughput time (min)
1	7001,7	122,46	37,53	156,85	316,84	380,77
2	7003,3	122,19	36,89	157,19	316,27	382,49
3	7000,3	121,85	38,15	157,78	317,78	385,97
4	7007,4	121,11	36,59	157,03	314,73	387,51
5	7002,4	122,15	37,64	156,66	316,45	378,56
6	6993,1	125,08	38,42	157,25	320,75	375,89
7	6993,6	125,29	38,77	156,96	321,03	373,64
8	7005,6	121,75	36,69	157,42	315,86	381,36
9	7007,1	120,46	36,97	157,46	314,90	382,71
10	7010,4	119,93	36,68	156,46	313,07	384,25
11	6993,9	124,09	38,96	157,02	320,07	379,94
12	6998,8	124,07	38,21	156,11	318,39	378,07
13	6987,0	129,48	38,00	156,31	323,79	376,99
14	7003,5	124,50	36,46	155,90	316,86	380,71
15	7013,1	119,93	35,80	155,82	311,55	381,78
16	7010,2	118,87	36,78	156,82	312,47	383,20
17	6990,6	125,93	38,12	157,91	321,97	379,87
18	6986,3	129,96	38,73	155,44	324,13	379,05
19	7004,3	124,35	35,53	156,48	316,37	380,41
20	7007,6	120,70	35,49	157,71	313,90	381,97
21	7016,4	119,44	33,84	156,88	310,15	382,43
22	6997,2	126,33	38,20	155,17	319,69	379,45
23	7012,9	120,75	33,73	156,58	311,07	380,53
24	7018,5	119,16	30,26	157,22	306,64	379,06
25	7023,6	117,21	28,17	158,43	303,82	378,97
26	6980,9	123,46	44,93	157,16	325,55	383,41
27	7002,6	125,01	36,30	156,48	317,79	379,77
28	7003,1	124,69	36,36	156,75	317,81	381,30
29	6976,5	107,57	46,39	158,66	312,62	384,45
30	6998,6	122,97	37,90	156,09	316,96	379,92
31	6990,1	112,46	42,43	157,99	312,88	382,47
32	7004,3	125,19	35,67	156,75	317,60	380,57
33	7003,6	126,50	35,66	156,46	318,62	381,07
34	7007,5	129,16	33,31	155,11	317,58	380,50
35	6995,6	119,73	40,58	157,66	317,97	381,84
36	6989,7	121,18	41,16	157,16	319,51	380,34
37	7007,6	122,53	36,29	156,31	315,13	380,64
38	7005,5	127,51	33,80	155,69	317,00	379,73
39	6997,2	126,44	36,40	157,20	320,04	381,95
40	6999,4	121,19	39,21	156,31	316,72	380,78
41	7029,1	122,45	28,06	156,84	307,34	383,84
42	7043,4	123,88	22,04	156,63	302,55	387,71
43	7028,4	102,12	29,64	159,02	290,79	402,77
44	6954,8	128,81	50,18	155,68	334,67	377,17
45	6927,3	129,58	56,82	156,47	342,87	372,69
46	6926,7	129,85	57,23	156,03	343,11	368,45
47	6977,5	123,49	47,60	155,14	326,24	387,00
48	6979,5	120,47	48,53	157,06	326,06	391,74

The mean cabs produced over 100 simulation runs are presented in Figure 25 below.

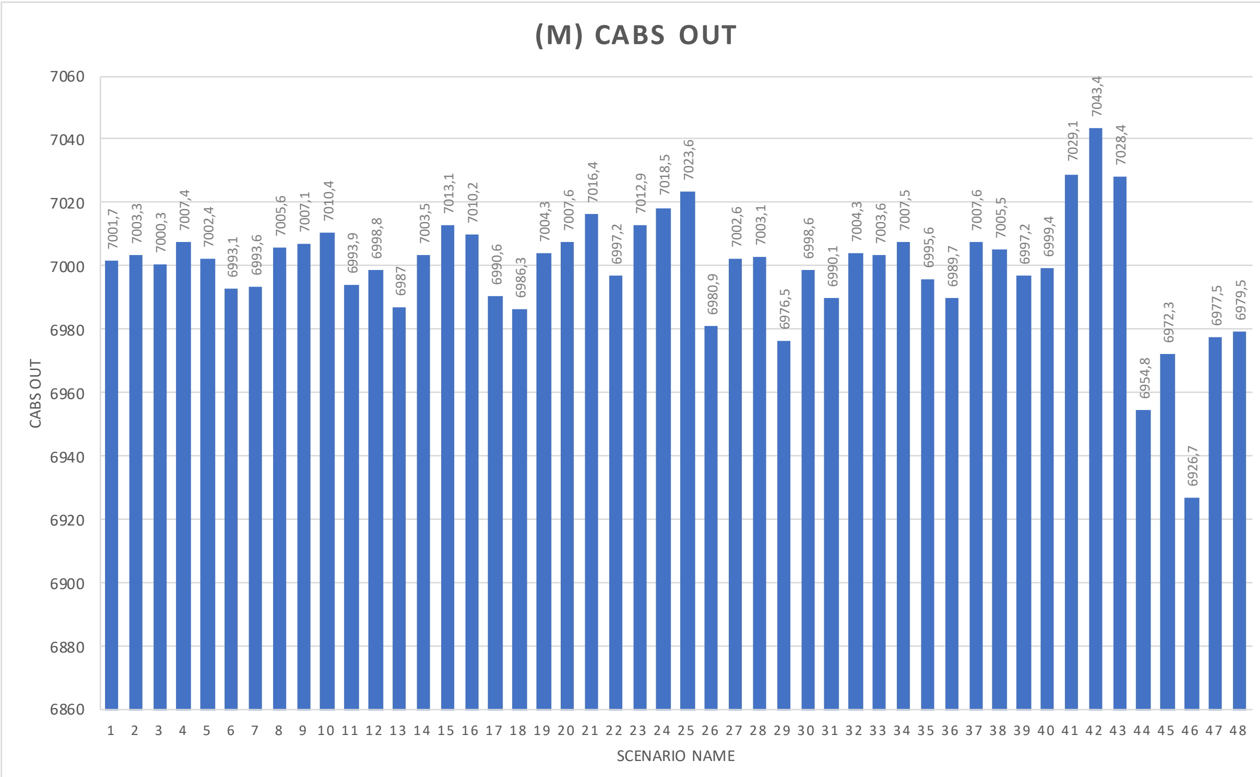


Figure 25: The mean amount of cabs assembled over 100 simulation runs for different buffer amount scenarios. The x-axis displays the different scenarios and the y-axis displays the mean cabs assembled.

Buffer speed

In Table 17 below the result for 38 scenarios over 100 simulation runs are presented. The values have been selected from the full scenario manager result. See Appendix H for the complete result from the scenario manager.

Table 17: Results for 38 scenarios over 100 simulation runs. The colour coding for the cabs out are green for high values and red for low. The rest are green for low values and red for high.

Scenario name	(M) Cabs out (h)	(M) Total wait in (h)	(M) Total wait out (h)	(M) Total andon, safety and technical (h)	(M) Total shutdown time (h)	(M) Throughput time (min)
1	7007,5	121,06	36,81	156,75	314,62	380,70
2	7003,4	124,40	36,85	155,89	317,15	380,23
3	7001,7	123,44	37,50	157,04	317,98	380,88
4	7003,2	123,60	37,53	155,95	317,08	379,54
5	7006,4	122,35	37,50	155,97	315,81	380,08
6	7004,3	124,52	35,82	156,26	316,60	379,07
7	7003,9	118,19	38,84	158,48	315,51	382,06
8	7011,1	118,50	37,33	156,94	312,76	380,19
9	7010,0	118,07	37,60	158,18	313,85	380,41
10	7004,9	122,05	36,93	157,16	316,14	379,82
11	6999,3	122,06	38,65	157,43	318,14	381,12
12	7006,6	120,61	37,67	156,54	314,83	380,10
13	7007,2	122,75	36,44	155,89	315,08	380,13
14	7003,8	122,45	36,89	156,98	316,32	379,97
15	7004,0	123,51	36,78	155,89	316,18	379,94
16	6997,4	122,73	38,56	157,26	318,54	381,08
17	6998,1	123,34	37,71	157,46	318,51	380,24
18	6999,7	123,30	37,07	157,67	318,04	380,32
19	7004,4	124,03	36,61	155,75	316,39	379,92
20	7000,7	124,47	36,40	157,10	317,98	379,82
21	6999,4	123,12	37,45	157,47	318,04	380,40
22	7002,8	122,08	37,93	156,54	316,56	380,55
23	7000,7	123,34	38,12	157,45	318,91	380,15
24	7009,3	124,02	36,10	155,43	315,55	377,78
25	7012,3	123,63	36,79	155,59	316,01	377,63
26	7001,7	124,08	36,83	156,75	317,66	380,14
27	7004,3	123,37	36,21	156,78	316,37	379,38
28	7000,8	123,77	36,87	157,16	317,80	380,13
29	7003,2	125,50	36,22	155,84	317,57	379,03
30	6993,2	123,10	39,32	157,83	320,25	382,06
31	7003,8	120,63	38,48	156,97	316,09	381,12
32	7006,3	125,03	35,62	155,12	315,76	378,94
33	7006,6	123,04	36,10	156,26	315,40	379,28
34	7009,0	120,57	37,59	157,04	315,19	379,98
35	7022,2	118,51	34,89	156,42	309,82	376,19
36	7022,5	118,59	35,92	156,33	310,84	375,16
37	7026,2	120,08	34,97	156,11	311,15	372,13
38	7001,8	125,06	36,81	156,46	318,33	378,92

The mean cabs produced over 100 simulation runs are presented in Figure 26 below.

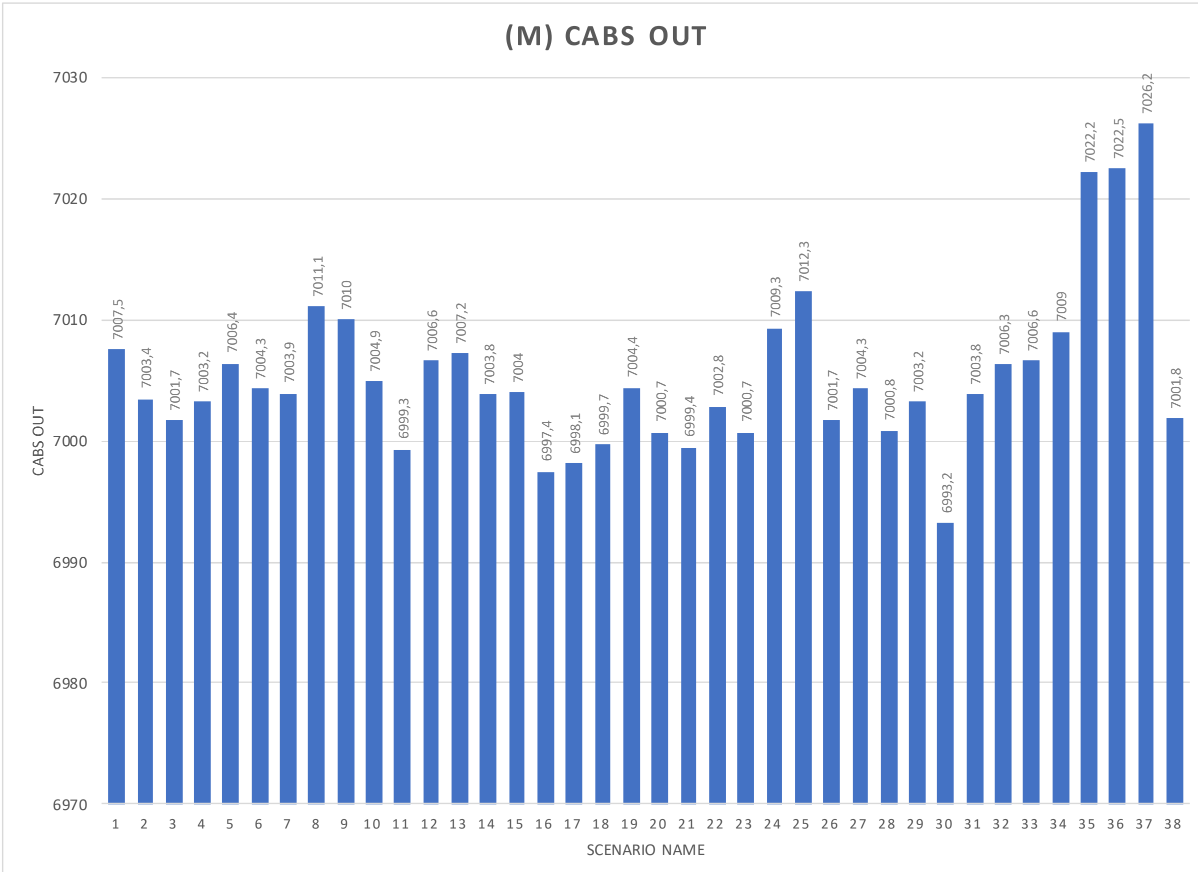


Figure 26: The mean amount of cabs assembled over 100 simulation runs for different buffer transport speed scenarios. The x-axisdisplays the different scenarios and the y-axis displays the mean cabs assembled.

Takt time

In Table 18 below the result for 4 scenarios over 100 simulation runs are presented. The values have been selected from the full scenario manager result. See Appendix I for the complete result from the scenario manager.

Table 18: Results for 4 scenarios over 100 simulation runs. The colour coding for the cabs out are green for high values and red for low. The rest are green for low values and red for high.

Scenario name	(M) Cabs out	(M) Total wait in (h)	(M) Total wait out (h)	(M) Total andon, safety and technical (h)	(M) Total shutdown time (h)	(M) Throughput time (min)
1	7008,0	120,99	37,00	156,30	314,29	380,17
2	6831,8	118,51	51,94	155,50	325,95	401,36
3	7174,7	66,74	69,88	158,19	294,81	398,74
4	7075,2	186,42	24,72	153,61	364,75	357,46

8 Discussion

In this section the results and the applied methods are discussed as well as recommendations for future work.

8.1 Simulation model and validation

In this section the simulation model and its validity is discussed.

Intended purpose

The model have been specifically built to simulate scenarios and generate results to investigate the stated problem formulations. Since all essential parameters are dynamically linked to a database and to each other it makes it practical to run user defined scenarios. The amount of buffer can be adjusted by adding or removing up to three buffer spaces for each buffer system which is a reasonable amount for possible changes to the actual buffer systems. The buffer speed for each buffer system can be adjusted either by multiplying all the associated buffer transport with a factor or by adjusting specific buffer transports. Changing specific buffer transports can be done in the database which can be used for specific buffer management scenarios but to adjust a factor is much easier and efficient. Since the assembly stations on an assembly line all have the same takt time only one parameter needs to be specified to set the takt time for the whole assembly line.

Since a control panel with specific simulation settings and simulation results was built, it makes it easy for anyone to use the model without much simulation knowledge. In the simulation settings the user can adjust all the essential parameters and run one scenario at a time for any amount of runs and run time. The assembly line and buffer system result windows makes it practical for the user to analyse the specific scenario and to draw conclusions based on essential values and graphs for all the assembly lines and buffer systems. The animation effects also makes it easy for the user to analyse the current state during a simulation run.

Concept two has a good level of detail with regards to the problem formulations and the available data from Power BI and weekly statistics. The concept makes it possible to set limitations and apply new andon shutdowns for specific assembly processes.

Since the simulation settings can be adjusted to run scenarios regarding the problem formulations and the results presented is viable to draw decisive conclusions, the model fulfill its intended purpose.

Mathematical character

As the theory states the impossibility to build an exact model with exact results the discussion regarding how phase 2-4 are achieved is essential. As always, assumptions and limitations has been made to manage the project within the given time frame. To validate the mathematical character a comparison between the model results from multiple sets to each other and to see how well the results correspond to the real system data. This to validate the result variations and accuracy in comparison with the real system data. The results from comparing 24 sets to each other, a median standard deviation of 0,91 % with a maximum of 6,78 % was achieved which proves that the model is of highly consistent over multiple runs. Something to be aware of when comparing the amount of shutdown times is to know how the shutdowns are occurring in the model. More specifically meaning, since the wait in and wait out shutdowns are generated by the state of the model the result must be interpreted. Worth pinpointing is to look at how small the variation is of the total amount of andon, safety and technical shutdowns independently of which scenario. This is because they are generated by predefined distributions and are therefor the similar for all scenarios. This makes it important to take simulation settings into consideration when comparing different wait in and out shutdown times.

When comparing the total amount of cabs assembled according to the model and the weekly statistical reports a difference of 4,77% was achieved. A reason for the difference might be that the simulation model is set to run 14,2 hours each day. Because the assembly production does not precisely operate 14,2 hours each day the model might have too many working hours and therefore generates too many assembled cabs. Comparing the model results with the real system data resulted in a maximum difference for wait out shutwdown of 19,82% but when comparing the total amount of shutdown time a difference of 1,85% was achieved. This then gives good credibility that the model generates a good amount of shutdown time with a variance of wait in and out shutdown time.

A difference of 2,87% was achieved for the total andon, safety and technical shutdown time when comparing the models result to the Power BI. This gives a good credibility of the data management method. The reason for the difference could be the lack of raw quality input data.

Looking closer at the simplifications, assumptions and how they affects the results the most fundamental aspect is that a simulation model is never better than the input data. In the beginning of the project when setting up meetings with different departments to find the most optimal way to extract data, one thing came to mind. It was difficult to gain information of the assembly process as a whole. This since each department is its own expert the bigger picture gets lost.

Since the data was unprocessed and far from TBF and TTR value, lots of work before it was ready to be used needed to be done. This opens up for errors along the data management process. The method needed for extracting and handling data was far from ideal for simulation projects which are reliable on quality input data. Therefore an investigation in how data could be handled and stored is of great interest for Scania. Data handling and storage is a bit out of the scope for this master thesis project but is of great value and therefore worth mentioning. This will enable a more secure and faster method for Scania to continue using the simulation model and incorporating new distributions to gain decision making information in the time to come.

The limitations that was set also had contributions to result errors. Since the logistical flow and pre assemblies were excluded from the model their affect can not be seen in the results. This since their reasons for shutdown is included in the andon shutdowns. The limitations for excluding wait in shutdown for assembly line 1 and wait out for line 9 was set due to the project time frame and information shortage. This could be one of the reasons for having variance between the simulation model results and the real time process data.

As the simulation model was considered to have the mathematical character of phase 4 a discussion regarding the grading system came to mind. Since the purpose of the project is fulfilled and valid information has been extracted from the model, the project is in our mind a success. But according to the grading system the model is of lowest value, therefore it might too uncertain to grade different models. This due to the assumption to build either an exact model or to extract exact results are impossible.

Time

As the intended purpose of this project has been reached where valid decision making information has been delivered, the time aspect comes in hand. Since the simulation model is built and validated trough stop data the time frame of its application matter. This means that when the real system changes over time the simulation models results gets more and more incorrect with regards to the new system. A variance as a bad deliverance of assembly parts or rebuilding the system is something that would effect the credibility of the results from the simulation model. This empathises the importance of constantly updating distributions to be able to gain decision making information that is relevant for a specific time period.

There is great advantage of having a simulation model that can be used to adapt to critical situations. For example, if a bad deliverance during the last few weeks has affected the assembly process causing the productivity to drop and therefore being behind. By using the stop data logged for these bad weeks and calculating new distributions the real system can be investigated in a way Scania does not posses today. The biggest bottle necks can easily be found and by gaining that information the optimization can begin. By running multiple scenarios the most optimal approach can be determined and by that way the deliverance of bad parts has been bypassed. As discussed earlier it is of the essence to know about changes in the assembly process to constantly use the simulation model within the specific time frame. In this project the scope was to investigate and find improvements of the existing system which enables Scania to use the simulation model in the near future.

Worth knowing when changing simulation parameters the circumstances for the assembly lines are affected. But the simulation model still generates andon, safety and technical shutdowns with the same probability since they are generated by predefined distributions. This is therefore important to take into consideration when interpreting the results. For example, increasing the takt time for an assembly line practically generates more shutdown time since the work load is higher.

8.2 Simulation model results

In this section the scenario results are discussed.

Amount of buffers

The problem formulation state: ***How does the amount of cab buffers affect the production productivity?***

There are a lot of information and conclusions that can be drawn based on the results from all the scenarios where the amount of buffers were changed. From the exhaustive search the biggest effect on cabs assembled was for scenario 23-25 when one to three buffer spaces were added to buffer system 6A. In these three scenarios a decrease of the total shutdown time can be seen. The wait out shutdown time for all the assembly lines before buffer system 6A are decreased while they are slightly increased for all the assembly lines after buffer system 6A. The wait in shutdown has the opposite effect where it is increased for all assembly lines before and decreased for all assembly lines after buffer system 6A. Worth noting is that the total wait in and out shutdown times, as well as the total shutdown time for the whole assembly process is lower for these scenarios. Even though buffer spaces are added to buffer system 6A the total throughput time is lowered, this is achieved due to the lowered shutdown times. Since the biggest effects are achieved when adding spaces to buffer system 6A, this should be the first investigation Scania should lock closer into. Since adding three buffer spaces gave the best results, a business case of this application should be done.

A small trend can be seen when increasing the amount of buffers for buffer system 1 and 3. The amount of cabs assembled slightly increases but the total throughput time is also increased. The opposite effect occur when removing the amount of buffer spaces to these buffer systems. The effect by increasing all buffer systems with one to three buffer spaces is big. This entails that the amount of cabs assembled is drastically increased while the total shutdown time is lowered. But the total throughput time is increased due to the overall higher buffer levels. By adding spaces to these buffer system a positive trend is showing, therefore Scania should further investigate this as well.

Buffer transport speed

The problem formulation state: ***How is the production productivity affected by vary the speed for cab buffer transports?***

The amount of cabs produced when adjusting the buffer transport speed does not change drastically unless all buffer system transports are increased. The effect from the exhaustive search can be seen in scenario 7-9 where the transport speed of buffer system 3 increased by 40-80%. This change entails that the wait in shutdown time for line 4 is drastically lowered while the wait out shutdown time for line 4 is increased. But the total shutdown time for line 4 is lowered and the assembly process total shutdown time is also slightly lowered. When increasing the buffer transport speed for a single buffer system in the other scenarios there is no clear positive effect. A combination of change for multiple buffer systems (excluded of a change for all) was not included in the tests. This is something that can achieve positive results and should therefore be further investigated by Scania.

The biggest overall effect is for scenario 34-37 where all buffer systems transports are increased by 20-80%. In these scenarios the total cabs assembled is drastically increased while the total wait in and wait out shutdown time is improved, so is the total shutdown time for the whole assembly process. The throughput time for these scenarios is also improved. The practical application of increasing the transport speed of a buffer system by 80% is not realistic with regards to its limitations. But a change of 20-40% might be possible and should therefore be taken into consideration.

Takt time

The problem formulation state: ***What is the optimal assembly line takt times with regard of each OPE?***

The tailored test where the takt times were set based on the RBD availability results did not show a positive outcome. In this test there was a small improvement on the total wait in shutdown time but the total shutdown time was increased. Even though the tailored test showed a poor result there is still great potential in optimizing individual takt times. This can be done by either increase or decrease individual takt times. Our method was not extensive enough, therefore Scania should continue working towards finding a valid method.

For the push system the total shutdown time and the total wait in shutdown time was drastically lowered even though the total wait out shutdown time was increased. This is possible due to the buffer levels are much higher compared with the current state. This entails a higher availability for later assembly lines in the assembly process. The time between cabs exiting assembly line 9 is therefore lowered by 3,6 seconds in comparison to its takt time of 167 seconds. The throughput time for this scenario was increased by 18,57 minutes which is worth highlighting.

The pull system gave a lower total wait out shutdown time but the total wait in shutdown time was increased drastically resulting in an overall higher total shutdown time. The time between cabs exiting line 9 did not show great outcome with regards to its takt time of 159 seconds. Even though the poor results for this test the throughput time was lowered by 22,71 minutes which is an great improvement. This can be a consequence of the overall lower buffer levels.

The push and pull system tests both gave positive results for the amount of assembled cabs but are not to be blindly compared with the current state test. This is because the takt time for one assembly line is set to 167 seconds and lowered for the others, resulting in an overall faster production rate. Investigating push and pull systems was out of the scope for this project. Never the less the tests gave interesting results showing benefits of both systems. The push system gave a better result and its something Scania could benefit from. Both to increase their productivity and to minimise wait in shutdowns for line 9 and thereby deliver within the takt time.

An interesting scenario to further investigate is to dynamically switch the takt times between the initial state, a push system and a pull system depending on the the overall buffer state throughout the model. This will result in more stable buffer levels, reducing the wait in and out shutdown times. In order to simulate this scenario, some re-modifications in the simulation model needs to be done.

9 Conclusions

In this section the most essential conclusions are stated.

- The simulation model generates viable decision making information, therefore fulfills its purpose.
- The simulation model produces results with a median standard deviation of 0,91 % for 24 sets over 100 runs with the same settings.
- The total amount of assembled cabs differ by 4,77 % between the simulation model and weekly statistical reports.
- The total shutdown time differ by 1,85 % between the simulation model and Power BI.
- The simulation model is accurate for the current assembly process and can be used within Scania in the near future.
- By increasing the amount of spaces for buffer system 6A an increasement of assembled cabs up to 20 is achieved for a time period of five weeks. A positive trend by increasing the amount of spaces for buffer system 1 and 3 can be seen.
- By increasing all the buffer transport speeds by 40 % up to 20 more cabs are assembled over a time period of five weeks.
- A push production system lowers the total shutdown time by 22 hours over a time period of five weeks compared with the current state.
- A push production system increases the amount of assembled cabs by 113 over a time period of five weeks compared to the current state.

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Appendices

A Excel macro

A representation of the Raw data before and after the macro has been used in Excel. 1 shows before and 2 shows after the macro was used.

1

3	Timestamp Sta	Timest	WeekN	LineNa	AlarmT	Positio	FBG	ShiftNr	MhtTag	Catego	Reason	Montag	DurTim	Summa
4	2020-03-12 20:37	kl 20:37	2020w11	Line 4	Andonsto	410L	Blå	1	L4.3	Annan lin	WCM		0:06:01	1
5	2020-03-12 18:36	kl 18:36	2020w11	Line 4	Andonsto	410L	Blå	1	L4.3	Eget - Mo		Bakre inst	0:01:41	1
6	2020-03-12 11:47	kl 11:47	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Annan lin	WCM		0:04:46	1
7	2020-03-12 11:43	kl 11:43	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Annan lin	WCM		0:00:31	1
8	2020-03-11 13:01	kl 13:01	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Eget - Mo		Bakre inst	0:00:24	1
9	2020-03-11 08:32	kl 08:32	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Organisati	Fel från Ka		0:02:39	1
10	2020-03-11 07:57	kl 07:57	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Organisati	Fel från Ka		0:01:24	1
11	2020-03-11 07:41	kl 07:41	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Eget - Mo	Fel från Ka	Bakre inst	0:00:12	1
12	2020-03-10 22:34	kl 22:34	2020w11	Line 4	Andonsto	410L	Blå	1	L4.3	Eget - Mo		Bakre inst	0:00:25	1
13	2020-03-10 22:08	kl 22:08	2020w11	Line 4	Andonsto	410L	Blå	1	L4.3	Eget - Mo		Bakre inst	0:01:03	1
14	2020-03-10 09:47	kl 09:47	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Annan lin	WCM		0:09:34	1
15	2020-03-09 14:06	kl 14:06	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3				0:01:18	1
16	2020-03-09 13:52	kl 13:52	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Annan lin	Line 1		0:02:48	1
17	2020-03-09 12:55	kl 12:55	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Annan lin	Line 1		0:02:06	1
18	2020-03-09 09:19	kl 09:19	2020w11	Line 4	Andonsto	410L	Blå	2	L4.3	Annan lin	Tiltline		0:01:25	1
19	2020-03-06 13:50	kl 13:50	2020w10	Line 4	Andonsto	410L	Blå	2	L4.3	Annan lin	Line 1		0:00:20	1

2

3	Timestamp Star	Kolumn1	Kolum	Kolum
4	2020-03-12 20:37	7285		0:06:01
5	2020-03-12 18:36	24548		0:01:41
6	2020-03-12 11:47	190		0:04:46
8	2020-03-11 13:01	16171		0:00:24
9	2020-03-11 08:32	2086		0:02:39
10	2020-03-11 07:57	992		0:01:24
12	2020-03-10 22:34	1585		0:00:25
15	2020-03-09 14:06	834		0:01:18
16	2020-03-09 13:52	3388		0:02:48
17	2020-03-09 12:55	12975		0:02:06
19	2020-03-06 13:50	5404		0:00:20
21	2020-03-05 21:52	1428		0:09:33
22	2020-03-05 21:28	18		0:00:26
24	2020-03-05 10:46	973		0:02:52
25	2020-03-05 10:29	12376		0:02:51
29	2020-03-03 20:11	16240		0:00:04
34	2020-02-26 11:23	13864		0:00:05
36	2020-02-25 14:55	20056		0:02:27
37	2020-02-25 09:20	3859		0:03:28

B Filtered process stop data

A representation of the filtered process stop data for two work stations. The colour scaled columns *TBF* and *TTR* is the data which is used to generate a distribution.

Work station QG 445			
Andon stop			
Time interval: 2020/01/01-2020/03/09			
Timestamp (PBI data)	**TBF**	**TTR (PBI data)**	**TTR**
2020-03-09 17:09	19198	0:00:24	24
2020-03-09 11:49	2061	0:02:40	160
2020-03-09 11:15	197	0:00:36	36
2020-03-09 11:11	1303	0:00:31	31
2020-03-09 10:50	14604	0:00:42	42
2020-03-09 06:46	666	0:00:10	10
2020-03-06 13:33	13197	0:00:16	16
2020-03-06 13:22	1032	0:00:04	4
2020-03-06 09:42	8748	0:00:23	23
2020-03-06 09:25	13105	0:00:32	32
2020-03-06 06:59	2988	0:00:56	56
2020-03-05 20:57	4907	0:07:55	475
2020-03-05 11:35	12836	0:00:53	53
2020-03-05 07:56	7531	0:00:57	57
2020-03-05 07:06	23794	0:00:02	2
2020-03-04 22:04	1580	0:00:03	3
2020-03-04 20:42	5710	0:00:49	49
2020-03-04 17:08	584	0:00:04	4
2020-03-04 15:02	1043	0:00:05	5
2020-03-04 08:26	2207	0:00:25	25
2020-03-03 19:57	7662	0:00:09	9
2020-03-02 13:04	205	0:00:13	13
2020-03-02 12:37	12729	0:00:14	14
2020-03-02 11:02	8273	0:00:12	12
2020-03-02 10:52	1367	0:01:25	85
2020-03-02 10:35	3386	0:00:43	43
2020-03-02 09:58	1400	0:00:08	8
2020-02-28 16:09	3714	0:00:14	14
2020-02-28 14:01	862	0:00:27	27
2020-02-28 13:58	6703	0:00:39	39
2020-02-28 10:25	9857	0:00:24	24
2020-02-28 08:08	14199	0:00:06	6
2020-02-28 07:45	496	0:00:31	31
2020-02-28 06:48	11	0:00:44	44
2020-02-27 22:06	2143	0:00:21	21
2020-02-27 21:43	4397	0:00:13	13
2020-02-27 20:41	584	0:00:28	28
2020-02-27 20:26	2532	0:01:07	67
2020-02-27 18:35	389	0:00:23	23
2020-02-27 15:50	22582	0:00:36	36
2020-02-27 11:54	10393	0:00:20	20
2020-02-27 11:45	1584	0:02:58	178
2020-02-27 11:45	10630	0:00:09	9
2020-02-27 11:10	1259	0:00:31	31
2020-02-27 09:56	12401	0:02:18	138
2020-02-27 09:47	1742	0:00:47	47
2020-02-26 20:30	19851	0:00:04	4
2020-02-26 19:48	3773	0:00:25	25
2020-02-26 19:41	1928	0:00:02	2
2020-02-26 13:25	1540	0:00:15	15
2020-02-26 10:32	110	0:01:24	84
2020-02-26 10:05	426	0:01:57	117
2020-02-25 20:04	4699	0:00:04	4
2020-02-25 17:07	17633	0:00:25	25
2020-02-25 16:46	237	0:01:41	101
2020-02-25 13:19	669	0:00:53	53

Work station 450			
Andon stop			
Time interval: 2020/01/01-2020/03/09			
Timestamp (PBI data)	**TBF**	**TTR (PBI data)**	**TTR**
2020-03-09 22:15	3460	0:00:52	52
2020-03-09 21:17	4634	0:00:53	53
2020-03-09 20:00	23620	0:00:07	7
2020-03-09 13:26	9281	0:00:13	13
2020-03-09 10:51	11342	0:01:48	108
2020-03-09 07:42	9755	0:00:18	18
2020-03-06 16:55	112	0:01:13	73
2020-03-06 14:13	64	0:00:29	29
2020-03-06 06:50	1564	0:01:28	88
2020-03-05 18:49	3185	0:00:07	7
2020-03-05 18:47	4529	0:00:03	3
2020-03-05 18:46	4782	0:01:03	63
2020-03-04 17:52	4895	0:01:03	63
2020-03-04 10:29	19397	0:00:39	39
2020-03-04 10:03	5144	0:00:11	11
2020-03-04 09:10	7457	0:00:13	13
2020-03-04 07:54	1240	0:00:35	35
2020-03-03 09:58	4223	0:00:14	14
2020-03-03 08:38	4942	0:00:10	10
2020-03-02 22:11	3011	0:00:26	26
2020-03-02 20:49	3212	0:00:04	4
2020-03-02 15:26	7812	0:02:35	155
2020-03-02 14:00	207	0:00:30	30
2020-03-02 11:56	14944	0:00:39	39
2020-03-02 11:35	224	0:00:07	7
2020-03-02 10:25	12486	0:00:12	12
2020-03-02 09:03	7497	0:00:31	31
2020-02-28 17:47	870	0:00:23	23
2020-02-28 16:56	16166	0:00:41	41
2020-02-26 18:44	2727	0:00:11	11
2020-02-25 22:46	716	0:00:07	7
2020-02-25 21:53	1778	0:00:09	9
2020-02-25 19:42	769	0:00:50	50
2020-02-25 19:39	343	0:00:40	40
2020-02-25 15:30	49	0:01:56	116
2020-02-25 15:26	6376	0:00:57	57
2020-02-25 11:58	12586	0:00:57	57
2020-02-25 09:53	401	0:00:27	27
2020-02-25 09:39	334	0:00:04	4
2020-02-24 22:03	26	0:00:16	16
2020-02-24 17:34	3181	0:01:41	101
2020-02-24 16:48	8202	0:00:30	30
2020-02-24 16:37	15891	0:00:09	9
2020-02-24 16:07	1931	0:02:20	140
2020-02-24 15:54	1827	0:00:56	56
2020-02-24 15:48	4461	0:00:04	4
2020-02-24 15:48	685	0:00:33	33
2020-02-24 14:01	331	0:00:06	6
2020-02-24 10:32	7	0:00:05	5
2020-02-21 17:24	7978	0:00:35	35
2020-02-21 17:17	6983	0:02:30	150
2020-02-21 17:12	17971	0:00:21	21
2020-02-21 17:11	2579	0:00:22	22
2020-02-21 16:18	10076	0:01:12	72
2020-02-21 14:02	5043	0:00:38	38
2020-02-21 09:37	4496	0:00:13	13

C Distributions

Tabulated empirical distributions imported into the simulation model. The green indicates a high amount of data points and the red indicates a low amount.

NAME	PURPOSE	DISTRIBUTION	PARAM 1	PARAM 2	PARAM 3	PARAM 4	Min Boundary	Max Boundary	Time Units	Color coding
101 andon	TBD	Gamma	4340	0,547	159				Seconds	
101 andon	TTU	Weibull	11,2	0,624	1				Seconds	
105 andon	TBD	Gamma	6150	0,904	2				Seconds	
105 andon	TTU	Log-Logistic	21,5	1,3	2				Seconds	
115-120 andon	TBD	Power function	8	188000	0,364				Seconds	
115-120 andon	TTU	Weibull	25,6	0,627	3				Seconds	
125 andon	TBD	Gamma	9980	0,651	46				Seconds	
125 andon	TTU	Log-Logistic	26,4	1,42	1				Seconds	
130 andon	TBD	Beta	0,657	2,83	31189	11			Seconds	
130 andon	TTU	Pearson VI	25,9	1,71	2,14	2			Seconds	
135 andon	TBD	Gamma	10400	0,594	7				Seconds	
135 andon	TTU	Weibull	46,3	0,877	3				Seconds	
145 andon	TBD	Gamma	4740	0,734	8				Seconds	
145 andon	TTU	Pearson VI	35,5	1,4	1,92	2			Seconds	
150 QG andon	TBD	Beta	0,738	3,71	34294	6			Seconds	
150 QG andon	TTU	Lognormal	61,5	158	2				Seconds	
Line 1 safety	TBD	Uniform Real	3930	937000					Seconds	
Line 1 safety	TTU	Pearson VI	109	0,847	1,54	5			Seconds	
305 andon	TBD	Exponential	62300	668					Seconds	
305 andon	TTU	Johnson SB	29900	5,37	0,627	3			Seconds	
310 andon	TBD	Beta	0,63	2,67	236597	403			Seconds	
310 andon	TTU	Lognormal	81,3	261	3				Seconds	
315 andon	TBD	Lognormal	7120	28300	360				Seconds	
315 andon	TTU	Pearson VI	63,1	1,04	1,64	3			Seconds	
320 andon	TBD	Weibull	7280	0,952	182				Seconds	
320 andon	TTU	Pearson VI	70,7	0,961	1,48	3			Seconds	
325 andon	TBD	Weibull	4380	0,843	2				Seconds	
325 andon	TTU	Weibull	109	0,798	2				Seconds	
335 andon	TBD	Beta	0,63	2,11	28492	8			Seconds	
335 andon	TTU	Lognormal	108	328	1				Seconds	
340 andon	TBD	Gamma	46700	0,632	188				Seconds	
340 andon	TTU	Pearson VI	295	0,78	2,93	4			Seconds	
345 QG andon	TBD	Beta	0,689	1,73	27597	3			Seconds	
345 QG andon	TTU	Weibull	52,3	0,837	3				Seconds	
Line 3 technical	TBD	Weibull	239000	0,855	7200				Seconds	
Line 3 technical	TTU	Pearson V	21,6	0,849	3				Seconds	
Line 3 safety	TBD	Uniform Real	4090	450000					Seconds	
Line 3 safety	TTU	Pearson VI	28,1	1,81	1,13	0			Seconds	
405 andon	TBD	Gamma	73200	0,582	8				Seconds	
405 andon	TTU	Weibull	79,7	0,682	2				Seconds	
410 andon	TBD	Beta	0,705	2,37	29392	8			Seconds	
410 andon	TTU	Weibull	63,8	0,712	2				Seconds	
415 andon	TBD	Beta	0,772	2,03	25296	4			Seconds	
415 andon	TTU	Pearson VI	56	1,32	3,55	2			Seconds	
420 andon	TBD	Power function	8	193000	0,442				Seconds	
420 andon	TTU	Weibull	10,8	0,723	3				Seconds	
430 andon	TBD	Weibull	7480	1,18	3				Seconds	
430 andon	TTU	Log-logistic	12,3	1,52	2				Seconds	
435 andon	TBD	Johnson SB	25900	0,883	0,491	8			Seconds	
435 andon	TTU	Pearson VI	20,2	1,66	0,763	1			Seconds	
440 andon	TBD	Gamma	45300	0,709	19				Seconds	
440 andon	TTU	Pearson VI	26	1,39	1,47	2			Seconds	
445 QG andon	TBD	Johnson SB	25800	0,877	0,471	8			Seconds	
445 QG andon	TTU	Pearson VI	44,5	1,27	2,52	2			Seconds	
450 andon	TBD	Gamma	9570	0,69	7				Seconds	
450 andon	TTU	Johnson SB	168	1,29	0,618	2			Seconds	
Line 4 safety	TBD	Uniform Real	3680	395000					Seconds	
Line 4 safety	TTU	Log-logistic	31,6	1,3	3				Seconds	

NAME	PURPOSE
140 andon	Missing data (Slide position)
330 andon	Missing data (Slide position)
425 andon	Missing data
505 andon	Missing data (slide position)
515 andon	Missing data (slide position)
525 andon	Missing data (slide position)
535 andon	Missing data (slide position)
550 andon	Missing data (slide position)
610 andon	Missing data (slide position)
670 andon	Missing data
675 andon	Missing data
705 andon	Missing data
710 andon	Missing data (Slide position)
735 andon	Missing data (slide position)
830 andon	Missing data (slide position)
915 andon	Missing data
925 andon	Missing data
Line 1 technical	Missing data
Line 4 technical	Missing data
Line 5 technical	Missing data
Line 6 A technical	Missing data
Line 6 C technical	Missing data
Line 7 technical	Missing data
Line 8 technical	Missing data
Line 9 technical	Missing data

510 andon	TBD	Beta	0,621	1,185	25194	6	Seconds
510 andon	TTU	Lognormal	28	52,3	2		Seconds
520 andon	TBD	Beta	0,617	2,59	31698	2	Seconds
520 andon	TTU	Log-logistic	16,3	1,51	2		Seconds
530 andon	TBD	Exponential	8180	172			Seconds
530 andon	TTU	Log-logistic	61,6	1,11	2		Seconds
535 andon	TBD	Weibull	9160	1,05			Seconds
535 andon	TTU	Log-logistic	17,6	2,44	4		Seconds
540 andon	TBD	Gamma	63400	0,847	9		Seconds
540 andon	TTU	Lognormal	58,1	248	3		Seconds
545 QG andon	TBD	Gamma	8420	0.736	22		Seconds
545 QG andon	TTU	Pearson VI	44,3	1,22	1,68	2	Seconds
Line 5 safety	TBD	Uniform Real	6140	876000			Seconds
Line 5 safety	TTU	Lognormal	68,2	139	4		Seconds
605 andon	TBD	Beta	0,674	1,61	26394	6	Seconds
605 andon	TTU	Log-logistic	16,3	1,02	3		Seconds
615 andon	TBD	Exponential	40500	8			Seconds
615 andon	TTU	Lognormal	22,5	51	2		Seconds
620 andon	TBD	Beta	0,522	1,07	161992	8	Seconds
620 andon	TTU	Log-logistic	7,67	1,22	3		Seconds
625 andon	TBD	Gamma	44200	0,797	188		Seconds
625 andon	TTU	Log-logistic	14,5	1,15	3		Seconds
630 andon	TBD	Gamma	66200	0,697	23		Seconds
630 andon	TTU	Pearson VI	4,74	3,13	1,21	2	Seconds
635 andon	TBD	Gamma	53400	0,656	7		Seconds
635 andon	TTU	Pearson VI	38,4	1,53	2,57	2	Seconds
640 andon	TBD	Beta	0,491	2,24	228992	8	Seconds
640 andon	TTU	Weibull	33,9	0,671	3		Seconds
645 QG andon	TBD	Beta	0,611	2,42	30192	8	Seconds
645 QG andon	TTU	Pearson VI	31,2	1,35	1,63	2	Seconds
Line 6A safety	TBD	Uniform Real	5230	5180000			Seconds
Line 6A safety	TTU	Pearson VI	7,88	1,96	1,01	8	Seconds
665 andon	TBD	Beta	0,441	1,89	28193	7	Seconds
665 andon	TTU	Log-logistic	29,5	1,03	3		Seconds
Robot station 6C.1 andon	TBD	Log-Logistic	573	1,52	3		Seconds
Robot station 6C.1 andon	TTU	Beta	0,285	8,54	6929	1	Seconds
Robot station 6C.1 technical	TBD	Uniform Real	103	21400			Seconds
Robot station 6C.1 technical	TTU	Log-logistic	76	2,15	2		Seconds
680 andon	TBD	Weibull	12200	0,702	173		Seconds
680 andon	TTU	Inverse Weibull	0,5130,104	3			Seconds
692 andon	TBD	Weibull	8120	0,767	182		Seconds
692 andon	TTU	Log-logistic	18,4	0,719	3		Seconds
Line 6C safety	TBD	Uniform Real	4910	6940000			Seconds
Line 6C safety	TTU	Inverse Gaussian	34,2	152	6		Seconds
715 andon	TBD	Beta	0,484	1,99	24891	9	Seconds
715 andon	TTU	Pearson V	1,8	4,97	0,854	2	Seconds
720 andon	TBD	Power function	8	203000	0,531		Seconds
720 andon	TTU	Pearson VI	0,288	14,8	0,616	2	Seconds
725 andon	TBD	Gamma	7200	0,604	2		Seconds
725 andon	TTU	Pearson VI	29,5	1,85	2,98	2	Seconds
730 andon	TBD	Power function	9	25500	0,544		Seconds
730 andon	TTU	Log-Logistic	8,63	1,53	2		Seconds
740 andon	TBD	Weibull	8350	1,1	7		Seconds
740 andon	TTU	Weibull	10,9	0,789	3		Seconds
745 andon	TBD	Gamma	82600	0,447	3		Seconds
745 andon	TTU	Lognormal	29	38,1	1		Seconds
750 QG andon	TBD	Beta	0,627	1,21	25994	6	Seconds
750 QG andon	TTU	Lognormal	28,8	52,3	2		Seconds
Line 7 safety	TBD	Uniform Real	9050	756000			Seconds
Line 7 safety	TTU	Pearson VI	14,2	4,63	1,26	12	Seconds
805 andon	TBD	Weibull	2830	0,684	1		Seconds
805 andon	TTU	Pearson VI	22,8	1,59	1,82	2	Seconds
810 andon	TBD	Beta	0,627	2,89	33298	2	Seconds
810 andon	TTU	Gamma	15,6	1,38	2		Seconds
815 andon	TBD	Weibull	6910	0,914	172		Seconds
815 andon	TTU	Lognormal	34,2	62	2		Seconds
820 andon	TBD	Log-logistic	1170	1,33	2		Seconds
820 andon	TTU	Pearson VI	84,1	1,48	5,26	2	Seconds
825 andon	TBD	Weibull	7960	1,19	32		Seconds
825 andon	TTU	Pearson VI	10,6	2,27	2,27	4	Seconds
835 andon	TBD	Power function	5	25700	0,557		Seconds
835 andon	TTU	Pearson V	10,2	0,616	0		Seconds
845 QG andon	TBD	Gamma	5740	0,877	5		Seconds
845 QG andon	TTU	Log-logistic	26,4	1,4	2		Seconds
Line 8 safety	TBD	Uniform Real	12100	907000			Seconds
Line 8 safety	TTU	Pearson VI	8,24	3,42	0,91	12	Seconds
905 andon	TBD	Power function	8	181000	0,378		Seconds
905 andon	TTU	Pearson VI	164	0,747	1,85	2	Seconds
910 andon	TBD	Gamma	7560	0,842	4		Seconds
910 andon	TTU	Beta	1,06	3,85	299	2	Seconds
920 andon	TBD	Weibull	6180	0,963	8		Seconds
920 andon	TTU	Weibull	21	0,747	3		Seconds
930 andon	TBD	Beta	0,577	1,95	27292	8	Seconds
930 andon	TTU	Pearson VI	254	1,14	2,93	2	Seconds
Line 9 safety	TBD	Uniform Real	3620	331000			Seconds
Line 9 safety	TTU	Log-logistic	54,3	1,74	11		Seconds

D Event cycles

Tabulated event cycles imported into the simulation model.

Event name	Event type	Shift	TBD/TTD: Dist ID	TBD/TTD: Progress type	TBD/TTU: Prob > 0	TTU: Dist ID	TTU: Progress Type	Item Animation
101 andon	Distribution		TBD - 101 andon	Time	1	TTU - 101 andon	Time	
105 andon	Distribution		TBD - 105 andon	Time	1	TTU - 105 andon	Time	
115-120 andon	Distribution		TBD - 115-120 andon	Time	1	TTU - 115-120 andon	Time	
125 andon	Distribution		TBD - 125 andon	Time	1	TTU - 125 andon	Time	
130 andon	Distribution		TBD - 130 andon	Time	1	TTU - 130 andon	Time	
135 andon	Distribution		TBD - 135 andon	Time	1	TTU - 135 andon	Time	
145 andon	Distribution		TBD - 145 andon	Time	1	TTU - 145 andon	Time	
150 QG andon	Distribution		TBD - 150 QG andon	Time	1	TTU - 150 QG andon	Time	
Line 1 safety	Distribution		TBD - Line 1 safety	Time	1	TTU - Line 1 safety	Time	
305 andon	Distribution		TBD - 305 andon	Time	1	TTU - 305 andon	Time	
310 andon	Distribution		TBD - 310 andon	Time	1	TTU - 310 andon	Time	
315 andon	Distribution		TBD - 315 andon	Time	1	TTU - 315 andon	Time	
320 andon	Distribution		TBD - 320 andon	Time	1	TTU - 320 andon	Time	
325 andon	Distribution		TBD - 325 andon	Time	1	TTU - 325 andon	Time	
335 andon	Distribution		TBD - 335 andon	Time	1	TTU - 335 andon	Time	
340 andon	Distribution		TBD - 340 andon	Time	1	TTU - 340 andon	Time	
345 QG andon	Distribution		TBD - 345 QG andon	Time	1	TTU - 345 QG andon	Time	
Line 3 technical	Distribution		TBD - Line 3 technical	Time	1	TTU - Line 3 technical	Time	
Line 3 safety	Distribution		TBD - Line 3 safety	Time	1	TTU - Line 3 safety	Time	
405 andon	Distribution		TBD - 405 andon	Time	1	TTU - 405 andon	Time	
410 andon	Distribution		TBD - 410 andon	Time	1	TTU - 410 andon	Time	
415 andon	Distribution		TBD - 415 andon	Time	1	TTU - 415 andon	Time	
420 andon	Distribution		TBD - 420 andon	Time	1	TTU - 420 andon	Time	
430 andon	Distribution		TBD - 430 andon	Time	1	TTU - 430 andon	Time	
435 andon	Distribution		TBD - 435 andon	Time	1	TTU - 435 andon	Time	
440 andon	Distribution		TBD - 440 andon	Time	1	TTU - 440 andon	Time	
445 QG andon	Distribution		TBD - 445 QG andon	Time	1	TTU - 445 QG andon	Time	
450 andon	Distribution		TBD - 450 andon	Time	1	TTU - 450 andon	Time	
Line 4 safety	Distribution		TBD - Line 4 safety	Time	1	TTU - Line 4 safety	Time	
510 andon	Distribution		TBD - 510 andon	Time	1	TTU - 510 andon	Time	
520 andon	Distribution		TBD - 520 andon	Time	1	TTU - 520 andon	Time	
530 andon	Distribution		TBD - 530 andon	Time	1	TTU - 530 andon	Time	
535 andon	Distribution		TBD - 535 andon	Time	1	TTU - 535 andon	Time	
540 andon	Distribution		TBD - 540 andon	Time	1	TTU - 540 andon	Time	
545 QG andon	Distribution		TBD - 545 QG andon	Time	1	TTU - 545 QG andon	Time	
Line 5 safety	Distribution		TBD - Line 5 safety	Time	1	TTU - Line 5 safety	Time	
605 andon	Distribution		TBD - 605 andon	Time	1	TTU - 605 andon	Time	
615 andon	Distribution		TBD - 615 andon	Time	1	TTU - 615 andon	Time	
620 andon	Distribution		TBD - 620 andon	Time	1	TTU - 620 andon	Time	
625 andon	Distribution		TBD - 625 andon	Time	1	TTU - 625 andon	Time	
630 andon	Distribution		TBD - 630 andon	Time	1	TTU - 630 andon	Time	
635 andon	Distribution		TBD - 635 andon	Time	1	TTU - 635 andon	Time	
640 andon	Distribution		TBD - 640 andon	Time	1	TTU - 640 andon	Time	
645 QG andon	Distribution		TBD - 645 QG andon	Time	1	TTU - 645 QG andon	Time	
Line 6A safety	Distribution		TBD - Line 6A safety	Time	1	TTU - Line 6A safety	Time	
665 andon	Distribution		TBD - 665 andon	Time	1	TTU - 665 andon	Time	
Robot station 6C.1 andon	Distribution		TBD - Robot station 6C.1 andon	Time	1	TTU - Robot station 6C.1 andon	Time	
Robot station 6C.1 techical	Distribution		TBD - Robot station 6C.1 techical	Time	1	TTU - Robot station 6C.1 techical	Time	
Line 6C safety	Distribution		TBD - Line 6C safety	Time	1	TTU - Line 6C safety	Time	
715 andon	Distribution		TBD - 715 andon	Time	1	TTU - 715 andon	Time	
720 andon	Distribution		TBD - 720 andon	Time	1	TTU - 720 andon	Time	
725 andon	Distribution		TBD - 725 andon	Time	1	TTU - 725 andon	Time	
730 andon	Distribution		TBD - 730 andon	Time	1	TTU - 730 andon	Time	
740 andon	Distribution		TBD - 740 andon	Time	1	TTU - 740 andon	Time	
745 andon	Distribution		TBD - 745 andon	Time	1	TTU - 745 andon	Time	
750 QG andon	Distribution		TBD - 750 QG andon	Time	1	TTU - 750 QG andon	Time	
Line 7 safety	Distribution		TBD - Line 7 safety	Time	1	TTU - Line 7 safety	Time	
805 andon	Distribution		TBD - 805 andon	Time	1	TTU - 805 andon	Time	
810 andon	Distribution		TBD - 810 andon	Time	1	TTU - 810 andon	Time	
815 andon	Distribution		TBD - 815 andon	Time	1	TTU - 815 andon	Time	
820 andon	Distribution		TBD - 820 andon	Time	1	TTU - 820 andon	Time	
825 andon	Distribution		TBD - 825 andon	Time	1	TTU - 825 andon	Time	
835 andon	Distribution		TBD - 835 andon	Time	1	TTU - 835 andon	Time	
845 QG andon	Distribution		TBD - 845 QG andon	Time	1	TTU - 845 QG andon	Time	
Line 8 safety	Distribution		TBD - Line 8 safety	Time	1	TTU - Line 8 safety	Time	
905 andon	Distribution		TBD - 905 andon	Time	1	TTU - 905 andon	Time	
910 andon	Distribution		TBD - 910 andon	Time	1	TTU - 910 andon	Time	
920 andon	Distribution		TBD - 920 andon	Time	1	TTU - 920 andon	Time	
930 andon	Distribution		TBD - 930 andon	Time	1	TTU - 930 andon	Time	
Line 9 safety	Distribution		TBD - Line 9 safety	Time	1	TTU - Line 9 safety	Time	

E Stopwatch times

Compilation of all processes that was determined manually by a stopwatch.

Buffer system	Activity	Activity time (s)	Reset time (s)	Definition
0	Lower elevator line 1	45	-	Cab moves into elevator and is lowered to its bottom position.
1	Lift elevator line 1	45	15	Cab moves into elevator and is raised to top position.
1	Buffer transport 1.0	10	-	Cab moves out from elevator to the first buffer position
1	Buffer transport 1.1	11	-	Cab moves from one buffer position and stops at the next.
1	Buffer transport 1.2	10	-	Cab moves from one buffer position and stops at the next.
1	Buffer transport 1.3	25	-	Cab moves from one buffer position and stops at the next.
1	Buffer transport 1.4	16	-	Cab moves from one buffer position and stops at the next.
1	Buffer transport 1.5	60	-	Cab moves from one buffer position and stops at the next.
1	Buffer transport 1.6	35	-	Cab moves from one buffer position and stops at the next.
1	Tilt cab 1	160	-	Cab moves from one buffer position, is tilted and stops at the next.
1	Buffer transport 1.7	18	-	Cab moves from one buffer position and stops at the next.
1	Buffer transport 1.8	18	-	Cab moves from one buffer position and stops at the next.
1	Buffer transport 1.9	18	-	Cab moves from one buffer position and stops at the next.
1	Lower elevator line 3	31	120	Cab moves into elevator and is lowered to its bottom position.
3	Lift elevator line 3	36	15	Cab moves into elevator and is raised to top position.
3	Buffer transport 3.0	10	-	Cab moves out from elevator to the first buffer position
3	Buffer transport 3.1	30	-	Cab moves from one buffer position, is turned and stops at the next.
3	Tilt cab 2	110	-	Cab moves from one buffer position, is tilted and stops at the next.
3	Buffer transport 3.2	15	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.3	50	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.4	32	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.5	32	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.6	32	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.7	32	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.8	32	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.9	13	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.10	13	-	Cab moves from one buffer position and stops at the next.
3	Buffer transport 3.11	13	-	Cab moves from one buffer position and stops at the next.
3	Lower elevator line 4	39	45	Cab moves into elevator and is lowered to its bottom position.
4	Lift elevator line 4	70	17	Cab moves into elevator and is raised to top position.
4	Buffer transport 4.0	10	-	Cab moves out from elevator to the first buffer position
4	Buffer transport 4.1	21	-	Cab moves from one buffer position and stops at the next.
4	Buffer transport 4.2	21	-	Cab moves from one buffer position and stops at the next.
4	Lower elevator line 5	41	42	Cab moves into elevator and is lowered to its bottom position.
5	Lift elevator line 5	55	42	Cab moves into elevator and is raised to top position.
5	Buffer transport 5.0	10	-	Cab moves out from elevator to the first buffer position
5	Buffer transport 5.1	21	-	Cab moves from one buffer position and stops at the next.
5	Lower elevator line 6A	90	0	Cab moves into elevator and is lowered to its bottom position where it is turned.
6A	Lift elevator line 6A	70	35	Cab moves into elevator and is raised to top position.
6A	Buffer transport line 6A.0	10	-	Cab moves out from elevator to the first buffer position
6A	Buffer transport line 6A.1	30	-	Cab moves from one buffer position, is turned and stops at the next.
6A	Lower elevator line 6C	55	64	Cab moves into elevator and is lowered to its bottom position.
6C	Buffer transport line 6C.1	22	-	Cab moves from one buffer position and stops at the next.
6C	Buffer transport line 6C.2	88	-	Cab moves from one buffer position, the stand is altered and stops at the next.
6C	Buffer transport line 6C.3	18	-	Cab moves from one buffer position and stops at the next.
6C	Buffer transport line 6C.4	12	-	Cab moves from one buffer position and stops at the next.
6C	Buffer transport line 6C.5	28	-	Cab moves from one buffer position, is turned and stops at the next.
7	Lift elevator line 7	56	36	Cab moves into elevator and is raised to top position.
7	Buffer transport 7.0	10	-	Cab moves out from elevator to the first buffer position
7	Buffer transport 7.1	35	-	Cab moves from one buffer position, is turned and stops at the next.
7	Buffer transport 7.2	15	-	Cab moves from one buffer position and stops at the next.
7	Lower elevator line 8	47	45	Cab moves into elevator and is lowered to its bottom position.
8	Lift elevator line 8	66	27	Cab moves into elevator and is raised to top position.
8	Buffer transport 8.0	10	-	Cab moves out from elevator to the first buffer position
8	Buffer transport 8.1	37	-	Cab moves from one buffer position, is turned and stops at the next.

F Scenario manager dialog validation

Scenario name	(M) Cabs out	(M) Total wait in (h)	(M) Total wait out (h)	(M) Total andon, safety and technical (h)	(M) Total shutdown time (h)	(M) Wait out 1 (h)	(M) Andon, safety and technical 1	(M) Total 1 (h)
1	6993,8	122,51	39,81	157,74	320,06	6,98	21,47	28,45
2	7001,8	124,99	36,39	156,30	317,68	6,48	21,78	28,26
3	7002,3	122,86	37,86	156,17	316,89	6,75	21,40	28,15
4	7005,6	121,83	37,38	156,23	315,43	6,47	21,57	28,04
5	7000,9	122,61	37,74	157,38	317,72	6,60	21,62	28,22
6	7005,2	121,95	37,75	156,07	315,77	6,57	21,49	28,06
7	6998,5	121,73	39,18	156,85	317,76	6,75	21,62	28,37
8	7005,6	124,97	35,26	155,98	316,21	6,46	21,59	28,05
9	7004,7	120,35	37,89	156,77	315,01	6,51	21,53	28,04
10	7001,1	123,18	37,50	156,98	317,65	6,62	21,57	28,20
11	7004,0	122,02	37,37	156,73	316,11	6,48	21,61	28,09
12	6999,4	124,58	36,83	156,90	318,31	6,54	21,75	28,29
13	6997,5	122,93	38,47	157,14	318,53	6,92	21,43	28,36
14	7002,6	120,98	38,27	157,45	316,70	6,57	21,59	28,15
15	6996,7	123,82	37,91	157,76	319,49	6,88	21,48	28,36
16	7003,6	122,57	37,02	157,06	316,65	6,25	21,96	28,21
17	6999,2	123,68	37,69	157,04	318,41	6,72	21,58	28,30
18	7000,5	122,21	38,20	156,88	317,30	6,61	21,67	28,27
19	7005,2	121,84	37,48	156,74	316,06	6,67	21,40	28,07
20	7001,7	121,77	38,09	157,25	317,11	6,62	21,57	28,18
21	7000,2	121,24	38,51	157,80	317,55	6,65	21,60	28,26
22	7008,0	120,99	37,00	156,30	314,29	6,32	21,60	27,92
23	7007,5	121,06	36,81	156,75	314,62	6,48	21,49	27,97
24	7001,7	122,46	37,53	156,85	316,84	6,58	21,61	28,19
Mean	**7002,0**	**122,5**	**37,7**	**156,9**	**317,0**	**6,6**	**21,6**	**28,2**
Standard deviation	**3,48**	**1,25**	**0,91**	**0,53**	**1,44**	**0,17**	**0,12**	**0,14**
Standard deviation (%)	**0,05**	**1,02**	**2,43**	**0,34**	**0,45**	**2,62**	**0,57**	**0,49**

Scenario name	(M) Wait in 3 (h)	(M) Wait out 3 (h)	(M) Andon,safety and techical 3 (h)	(M) Total 3 (h)	(M) Wait in 4 (h)	(M) Wait out 4 (h)	(M) Andon, safety and technical 4 (h)	(M) Total 4 (h)	(M) Wait in 5 (h)
1	1,01	4,05	24,37	29,43	4,37	6,07	19,36	29,80	9,07
2	1,06	3,58	24,55	29,19	4,69	5,35	19,47	29,51	9,67
3	0,85	3,84	24,47	29,16	4,27	5,54	19,72	29,53	9,47
4	0,93	3,73	24,32	28,97	4,59	5,41	19,34	29,34	9,32
5	1,01	3,68	24,48	29,17	4,51	5,56	19,48	29,55	9,29
6	1,02	3,75	24,22	28,99	4,40	5,63	19,31	29,34	9,15
7	1,03	3,99	24,30	29,32	4,53	5,91	19,22	29,66	9,14
8	1,08	3,42	24,53	29,04	4,84	5,04	19,50	29,38	9,78
9	1,01	3,45	24,58	29,05	4,64	5,57	19,13	29,34	9,01
10	1,06	3,53	24,59	29,17	4,60	5,66	19,26	29,52	9,26
11	0,92	3,66	24,44	29,02	4,54	5,54	19,30	29,38	9,12
12	1,01	3,57	24,68	29,26	4,81	5,35	19,43	29,59	9,63
13	0,92	3,75	24,70	29,37	4,72	5,64	19,34	29,69	9,49
14	1,02	3,77	24,34	29,12	4,54	5,76	19,15	29,45	9,03
15	0,89	3,77	24,72	29,37	4,73	5,47	19,54	29,73	9,62
16	1,11	3,58	24,42	29,11	4,58	5,58	19,26	29,42	9,28
17	1,03	3,77	24,45	29,25	4,46	5,69	19,48	29,63	9,44
18	1,10	3,79	24,31	29,20	4,50	5,72	19,32	29,54	9,26
19	0,90	3,85	24,24	28,99	4,22	5,52	19,61	29,35	9,15
20	0,98	3,61	24,55	29,14	4,56	5,65	19,29	29,50	9,08
21	0,98	3,90	24,32	29,20	4,41	5,71	19,46	29,57	9,12
22	1,03	3,54	24,25	28,83	4,44	5,29	19,46	29,19	9,37
23	1,02	3,55	24,34	28,91	4,50	5,24	19,53	29,27	9,40
24	1,03	3,62	24,51	29,16	4,48	5,49	19,53	29,51	9,37
Mean	**1,0**	**3,7**	**24,4**	**29,1**	**4,5**	**5,6**	**19,4**	**29,5**	**9,3**
Standard deviation	**0,07**	**0,16**	**0,15**	**0,15**	**0,15**	**0,22**	**0,15**	**0,15**	**0,22**
Standard deviation (%)	**6,78**	**4,33**	**0,60**	**0,52**	**3,36**	**3,92**	**0,75**	**0,52**	**2,32**

Scenario name	(M) Wait out 5 (h)	(M) Andon, safety and technical 5 (h)	(M) Total 5 (h)	(M) Wait in 6A (h)	(M) Wait out 6A (h)	(M) Andon, safety and technical 6A (h)	(M) Total 6A (h)	(M) Wait in 6C (h)	(M) Wait out 6C (h)
1	6,37	13,74	29,18	13,07	11,10	4,83	29,00	40,26	0,98
2	5,67	13,62	28,96	13,60	10,26	4,90	28,75	41,78	0,96
3	5,90	13,56	28,94	13,28	10,53	4,90	28,71	41,24	1,03
4	5,89	13,52	28,73	13,06	10,49	4,97	28,52	40,83	1,05
5	5,91	13,74	28,94	13,11	10,73	4,89	28,74	40,57	1,03
6	5,88	13,72	28,76	13,11	10,66	4,78	28,54	40,93	1,04
7	6,11	13,78	29,04	13,14	10,84	4,84	28,82	40,06	1,13
8	5,39	13,65	28,83	13,70	10,02	4,89	28,60	41,80	0,90
9	6,03	13,68	28,72	12,87	10,67	4,98	28,52	39,88	1,18
10	5,89	13,78	28,94	13,27	10,68	4,80	28,75	40,94	0,98
11	5,89	13,78	28,80	13,08	10,55	4,96	28,58	40,85	1,04
12	5,76	13,62	29,01	13,51	10,44	4,87	28,81	41,15	1,00
13	6,03	13,56	29,08	13,09	10,87	4,89	28,85	40,14	1,09
14	6,04	13,76	28,83	12,88	10,79	4,96	28,63	39,95	1,05
15	5,97	13,54	29,14	13,26	10,74	4,93	28,93	40,54	0,95
16	5,92	13,64	28,84	13,13	10,55	4,97	28,65	40,70	0,99
17	5,85	13,77	29,06	13,35	10,44	5,04	28,83	41,45	0,94
18	5,95	13,75	28,96	13,20	10,67	4,87	28,74	40,62	1,08
19	5,89	13,73	28,77	13,16	10,51	4,89	28,56	40,78	0,95
20	6,06	13,73	28,87	12,95	10,83	4,90	28,68	40,57	1,06
21	6,08	13,74	28,95	12,89	10,92	4,91	28,73	39,85	1,02
22	5,79	13,45	28,61	12,93	10,58	4,88	28,39	40,57	1,08
23	5,70	13,57	28,67	13,05	10,48	4,92	28,46	40,16	1,05
24	5,86	13,67	28,90	13,31	10,50	4,89	28,70	40,91	1,06
Mean	**5,9**	**13,7**	**28,9**	**13,2**	**10,6**	**4,9**	**28,7**	**40,7**	**1,0**
Standard deviation	**0,18**	**0,10**	**0,15**	**0,22**	**0,23**	**0,06**	**0,15**	**0,55**	**0,06**
Standard deviation (%)	**3,10**	**0,70**	**0,51**	**1,64**	**2,15**	**1,23**	**0,52**	**1,35**	**6,16**

Scenario name	(M) Andon, safety and technical 6C (h)	(M) Total 6C (h)	(M) Wait in 7 (h)	(M) Wait out 7 (h)	(M) Andon, safety and technical 7 (h)	(M) Total 7 (h)	(M) Wait in 8 (h)	(M) Wait out 8 (h)	(M) Andon, safety and technical 8 (h)
1	43,29	84,53	23,48	2,96	2,46	28,91	13,71	1,29	15,22
2	41,58	84,32	23,34	2,83	2,47	28,64	13,57	1,26	15,04
3	41,63	83,90	23,08	2,99	2,47	28,53	13,45	1,29	15,10
4	41,90	83,78	22,86	3,02	2,50	28,38	13,25	1,31	15,11
5	42,71	84,31	23,20	2,95	2,52	28,68	13,59	1,27	15,04
6	41,97	83,94	22,89	2,99	2,52	28,40	13,31	1,23	15,17
7	42,38	83,57	22,94	3,17	2,54	28,65	13,48	1,29	15,24
8	41,46	84,17	23,08	2,82	2,55	28,45	13,56	1,20	14,93
9	42,21	83,27	22,65	3,13	2,55	28,33	13,21	1,35	15,14
10	42,40	84,33	23,25	2,88	2,52	28,65	13,53	1,25	15,11
11	42,09	83,98	22,99	2,98	2,48	28,45	13,33	1,25	15,18
12	42,19	84,34	23,36	2,88	2,51	28,75	13,68	1,29	15,01
13	42,74	83,96	23,32	2,96	2,49	28,77	13,71	1,21	15,15
14	43,04	84,04	23,04	2,98	2,51	28,52	13,38	1,30	15,15
15	43,04	84,54	23,55	2,86	2,49	28,90	13,71	1,26	15,13
16	42,32	84,00	23,09	2,89	2,56	28,53	13,48	1,26	15,05
17	41,99	84,39	23,33	2,90	2,48	28,71	13,45	1,37	15,13
18	42,20	83,90	22,98	3,07	2,50	28,55	13,30	1,32	15,29
19	42,43	84,16	23,05	2,85	2,54	28,44	13,45	1,24	15,02
20	42,47	84,10	23,01	3,01	2,57	28,59	13,33	1,25	15,29
21	43,15	84,01	23,15	2,96	2,52	28,64	13,53	1,26	15,15
22	42,00	83,66	22,66	3,08	2,52	28,26	13,11	1,32	15,13
23	42,36	83,57	22,74	3,03	2,51	28,28	13,19	1,30	15,11
24	41,87	83,84	22,94	3,04	2,53	28,51	13,33	1,38	15,14
Mean	**42,3**	**84,0**	**23,1**	**3,0**	**2,5**	**28,6**	**13,4**	**1,3**	**15,1**
Standard deviation	**0,49**	**0,32**	**0,24**	**0,09**	**0,03**	**0,18**	**0,17**	**0,05**	**0,09**
Standard deviation (%)	**1,17**	**0,38**	**1,04**	**3,09**	**1,20**	**0,62**	**1,29**	**3,56**	**0,56**

Scenario name	(M) Total 8 (h)	(M) Wait in 9 (h)	(M) Andon, safety and technical 9 (h)	(M) Total 9 (h)	(M) TBI exit line 9 (min)	(M) Buffer level 1	(M) Buffer level 3	(M) Buffer level 4
1	30,22	17,55	13,00	30,54	2,85	8,46	7,10	1,46
2	29,87	17,27	12,91	30,18	3,05	8,37	6,96	1,41
3	29,83	17,22	12,93	30,15	2,91	8,53	7,10	1,41
4	29,68	17,00	13,00	30,00	3,04	8,47	7,03	1,44
5	29,91	17,32	12,90	30,21	2,93	8,37	7,03	1,42
6	29,72	17,13	12,89	30,01	2,95	8,46	7,06	1,43
7	30,01	17,40	12,92	30,33	2,92	8,43	7,08	1,44
8	29,69	17,12	12,88	29,99	3,41	8,41	6,80	1,38
9	29,71	17,09	12,95	30,04	3,05	8,44	6,96	1,45
10	29,89	17,26	12,95	30,20	3,12	8,45	6,93	1,44
11	29,75	17,19	12,88	30,07	3,09	8,49	7,05	1,43
12	29,98	17,44	12,84	30,28	2,96	8,43	6,91	1,40
13	30,07	17,54	12,83	30,37	3,02	8,53	6,98	1,42
14	29,82	17,15	12,98	30,14	2,97	8,43	6,98	1,45
15	30,11	17,52	12,89	30,41	3,02	8,56	6,96	1,41
16	29,79	17,19	12,90	30,09	3,54	8,27	6,97	1,43
17	29,96	17,18	13,12	30,30	3,00	8,37	7,05	1,42
18	29,91	17,26	12,97	30,23	2,91	8,35	7,03	1,45
19	29,71	17,13	12,88	30,01	3,31	8,49	7,09	1,43
20	29,87	17,28	12,89	30,18	2,86	8,48	6,97	1,44
21	29,94	17,30	12,94	30,25	3,09	8,51	7,10	1,44
22	29,56	16,88	13,00	29,88	3,04	8,39	6,95	1,40
23	29,60	16,98	12,92	29,91	2,92	8,38	7,04	1,43
24	29,85	17,08	13,10	30,18	2,96	8,43	6,97	1,42
Mean	**29,9**	**17,2**	**12,9**	**30,2**	**3,0**	**8,4**	**7,0**	**1,4**
Standard deviation	**0,16**	**0,17**	**0,07**	**0,16**	**0,17**	**0,07**	**0,07**	**0,02**
Standard deviation (%)	**0,54**	**1,01**	**0,54**	**0,53**	**5,53**	**0,80**	**1,04**	**1,28**

Scenario name	(M) Buffer level 5	(M) Buffer level 6A	(M) Buffer level 6C	(M) Buffer level 7	(M) Buffer level 8	(M) Throughput time (min)
1	0,91	0,79	3,14	1,45	0,80	382,05
2	0,89	0,78	3,09	1,42	0,80	379,77
3	0,90	0,78	3,14	1,45	0,80	381,44
4	0,90	0,79	3,14	1,45	0,81	380,90
5	0,90	0,79	3,11	1,44	0,80	380,50
6	0,90	0,79	3,14	1,45	0,80	381,07
7	0,90	0,79	3,18	1,46	0,80	381,75
8	0,88	0,78	3,10	1,43	0,81	378,99
9	0,91	0,80	3,20	1,46	0,81	381,10
10	0,91	0,79	3,10	1,44	0,80	380,57
11	0,91	0,79	3,14	1,45	0,80	381,14
12	0,89	0,79	3,10	1,42	0,79	379,92
13	0,91	0,79	3,15	1,45	0,79	381,38
14	0,91	0,79	3,14	1,44	0,80	381,00
15	0,91	0,79	3,12	1,42	0,80	381,06
16	0,90	0,79	3,15	1,43	0,80	379,97
17	0,90	0,78	3,10	1,44	0,81	380,66
18	0,91	0,79	3,16	1,46	0,80	381,08
19	0,90	0,79	3,11	1,44	0,80	381,03
20	0,91	0,79	3,13	1,45	0,80	381,12
21	0,91	0,79	3,17	1,45	0,80	381,83
22	0,91	0,79	3,16	1,45	0,81	380,17
23	0,91	0,79	3,18	1,46	0,80	380,70
24	0,90	0,79	3,15	1,45	0,80	380,77
Mean	**0,9**	**0,8**	**3,1**	**1,4**	**0,8**	**380,8**
Standard deviation	**0,01**	**0,00**	**0,03**	**0,01**	**0,00**	**0,70**
Standard deviation (%)	**0,74**	**0,56**	**0,91**	**0,86**	**0,48**	**0,18**

G Scenario manager dialog amount of buffers

Complete result from the scenario manager. The colour coding for cabs out are green for high values and red for low, the rest have green for low values and red for high. The buffer levels have no colour coding since the value has no direct correlation to be bad or good.

Scenario name	BS1	BS3	BS4	BS5	BS6A	BS6C	BS7	BS8	(M) Cabs out (h)	(M) Total wait in (h)	(M) Total wait out (h)	(M) Total andon, safety and technical (h)	(M) Total shutdown time (h)
1	11	13	3	2	2	5	3	2	7001,7	122,5	37,5	156,8	311,3
2	12	13	3	2	2	5	3	2	7003,3	122,2	36,9	157,2	310,9
3	13	13	3	2	2	5	3	2	7000,3	121,8	38,1	157,8	312,1
4	14	13	3	2	2	5	3	2	7007,4	121,1	36,6	157,0	309,4
5	10	13	3	2	2	5	3	2	7002,4	122,2	37,6	156,7	310,9
6	9	13	3	2	2	5	3	2	6993,1	125,1	38,4	157,2	315,3
7	8	13	3	2	2	5	3	2	6993,6	125,3	38,8	157,0	315,6
8	11	14	3	2	2	5	3	2	7005,6	121,8	36,7	157,4	310,4
9	11	15	3	2	2	5	3	2	7007,1	120,5	37,0	157,5	309,2
10	11	16	3	2	2	5	3	2	7010,4	119,9	36,7	156,5	307,4
11	11	12	3	2	2	5	3	2	6993,9	124,1	39,0	157,0	314,4
12	11	11	3	2	2	5	3	2	6998,8	124,1	38,2	156,1	312,8
13	11	10	3	2	2	5	3	2	6987,0	129,5	38,0	156,3	318,4
14	11	13	4	2	2	5	3	2	7003,5	124,5	36,5	155,9	311,9
15	11	13	5	2	2	5	3	2	7013,1	119,9	35,8	155,8	307,1
16	11	13	6	2	2	5	3	2	7010,2	118,9	36,8	156,8	308,1
17	11	13	2	2	2	5	3	2	6990,6	125,9	38,1	157,9	316,0
18	11	13	1	2	2	5	3	2	6986,3	130,0	38,7	155,4	317,5
19	11	13	3	3	2	5	3	2	7004,3	124,4	35,5	156,5	311,4
20	11	13	3	4	2	5	3	2	7007,6	120,7	35,5	157,7	309,2
21	11	13	3	5	2	5	3	2	7016,4	119,4	33,8	156,9	305,7
22	11	13	3	1	2	5	3	2	6997,2	126,3	38,2	155,2	313,7
23	11	13	3	2	3	5	3	2	7012,9	120,8	33,7	156,6	306,2
24	11	13	3	2	4	5	3	2	7018,5	119,2	30,3	157,2	302,5
25	11	13	3	2	5	5	3	2	7023,6	117,2	28,2	158,4	300,0
26	11	13	3	2	1	5	3	2	6980,9	123,5	44,9	157,2	318,7
27	11	13	3	2	2	6	3	2	7002,6	125,0	36,3	156,5	312,5
28	11	13	3	2	2	7	3	2	7003,1	124,7	36,4	156,7	312,5
29	11	13	3	2	2	8	3	2	6976,5	107,6	46,4	158,7	305,3
30	11	13	3	2	2	4	3	2	6998,6	123,0	37,9	156,1	311,2
31	11	13	3	2	2	3	3	2	6990,1	112,5	42,4	158,0	306,3
32	11	13	3	2	2	5	4	2	7004,3	125,2	35,7	156,7	312,2
33	11	13	3	2	2	5	5	2	7003,6	126,5	35,7	156,5	313,2
34	11	13	3	2	2	5	6	2	7007,5	129,2	33,3	155,1	312,5
35	11	13	3	2	2	5	2	2	6995,6	119,7	40,6	157,7	312,1
36	11	13	3	2	2	5	1	2	6989,7	121,2	41,2	157,2	313,7
37	11	13	3	2	2	5	3	3	7007,6	122,5	36,3	156,3	309,7
38	11	13	3	2	2	5	3	4	7005,5	127,5	33,8	155,7	311,9
39	11	13	3	2	2	5	3	5	6997,2	126,4	36,4	157,2	314,4
40	11	13	3	2	2	5	3	1	6999,4	121,2	39,2	156,3	311,0
41	12	14	4	3	3	6	4	3	7029,1	122,5	28,1	156,8	303,7
42	13	15	5	4	4	7	5	4	7043,4	123,9	22,0	156,6	300,2
43	14	16	6	5	5	8	6	5	7028,4	102,1	29,6	159,0	287,1
44	10	12	2	1	1	4	2	1	6954,8	128,8	50,2	155,7	326,4
45	9	11	1	1	1	3	1	1	6927,3	129,6	56,8	156,5	333,3
46	8	10	1	1	1	3	1	1	6926,7	129,9	57,2	156,0	333,7
47	12	14	3	1	1	6	2	1	6977,5	123,5	47,6	155,1	318,7
48	13	15	3	1	1	7	2	1	6979,5	120,5	48,5	157,1	318,2

Scenario name	(M) Wait out 1 (h)	(M) Andon, safety and technical 1 (h)	(M) Total 1 (h)	(M) Wait in 3 (h)	(M) Wait out 3 (h)	(M) Andon,safety and techical 3 (h)	(M) Total 3 (h)	(M) Wait in 4 (h)
1	6,6	21,6	28,2	1,0	3,6	24,5	29,2	4,5
2	6,4	21,6	28,1	0,9	3,5	24,7	29,0	4,6
3	6,5	21,8	28,2	0,8	3,8	24,7	29,2	4,4
4	6,2	21,7	27,9	0,7	3,5	24,7	28,9	4,6
5	6,5	21,6	28,1	1,2	3,6	24,3	29,1	4,5
6	7,1	21,7	28,9	1,4	3,5	24,8	29,6	5,1
7	7,6	21,4	29,0	1,5	3,6	24,5	29,6	4,9
8	6,4	21,7	28,0	1,1	3,2	24,7	29,0	4,6
9	6,2	21,9	28,0	1,2	3,1	24,7	29,0	4,5
10	6,0	21,8	27,8	1,2	3,1	24,4	28,8	3,9
11	7,0	21,5	28,5	0,9	3,8	24,8	29,5	5,0
12	7,1	21,3	28,3	0,8	3,9	24,5	29,3	5,0
13	7,3	21,5	28,9	0,8	4,3	24,7	29,8	5,2
14	6,4	21,7	28,2	1,1	3,5	24,5	29,1	5,1
15	6,2	21,4	27,6	1,1	3,0	24,5	28,7	5,1
16	6,2	21,6	27,8	1,1	3,1	24,5	28,7	5,3
17	6,9	21,9	28,7	1,0	3,9	24,8	29,7	4,6
18	7,3	21,5	28,8	0,9	4,4	24,5	29,8	4,1
19	6,6	21,5	28,0	1,0	3,2	24,9	29,1	5,0
20	6,2	21,8	28,0	1,1	3,1	24,7	28,9	5,0
21	5,8	21,7	27,5	1,2	2,9	24,3	28,4	4,8
22	6,6	21,8	28,4	1,1	4,2	24,0	29,3	4,4
23	6,2	21,6	27,8	1,1	3,4	24,2	28,7	4,7
24	5,9	21,6	27,6	1,2	2,7	24,7	28,5	5,3
25	5,6	21,8	27,4	1,2	2,5	24,6	28,3	5,6
26	7,6	21,4	29,0	0,9	4,8	24,3	30,0	3,9
27	6,5	21,7	28,2	1,1	3,4	24,7	29,1	4,9
28	6,5	21,6	28,1	1,0	3,5	24,5	29,1	4,6
29	7,5	21,6	29,1	0,9	4,7	24,5	30,1	3,9
30	6,8	21,6	28,3	0,9	3,8	24,6	29,3	4,6
31	7,0	21,6	28,7	0,9	4,3	24,4	29,6	4,1
32	6,5	21,6	28,1	1,0	3,6	24,4	29,0	4,5
33	6,6	21,5	28,1	1,0	3,5	24,6	29,1	4,9
34	6,3	21,7	28,0	1,1	3,6	24,3	28,9	4,7
35	6,8	21,5	28,3	0,9	4,0	24,4	29,3	4,4
36	7,2	21,5	28,7	1,0	3,9	24,8	29,7	4,7
37	6,3	21,6	27,9	1,0	3,7	24,2	28,9	4,4
38	6,4	21,6	28,0	1,0	3,3	24,7	29,0	4,9
39	6,8	21,6	28,4	1,0	4,0	24,3	29,3	4,4
40	6,7	21,5	28,2	1,1	3,7	24,4	29,2	4,6
41	5,3	21,8	27,0	1,1	2,4	24,4	28,0	5,3
42	4,7	21,7	26,4	1,2	1,6	24,6	27,3	6,1
43	5,4	21,5	26,9	0,8	2,4	24,6	27,9	5,2
44	8,5	21,6	30,1	1,0	6,0	24,2	31,1	3,8
45	10,3	21,4	31,7	1,0	7,0	24,4	32,4	3,7
46	10,7	21,2	31,9	1,0	7,1	24,3	32,4	4,0
47	7,8	21,2	29,0	0,7	4,9	24,5	30,1	3,5
48	7,6	21,4	29,0	0,8	4,9	24,3	30,0	3,3

Scenario name	(M) Wait out4 (h)	(M) Andon, safety and technical 4 (h)	(M) Total 4 (h)	(M) Wait in 5 (h)	(M) Wait out 5 (h)	(M) Andon, safety and technical 5 (h)	(M) Total 5 (h)	(M) Wait in 6A (h)
1	5,5	19,5	24,0	9,4	5,9	13,7	28,9	13,3
2	5,4	19,4	24,0	9,4	5,8	13,7	28,8	13,2
3	5,7	19,4	23,9	9,3	6,2	13,5	28,9	12,9
4	5,4	19,3	23,9	9,2	5,8	13,6	28,7	13,2
5	5,6	19,3	23,8	9,2	5,9	13,7	28,9	13,1
6	5,5	19,3	24,4	9,6	6,1	13,6	29,3	13,4
7	5,4	19,5	24,5	9,7	6,0	13,6	29,2	13,4
8	5,5	19,3	23,9	9,2	5,9	13,6	28,7	13,0
9	5,7	19,2	23,6	9,0	6,0	13,7	28,6	12,9
10	5,7	19,5	23,4	8,9	5,8	13,8	28,5	12,8
11	5,7	19,2	24,2	9,5	6,1	13,6	29,3	13,3
12	5,6	19,1	24,1	9,5	5,9	13,7	29,1	13,4
13	5,4	19,6	24,8	10,1	5,6	13,9	29,7	14,3
14	5,0	19,3	24,5	9,3	6,0	13,6	28,8	13,2
15	4,5	19,4	24,5	8,7	6,1	13,6	28,4	12,7
16	4,3	19,4	24,8	8,3	6,4	13,6	28,4	12,3
17	6,0	19,4	24,0	10,1	5,7	13,6	29,4	13,7
18	6,7	19,4	23,5	10,7	5,4	13,6	29,7	14,6
19	5,0	19,5	24,4	10,1	5,1	13,7	28,9	13,3
20	4,7	19,5	24,5	10,3	4,8	13,6	28,7	12,5
21	4,5	19,5	24,3	10,2	4,3	13,8	28,4	12,2
22	6,0	19,4	23,8	8,9	6,4	13,7	29,1	14,0
23	4,8	19,5	24,2	9,9	4,8	13,8	28,6	14,7
24	4,2	19,3	24,6	10,6	4,1	13,7	28,4	15,8
25	3,8	19,2	24,7	11,0	3,8	13,5	28,2	16,2
26	6,8	19,7	23,6	8,4	7,6	13,6	29,6	11,4
27	5,2	19,3	24,2	9,7	5,7	13,4	28,9	13,4
28	5,3	19,5	24,1	9,6	5,6	13,7	28,9	13,6
29	7,4	19,4	23,2	8,1	8,1	13,6	29,7	11,2
30	5,7	19,4	24,0	9,4	6,0	13,7	29,1	13,4
31	6,5	19,3	23,5	8,5	7,0	13,7	29,3	12,1
32	5,4	19,4	24,0	9,5	5,7	13,7	28,8	13,5
33	5,4	19,1	24,1	9,4	5,8	13,7	28,9	13,4
34	5,1	19,5	24,2	9,9	5,2	13,7	28,8	14,1
35	5,9	19,4	23,8	9,0	6,4	13,7	29,1	12,7
36	5,8	19,6	24,3	9,6	6,2	13,7	29,5	13,3
37	5,4	19,4	23,8	9,3	5,8	13,5	28,7	13,1
38	5,1	19,3	24,2	9,7	5,3	13,8	28,8	14,0
39	5,6	19,7	24,1	9,5	5,9	13,7	29,1	13,5
40	5,7	19,3	23,9	9,3	5,9	13,8	29,0	13,3
41	3,7	19,3	24,6	10,2	3,9	13,8	27,9	14,4
42	2,4	19,1	25,2	10,9	2,8	13,6	27,4	15,2
43	3,7	19,3	24,5	9,3	4,8	13,6	27,7	12,1
44	8,2	19,6	23,4	8,7	8,3	13,7	30,7	12,8
45	9,6	19,5	23,3	9,5	8,9	13,6	32,0	13,0
46	9,4	19,5	23,6	9,8	8,7	13,5	32,0	13,2
47	7,5	19,6	23,0	7,9	8,3	13,5	29,7	12,1
48	7,8	19,4	22,7	7,3	8,6	13,6	29,5	11,4

Scenario name	(M) Wait out 6A (h)	(M) Andon, safety and technical 6A (h)	(M) Total 6A (h)	(M) Wait in 6C (h)	(M) Wait out 6C (h)	(M) Andon, safety and technical 6C (h)	(M) Total 6C (h)
1	10,5	4,9	28,7	40,9	1,1	41,9	83,8
2	10,5	5,0	28,6	40,6	1,0	42,3	83,9
3	10,9	5,0	28,8	40,2	1,0	43,0	84,2
4	10,5	4,8	28,5	40,4	1,0	42,2	83,6
5	10,6	5,0	28,7	40,4	1,1	42,3	83,7
6	10,7	5,0	29,1	41,0	1,1	42,0	84,1
7	10,8	4,9	29,1	41,0	1,1	42,3	84,4
8	10,7	4,9	28,5	40,2	1,0	43,0	84,1
9	10,6	4,9	28,5	40,1	1,1	42,5	83,8
10	10,5	4,9	28,3	40,7	1,1	41,6	83,3
11	10,9	4,9	29,1	40,6	1,1	42,4	84,1
12	10,5	5,0	28,9	41,0	1,0	42,1	84,1
13	10,2	5,0	29,5	42,8	0,9	41,3	85,0
14	10,6	4,9	28,7	41,5	1,0	41,7	84,2
15	10,4	5,0	28,2	40,4	1,1	41,3	82,8
16	11,1	4,9	28,2	39,6	1,1	42,2	83,0
17	10,5	5,0	29,2	41,0	1,0	42,7	84,7
18	10,0	5,0	29,5	43,5	0,9	40,8	85,2
19	10,4	4,9	28,6	41,6	1,0	41,5	84,1
20	11,0	4,9	28,3	39,4	1,2	42,5	83,0
21	10,8	5,0	28,0	39,8	1,1	41,8	82,7
22	10,2	4,8	29,0	42,8	0,9	41,1	84,7
23	8,8	5,0	28,4	38,7	1,3	41,6	81,6
24	7,6	4,9	28,2	35,2	1,3	42,5	79,0
25	6,9	5,0	28,1	32,7	1,3	43,9	77,8
26	13,0	5,0	29,4	42,0	0,9	42,6	85,5
27	10,4	4,9	28,7	42,2	0,8	42,0	84,9
28	10,2	4,9	28,7	42,6	0,7	42,0	85,4
29	13,4	4,8	29,5	25,0	1,7	44,5	71,1
30	10,5	5,0	28,9	39,8	1,2	41,4	82,5
31	12,0	5,0	29,1	31,0	1,6	43,3	75,9
32	10,2	5,0	28,6	42,3	0,7	42,1	85,1
33	10,4	4,9	28,7	42,5	0,7	42,2	85,4
34	9,6	4,9	28,6	44,4	0,5	40,6	85,6
35	11,4	4,8	28,9	38,9	1,3	43,3	83,4
36	11,0	4,9	29,2	39,2	1,5	41,9	82,6
37	10,4	5,0	28,5	41,0	0,9	42,0	83,9
38	9,8	4,9	28,6	43,4	0,8	40,5	84,8
39	10,5	4,9	28,9	41,6	0,8	42,5	84,9
40	10,5	4,9	28,8	40,6	1,3	41,5	83,4
41	8,4	4,9	27,6	40,8	0,8	41,9	83,5
42	7,0	4,9	27,1	41,2	0,6	41,7	83,6
43	10,2	5,1	27,4	21,8	1,1	44,1	67,0
44	13,1	4,8	30,6	42,6	1,2	41,7	85,5
45	13,9	4,9	31,8	39,4	1,8	42,3	83,5
46	13,8	4,9	31,8	39,0	1,9	42,4	83,4
47	12,8	4,8	29,6	43,5	0,9	41,5	85,8
48	13,2	4,9	29,5	42,3	0,8	43,2	86,3

Scenario name	(M) Wait in 7 (h)	(M) Wait out 7 (h)	(M) Andon, safety and technical 7 (h)	(M) Total 7 (h)	(M) Wait in 8 (h)	(M) Wait out 8 (h)	(M) Andon, safety and technical 8 (h)	(M) Total 8 (h)
1	22,9	3,0	2,5	28,5	13,3	1,4	15,1	29,8
2	23,0	3,0	2,5	28,5	13,4	1,3	15,1	29,8
3	23,4	2,8	2,5	28,7	13,7	1,3	15,0	29,9
4	22,8	3,0	2,5	28,3	13,1	1,3	15,2	29,6
5	23,1	3,0	2,5	28,5	13,4	1,3	15,1	29,8
6	23,4	3,1	2,5	29,0	13,7	1,4	15,2	30,3
7	23,4	3,0	2,5	29,0	13,8	1,3	15,2	30,2
8	23,1	2,9	2,4	28,4	13,4	1,2	15,0	29,7
9	22,6	3,1	2,5	28,2	13,0	1,2	15,3	29,6
10	22,5	3,1	2,5	28,1	13,1	1,4	15,0	29,4
11	23,4	3,0	2,5	28,9	13,8	1,3	15,1	30,2
12	23,2	3,0	2,5	28,7	13,7	1,2	15,1	30,0
13	24,0	2,9	2,5	29,3	14,2	1,2	15,1	30,6
14	23,3	2,8	2,5	28,6	13,8	1,2	14,8	29,8
15	22,3	3,1	2,5	27,9	12,8	1,3	15,2	29,3
16	22,5	3,2	2,4	28,1	13,0	1,4	15,1	29,4
17	23,7	2,9	2,5	29,1	13,9	1,2	15,2	30,4
18	24,0	2,8	2,5	29,4	14,1	1,2	15,3	30,6
19	23,0	3,0	2,5	28,4	13,3	1,3	15,1	29,7
20	22,5	3,2	2,5	28,2	13,1	1,3	15,2	29,6
21	22,0	3,1	2,5	27,7	12,6	1,3	15,3	29,2
22	23,7	2,7	2,4	28,9	13,8	1,2	15,0	30,1
23	22,3	3,2	2,5	28,0	12,8	1,3	15,3	29,3
24	22,0	3,1	2,6	27,7	12,7	1,3	15,0	29,1
25	21,9	3,1	2,5	27,4	12,4	1,3	15,1	28,8
26	24,2	3,0	2,5	29,7	14,4	1,3	15,1	30,8
27	23,0	3,0	2,5	28,5	13,4	1,2	15,3	29,8
28	22,7	3,2	2,5	28,4	13,4	1,3	15,1	29,8
29	25,1	2,5	2,5	30,1	14,9	1,1	15,0	31,0
30	23,5	2,7	2,6	28,8	13,9	1,2	15,0	30,0
31	24,0	2,8	2,4	29,3	14,0	1,2	15,2	30,4
32	24,0	2,3	2,5	28,8	13,4	1,3	15,1	29,7
33	24,6	1,9	2,5	29,0	13,5	1,2	15,1	29,8
34	24,8	1,6	2,5	28,9	13,3	1,3	15,0	29,6
35	22,5	3,6	2,4	28,6	13,7	1,2	15,3	30,2
36	21,6	4,4	2,5	28,5	14,0	1,2	15,3	30,4
37	23,0	2,8	2,6	28,4	13,6	0,9	15,1	29,7
38	23,6	2,5	2,5	28,6	14,0	0,7	15,2	29,8
39	24,1	2,4	2,5	29,0	14,6	0,4	15,2	30,2
40	22,4	3,5	2,5	28,5	12,7	1,8	15,4	29,9
41	22,3	2,6	2,5	27,4	12,3	1,0	15,4	28,7
42	22,2	2,2	2,5	26,9	12,0	0,8	15,2	28,0
43	24,1	1,4	2,5	28,0	13,0	0,5	15,3	28,8
44	24,9	3,3	2,5	30,7	15,5	1,6	14,9	32,0
45	25,4	3,9	2,5	31,8	16,8	1,6	14,9	33,3
46	25,3	4,0	2,5	31,8	16,8	1,6	14,9	33,3
47	23,2	3,7	2,5	29,4	14,2	1,7	15,0	30,9
48	22,9	3,8	2,5	29,2	14,1	1,8	14,9	30,8

Scenario name	(M) Wait in 9 (h)	(M) Andon, safety and technical 9 (h)	(M) Total 9 (h)	(M) TBI exit line 9 (min)	(M) Buffer level 1	(M) Buffer level 3	(M) Buffer level 4	(M) Buffer level 5	(M) Buffer level 6A
1	17,1	13,1	30,2	3,0	8,4	7,0	1,4	0,9	0,8
2	17,1	13,0	30,1	3,2	9,2	6,9	1,4	0,9	0,8
3	17,2	13,0	30,2	3,2	10,1	7,0	1,4	0,9	0,8
4	17,0	12,9	29,9	3,2	10,8	7,0	1,4	0,9	0,8
5	17,3	12,8	30,1	3,1	7,6	7,0	1,4	0,9	0,8
6	17,5	13,1	30,6	3,0	6,8	6,8	1,4	0,9	0,8
7	17,6	13,0	30,6	2,9	6,1	6,9	1,4	0,9	0,8
8	17,2	12,8	30,0	2,9	8,4	7,4	1,4	0,9	0,8
9	17,1	12,8	29,9	2,9	8,3	7,8	1,4	0,9	0,8
10	16,8	13,0	29,8	3,2	8,2	8,4	1,5	0,9	0,8
11	17,6	12,9	30,5	3,0	8,5	6,4	1,4	0,9	0,8
12	17,5	12,8	30,3	3,0	8,6	6,0	1,4	0,9	0,8
13	18,1	12,8	30,9	3,1	8,6	5,6	1,4	0,9	0,8
14	17,3	12,8	30,1	2,9	8,3	6,8	1,9	0,9	0,8
15	16,7	13,0	29,6	2,9	8,4	6,6	2,3	0,9	0,8
16	16,7	13,1	29,8	3,1	8,3	6,5	2,8	0,9	0,8
17	17,8	12,9	30,7	3,1	8,4	7,1	1,0	0,9	0,8
18	18,1	12,8	30,9	3,0	8,6	7,3	0,5	0,9	0,8
19	17,1	13,0	30,1	3,0	8,5	6,7	1,4	1,3	0,8
20	16,9	13,0	29,9	3,1	8,4	6,7	1,3	1,7	0,8
21	16,6	12,9	29,5	3,0	8,2	6,8	1,3	2,1	0,8
22	17,5	12,9	30,4	3,0	8,4	7,2	1,5	0,5	0,8
23	16,6	13,0	29,7	3,1	8,3	6,9	1,4	0,9	1,1
24	16,4	13,0	29,4	3,1	8,3	6,5	1,3	0,8	1,4
25	16,3	12,8	29,2	3,2	8,2	6,4	1,3	0,8	1,8
26	18,2	13,0	31,1	2,9	8,6	7,4	1,5	1,0	0,5
27	17,3	12,8	30,1	3,0	8,4	6,8	1,4	0,9	0,8
28	17,2	12,9	30,1	3,2	8,4	7,0	1,4	0,9	0,8
29	18,5	12,8	31,3	3,0	8,6	7,5	1,5	1,0	0,9
30	17,5	12,8	30,3	3,0	8,5	7,0	1,4	0,9	0,8
31	17,8	12,9	30,7	3,2	8,5	7,2	1,5	0,9	0,8
32	17,1	12,9	30,1	2,9	8,4	7,0	1,4	0,9	0,8
33	17,2	12,8	30,1	3,1	8,5	6,8	1,4	0,9	0,8
34	17,0	13,0	29,9	3,1	8,3	6,9	1,4	0,9	0,8
35	17,7	12,8	30,5	3,1	8,5	7,2	1,5	0,9	0,8
36	17,9	12,9	30,7	3,2	8,5	7,0	1,4	0,9	0,8
37	17,1	12,8	29,9	3,2	8,4	7,0	1,4	0,9	0,8
38	16,9	13,1	30,0	3,1	8,4	6,9	1,4	0,9	0,8
39	17,7	12,7	30,4	3,2	8,4	7,1	1,4	0,9	0,8
40	17,3	13,0	30,3	3,0	8,4	7,0	1,4	0,9	0,8
41	16,0	12,9	28,9	3,0	8,9	6,8	1,7	1,2	1,0
42	15,0	13,3	28,2	3,2	9,4	6,6	1,9	1,4	1,3
43	16,0	13,0	28,9	3,1	10,6	7,7	2,5	2,1	2,6
44	19,6	12,8	32,4	3,1	7,9	7,2	1,0	0,5	0,5
45	20,8	12,8	33,6	3,2	7,3	6,8	0,5	0,5	0,5
46	20,8	12,8	33,7	3,2	6,5	6,1	0,5	0,5	0,5
47	18,5	12,8	31,3	3,0	9,6	8,2	1,6	0,5	0,5
48	18,3	12,9	31,2	3,1	10,2	8,8	1,6	0,5	0,5

Scenario name	(M) Buffer level 6C	(M) Buffer level 7	(M) Buffer level 8	(M) Throughput time (min)
1	3,1	1,5	0,8	380,8
2	3,1	1,4	0,8	382,5
3	3,1	1,4	0,8	386,0
4	3,2	1,5	0,8	387,5
5	3,2	1,4	0,8	378,6
6	3,1	1,4	0,8	375,9
7	3,1	1,4	0,8	373,6
8	3,1	1,4	0,8	381,4
9	3,2	1,5	0,8	382,7
10	3,2	1,5	0,8	384,3
11	3,1	1,4	0,8	379,9
12	3,1	1,4	0,8	378,1
13	3,1	1,4	0,8	377,0
14	3,1	1,4	0,8	380,7
15	3,2	1,5	0,8	381,8
16	3,2	1,5	0,8	383,2
17	3,1	1,4	0,8	379,9
18	3,0	1,4	0,8	379,0
19	3,1	1,4	0,8	380,4
20	3,2	1,5	0,8	382,0
21	3,2	1,5	0,8	382,4
22	3,0	1,4	0,8	379,4
23	3,3	1,5	0,8	380,5
24	3,4	1,5	0,8	379,1
25	3,5	1,5	0,8	379,0
26	2,9	1,4	0,8	383,4
27	3,2	1,4	0,8	379,8
28	3,4	1,5	0,8	381,3
29	2,3	1,4	0,8	384,4
30	2,9	1,4	0,8	379,9
31	2,7	1,4	0,8	382,5
32	3,0	1,8	0,8	380,6
33	3,0	2,1	0,8	381,1
34	2,9	2,4	0,8	380,5
35	3,2	1,0	0,8	381,8
36	3,3	0,5	0,8	380,3
37	3,1	1,4	1,0	380,6
38	3,0	1,4	1,2	379,7
39	3,1	1,4	1,3	382,0
40	3,2	1,5	0,5	380,8
41	3,4	1,9	1,1	383,8
42	3,6	2,2	1,3	387,7
43	2,4	2,4	1,4	402,8
44	2,7	1,0	0,5	377,2
45	2,5	0,5	0,5	372,7
46	2,5	0,5	0,5	368,4
47	3,1	1,0	0,5	387,0
48	3,3	1,0	0,5	391,7

H Scenario manager dialog buffer speed

Complete result from the scenario manager. The colour coding for cabs out are green for high values and red for low, the rest have green for low values and red for high. The buffer levels have no colour coding since the value has no direct correlation to be bad or good.

Scenario name	BS1	BS3	BS4	BS5	BS6A	BS6C	BS7	BS8	(M) Cabs out (h)	(M) Total wait in (h)	(M) Total wait out (h)	(M) Total andon, safety and technical (h)	(M) Total shutdown time (h)
1	1	1	1	1	1	1	1	1	7007,5	121,06	36,81	156,75	314,62
2	0,8	1	1	1	1	1	1	1	7003,4	124,40	36,85	155,89	317,15
3	0,6	1	1	1	1	1	1	1	7001,7	123,44	37,50	157,04	317,98
4	0,4	1	1	1	1	1	1	1	7003,2	123,60	37,53	155,95	317,08
5	0,2	1	1	1	1	1	1	1	7006,4	122,35	37,50	155,97	315,81
6	1	0,8	1	1	1	1	1	1	7004,3	124,52	35,82	156,26	316,60
7	1	0,6	1	1	1	1	1	1	7003,9	118,19	38,84	158,48	315,51
8	1	0,4	1	1	1	1	1	1	7011,1	118,50	37,33	156,94	312,76
9	1	0,2	1	1	1	1	1	1	7010,0	118,07	37,60	158,18	313,85
10	1	1	0,8	1	1	1	1	1	7004,9	122,05	36,93	157,16	316,14
11	1	1	0,6	1	1	1	1	1	6999,3	122,06	38,65	157,43	318,14
12	1	1	0,4	1	1	1	1	1	7006,6	120,61	37,67	156,54	314,83
13	1	1	0,2	1	1	1	1	1	7007,2	122,75	36,44	155,89	315,08
14	1	1	1	0,8	1	1	1	1	7003,8	122,45	36,89	156,98	316,32
15	1	1	1	0,6	1	1	1	1	7004,0	123,51	36,78	155,89	316,18
16	1	1	1	0,4	1	1	1	1	6997,4	122,73	38,56	157,26	318,54
17	1	1	1	0,2	1	1	1	1	6998,1	123,34	37,71	157,46	318,51
18	1	1	1	1	0,8	1	1	1	6999,7	123,30	37,07	157,67	318,04
19	1	1	1	1	0.6	1	1	1	7004,4	124,03	36,61	155,75	316,39
20	1	1	1	1	0,4	1	1	1	7000,7	124,47	36,40	157,10	317,98
21	1	1	1	1	0,2	1	1	1	6999,4	123,12	37,45	157,47	318,04
22	1	1	1	1	1	0,8	1	1	7002,8	122,08	37,93	156,54	316,56
23	1	1	1	1	1	0,6	1	1	7000,7	123,34	38,12	157,45	318,91
24	1	1	1	1	1	0,4	1	1	7009,3	124,02	36,10	155,43	315,55
25	1	1	1	1	1	0,2	1	1	7012,3	123,63	36,79	155,59	316,01
26	1	1	1	1	1	1	0,8	1	7001,7	124,08	36,83	156,75	317,66
27	1	1	1	1	1	1	0,6	1	7004,3	123,37	36,21	156,78	316,37
28	1	1	1	1	1	1	0,4	1	7000,8	123,77	36,87	157,16	317,80
29	1	1	1	1	1	1	0,2	1	7003,2	125,50	36,22	155,84	317,57
30	1	1	1	1	1	1	1	0,8	6993,2	123,10	39,32	157,83	320,25
31	1	1	1	1	1	1	1	0,6	7003,8	120,63	38,48	156,97	316,09
32	1	1	1	1	1	1	1	0,4	7006,3	125,03	35,62	155,12	315,76
33	1	1	1	1	1	1	1	0,2	7006,6	123,04	36,10	156,26	315,40
34	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	7009,0	120,57	37,59	157,04	315,19
35	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	7022,2	118,51	34,89	156,42	309,82
36	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	7022,5	118,59	35,92	156,33	310,84
37	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	7026,2	120,08	34,97	156,11	311,15
38	1	1	0,9	0,8	0,6	0,7	0,8	0,8	7001,8	125,06	36,81	156,46	318,33

Scenario name	(M) Wait out 1 (h)	(M) Andon, safety and technical 1 (h)	(M) Total 1 (h)	(M) Wait in 3 (h)	(M) Wait out 3 (h)	(M) Andon,safety and techical 3 (h)	(M) Total 3 (h)	(M) Wait in 4 (h)	(M) Wait out4 (h)	(M) Andon, safety and technical 4 (h)
1	6,48	21,49	27,97	1,02	3,55	24,34	28,91	4,50	5,24	19,53
2	6,96	21,59	28,55	0,99	3,68	24,44	29,11	4,58	5,33	19,52
3	7,25	21,32	28,57	0,70	3,72	24,72	29,14	4,57	5,42	19,53
4	6,86	21,69	28,56	0,78	3,60	24,74	29,13	4,70	5,42	19,39
5	6,84	21,60	28,44	0,69	3,76	24,53	28,98	4,48	5,43	19,40
6	6,37	21,78	28,15	1,10	3,31	24,68	29,09	4,66	5,35	19,36
7	6,61	21,44	28,04	1,07	3,50	24,41	28,98	3,92	5,94	19,48
8	6,20	21,58	27,78	1,08	3,32	24,30	28,70	3,77	5,79	19,45
9	6,25	21,71	27,96	1,08	3,26	24,58	28,92	3,70	5,70	19,73
10	6,25	21,84	28,10	1,19	3,63	24,22	29,04	4,39	5,42	19,58
11	6,62	21,64	28,26	0,99	3,80	24,43	29,23	4,55	5,79	19,25
12	6,42	21,59	28,00	1,06	3,51	24,41	28,98	4,69	5,41	19,18
13	6,37	21,58	27,95	0,95	3,63	24,32	28,90	4,52	5,24	19,53
14	6,55	21,59	28,14	0,98	3,56	24,57	29,11	4,74	5,45	19,23
15	6,40	21,73	28,13	0,98	3,43	24,64	29,06	4,75	5,39	19,27
16	6,64	21,77	28,41	1,05	3,88	24,44	29,37	4,44	5,61	19,65
17	6,56	21,79	28,36	1,09	3,69	24,51	29,29	4,72	5,42	19,54
18	6,45	21,81	28,26	1,07	3,57	24,58	29,21	4,62	5,36	19,59
19	6,55	21,57	28,12	0,93	3,58	24,60	29,11	4,78	5,30	19,38
20	6,62	21,62	28,24	0,98	3,61	24,64	29,23	4,84	5,42	19,31
21	6,62	21,69	28,31	0,97	3,75	24,54	29,26	4,59	5,61	19,41
22	6,45	21,66	28,11	1,13	3,76	24,16	29,05	4,34	5,65	19,40
23	6,72	21,55	28,27	0,97	3,83	24,40	29,19	4,46	5,70	19,43
24	6,28	21,64	27,92	1,13	3,45	24,28	28,86	4,61	5,19	19,37
25	6,21	21,59	27,80	1,06	3,47	24,20	28,73	4,64	5,13	19,31
26	6,61	21,62	28,23	0,98	3,52	24,70	29,21	4,84	5,47	19,21
27	6,28	21,84	28,12	1,07	3,48	24,49	29,04	4,67	5,34	19,39
28	6,75	21,47	28,22	0,92	3,61	24,69	29,22	4,72	5,29	19,60
29	6,63	21,55	28,18	0,98	3,47	24,71	29,16	4,78	5,45	19,29
30	7,16	21,33	28,49	0,92	4,04	24,55	29,51	4,51	5,75	19,64
31	6,67	21,46	28,12	0,96	3,79	24,35	29,09	4,44	5,75	19,29
32	6,44	21,61	28,05	1,02	3,49	24,50	29,01	4,70	5,17	19,46
33	6,23	21,82	28,05	1,06	3,51	24,38	28,95	4,51	5,31	19,46
34	6,69	21,60	28,29	0,96	3,52	24,36	28,84	4,01	5,61	19,56
35	5,95	21,77	27,72	1,06	2,90	24,21	28,18	4,22	5,05	19,31
36	6,13	21,66	27,79	0,97	3,00	24,35	28,31	3,87	5,43	19,28
37	6,03	21,66	27,70	0,83	2,76	24,69	28,28	4,24	4,93	19,30
38	6,53	21,67	28,20	1,04	3,80	24,28	29,12	4,53	5,48	19,51

Scenario name	(M) Total 4 (h)	(M) Wait in 5 (h)	(M) Wait out 5 (h)	(M) Andon, safety and technical 5 (h)	(M) Total 5 (h)	(M) Wait in 6A (h)	(M) Wait out 6A (h)	(M) Andon, safety and technical 6A (h)	(M) Total 6A (h)	(M) Wait in 6C (h)	(M) Wait out 6C (h)
1	29,27	9,40	5,70	13,57	28,67	13,05	10,48	4,92	28,46	40,16	1,05
2	29,44	9,54	5,68	13,63	28,85	13,56	10,16	4,94	28,66	41,88	0,95
3	29,52	9,56	5,65	13,76	28,96	13,46	10,39	4,89	28,74	41,07	0,94
4	29,51	9,47	5,85	13,56	28,88	13,36	10,34	5,01	28,71	42,04	1,02
5	29,31	9,33	5,72	13,70	28,76	13,30	10,37	4,87	28,54	41,45	1,06
6	29,38	9,43	5,65	13,75	28,83	13,49	10,16	4,99	28,64	41,88	0,93
7	29,34	8,73	6,22	13,76	28,71	12,43	11,02	5,07	28,52	39,15	1,09
8	29,02	8,71	5,94	13,81	28,46	12,67	10,67	4,90	28,24	39,91	1,07
9	29,13	8,68	6,06	13,75	28,49	12,49	10,81	5,00	28,30	39,61	1,11
10	29,39	9,22	5,80	13,79	28,80	13,18	10,51	4,89	28,57	40,90	1,02
11	29,59	8,96	6,32	13,67	28,96	12,87	11,07	4,83	28,77	40,26	0,91
12	29,28	9,06	5,96	13,67	28,68	12,80	10,74	4,93	28,47	40,31	1,21
13	29,29	9,17	5,69	13,82	28,67	13,24	10,30	4,94	28,47	41,43	1,05
14	29,42	9,26	5,62	13,97	28,86	13,42	10,34	4,87	28,63	40,77	1,05
15	29,41	9,56	5,76	13,52	28,84	13,37	10,39	4,90	28,66	41,59	1,05
16	29,71	9,45	6,03	13,64	29,12	13,14	10,84	4,93	28,90	40,51	1,10
17	29,67	9,60	5,96	13,49	29,05	13,23	10,76	4,86	28,85	40,67	1,02
18	29,57	9,57	5,90	13,50	28,97	13,30	10,62	4,86	28,79	40,45	1,04
19	29,45	9,66	5,61	13,60	28,87	13,56	10,20	4,88	28,63	41,74	1,00
20	29,57	9,56	5,60	13,85	29,01	13,76	10,13	4,93	28,83	40,98	0,94
21	29,62	9,43	5,82	13,78	29,03	13,47	10,46	4,92	28,85	40,19	1,03
22	29,39	9,23	5,95	13,66	28,84	13,18	10,52	4,95	28,65	41,12	1,14
23	29,58	9,21	5,94	13,83	28,99	13,21	10,68	4,90	28,79	41,34	1,05
24	29,17	9,49	5,42	13,72	28,63	13,68	9,86	4,90	28,44	43,04	1,29
25	29,07	9,38	5,56	13,55	28,49	13,33	10,04	4,96	28,32	42,89	2,14
26	29,51	9,35	5,75	13,85	28,95	13,42	10,35	4,98	28,76	41,61	0,95
27	29,40	9,40	5,64	13,77	28,81	13,32	10,41	4,88	28,61	41,13	1,01
28	29,61	9,71	5,72	13,59	29,02	13,40	10,44	4,95	28,79	40,86	0,99
29	29,52	9,45	5,62	13,89	28,96	13,79	10,05	4,90	28,75	42,63	0,92
30	29,90	9,38	6,11	13,78	29,28	13,19	10,94	4,93	29,06	39,92	1,12
31	29,48	9,07	6,08	13,69	28,83	12,94	10,83	4,86	28,63	39,91	1,09
32	29,33	9,63	5,51	13,67	28,80	13,70	9,96	4,92	28,58	42,51	0,99
33	29,28	9,46	5,65	13,62	28,73	13,34	10,28	4,90	28,52	41,22	1,05
34	29,17	8,91	5,85	13,87	28,63	12,95	10,56	4,90	28,42	41,02	1,05
35	28,58	8,94	5,33	13,74	28,01	12,89	9,93	4,98	27,80	41,09	1,23
36	28,59	8,58	5,74	13,70	28,02	12,73	10,19	4,92	27,84	41,52	1,24
37	28,47	9,03	5,15	13,75	27,93	13,18	9,57	4,98	27,72	42,31	2,35
38	29,52	9,52	5,69	13,77	28,97	13,63	10,21	4,96	28,79	42,18	1,01

Scenario name	(M) Andon, safety and technical 6C (h)	(M) Total 6C (h)	(M) Wait in 7 (h)	(M) Wait out 7 (h)	(M) Andon, safety and technical 7 (h)	(M) Total 7 (h)	(M) Wait in 8 (h)	(M) Wait out 8 (h)	(M) Andon, safety and technical 8 (h)	(M) Total 8 (h)
1	42,36	83,57	22,74	3,03	2,51	28,28	13,19	1,30	15,11	29,60
2	41,29	84,12	23,21	2,82	2,52	28,54	13,53	1,27	14,98	29,78
3	42,34	84,35	23,26	2,90	2,49	28,64	13,58	1,25	15,06	29,88
4	40,85	83,91	22,95	3,08	2,45	28,48	13,32	1,36	15,12	29,80
5	41,30	83,81	22,83	3,00	2,53	28,36	13,21	1,31	15,13	29,65
6	41,34	84,16	23,23	2,83	2,46	28,53	13,47	1,21	15,09	29,76
7	43,43	83,67	22,75	3,11	2,54	28,40	13,13	1,35	15,28	29,76
8	42,36	83,35	22,53	3,01	2,53	28,07	13,06	1,31	15,04	29,42
9	42,88	83,61	22,57	3,11	2,50	28,18	13,01	1,31	15,15	29,47
10	42,16	84,08	22,93	2,98	2,51	28,41	13,27	1,32	15,13	29,72
11	43,18	84,35	23,37	2,84	2,51	28,72	13,69	1,29	14,99	29,97
12	41,96	83,48	22,67	3,13	2,53	28,34	13,01	1,30	15,33	29,64
13	41,42	83,89	22,91	2,95	2,49	28,36	13,37	1,21	15,05	29,63
14	42,06	83,88	22,88	3,04	2,52	28,44	13,27	1,27	15,22	29,77
15	41,15	83,79	22,87	3,06	2,52	28,45	13,24	1,29	15,22	29,75
16	42,25	83,86	23,05	3,15	2,52	28,72	13,52	1,30	15,26	30,07
17	42,53	84,22	23,31	2,92	2,49	28,72	13,59	1,39	15,03	30,01
18	42,76	84,26	23,31	2,90	2,53	28,74	13,61	1,23	15,13	29,98
19	41,26	84,00	22,96	2,98	2,50	28,44	13,41	1,40	14,92	29,73
20	42,30	84,22	23,35	2,81	2,56	28,72	13,70	1,26	14,97	29,93
21	42,73	83,95	23,39	2,83	2,53	28,75	13,74	1,32	14,90	29,97
22	41,92	84,18	22,70	3,16	2,54	28,41	13,20	1,29	15,33	29,81
23	42,93	85,33	23,18	2,97	2,47	28,62	13,55	1,23	15,14	29,92
24	40,77	85,11	22,39	3,20	2,50	28,10	12,85	1,39	15,26	29,50
25	41,50	86,53	22,57	2,96	2,49	28,02	13,05	1,28	15,04	29,36
26	41,80	84,35	23,21	2,90	2,51	28,62	13,46	1,28	15,12	29,87
27	41,93	84,07	23,14	2,86	2,51	28,51	13,37	1,20	15,18	29,75
28	42,27	84,13	23,38	2,81	2,50	28,68	13,54	1,26	15,11	29,91
29	40,88	84,43	23,41	2,70	2,55	28,66	13,40	1,37	15,02	29,79
30	43,11	84,15	23,45	3,00	2,53	28,99	13,96	1,20	15,13	30,29
31	42,61	83,61	22,88	3,06	2,52	28,46	13,33	1,22	15,22	29,78
32	40,46	83,96	23,01	2,87	2,51	28,40	13,41	1,19	15,07	29,67
33	41,59	83,86	23,01	2,87	2,53	28,40	13,38	1,20	15,08	29,67
34	42,22	84,29	22,68	2,99	2,54	28,21	13,16	1,31	15,04	29,51
35	41,59	83,91	21,75	3,18	2,57	27,50	12,34	1,31	15,24	28,89
36	41,84	84,61	22,01	3,02	2,51	27,54	12,51	1,16	15,25	28,92
37	41,18	85,84	21,92	2,93	2,57	27,42	12,42	1,25	15,08	28,75
38	41,85	85,04	23,32	2,83	2,48	28,64	13,58	1,26	15,02	29,87

Scenario name	(M) Wait in 9 (h)	(M) Andon, safety and technical 9 (h)	(M) Total 9 (h)	(M) TBI exit line 9 (min)	(M) Buffer level 1
1	16,98	12,92	29,91	2,92	8,38
2	17,11	12,99	30,10	2,88	8,35
3	17,25	12,93	30,18	2,91	8,47
4	16,98	13,13	30,11	3,35	8,22
5	17,05	12,91	29,96	2,97	8,14
6	17,25	12,81	30,06	2,93	8,31
7	17,01	13,07	30,07	2,97	8,42
8	16,77	12,97	29,74	2,94	8,29
9	16,91	12,88	29,79	3,13	8,33
10	16,99	13,04	30,03	2,91	8,28
11	17,36	12,93	30,29	3,05	8,42
12	17,00	12,95	29,95	2,89	8,38
13	17,18	12,75	29,92	3,56	8,47
14	17,13	12,95	30,08	3,05	8,41
15	17,14	12,93	30,07	2,91	8,45
16	17,57	12,81	30,38	3,14	8,40
17	17,13	13,21	30,34	3,01	8,40
18	17,36	12,91	30,27	3,22	8,41
19	17,00	13,05	30,05	2,86	8,48
20	17,30	12,93	30,23	2,95	8,47
21	17,33	12,95	30,29	2,93	8,43
22	17,19	12,94	30,12	3,00	8,31
23	17,42	12,80	30,22	3,07	8,43
24	16,83	12,99	29,83	3,11	8,36
25	16,73	12,96	29,68	2,99	8,38
26	17,22	12,96	30,18	2,93	8,51
27	17,27	12,78	30,06	2,93	8,36
28	17,25	12,96	30,22	3,13	8,48
29	17,06	13,05	30,11	3,09	8,45
30	17,76	12,81	30,57	3,34	8,50
31	17,10	12,98	30,08	2,99	8,45
32	17,05	12,92	29,96	2,94	8,42
33	17,06	12,89	29,95	3,04	8,34
34	16,89	12,95	29,84	2,88	8,29
35	16,22	13,00	29,22	3,16	8,02
36	16,40	12,81	29,21	2,88	7,98
37	16,14	12,90	29,05	2,91	7,86
38	17,26	12,92	30,17	2,99	8,42

Scenario name	(M) Buffer level 3	(M) Buffer level 4	(M) Buffer level 5	(M) Buffer level 6A	(M) Buffer level 6C	(M) Buffer level 7	(M) Buffer level 8	(M) Throughput time (min)
1	7,04	1,43	0,91	0,79	3,18	1,46	0,80	380,70
2	7,00	1,41	0,89	0,78	3,10	1,43	0,80	380,23
3	7,00	1,41	0,90	0,79	3,11	1,43	0,80	380,88
4	6,90	1,40	0,89	0,78	3,10	1,44	0,80	379,54
5	7,02	1,43	0,90	0,78	3,14	1,48	0,81	380,08
6	6,83	1,42	0,89	0,78	3,09	1,43	0,80	379,07
7	7,13	1,48	0,92	0,80	3,20	1,47	0,81	382,06
8	6,85	1,45	0,91	0,79	3,18	1,45	0,80	380,19
9	6,78	1,46	0,92	0,80	3,18	1,47	0,80	380,41
10	6,99	1,41	0,90	0,78	3,14	1,46	0,80	379,82
11	7,06	1,44	0,92	0,79	3,13	1,44	0,80	381,12
12	6,92	1,41	0,91	0,79	3,18	1,46	0,80	380,10
13	7,02	1,39	0,90	0,78	3,13	1,45	0,80	380,13
14	6,85	1,42	0,89	0,79	3,14	1,45	0,80	379,97
15	6,87	1,41	0,89	0,78	3,13	1,45	0,80	379,94
16	7,07	1,41	0,90	0,79	3,18	1,46	0,80	381,08
17	6,92	1,41	0,89	0,79	3,13	1,45	0,81	380,24
18	6,96	1,41	0,90	0,79	3,14	1,44	0,80	380,32
19	6,92	1,39	0,89	0,78	3,11	1,44	0,81	379,92
20	6,88	1,41	0,89	0,78	3,14	1,43	0,80	379,82
21	6,98	1,42	0,89	0,78	3,16	1,44	0,81	380,40
22	7,10	1,44	0,90	0,79	2,96	1,47	0,81	380,55
23	7,07	1,43	0,90	0,78	2,73	1,45	0,80	380,15
24	6,88	1,40	0,88	0,77	2,56	1,46	0,81	377,78
25	6,96	1,41	0,89	0,77	2,41	1,46	0,80	377,63
26	6,88	1,42	0,90	0,78	3,11	1,42	0,80	380,14
27	6,92	1,41	0,90	0,78	3,10	1,41	0,80	379,38
28	6,93	1,40	0,91	0,79	3,14	1,39	0,80	380,13
29	6,88	1,42	0,89	0,77	3,06	1,37	0,80	379,03
30	7,11	1,44	0,91	0,80	3,17	1,43	0,79	382,06
31	7,03	1,44	0,91	0,79	3,17	1,45	0,79	381,12
32	6,86	1,40	0,88	0,78	3,08	1,44	0,78	378,94
33	6,99	1,41	0,90	0,79	3,12	1,43	0,77	379,28
34	7,13	1,44	0,90	0,78	2,95	1,46	0,80	379,98
35	6,84	1,40	0,89	0,78	2,82	1,46	0,79	376,19
36	6,64	1,41	0,89	0,77	2,64	1,45	0,78	375,16
37	6,38	1,38	0,88	0,76	2,50	1,42	0,78	372,13
38	7,02	1,41	0,89	0,77	2,77	1,42	0,79	378,92

I Scenario manager dialog takt time

Complete result from the scenario manager. The colour coding for cabs out are green for high values and red for low, the rest have green for low values and red for high. The buffer levels have no colour coding since the value has no direct correlation to be bad or good.

Scenario name	Takt line 1	Takt line 3	Takt line 4	Takt line 5	Takt line 6A	Takt line 6C	Takt line 7	Takt line 8	Takt line 9	(M) Cabs out	(M) Total wait in (h)
1	167	167	167	167	167	137	167	167	167	7008,0	120,99
2	160,5	172	165,5	173	172,5	137	172,5	174,5	167	6831,8	118,51
3	159	160	161	162	163	134	165	166	167	7174,7	66,74
4	167	166	165	164	163	132	161	160	159	7075,2	186,42

Scenario name	(M) Total wait out (h)	(M) Total andon, safety and technical (h)	(M) Total shutdown time (h)	(M) Wait out 1 (h)	(M) Andon, safety and technical 1	(M) Total 1 (h)	(M) Wait in 3 (h)	(M) Wait out 3 (h)	(M) Andon,safety and techical 3 (h)
1	37,00	156,30	314,29	6,32	21,60	27,92	1,03	3,54	24,25
2	51,94	155,50	325,95	18,15	20,95	39,10	0,12	2,83	24,72
3	69,88	158,19	294,81	13,25	21,11	34,35	0,44	9,22	24,08
4	24,72	153,61	364,75	3,84	21,77	25,61	2,03	1,79	24,40

Scenario name	(M) Total 3 (h)	(M) Wait in 4 (h)	(M) Wait out 4 (h)	(M) Andon, safety and technical 4 (h)	(M) Total 4 (h)	(M) Wait in 5 (h)	(M) Wait out 5 (h)	(M) Andon, safety and technical 5 (h)	(M) Total 5 (h)	(M) Wait in 6A (h)	(M) Wait out 6A (h)
1	28,83	4,44	5,29	19,46	29,19	9,37	5,79	13,45	28,61	12,93	10,58
2	27,67	8,97	8,86	19,19	37,02	5,95	5,62	13,80	25,37	10,86	10,23
3	33,74	2,10	10,89	19,51	32,50	5,08	10,43	13,76	29,27	6,95	15,40
4	28,23	7,68	3,44	19,24	30,36	14,30	4,15	13,44	31,90	20,05	8,71

Scenario name	(M) Andon, safety and technical 6A (h)	(M) Total 6A (h)	(M) Wait in 6C (h)	(M) Wait out 6C (h)	(M) Andon, safety and technical 6C (h)	(M) Total 6C (h)	(M) Wait in 7 (h)	(M) Wait out 7 (h)	(M) Andon, safety and technical 7 (h)	(M) Total 7 (h)
1	4,88	28,39	40,57	1,08	42,00	83,66	22,66	3,08	2,52	28,26
2	4,92	26,01	41,74	1,67	41,46	84,86	17,52	4,06	2,54	24,12
3	4,88	27,22	23,26	2,98	43,89	70,13	13,67	5,72	2,56	21,94
4	4,81	33,57	53,52	0,41	40,34	94,27	33,98	1,52	2,48	37,97

Scenario name	(M) Wait in 8 (h)	(M) Wait out 8 (h)	(M) Andon, safety and technical 8 (h)	(M) Total 8 (h)	(M) Wait in 9 (h)	(M) Andon, safety and technical 9 (h)	(M) Total 9 (h)	(M) TBI exit line 9 (min)	(M) Buffer level 1	(M) Buffer level 3	(M) Buffer level 4
1	13,11	1,32	15,13	29,56	16,88	13,00	29,88	3,04	8,39	6,95	1,40
2	7,84	0,52	15,38	23,74	25,51	12,54	38,06	3,02	10,29	6,06	1,87
3	6,16	2,01	15,34	23,50	9,09	13,06	22,15	2,98	9,51	8,92	1,82
4	24,88	0,85	14,63	40,35	29,98	12,51	42,49	2,96	7,31	5,59	1,16

Scenario name	(M) Buffer level 5	(M) Buffer level 6A	(M) Buffer level 6C	(M) Buffer level 7	(M) Buffer level 8	(M) Throughput time (min)
1	0,91	0,79	3,16	1,45	0,81	380,17
2	0,93	0,80	3,63	1,80	0,61	401,36
3	1,12	0,97	4,34	1,94	0,97	398,74
4	0,78	0,72	2,46	1,01	0,67	357,46