Thesis for the Degree of Master of Science

Design and Implementation of Systematic Production Analysis

Collecting and analysing production data to monitor and improve OEE using a commercial production monitoring software

Albert Larsson & Elsa Höjbert

LUND UNIVERSITY

Department of Production and Materials Engineering
Faculty of Engineering, Lund University
Lund, Sweden

2020-06-10

Supervisor: Christina Windmark, PhD
Industrial supervisor: Niclas Johansson, Operational Coordinator (Nolato MediTech)
Examiner: Jan-Eric Ståhl, Prof.

Authors: Albert Larsson & Elsa Höjbert
Lund, Sweden 2020

Abstract

The purpose of this master thesis project was to design and implement a systematic procedure to analyse and improve OEE for Nolato Meditech using a specific commercial production monitoring system, as well as solving operational system issues and evaluating the performance of the system.

The method employed consisted of learning the software, adapting it to comply with the given production environment, collecting appropriate production disturbance reasons and investigating current organisational structures at the company. Interviews and observations were mostly used to gather the information needed.

The project is mainly based on systematic production analysis (SPA) using OEE as the main KPI. Deliverables include specific system settings to be used, an action plan to solve the operational system issues, specific production disturbance reasons, suggested organisational alterations to facilitate follow-up of OEE, complementing roles and responsibilities, suggested education and training for production personnel as well as an evaluation of the production monitoring system.

It is concluded that Nolato MediTech has all the prerequisites for succeeding in implementing a systematic monitoring of OEE. The specific system is deemed sufficient for this purpose, although not optimal since it cannot categorise reduced production rate, which means losing one of the cornerstones in SPA. The system will use previously existing reject reasons as well as a set of downtime reasons for each production department that has been designed by the authors. Follow-up regarding OEE and its underlying causes will be done on a daily and weekly basis according to a procedure suggested by the authors to visualise production disturbances and trends.

Keywords: Systematic Production Analysis, Overall Equipment Effectiveness, Production Disturbance Reasons, Human Machine Interface.

Sammanfattning

Syftet med detta examensarbete var att utforma och implementera ett systematisk arbetssätt för att analysera och förbättra OEE åt Nolato Meditech med hjälp av ett specifikt kommersiellt produktionsövervakningssystem, samt att lösa operativa problem med systemet och utvärdera dess prestanda.

Arbetets metod bestod av att lära sig mjukvaran, anpassa den till att uppfylla den givna produktionsmiljön, samla in lämpliga faktorer för produktionsstörningar och undersöka aktuella organisatoriska strukturer i företaget. Intervjuer och observationer låg mestadels till grund för att samla in den information som behövdes.

Projektet är huvudsakligen baserat på systematisk produktionsanalys (SPA) med OEE som huvudsakligt KPI. Målet med projektet är att leverera specifika systeminställningar som ska användas, en handlingsplan för att lösa de operativa systemfrågorna, specifika faktorer för produktionsstörningar, föreslagna organisatoriska förändringar för att underlätta uppföljning av OEE, kompletterande roller och ansvarsområden, förslag på utbildning för produktionspersonal samt en utvärdering av produktionsövervakningssystemet.

Slutsatsen dras att Nolato MediTech har alla förutsättningar för att lyckas med en implementering av systematisk övervakning av OEE. Det specifika produktionsövervakningssystemet bedöms vara tillräckligt för detta ändamål, även om det inte är optimalt då det inte kan kategorisera reducerad produktionshastighet, vilket innebär att man förlorar en av hörnstenarna i SPA. Systemet kommer använda sig av redan befintliga kassationskoder samt en uppsättning av stilleståndsorsaker för varje produktionsavdelning som har utformats av författarna. Uppföljning av OEE och dess underliggande orsaker kommer att göras dagligen och veckovis enligt ett förfarande föreslaget av författarna för att visualisera produktionsstörningar och trender.

Nyckelord: Systematisk Produktionsanalys, Overall Equipment Effectiveness, Faktorer för Produktionsstörningar, HMI.

Preface

This master thesis project concludes our education in mechanical engineering at Lund University, Faculty of Engineering (LTH). The project was conducted in collaboration with Nolato MediTech Hörby and spanned over the spring term of 2020.

We would like to extend a big thank you to Nolato MediTech and Pia Rohne for enabling this project. A special thank you to Niclas Johansson, our supervisor at Nolato MediTech - thank you for everything you have helped us with, big and small, and for making sure we got in touch with the right people to be able to move forward with the project.

We would also like to thank Christina Windmark, our supervisor at LTH - thank you for all your valuable input and for making us see new sides to the problems we faced.

A big thank you to everyone at Nolato MediTech whom we have interviewed and discussed different issues with, especially Joakim Tillström, Nihad Sijercic and Kamil Bobrowski, without your expertise and valuable input this project wouldn't have been possible. Thank you for making us feel welcome and for giving us a fun and rewarding last term.

Lastly we would like to thank our families for supporting us through it all.

Lund, 2020-05-31
Elsa Höjbert & Albert Larsson

Table of Contents

1 Introduction **13**
1.1 Nolato Group . . . 13
1.2 Nolato MediTech AB . . . 13
1.2.1 Production Department A . . . 14
1.2.2 Production Department B . . . 14
1.2.3 Production Department C . . . 14
1.3 Background . . . 15
1.4 Purpose and Goals . . . 15
1.5 Demarcations . . . 15
1.6 RS Production . . . 16
1.7 Structure of the Thesis . . . 16

2 Theory **17**
2.1 Systematic Production Analysis . . . 17
2.1.1 Production Performance . . . 17
2.1.2 Result Parameters . . . 17
2.1.3 Influencing Factors and Factor Groups . . . 19
2.1.4 Production Performance Matrix . . . 19
2.1.5 Monitoring . . . 20
2.1.6 Data Collection . . . 21
2.2 Five Why . . . 21
2.3 Ishikawa Diagram . . . 22
2.4 Key Performance Indicators . . . 23
2.4.1 Overall Equipment Effectiveness . . . 25
2.5 Human Machine Interface . . . 29
2.5.1 General Design Principles . . . 30
2.5.2 Screen Layout Design Principles . . . 30
2.5.3 Menu Design Principles . . . 31
2.6 Colour Coding . . . 31
2.7 Injection Moulding . . . 31
2.7.1 Thermoplastics . . . 32
2.7.2 Liquid Silicone Rubber . . . 34
2.8 Interviews as a Qualitative Research Technique . . . 35

3 Methodology **37**
3.1 Current Monitoring System . . . 37
3.1.1 Learning the Software . . . 37
3.1.2 Main Screen and Menus . . . 37

3.1.3 Software Settings . . . 37
3.1.4 Calculation of OEE . . . 37
3.1.5 SPA Using the Current Monitoring System . . . 38
3.2 Technical Problem Solving . . . 38
3.2.1 System Monitoring . . . 38
3.2.2 Action Proposal . . . 38
3.3 Reason Collection . . . 38
3.3.1 Reason Categorisation . . . 38
3.3.2 Reason Structure and Naming . . . 38
3.4 Systematic Monitoring of OEE . . . 39
3.4.1 Current Organisational Structure . . . 39
3.4.2 Design of Systematic Procedure . . . 39
3.4.3 Routine to Collect New Reasons . . . 39
3.4.4 Roles and Responsibilities . . . 39
3.4.5 Education . . . 39
3.4.6 Benchmarking . . . 40

4 Execution and Empirical Findings **41**
4.1 The Current Monitoring System . . . 41
4.1.1 Learning the Software . . . 41
4.1.2 Hardware and Technical Workings . . . 41
4.1.3 Operator Tools, Office Tools & Screens . . . 42
4.1.4 Users and Login . . . 42
4.1.5 System Configuration . . . 43
4.1.6 Main Screen for Operator Tools . . . 43
4.1.7 OEE in the Current Monitoring System . . . 46
4.1.8 Cycle Time . . . 48
4.1.9 Categorising Downtime in the Current Monitoring System . 48
4.1.10 Categorising Rejects in the Current Monitoring System . . . 49
4.1.11 Reasons in the Current Monitoring System . . . 49
4.1.12 Reports in the Current Monitoring System . . . 51
4.1.13 SPA Using the Current Monitoring System . . . 52
4.2 Technical Problem Solving . . . 54
4.2.1 System Monitoring . . . 54
4.2.2 Identified Problems . . . 54
4.2.3 Action Proposal . . . 56
4.3 Reason Collection . . . 56
4.3.1 Reasons . . . 56
4.3.2 Reason Structure . . . 57
4.3.3 Reason Numbering . . . 58
4.4 Systematic Monitoring of OEE . . . 60
4.4.1 Visions about the Current Monitoring System . . . 60
4.4.2 Existing Structures for Production Monitoring and Continuous Improvements at Nolato MediTech . . . 61
4.4.3 Education . . . 61
4.4.4 Benchmarking . . . 62
4.5 Special Considerations . . . 64
4.5.1 Validation Orders . . . 64

4.5.2 Current Reject Registration 65
4.5.3 Line Clearance 65

5 Results **67**
5.1 The Current Monitoring System 67
5.1.1 Machine-specific Settings 67
5.1.2 Measure Point Configurations 68
5.1.3 SPA Using the Current Monitoring System 72
5.2 Technical Problems 72
5.3 Reasons 73
5.3.1 Downtime Reasons 73
5.3.2 Reject Reasons 75
5.4 Systematic Monitoring of OEE 76
5.4.1 Downtime Categorisation 76
5.4.2 Reject Registration and Categorisation 77
5.4.3 OEE Follow-up 77
5.4.4 Standardised Reports in the Current Monitoring System . . 77
5.4.5 Routine to Collect New Reasons 80
5.5 Roles and Responsibilities 83
5.5.1 Operators 83
5.5.2 Operationally Responsible 83
5.5.3 Administratively Responsible 84
5.5.4 User Accounts and Software Installations 84
5.6 Education and Training 85
5.6.1 Operators 85
5.6.2 Operationally Responsible 87
5.6.3 Administratively Responsible 88
5.6.4 Report Users 88

6 Discussion and conclusion **89**
6.1 The Current Monitoring System 89
6.1.1 Optimal Cycle Time 89
6.1.2 Micro Stop Limit 89
6.1.3 The Current Monitoring System Interface 89
6.1.4 SPA Using the Current Monitoring System 90
6.2 Technical Problems 91
6.3 Reasons 91
6.3.1 Reason Resolution 91
6.3.2 The Difference in Reason Resolution Between Departments 92
6.3.3 Reason Structure and Numbering 92
6.3.4 Reject Reasons 92
6.4 Systematic Monitoring of OEE 93
6.4.1 Standardised Reports in the Current Monitoring System . . 93
6.4.2 Planned Downtime in OEE Calculations 94
6.4.3 Existing Structures for Production Monitoring and Continuous Improvements at Nolato MediTech 94
6.4.4 Benchmarking towards the Lomma factory 94

A APQ-components as Defined in the Current Monitoring System **99**

B **Previous Downtime Reasons Nolato MediTech Hörby** **100**

C **Different Reason Formats** **101**

D **Interview Summary - Visions about the Current Monitoring System** **103**

E **Downtime Reasons Nolato MediTech Lomma** **105**

F **Final Settings in the Current Monitoring System** **109**

G **Downtime Reason Settings** **111**

H **Downtime Reasons Department A** **115**

I **Downtime Reasons Department B** **119**

J **Reject Reason Settings** **121**

K **Reject Reasons Department A** **123**

L **Reject Reasons Department B** **124**

M **Altering the Micro Stop-limit (Swedish)** **125**

N **Step-by-step Handling Instructions** **126**

1. Introduction

1.1 Nolato Group

Nolato AB is a Swedish multinational publicly traded group mainly within development and production of polymer products [1]. Nolato was established in Torekov, Sweden in 1938. The current name, which has been in use since 1982, is an acronym of the original name Nordiska Latexfabriken i Torekov (transl. the Nordic Latex Factory in Torekov). Today, thanks to organic growth and various acquisitions, Nolato is a multinational group with many subsidiaries in Europe, Asia and North America. The headquarters are still located in Torekov, while the bigger part of the operations are carried out outside of Sweden.

Nolato has divided all of its subsidiaries into three business groups; medical solutions, integrated solutions and industrial solutions. Nolato's own description of the respective business areas can be found below, and their respective share of sales and profits are found in figure 1.1.

> Medical Solutions develops and manufactures complex product systems and components within medical technology, as well as advanced packaging solutions for pharmaceuticals and dietary supplements [2].
>
> Integrated Solutions designs, develops and produces advanced components, subsystems and ready-packaged products for consumer electronics. EMC & Thermal develops and manufactures EMC shielding and heat dissipation products and systems for electronics [3].
>
> Industrial Solution consists of nine strong specialist companies that develop and manufacture products and product systems in mainly polymer materials for a range of customer segments. These companies create business opportunities both individually and in cooperation with one another [4].

1.2 Nolato MediTech AB

Nolato MediTech AB is a subsidiary to Nolato within Medical Solutions, with two sites in the south of Sweden; the headquarters in Hörby and a second site in Lomma. Both sites develop and produce polymer products and systems within medical technology and pharmaceuticals. This thesis will be conducted exclusively at the Hörby-site.

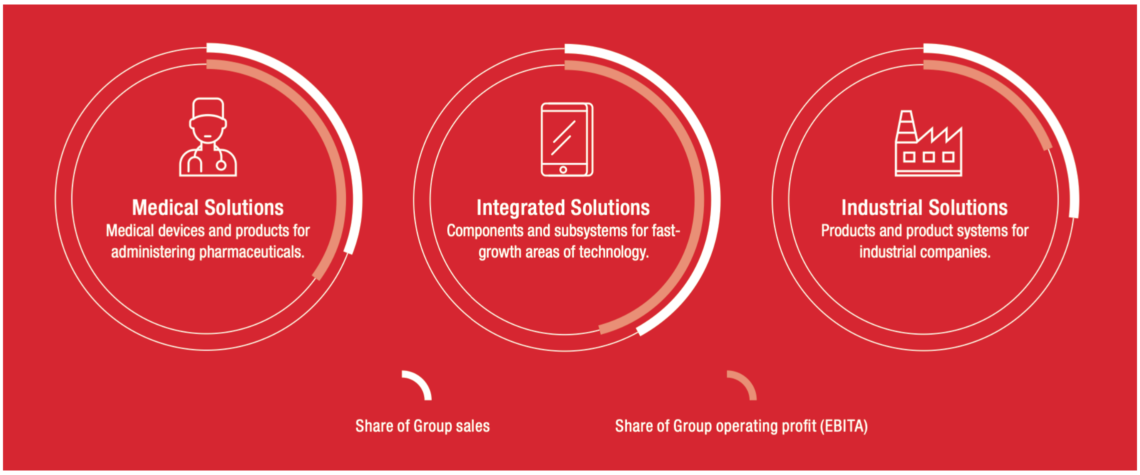


Figure 1.1: Nolato's business areas and their respective share of sales and profits [5].

Nolato MediTech AB strictly follows the internally developed continuous improvements program Medical Excellence and was awarded the Swedish Lean Award in 2015.

The corporate language of Nolato MediTech is primarily Swedish and for this reason some of the material presented in this report will be in Swedish. In that case the material will be thoroughly described in English adjacent to its Swedish source.

1.2.1 Production Department A

Department A houses nine injection moulding machines that produce silicone rubber products. All machines produce products from the same product family and production is highly automated. Mounted to each machine is a robot that extracts the finished products and puts them in plastic bags. Refills of raw material, quality control and final packaging is handled by operators.

1.2.2 Production Department B

Department B is a cleanroom of ISO class 8 and houses ten injection moulding machines that produce plastic products. The grade of automation is similar to the one in department A, with the operators tasks being refills of raw material, quality control and final packaging. Instead of utilizing a robot, the finished products are dropped onto a conveyor that transports the products to plastic boxes.

1.2.3 Production Department C

Department C is a cleanroom of ISO class 8 as well, and houses four assembly machines.

1.3 Background

Nolato MediTech work in multiple ways to improve their productivity, and through this master thesis project the company wishes to focus on improving OEE on their injection moulding machines and assembly machines. Nolato MediTech already have a number of production cells connected to a system which measures OEE, RS Production from Good Solutions. The system has not been in use for quite some time, but with a new factory manager it is once again on the agenda and it has been decided to take the system into operation again.

1.4 Purpose and Goals

The assignment consists of the three following parts

- Coordinate between departments at Nolato MediTech and system supplier in order to solve the current technical problems with RS Production at each machine, so that the systems can be taken into operation again.
- To design and implement a standardised procedure to systematically analyse data from the producing units and thereby enabling improvement of their OEE.
- Evaluate whether RS Production is the right system for Nolato MediTech in the future.

1.5 Demarcations

This master thesis project will exclusively include the 14 machines which already have RS Production installed. They are divided between the three departments as follows:

- Department A
  - IMS1, IMS2, IMS3, IMS4, IMS5, IMS6, IMS7, IMS8, IMS9
- Department B
  - IMP1, IMP2, IMP3, IMP4
- Department C
  - A1

Only the current technical problems will be investigated in this project, and OEE is the only key performance indicator included in the analysis. The standardised procedure, which shall be constructed during the project, will be implemented exclusively into existing operating teams.

Note: Department C have taken action to start using RS Production by themselves before this project started, therefore focus will lie on the other two departments firstly. Furthermore, machine IMS5 was moved to another department during the middle of the project and consequently fell outside the scope of the project.

1.6 RS Production

RS Production is a system for production- and disturbance monitoring delivered by Good Solutions AB. It is currently installed on all machines in department A, some in B and one in C. The software logs all downtime, with the use of machine signals, and presents the downtime on a computer screen. It is then up to the operator to categorise the downtime, which means that he or she assigns the downtime to a predetermined category. Production rate losses are automatically calculated by the software but not categorised. Rejects have to be registered manually via the computer screen and then categorised in a similar manner to downtime, unless there is an automatic quality control which can then be used as input to RS Production.

Based on information regarding downtime, production rate losses and rejects, the software calculates OEE and related performance indices. The software is comprehensive and performance indices can be presented for a certain machine, time period, downtime category etc.

1.7 Structure of the Thesis

Firstly, theory on relevant subjects is presented. The theory is gathered from academic literature as well as various online sources. The general methodology to be used and its connection with the theory is then introduced, after which an execution-part goes into detail and fully describes the approach as well as any interim results and empirical findings. The final results of the project along with a discussion follows.

2. Theory

In this chapter, theory relevant to the project is presented. Firstly, systematic production analysis along with associated concepts, tools, procedures as well as some complementing tools are introduced. General theory on key performance indicators is then presented, including e.g. purpose, design, use, positive and negative traits, after which the key performance indicator OEE is thoroughly explained. Then, some design principals regarding human-machine-interface are introduced, and basic information on the manufacturing process of injection moulding of thermoplastics and liquid silicone rubber is presented. Lastly, how to use interviews as a qualitative research technique is explained since a major part of the information collection has been conducted through interviews with key people at Nolato MediTech.

2.1 Systematic Production Analysis

Systematic production analysis (SPA) is a systematic process of collecting and analysing various production data in order to represent real production conditions [6]. A SPA is to be used as a foundation when calculating production losses as well as form a basis for decisions regarding production development.

2.1.1 Production Performance

SPA is built around the three main result parameter groups prevalent in all types of industrial production of goods; rejects, downtime and production rate losses. These parameters, along with production cost, are all connected in a complex manner [6].

The three result parameter groups and their mutual influence can be translated to the concept of production performance. An adequate production performance essentially means that products are produced with the *right quality*, at the *right time* and for the *right cost* [6].

2.1.2 Result Parameters

The result parameter groups, as explained above, are essentially a break-down of the production performance into quantifiable terms, which will be further explained and exemplified by specific result parameters within the respective group.

Quality

Losses related to the quality of the product, such as rejects and reworks. The parameters should be divided based on the reason the product did not meet the quality requirement. Example:

- Q_1 - Dimension outside of tolerance.
- Q_2 - Surface quality outside of tolerance.
- Q_3 - Sub par material properties.

Downtime

Losses related to internal or external disturbances that require production to be halted. These parameters are preferably divided into two main groups:

- S_1 - Planned downtime.
- S_2 - Unplanned downtime.

The aforementioned division is interesting since planned downtime, such as maintenance, generally causes less problems than unplanned downtime, such as sudden break-downs or power outages.

Production Rate

Losses related to the need for reduced production rate. Ståhl [6] suggests that the parameters are divided into some levels of production rate that are easily identifiable. Example:

- P_1 - Production with 1/4 of optimal rate.
- P_2 - Production with 2/4 of optimal rate.
- P_3 - Production with 3/4 of optimal rate.

Environment and Recycling

This result parameter group, unlike the ones described above, does not describe production losses that amount to direct increased cost, but rather the environmental impact of the production. Example:

- MK_1 - Energy consumption.
- MK_2 - Material waste.
- MK_3 - Process additives.

2.1.3 Influencing Factors and Factor Groups

The production performance and subsequently the result parameters are governed by what's referred to as factors. It is according to Ståhl [6] not uncommon to identify up to 70 individual factors that have a significant influence on the production performance for a specific production segment, which means that some systematisation in the form of division is required. The factors are therefore divided into the following generic factor groups [6] that are applicable and adaptable to all kinds of manufacturing.

A. Tools and tooling systems - Problems caused by the tool used (in its non-worn state).

B. Workpiece and workpiece material - Problems caused by the workpiece, e.g. the material, its geometry and its surface.

C. Process and process data - Problems caused by the manufacturing process, e.g. equipment, process parameters and additives.

D. Personnel and organisation - Problems caused by e.g. handling, instructions and organisational structures.

E. Maintenance and service - Problems caused by the wear of tools and equipment.

F. Special factors - Problems caused by process-specific phenomena that sometimes occur despite correct process data.

G. Peripheral equipment - Problems caused by e.g. material handling equipment.

H. Unidentified factors - Problems caused by factors that are difficult to place in one of the factor groups above.

Factor groups A through D represent input to the manufacturing method, while E and F are consequences of ongoing production. Factor group H exists with the purpose of not tainting the other factor groups, thereby keeping a high data quality.

It is very difficult to identify all relevant factors before the monitoring process has begun. Even with an excellent understanding of the process in question, one cannot expect to be able to identify more than three quarters of the factors during the planning phase [6].

2.1.4 Production Performance Matrix

The production performance matrix, with the acronym PPM, is a tool to be used for SPA introduced by Ståhl [6] and presented in figure 2.1. Using the tool properly, it is possible to break down various production losses into their elements, clearly visualizing the biggest production pitfalls where the biggest room for improvement exist.

The PPM is built up by the factor groups as rows and the result parameters as columns. Factors and result parameters can, as previously suggested, be seen as the causes and effects related to production performance. The PPM is practically used to identify and quantify relations between factors and result parameters as well as calculate total losses related to a certain factor or a certain result parameter. The PPM can be seen in figure 2.1.

	Q. Quality	S. Downtime	P. Production Rate	MK. Environmental Impact	Σ Factors
A. Tools					
B. Workpiece and material					
C. Process					
D. Personell and organization					
E. Wear and maintenance					
F. Special process-related phenomena					
G. Peripherals					
H. Unidentified factors					
Σ Result parameters					

Figure 2.1: The Production Performance Matrix [6].

2.1.5 Monitoring

Ståhl [6] suggests a certain process be used when monitoring production with the use of a PPM:

1. Identification of result parameters.
2. Identification of influencing factors for each factor group.
3. Identification of possible connections between result parameters and factors.
4. Prioritisation of aforementioned connections.
5. Production monitoring where events connected to the result parameters are registered and corresponding factors are identified.
6. Analysis and preparation of collected data.
7. Making of a plan of action to optimise the production segment.
8. Manufacturing economic analysis and possible implementation of the aforementioned plan of action.
9. Follow-up and evaluation of implementation.

The quality of the production monitoring process explained above is highly dependent on competence. It is up to the operator to assign e.g. a certain downtime to a certain factor. This is often a subjective assessment, and requires a thorough understanding of the process. The factor group H exists with the purpose of not degrading the quality of information related to the other factor groups. A particularly large number of entries in factor group H speaks for a lack of understanding of the process, and competence development might be necessary.

2.1.6 Data Collection

The PPM is reliant on large amounts of production data, meaning that reliable data collection is the foundation of SPA. Ståhl has subsequently identified some common drawbacks of data collection- and monitoring systems [6]:

- Insufficient information resolution. Error codes are not sufficiently precise in their nature, making it difficult to identify the real causes of disturbance.
- Lacking use of collected information. The information collected is not used, often because of a lack of time and the complexity of proper analysis. This demotivates operators to continue using the PPM.
- The system offers low flexibility. The operators' possibility to describe and input the disturbances in a structured way is limited.
- Poor adaptation to current application. The system does not sufficiently represent the reality in which machines and operators operate.
- Lacking identification of connections. The system lacks ability to connect causes to effects, i.e. the system does not connect factors to result parameters.

2.2 Five Why

If one struggles to find influencing factors for the SPA, Five Why can be used as a complementing tool. Five Why is a method used to find root causes of problems originally developed by Sakichi Toyoda in the 1930s. In the 1970s it was implemented in Toyota Motor Corporation's Toyota Production System by its architect Taiichi Ohno [7], whereupon it became widespread.

The method is very simple. When presented with a problem, one should ask oneself "why" until the root cause of the problem has been identified. The method has gotten its name because five questions usually suffice and can be used as a rule of thumb, but the required number of questions can vary. Below follows an example of the method in practice, devised by the authors.

Problem: Machine has stopped.

1. Why has it stopped?
   (a) Because it overheated.
2. Why did it overheat?
   (a) Because there wasn't enough coolant.
3. Why wasn't there enough coolant?
   (a) Because it hadn't been refilled.
4. Why wasn't it refilled?

   (a) Because no one noticed the low coolant level.

5. Why didn't anyone notice that the coolant level was low?

   (a) Because checking the coolant level isn't part of the daily routine.

Solution: Include checking of coolant level in daily routine.

The method has however been criticised by former managing director of global purchasing at Toyota Motor Corporation Teruyuki Minoura [8]:

- Investigators have a tendency to stop the analysis prematurely, only reaching symptoms and not actual root causes.

- The method is only effective if the investigator has enough knowledge of the problem in question.

- Non-repeatable results. The method applied to the same problem can generate different root causes depending on the investigator.

- Investigators have a tendency to isolate one root cause, while there may actually be several.

2.3 Ishikawa Diagram

Another tool complementing SPA that can be used to identify connections between result parameters and factors is the Ishikawa diagram, also called fishbone diagram. The Ishikawa diagram is a tool which is used to explore possible causes for a problem that was devised in the 1960s by Kaoru Ishikawa, but published in 1990 [9]. The tool was originally developed for quality control, but can be applied to most situations. There are essentially four steps related to using the tool:

1. Identify the problem.

2. Identify major factors.

3. Identify causes related to the major factors.

4. Analyze the diagram.

An example of an Ishikawa diagram can be seen in figure 2.2. The yellow box to the left is the problem (if used with SPA, the result parameter), the first level branches are the major factors (factor groups) and the second level branches are the causes (factors). Note that there can be more levels of branches if necessary.

The comprehensive nature of the Ishikawa diagram makes it an appropriate tool for handling complex problems, contrary to the Five Why-method discussed in section 2.2. Five Why can however be used in conjunction with the making of an Ishikawa diagram, if one struggles to find root causes.

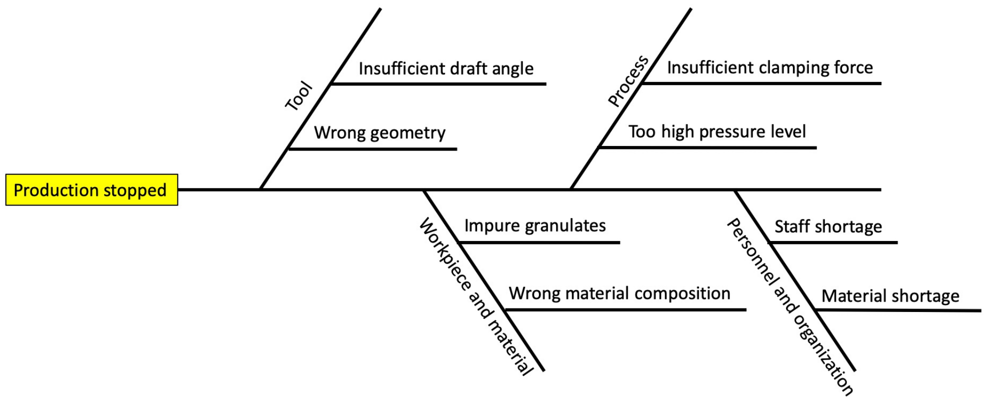


Figure 2.2: Ishikawa diagram, created by the authors.

2.4 Key Performance Indicators

The purpose of a key performance indicator (KPI) is to verify that the company actually follows the corporate strategy, and to help in decision-making. Three primary ways of using KPIs are reporting, verification and monitoring as well as working with improvements. Reasons for reporting could be mandatory reporting based on legislation, annual reports or CSR reports, internal benchmarking or internal reporting. Verification and monitoring is performed to secure that a measure is within its acceptable interval. When working with improvements, KPIs provide an understanding of where improvements need to be done and also an understanding of when they have been achieved [10].

A KPI should be easy to understand with a distinct definition that can be tied to corporate goals and the manufacturing strategy. The input parameters must be easy to collect and the KPI should give fast feedback. All KPIs must have a clear purpose and be independent of one another, to the maximum extent possible. Some common pitfalls when using KPIs [10] are:

- Using too many KPIs.
- The KPIs that are in use have no clear definition.
- The personnel actually using the KPIs further down in the company are at risk of having little say in which KPIs are being used, and how they are used, which can lead to low acceptance and frustration.
- Measuring what is available instead of what is necessary.
- Suboptimisation among the KPIs.
- False reassurance of understanding the process better than in reality.
- Less communication face to face.

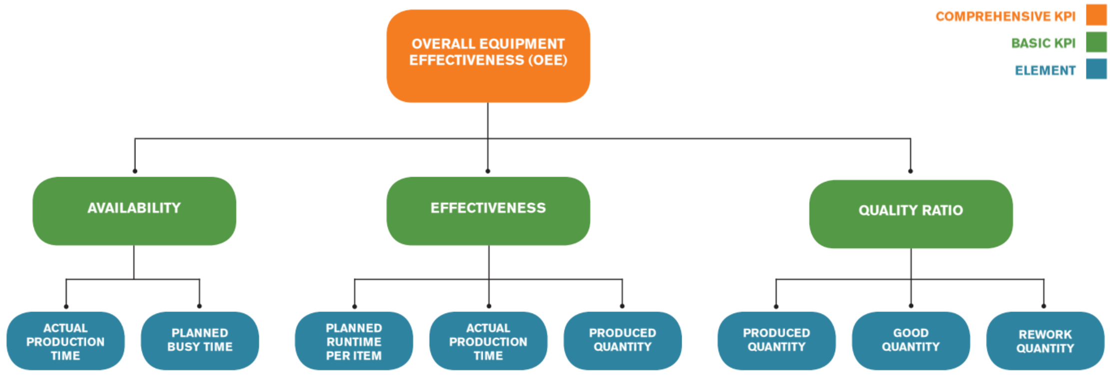


Figure 2.3: Elements building up basic KPIs and comprehensive KPIs. Example of OEE from the SuRE BPMS project [10].

It is important to set clear goals and target values and then communicate these goals to everyone that is affected by the KPI. It is also important to monitor the chosen KPIs before, during and after an improvement project. When using KPIs as improvement drivers it is essential to use reliable input data for all calculations. To collect reliable data from a production process requires an implemented procedure regarding data collection, preferably supported by automatic data collection and software with user-friendly templates [11]. To make each team responsible for setting targets and define measurements for their own unit will motivate employees throughout the company to participate in data acquisition and improvement work. To achieve success there is a great need for management attention, training and education, as well as employee empowerment and alignment to a long term strategy [10].

When working with KPIs it is important to understand how they are constructed. A measure is a direct result of a measurement, while an indicator is often compiled using two or more measurements. A measure could be a KPI in itself but is often aggregated or mathematically transformed into a KPI. In its turn basic KPIs could be compiled into a more comprehensive KPI, like OEE for example, see figure 2.3. It is essential to have an understanding of each element building up the KPIs, as well as to have a support system of measurement equipment and analytical tools. To write an effective objective for a KPI, the acronym SMART is worth having in mind, which is defined by Doran [12] as:

- ***S**pecific - target a specific area for improvement.*
- ***M**easurable - quantify or at least suggest an indicator of progress.*
- ***A**ssignable - specify who will do it.*
- ***R**ealistic - state what results can realistically be achieved, given available resources.*
- ***T**ime-related - specify when the result(s) can be achieved*[12, p. 36].

Figure 2.4 displays the life cycle of a KPI, which gives a good overview of how everything around a KPI is connected and how it should be used.

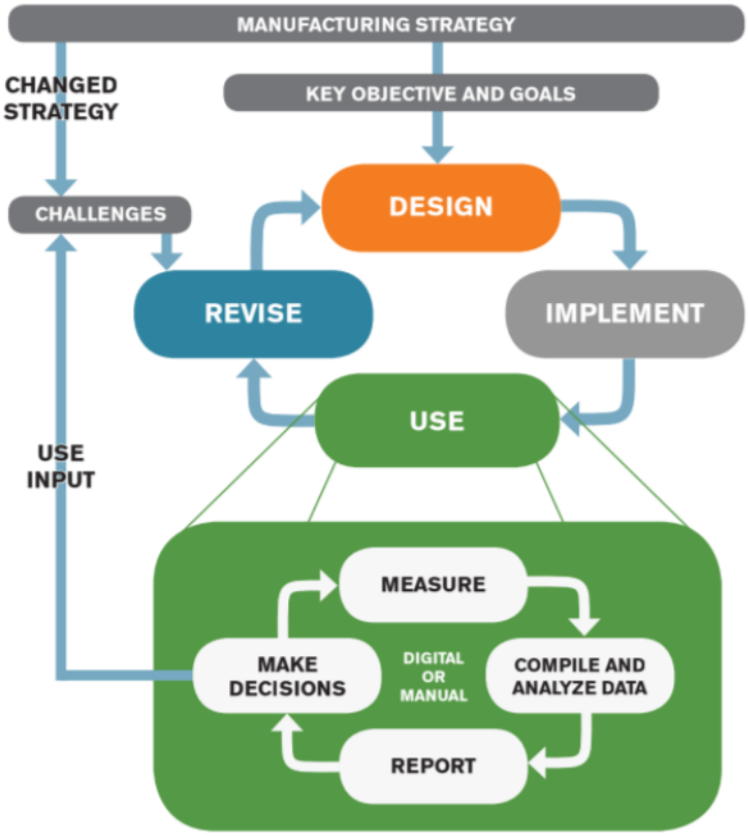


Figure 2.4: The life cycle of a KPI, as defined in the SuRE BPMS project [10].

2.4.1 Overall Equipment Effectiveness

Overall Equipment Effectiveness, acronym OEE, is one of the most commonly used KPIs in modern industry. The KPI was originally defined within the concept Total Productive Maintenance (TPM) [6]. TPM works to eliminate six big losses in order to achieve overall equipment effectiveness. The losses [13] are:

Downtime

1. Equipment failure - from breakdowns.
2. Setup and adjustment - from exchange of die in injection moulding machines, etc.

Speed losses

3. Idling and minor stoppages - due to the abnormal operation of sensors, blockage of work on chutes, etc.
4. Reduced speed - due to discrepancies between designed and actual speed of equipment.

Defects

5. Process defects - due to scraps and quality defects to be repaired.

6. Reduced yield - from machine startup to stable production.

When calculating OEE three aspects of the production process are taken into account, the *Availability*, the *Performance* and the *Quality* of the process, see figure 2.5.

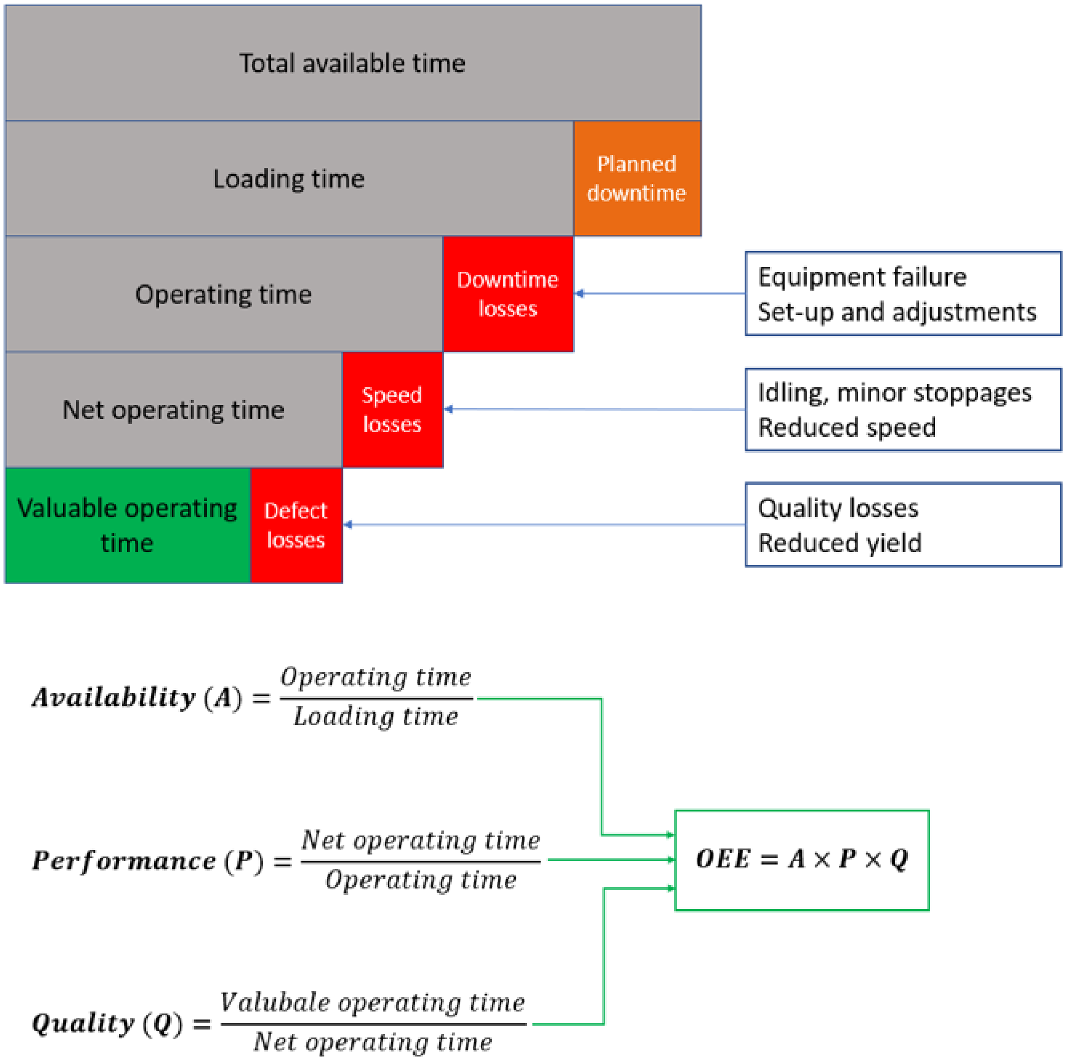


Figure 2.5: The definition and computation of OEE as originally defined by Nakajima [13], visualisation inspired by the processing of Andersson et al [14].

The availability of a process is calculated according to equation 2.1, where the loading time, which is the same as the available time, is given by subtracting the planned downtime from the total available time. The planned downtime includes scheduled maintenance and management activities, and is the amount of downtime officially scheduled in the production plan. The operation time is obtained by subtracting downtime losses from loading time, which gives the time during which the equipment is actually operating. Downtime losses include failures, setup and adjustment procedures, exchange of dies etc [13].

$$Availability = \frac{Loading\ time\ \text{-}\ Downtime\ losses}{Loading\ time} = \frac{Operating\ time}{Loading\ time} \quad (2.1)$$

Performance efficiency is calculated according to equation 2.2. The net operating rate, see equation 2.3, measures how well a given speed is maintained during a given period, not taking into account the speed itself. It captures losses from minor recorded stoppages, and the ones that go unrecorded, like adjustment losses and small problems. The operating speed rate refers to the deviation between the ideal speed of an operation and its actual operating speed, see equation 2.4.

$$\begin{aligned} Performance &= Net\ operating\ rate \times Operating\ speed\ rate = \\ &= \frac{Processed\ amount \times Ideal\ cycle\ time}{Operating\ time} = \\ &= \frac{Net\ operating\ time}{Operating\ time} \end{aligned} \tag{2.2}$$

$$\begin{aligned} Net\ operating\ rate &= \frac{Actual\ processing\ time}{Operating\ time} = \\ &= \frac{Processed\ amount \times Actual\ cycle\ time}{Operating\ time} \end{aligned} \tag{2.3}$$

$$Operating\ speed\ rate = \frac{Ideal\ cycle\ time}{Actual\ cycle\ time} \tag{2.4}$$

The rate of quality products, i.e. the share of approved products, can be calculated in amount of products as well as in production time, see equation 2.5.

$$\begin{aligned} Quality &= \frac{Processed\ amount\ \text{-}\ Defect\ amount}{Processed\ amount} = \\ &= \frac{Net\ operating\ time\ \text{-}\ Defect\ losses}{Net\ operating\ time} = \frac{Valuable\ operating\ time}{Net\ operating\ time} \end{aligned} \tag{2.5}$$

Based on experience, Nakajima [13] states that the ideal conditions for a producing company are:

- Availability - greater than 90 %
- Performance efficiency - greater than 95 %
- Rate of quality products - greater than 99 %

These ideal conditions lead to an overall equipment effectiveness of 85 % or higher, as shown in equation 2.6. For non-process industry, an OEE level of 85-92 % is considered world class [11].

$$OEE = 0.90 \times 0.95 \times 0.99 = 0.85 \tag{2.6}$$

OEE does have a globally standardised definition, as explained above, but how it is interpreted differs somewhat between companies. According to Andersson et al. [11], what should be counted as planned or unplanned time is what varies, as well as how to define the ideal cycle time.

OEE is used for monitoring production performance and is often included in a company's performance measurement system. It can be used for improvement work and internal benchmarking. OEE is mainly used by companies who have high volume processes, who prioritise capacity utilisation and where disruptions are expensive. Because of the fixed cycle time parameter, automatic or semi-automatic processes are the most common area of use for OEE. For producing companies, in general, a real challenge is to attain and keep a stable and robust performance level, which can be indicated by a stable OEE.

Since OEE combines availability, performance and quality, it is a very useful production performance measure and probably one of the best to be used by production management. On the other hand there is no clear relation between cause and effect on the OEE value, when changing one or more of the three factors which can make the understanding of the measure a bit complicated [11]. Also, when calculating OEE the ideal cycle time will have to be assumed fixed for each machine and product, at least in short term, which controls the capacity of the process [14]. This, in combination with OEE not including the number of people working in a process, means that OEE does not fully capture improvements in productivity that comes from altering the process constraints, like the input or the optimal cycle time of a process, because OEE is not designed to relate input to output. Instead, OEE is useful in a more reactive approach to improve capacity, since reduction or elimination of disturbances and deviations will have a greater impact on the OEE numbers, making OEE an excellent driver for achieving and improving process stability. Because OEE does not fully capture and push productivity improvements, the measure needs to be combined with other measures which cover the gaps of OEE to give a complete view of the productivity of a process. Other measures could for example be production pace or part cost [11].

A possible strategy for achieving productivity improvements could be to first gain a stable and high OEE value by increasing the performance, availability and quality parameters, then switch to an approach that instead focuses on decreasing the ideal cycle time or improving other process constraints. The latter might result in a drop of the OEE value, even though the actual process output is increased, and therefore it is important not to stare blindly at the OEE value. When the improvement of the process parameters are completed, it is once again advantageous to aim for a high and stable OEE, working with the performance, availability and quality parameters [11].

There are some challenges when it comes to implementing OEE as a tool for monitoring and managing production performance, according to Andersson et al.[11]:

- *how it is defined, interpreted and compared;*
- *how the OEE data is collected and analyzed;*
- *how it is monitored and by whom;*
- *how it aligns with the overall production strategy;*
- *how it could be utilized for sustainability purposes [11, p. 145].*

These challenges involve management as to how the structure of the procedure should look, what approach to use, how to create involvement throughout the company, from managers to team leaders and operators, and make sure everyone gets appropriate training and have an awareness of why the implementation is necessary. But if implemented in a correct and structured way, OEE as a driver for improvements could increase production performance. As stated by Andersson et al. [11], to evaluate the success of an implemented improvement it is not enough to track changes. The expected or set goal needs to be evaluated as well, and there needs to be an alternative plan if the goals are not reached [11].

In their study on OEE and productivity as performance measures, Andersson et al. defined some success factors of generic interest [11]:

- Having a common level of understanding regarding definition of OEE and data collection technique with their potentials and limitations is fundamental. Therefore extensive training regarding the standard definition of the measures used must be performed.

- Correct input data is essential, which requires support from software, templates or calculation sheets, as well as a structured approach in identifying potential causes of disturbance in the production process.

- To support the need for an organisation to grow in awareness and with the knowledge of how to work with improvements, it is advantageous to use the approach of starting with OEE and continuing with productivity.

- The risk of making ad hoc decisions and activities increases if KPIs are used without a structured approach for making improvements.

- To analyse the combined effect of an improvement activity and be able to prioritise between different activities with cost efficiency as a target is a valuable opportunity and therefore it would be advantageous to add a cost parameter to drive improvements.

2.5 Human Machine Interface

The purpose of a Human Machine Interface (HMI) is in essence to transfer information between the user and the computer system. A well designed HMI is essential to reduce user errors and improve various aspects of decision making. Since it involves human behaviour and cognition, it is a complex subject for which problems do not have one correct answer. Basic principles based on psychological considerations do however exist, some of which will be presented here.

All theory presented in this section is collected from *Computer Systems for Automation and Control* by G. Olsson and G. Piani [15]. HMI is a term that generally is used for systems that are to be controlled by a graphical interface. In this case, however, no physical process will be controlled by the system. Some of the otherwise important aspects of HMI, mainly design of commands, will therefore be excluded.

Some principles regarding general design, screen layout and menus are presented below.

2.5.1 General Design Principles

- Average computer users treat everything presented on-screen as equally important. It is therefore important to not show too much information.

- It is important to know the user, both in terms of background and information need. What's important to an operator might not be important to a production manager, and a certain colour or symbol might have different meanings for a Swedish person and for a Chinese person.

- Structuring is hugely important. Each screen should only show one main concept, meaning that everything on-screen at the same time should be related in some way, shape or form.

- You should not have to click your way through many menus to get to the info you want.

- All data should be presented in a consistent manner. Once you've learned how to navigate one menu/page/screen, you should be able to navigate them all.

- Tactility. It is very important that the user gets immediate response from their action. E.g. the clicked button gets highlighted, a vibration, a sound or a written message of acknowledgement, letting the user know that the system works as intended. Any delay will confuse the user, making them believe that the system is faulty or the button press hasn't been registered.

2.5.2 Screen Layout Design Principles

- Natural movement of the eye is from left to right. Drawings or evolutions of processes should be represented on the horizontal axis, from left to right.

- All screen layouts should be consistent. One big work area in the middle, one small static information area at the top, and two small areas for Control and System Message at the bottom.

- Proximity (grouping), symmetry or similarity should be used in order to represent a structure.

- Colours are a powerful tool, but should be used with care. Four to five colours can be understood easily, with seven colours being the absolute maximum. More colours will just confuse the user.
  - Consistent use of colours. One colour should have one meaning throughout the interface.
  - Natural colours can be used to represent functionality. Some classic examples, that apply through most cultures, are red = bad, green = good, yellow = warning.
  - Colour combinations should be pleasant and easy on the eye, meaning high contrast between foreground and background.

  - Important information should not be conveyed by colours alone. Because of colour blindness, redundancy should always be used when dealing with colours and important information.

- A drawing is the most natural representation of an object and a very powerful tool.

- Text should never blink to emphasize a message, because it makes the text harder to read. A small symbol beside the text can blink instead.

- The display layout should interest and motivate the user.

2.5.3 Menu Design Principles

- The structure of the menu should be easily understandable, with an explanatory title or headline.

- It should always be possible to easily return to the higher menu level.

- All items in a menu should be of the same abstraction level.

- The number of choices in one menu should be limited. The rule of 7 ± 2 as suggested by Miller [15] should be applied.

- Unrelated questions should not be put on the same menu. This ties in with the "one screen - one concept"-principle.

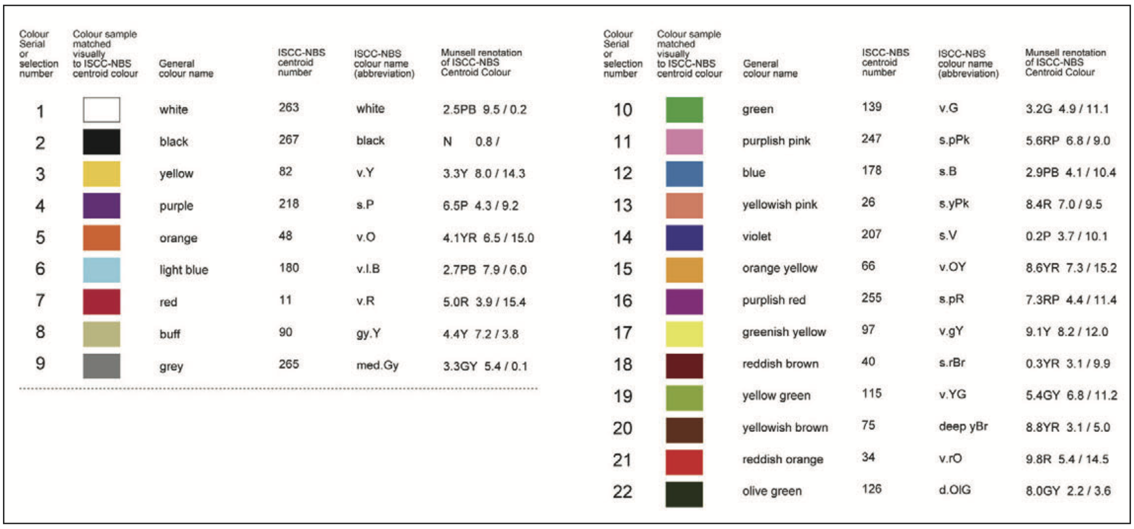
2.6 Colour Coding

Colour coding, as mentioned in section 2.5, can be a powerful tool to convey information. However, when colours are not really used to convey a certain piece of information, but only used to accentuate different entities, how should the colours be selected for maximum distinguishability? Kenneth L. Kelly has proposed a list of 22 colours that, when used in the suggested order, maximizes contrast [16]. A list of the colours can be seen in figure 2.6.

The first nine colours are designed to work for observers with normal as well as red-green-deficient vision, whereas the remaining 13 colours only work for observers with normal vision [16].

2.7 Injection Moulding

Injection moulding is the process of forcing a liquid substance into a mold cavity where it's subsequently set. A schematic example of a plastics injection moulding machine can be seen in figure 2.7.



Colour Serial or selection number	Colour sample matched visually to ISCC-NBS centroid colour	General colour name	ISCC-NBS centroid number	ISCC-NBS colour name (abbreviation)	Munsell renotation of ISCC-NBS Centroid Colour
1		white	263	white	2.5PB 9.5 / 0.2
2		black	267	black	N 0.8 /
3		yellow	82	v.Y	3.3Y 8.0 / 14.3
4		purple	218	s.P	6.5P 4.3 / 9.2
5		orange	48	v.O	4.1YR 6.5 / 15.0
6		light blue	180	v.l.B	2.7PB 7.9 / 6.0
7		red	11	v.R	5.0R 3.9 / 15.4
8		buff	90	gy.Y	4.4Y 7.2 / 3.8
9		grey	265	med.Gy	3.3GY 5.4 / 0.1
10		green	139	v.G	3.2G 4.9 / 11.1
11		purplish pink	247	s.pPk	5.6RP 6.8 / 9.0
12		blue	178	s.B	2.9PB 4.1 / 10.4
13		yellowish pink	26	s.yPk	8.4R 7.0 / 9.5
14		violet	207	s.V	0.2P 3.7 / 10.1
15		orange yellow	66	v.OY	8.6YR 7.3 / 15.2
16		purplish red	255	s.pR	7.3RP 4.4 / 11.4
17		greenish yellow	97	v.gY	9.1Y 8.2 / 12.0
18		reddish brown	40	s.rBr	0.3YR 3.1 / 9.9
19		yellow green	115	v.YG	5.4GY 6.8 / 11.2
20		yellowish brown	75	deep yBr	8.8YR 3.1 / 5.0
21		reddish orange	34	v.rO	9.8R 5.4 / 14.5
22		olive green	126	d.OlG	8.0GY 2.2 / 3.6

Figure 2.6: The 22 colours of maximum contrast. Figure designed by Green-Armytage [17] based on the research of Kelly [16].

2.7.1 Thermoplastics

Material Supply and Injection Unit

Plastic granules are stored in containers separate from the injection moulding machine. Using vacuum pumps, the granules are transported to dryers since moisture has a negative effect on the manufacturing process. The desiccated granules are then transported to the hopper of the injection moulding machine, yet again using vacuum pumps. From the hopper, the granules enter the barrel. In the barrel one finds a reciprocating screw. The flights of the screw transport the granules towards the mould and mixes the granules homogeneously. The shaft of the screw, contrary to what can be seen in figure 2.7, gets thicker towards the right end. This introduces a shearing action to the granules as they are pushed to the inner wall of the barrel, supplying up to 90% of the heat required for them to melt. The remainder of the heat is supplied by the external heater, ensuring that the mixture is completely molten as it reaches the end of the barrel. When enough molten material has been brought forward by the rotating action of the screw, the screw moves linearly along its axis, pushing molten material into the mould. Backflow of molten material is prevented by closing off the barrel with the use of a thrust ring and a check ring that together form a seal as the screw moves forward.

Clamping Unit

As the molten material is pushed through the nozzle it enters the mould. The mould consists of two main blocks of high strength steel. Note that each block can consist of several assembled smaller blocks depending on the exact mould. The geometry of the product to be formed is machined into the faces of the mould halves in such a way that when the two mould halves are brought together, the resulting cavity shares the final product's shape. To be able to fill the cavity with plastic, a channel is needed between the nozzle and the cavity. If the mould has

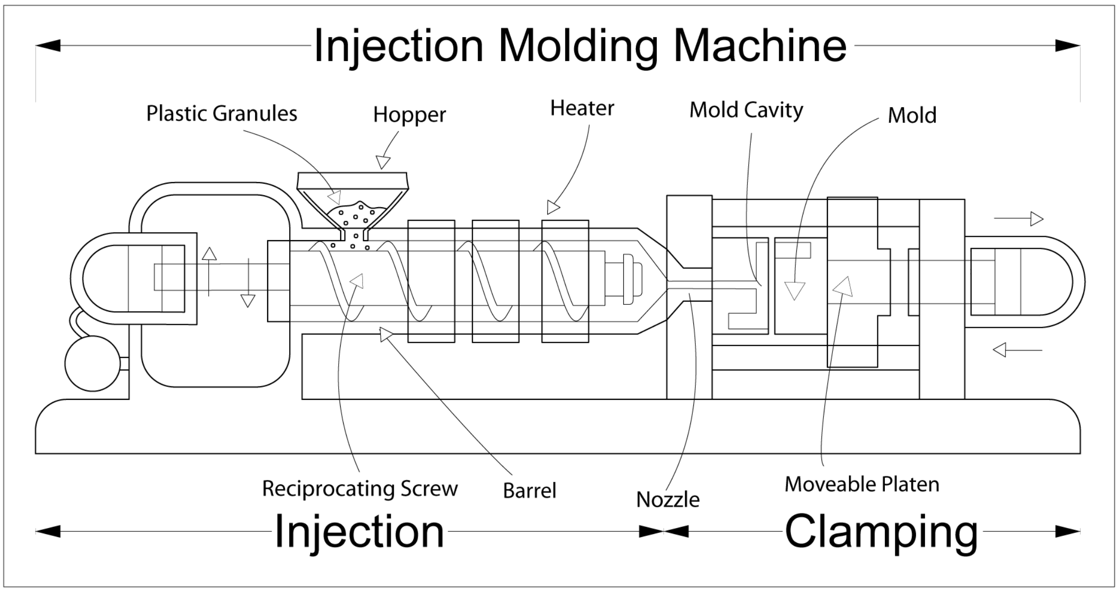


Figure 2.7: Schematic view of an injection moulding machine [18].

several cavities, meaning that several products can be made with a single shot of plastic, runners are necessary. Runners are smaller channels that connect the cavities with the main channel. The runners can be cold or heated. Cold runners are cheaper, but require excess plastic that has solidified in the runners and the main channel to be removed. Hot runners require additional technology and is subsequently more expensive, but they eliminate the need of removing material from the product, since the material in the runners never solidify. To enable a faster cooling process, cooling channels close to the cavity are machined into the mould as well. Prior to the cavity being filled with molten material, it is filled with air. For the air to be able to escape, air vents need to be made. Air vents are machined into the face of the mould and are so shallow that the viscosity of the molten material does not let it through, usually in the micrometer territory.

When the mould halves are brought together, they are never perfectly aligned, nor are the corners ever completely sharp. For these reasons, a so called parting line is visible on the final product. This is something that has to be accounted for, since a parting line affects the look and functionality of a surface.

When the material has solidified in the cavity and adopted the final shape, the mould is opened by separating the mould halves. Since the material shrinks slightly as it solidifies and cools, the product sticks to the core-half of the mould. To free the product, ejector pins are used. These pins simply push the product off the mould. The ejector pins are part of the mould, and they never sit completely flush with the face of the mould, resulting in what's referred to as ejector pin witness marks. In order to be able to free the product from the core-half of the mould without it being damaged, the product needs to be designed with a draft angle of 1-2 degrees. Otherwise, if the walls of the product are parallel to the horizontal axis, the product will scrape the core-half of the mould, and a hard-to-break vacuum will form between the mould and the product making it very difficult to remove.

2.7.2 Liquid Silicone Rubber

Material Properties

Liquid silicone rubber is a thermosetting material with a wide range of advantageous properties making it suitable for many demanding applications. For starters it is bio-compatible, hypoallergenic, tasteless, odorless and highly inert [19]. Thanks to these properties, silicone rubber is widely used within medical technology and healthcare as well as for cookware and various food-contact products. The material is fire retardant and highly resilient to fluctuations in temperature, maintaining its high tear strength and high elongation from roughly -60 to +180 °C [20]. Resistance to electromagnetic radiation, particle radiation and many chemicals in combination with the aforementioned heat resistance makes it compatible with most sterilization methods, further improving its use in medical applications [19]. Other properties include excellent non-stick capacity, optical transparency, excellent electrical insulation and excellent resistance to oxygen, ozone and ultraviolet radiation [19].

Material Supply and Injection Unit

Liquid silicone rubber is a two-component material delivered in two containers, typically denoted A and B. The material starts to cure immediately upon mixing of the two components, and the cure rate is strongly dependent on temperature [20].

Each component is pumped from the container to a metering unit. The metering unit ensures that the two components are supplied in equal parts. The components then enter a static mixer in order to obtain a homogeneous mixture. This is where curing commences, and it is therefore imperative to keep the mixture cool until it enters the mould. A static mixer, as opposed to a dynamic mixer, is used as it has no moving parts and therefore generates little heat. The metering unit and the mixer are conceptually the counterpart of the hopper in thermoplastics injection moulding machines, and after mixing the mixture enters the injection moulding machine [20].

Since the material is supplied in liquid form, as opposed to granular form, the rest of the injection unit also differs somewhat from that used in a thermoplastics injection moulding machine. The mixture enters the barrel and the reciprocating screw is used to pressurize the mixture before injecting it into the mold. Since the mixture is already liquid, the sole purpose of the screw is to transport/pressurize the material. For this reason, the flights of the screw have a constant depth [21]. Contrary to thermoplastics injection moulding, because of the thermosetting nature of the material, the barrel is liquid cooled [21].

Clamping Unit

The clamping unit of a liquid silicone rubber injection moulding machine is largely similar to the one of a thermoplastics injection moulding machine. The design of the moulds follow the same general principles as for thermoplastics, with one key difference being that the tool is heated instead of cooled, and the runners are cooled instead of heated. To minimize the curing time once the material has entered the mould, the mould should be kept at over 150 °C [20]. As liquid silicone rubbers are shear-thinning and some liquid silicone rubbers have a very low viscosity even at low shear rates, high demands are placed on the mould to avoid flashing [20].

Liquid silicone rubbers are very flexible, but thanks to their high tear-strength an array of demolding techniques can be used, such as ejector pins, air ejection and robotic handling. [20].

2.8 Interviews as a Qualitative Research Technique

Interviews are commonly used as a qualitative research technique and can be divided into three different types; structured, semi-structured and unstructured interviews. These will be explained further into this section.

The advantage of using interviews as a qualitative research technique is that the interviewer are able to collect detailed information and has direct control over the process, being able to clarify any issues that arise during the interview if needed.

Difficulties, on the other hand, include longer time requirement and arranging an appropriate time for conducting the interview that suits all participants.

To hold a successful interview, it is important to keep an open mind during the interview and create a friendly atmosphere as well as giving a brief introduction to the study and stress the importance of the interviewees participation. Assure anonymity or confidentiality if that is of importance to the study and to the interviewee. It is also important to avoid interviewer bias by not overreacting to responses during the interview [22].

Structured Interviews

Structured interviews consist of a predetermined set of questions that will have to be answered in a certain order. Having the exact same structure on every interview makes data analysis more straightforward, since answers given to the same questions can be compared and contrasted [22].

Semi-structured Interviews

In a semi-structured interview, the interviewer asks all interviewees the same set of questions. Additional questions can however be asked during the interview to further expand certain issues, or to clarify something. These additional questions can differ between interviews [22].

Unstructured Interviews

Unstructured interviews are conducted without any prepared questions and the data collection is quite informal. Comparing answers from different interviews tend to be difficult and this type of interview is often associated with a high level of bias, which is why unstructured interviews are the least reliable sort of interview from a research perspective [22].

3. Methodology

In this chapter, the general methodology applied to the project is explained in detail.

3.1 Current Monitoring System

3.1.1 Learning the Software

The software offers a wide range of features, some of which are not of interest in this project. Instead of becoming experts in managing the software and letting the capabilities of the software dictate its use, the authors' approach is to investigate which features that are necessary for sufficient production monitoring, locate adequate features in the software and subsequently learn them. Using this approach is more time efficient.

The identification of necessary steps to perform an adequate production monitoring will be based on the theory regarding systematic production analysis, key performance indicators and OEE, and software features corresponding to these steps shall be identified and learned.

Since learning how to use the software will be a highly dynamic issue, the process will be carried out during the majority of the project.

3.1.2 Main Screen and Menus

The main screen and the various menus will be designed in accordance with the required features according to above and with the theory presented on HMI in section 2.5.

3.1.3 Software Settings

The advanced settings of the software will be controlled, tweaked and validated to ensure that the production data is collected, analysed and prepared according to the theory presented on OEE.

3.1.4 Calculation of OEE

A thorough comparison between how OEE is calculated in the current monitoring system, from hereby referred to as the CMS, vs. the original definition presented in chapter 2.4.1 will be conducted.

3.1.5 SPA Using the Current Monitoring System

In order to assess whether the CMS is the right production monitoring system for Nolato MediTech, the capabilities and limitations of the system will be investigated and compared with the use of a PPM for SPA.

3.2 Technical Problem Solving

The CMS was implemented and installed on some machines in 2017. Frequent technical problems and a lack of drive however lead to the system not being used at all. These technical problems will have to be resolved before a live implementation is in question.

3.2.1 System Monitoring

In order to find the causes of the problems and thereby be able to solve them, the systems will be monitored. Since there is no data on the previous problems, it is not possible to predict how frequently the problems appear. It is therefore decided that the systems will be monitored until a week has passed without new, unfamiliar problems surfacing.

3.2.2 Action Proposal

When the systems have been monitored for a sufficient amount of time and all current technical problems have been identified, a list of solutions to the problems will be prepared and presented to the factory manager.

3.3 Reason Collection

As suggested in section 2.1.4, a fundamental principle of systematic production analysis is to relate the right result parameter to the right factor (referred to as a *reason* in the software). To find the most common reasons, experienced operators and process technicians will be interviewed and the production process will be researched. Based on the interviews and gathered information, reasons will be added to the software.

3.3.1 Reason Categorisation

The reasons will be categorised according to the factor groups in the production performance matrix presented in section 2.1.4. Some factor groups might be divided into subcategories with the purpose of increasing intuitiveness.

3.3.2 Reason Structure and Naming

The reasons are to be structured in an intuitive, systematic way. The names of the reasons are to be designed in such a way that they are easily structured and handled in environments other than the CMS, e.g. an external database.

3.4 Systematic Monitoring of OEE

3.4.1 Current Organisational Structure

The current organisational structure at the company, with a considerable focus on the production departments, will be investigated and mapped. This investigation will be conducted by performing semi-structured interviews with key figures as well as observing different organisational meetings and examining documents regarding organisational structures and procedures.

3.4.2 Design of Systematic Procedure

Based on the theory presented on SPA, key performance indicators and OEE, a systematic procedure of monitoring, analysing and improving OEE will be designed. The current organisational structure will be taken into account so that the procedure can be effectively merged with the organisation without requiring major altercations.

3.4.3 Routine to Collect New Reasons

As mentioned in 2.1.3, not all reasons can be collected before production monitoring is begun. For this reason, a systematic way of intercepting new reasons and adding them to the software after which monitoring has begun will be implemented. This routine will be dictated by the available software functions.

3.4.4 Roles and Responsibilities

Since an implementation of systematic data collection and analysis is highly reliant on not only well working technical equipment, but also on well working organisational structures it is imperative that the suggested systematic procedure is divided into appropriate chunks, with clearly defined roles and responsibilities, mainly focused on handling the software. To aid in deciding the scopes of these roles, the current organisational structures will be considered.

The authors will then prepare documentation on which roles and responsibilities that are required, and it is then up to the company to appoint certain people.

3.4.5 Education

Before the systematic procedure can go live, people will have to be properly informed and educated. All machine operators will have to be educated in using the software to log production data, and depending on the established roles and responsibilities, additional personnel have to be educated in using various parts of the software, e.g adding or altering reasons and using the analytical and administrative parts of the software. The authors will be required to assess the level of interaction needed for every role and design educational material accordingly.

In addition to education concerning the technical workings of the software, all affected personnel have to be informed about how the systematic procedure will look, what is to be done, when, by whom etc.

It is also of great importance to explain, especially to the blue-collar personnel that might not have the same insight into production monitoring, what is measured, how it's measured and why it's measured.

Documents containing specific information regarding the aforementioned material will be prepared.

3.4.6 Benchmarking

Nolato MediTech's factory in Lomma also uses the CMS to some extent. The system is installed on approximately 15 % of their machines, all of them injection moulding machines. By interviewing their Lean Coordinator and CMS-responsible, a comparison will be made between their approach and the one in this project. The comparison will cover the follow-up process, including responsibilities and necessary education, reason categorisation, system stability as well as software settings.

4. Execution and Empirical Findings

The following chapter describes the execution of the project in detail, together with empirical findings that will in its turn lay the foundation for the final results of this project.

4.1 The Current Monitoring System

4.1.1 Learning the Software

The supplier of the software offers digital training for the CMS in the form of interactive online tutorials. These, in combination with user training material provided to Nolato MediTech prior to this project, were utilised.

The software offers the ability to export the system data to a local model. Working on the local models enables one to make various changes without the live model being affected. This eliminates the need to worry that one might change an important setting or push a button that degrades the monitoring, and enables a great deal of freedom for learning. The tutorials provided by the supplier were conducted in this protected environment.

4.1.2 Hardware and Technical Workings

A simplified, schematic overview of the current monitoring system can be seen in figure 4.1. The machine is connected to a so called Black Box. This device interprets the signals from the machine to register when the machine is running, when it is stopped, how many products that have been produced, how long the cycle time is etc. and sends the data to the computer placed by the machine, referred to as the operator terminal. The operator terminal then transmits the data to a server where it's stored and processed so that it can then be accessed from multiple clients.

Input data

The CMS is connected to Nolato MediTechs ERP system as shown in figure 4.1 and it is from the ERP system that the CMS receives information regarding production orders. Information about an order includes order number, article, ordered quantity, scheduled start of production, the optimally produced amount per hour, which machine the order is assigned to and the expected efficiency of the order (i.e. the expected OEE-value). There is also more detailed input data regarding each article, such as units per cycle which specify the number of cavities in the tool being used.

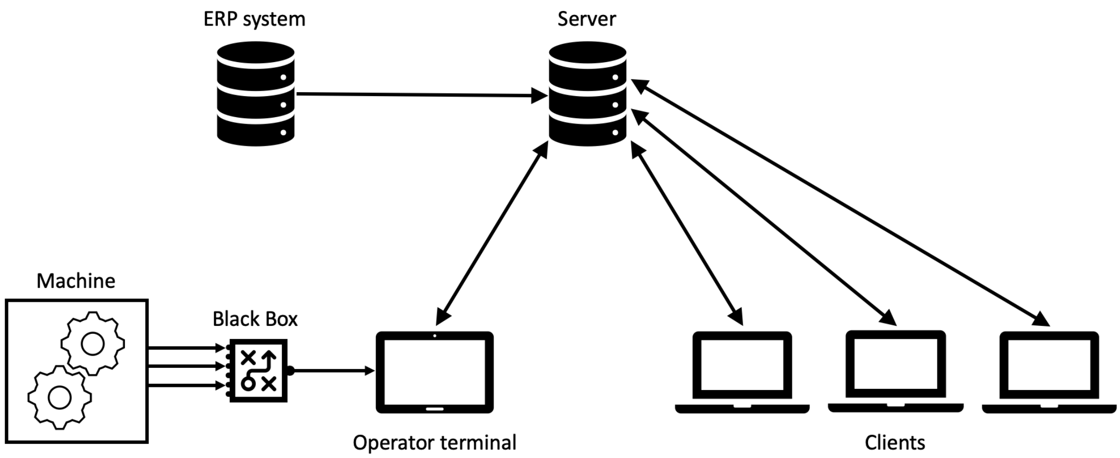


Figure 4.1: Schematic overview of the current monitoring system.

4.1.3 Operator Tools, Office Tools & Screens

When first launching the software, one is presented with a choice of three alternatives; Operator Tools, Office Tools and Info Screen.

Operator Tools

Operator Tools is the part of the software intended to run on the terminals placed by the machines and subsequently used by the operators. It is here that all downtime, rejects and production rate losses are added and categorised.

Office Tools

Office Tools is the part of the software that handles all types of analytic and administrative features. It is also here that the system is configured, and it's subsequently used by e.g. production managers.

Infoscreen

Infoscreen is the part of the software that should be used, as the name suggests, by terminals intended to be used as information visualization screens. This will not be used in this project.

4.1.4 Users and Login

To access the software, one has to log in using a username, a password and an installation number. There are several types of users with different rights and access to different menu items; report user, user, super user and developer, see figure 4.2.

- **Report user** - A report user has very limited access to the functions of the CMS software, mainly working with the analysis tools.
- **User** - Apart from using the analysis tools, a user has ability to make alterations in the configuration of measure points.

- **Super user** - A super user has more administrative rights as well as access to hardware and systems.

- **Developer** - Has the ability to add new measure points, normally the developer rights belong to the system vendor.

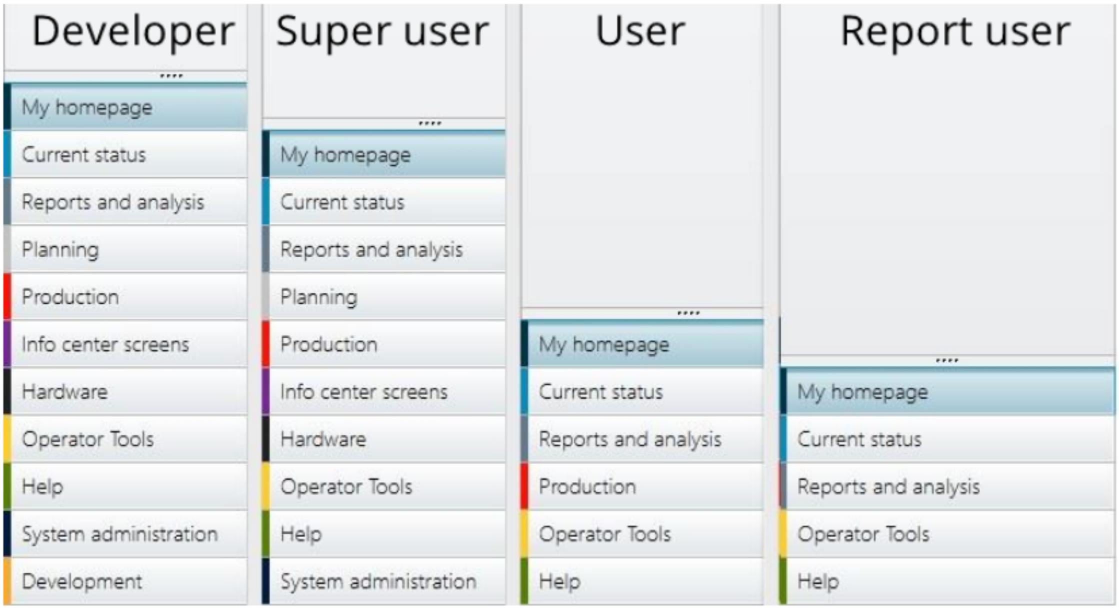


Figure 4.2: The different types of users and their accessible menu items [23].

4.1.5 System Configuration

There is essentially two ways of configuring the production monitoring software. A setting is either *machine-specific*, or it is included in a *measure point configuration*. The latter is created independent of any machine, but can be linked to one or multiple machines. This allows for using the same settings for a group of machines.

Adjacent to explanations of software settings in the following sections, it will be stated if the setting is machine specific or belongs to a measure point configuration.

4.1.6 Main Screen for Operator Tools

Header and Main Menu

The screen for Operator Tools consists of two static parts; a header that can display up to six pieces of information and a bottom row that fits up to five buttons which enable instant access to different menus. Depending on what button is pressed, the large middle section of the screen will display different content. The screen for Operator Tools is designed in a measure point configuration.

The following information can be displayed in the header:

- Number of operators.

- Article name.
- Article number.
- Estimated time of completion for current order.
- Order quantity.
- Production rate (units per hour).
- Number of rejects.
- Machine contact.
- Number of reworks.
- Operators.
- Order number.
- Number of produced units.
- Current shift.
- OEE for current shift.

The following menu items can be selected for the bottom row:

- Data series.
- Documents.
- Forms.
- Main menu.
- Rejects.
- Production plan.
- Messages.
- Momentary production statistics.
- Reworks.
- Operators.
- Production report.
- Latest article.
- Latest stop.
- Shift report.
- Home screen.

- Downtime coding.

Rejects, *downtime coding* and *production plan* are absolutely vital, since downtime and rejects cannot be categorised without them. *Documents* is useful for having instructions on how to use Operator Tools readily accessible. *Home screen* offers the opportunity to view some standardised reports on production performance directly on the machine terminal.

Production Orders

It is possible to control how much and what kind of information or functions that is displayed or activated for production orders and shown on the Operator Tools screen. These settings are a part of a measure point configuration. The following options are available:

- Display article settings.
- Make comments on an order.
- Requirement for operator at start of order/article.
- Display planned start of production.
- Enable a function that allows operators to search for specific production orders.
- Start the next order automatically at the end of the previous order.
- Limit the number of orders visible backwards in time.
- Limit the number of orders visible ahead in time.

There are several options for manual production as well but these are omitted since manual production does not occur at Nolato MediTech.

APQ Periods

For Operator Tools, as well as Office Tools, there is an option to view the current status of production for each machine based on three periods of time. A sort of "fast track" to view production performance easily. These so called APQ periods can be freely chosen and are indicated in minutes. One could for example choose the last hour, day and week for APQ periods. These settings belong to a measure point configuration.

Synchronisation indicator

The Operator Tools screen always has a synchronisation indicator at the bottom right corner of the screen, a small two-piece rectangular field. By displaying different colours in this field it is indicated whether or not the terminal works as intended.

- Upper field, which displays information about loading and saving data.

  - Grey, indicates that no new data is available.
  - Green, indicates that data is successfully saved.
  - Blue, indicates that the terminal is currently transmitting data to the server.
  - Yellow, indicates that saving data is delayed.
  - Red, indicates that the system cannot save changes to the server database. *(Contact system supplier if this happens).*

- Lower field, which displays information about server contact.
  - Green, indicates that the terminal has contact with the server.
  - Yellow, indicates that the terminal has no contact with the server.

4.1.7 OEE in the Current Monitoring System

Comparison to theory

To properly understand how the production monitoring software calculates data regarding OEE and its components, the methods employed by the CMS were compared to the original definition of OEE by Nakajima [13], as described in chapter 2.4.1.

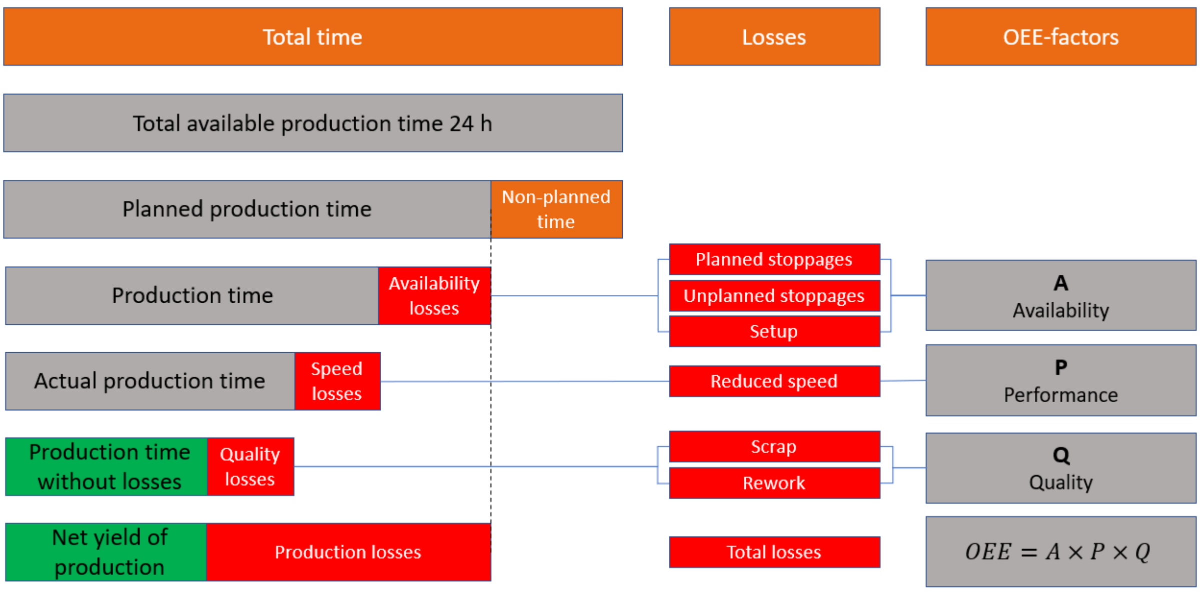


Figure 4.3: OEE as defined in the CMS [23].

Figure 4.3 shows a schematic view over how time, losses and OEE-factors are related in the CMS. Comparing it to figure 2.5 in chapter 2.4.1, the definition of OEE and its components in the CMS are very similar to the original definition by Nakajima [13]. However, in the CMS *planned stoppages* such as scheduled maintenance are included in the availability losses while in the original OEE definition these stoppages are excluded and the only availability losses are *equipment failure* and *setup and adjustments*. Planned downtime is the amount of downtime officially scheduled in the production plan, according to Nakajima [13], and it should not be included in OEE calculations. Otherwise the difference lies in the naming of the time and loss components.

Looking more closely into how the APQ-components are calculated in the CMS software, the availability is defined according to equation 4.1, the performance according to equation 4.2 and the quality according to equation 4.3. In appendix A an excerpt from the CMS shows an example of the APQ-components for one of the injection moulding machines, as well as their original definitions in Swedish which have been translated by the authors into equations 4.1, 4.2 and 4.3.

$$Availability_{CMS} = \frac{\textit{Scheduled time} - \textit{Downtime}}{\textit{Scheduled time} - \textit{Excluded time}} \tag{4.1}$$

$$Performance_{CMS} = \frac{\textit{Produced amount} - \textit{Reworked amount}}{\textit{Optimally produced amount}} \tag{4.2}$$

$$Quality_{CMS} = \frac{\textit{Produced amount} - \textit{Scrapped amount}}{\textit{Produced amount}} \tag{4.3}$$

For an easier comparison to the original definition by Nakajima [13], equation 2.1, 2.2 and 2.5 in chapter 2.4.1 have been simplified and rewritten in this chapter as equation 4.4, 4.5 and 4.6.

$$Availability_{Nakajima} = \frac{\textit{Loading time - Downtime losses}}{\textit{Loading time}} \tag{4.4}$$

$$Performance_{Nakajima} = \frac{\textit{Processed amount} \times \textit{Ideal cycle time}}{\textit{Operating time}} \tag{4.5}$$

$$Quality_{Nakajima} = \frac{\textit{Processed amount - Defect amount}}{\textit{Processed amount}} \tag{4.6}$$

Comparing equation 4.1 to equation 4.4, what is called *Scheduled time* and *Loading time* is essentially the same thing, as well as *Downtime* and *Downtime losses*. See figure 2.5 and 4.3 for clarification. However, what differs between the two equations is that in the denominator of equation 4.1, there is a variable called *Excluded time*. The software gives the opportunity to exclude certain types of stoppages from the OEE calculations, hence this variable. If all planned downtime is excluded from the OEE calculations, the definition of the availability parameter in the CMS matches that of the original definition by Nakajima [13].

Comparing equation 4.2 and equation 4.5, the first calculates performance by using amount of products as a unit, the other using time. *Produced amount* subtracted by *Reworked amount* gives the amount of products that were actually produced during a certain time period. Dividing that amount of products by the *Optimally produced amount* during the same time period, i.e. the amount of products that would have been produced if there were no disturbances in the production process, gives the performance component in the CMS. *Processed amount* times *Ideal cycle time* gives the amount of time it should have taken to produce a certain amount of products if there were no disturbances in the production process. The *Operating time* represents how long it actually took to produce that same amount of products and the quotient gives the performance as defined by Nakajima [13]. Though the two equations differ by their input variables, they will still produce the same performance quota.

Comparing equation 4.3 and equation 4.6, the equations are basically identical except for the naming of the variables which differs somewhat, though they have the same meaning.

OEE target value

As mentioned in 4.1.2, the OEE target value for each order is retrieved from Nolato MediTechs ERP system. It is however possible to set a target value linked to each machine as well, but this will be secondary to the target value for an order. Setting an OEE target value for each machine is a machine-specific setting.

4.1.8 Cycle Time

The cycle time parameter for injection moulding machines in the CMS is defined as the time from the beginning of one shot to the beginning of the following shot. Since one shot can produce different amounts of products depending on the number of cavities in the mould, which is almost always more than one, the cycle time parameter is not specified per produced product as it usually is, but rather per shot. For the assembly machine though, the cycle time is defined per product since the products goes through the assembly machine one at the time.

Based on the input values on optimally produced amount per hour and units per cycle, which is registered on every production order and article, the CMS calculates an optimal cycle time for every order. The optimal cycle time is then used as a reference to compare the actual cycle time to during production, and possible production rate losses are calculated.

4.1.9 Categorising Downtime in the Current Monitoring System

All downtime logged by the CMS need to be categorised manually, with a few exceptions. A production stop shorter than a certain predefined time is automatically categorised as a *Micro stop*. Downtime right at the beginning of an order can be automatically categorised with a freely chosen downtime code, for example *Setup*. Following the same fashion, when there is no order available this downtime can be automatically categorised as *Lack of order*, for example. All settings concerning micro stops and other automatically categorised downtime are machine-specific settings.

Manual categorisation of downtime goes as follows. The uncategorised stoppage is chosen and, if necessary, split into several shorter stoppages to enable a more detailed categorisation. Then an appropriate downtime code is chosen from a predefined set of codes to explain why there has been a production stop. A more elaborate explanation could be added in form of a comment in free text.

All downtime should be categorised as soon as possible, though it is possible to categorise retroactively.

Micro Stops

Micro stops exist to avoid having to categorise production stops shorter than a certain time. There is a balance between when it is rewarding to spend the time it takes to categorise a stoppage and when it is more valuable to use that time for something else. If the stoppage is very brief, it is probably not worth the time it takes to categorise it. Categorising a stoppage is estimated to approximately 30-60 seconds.

In the CMS, the current time limit of a micro stop is 240 seconds (4 minutes). When evaluating if 4 minutes is a reasonable limit for a micro stop, and possibly deciding on a different limit, there are a couple of factors that have to be considered:

- When the machine is down for daily maintenance, the stop is sometimes as short as just above 3 minutes (the shortest one noted as of now is 3 minutes 6 seconds). This means that some stops for daily maintenance are automatically categorised as micro stops, when they should be categorised as *Daily maintenance*. Of course it is possible to recode a stop, but there might be a risk of missing to categorise the stop correctly if it does not stand out as *Uncategorised* from the start. Therefore the limit for micro stops should be less than 3 minutes since the stops for daily maintenance is not far from 3 minutes.

- The assembly machine that already has the CMS up and running has a micro stop limit of 60 s (1 minute). Since the micro stop limit should be lowered bit by bit to find the balance between visualising problems and having a reasonable workload for the operators, the limit won't be set as low as 1 minute to begin with without seeing a need for it.

4.1.10 Categorising Rejects in the Current Monitoring System

All rejects have to be registered and categorised manually in the CMS, unless a certain process has automatic quality control which can then be set as an input signal to the software.

Manual reporting and categorisation of rejects goes as follows. Firstly the number of products that have been rejected are entered into the software, then an appropriate reject code is chosen from a predefined set of codes to explain why these products are rejected. Lastly a more elaborate explanation could be added as a comment to the reject. Rejects should be logged in the software during ongoing production as soon as they appear to maintain a true OEE value. However, it is possible to add rejects retroactively.

4.1.11 Reasons in the Current Monitoring System

The predefined set of codes mentioned in 4.1.9 and 4.1.10 are actually called *reasons* in the CMS. When creating a reason in the software it can be defined as either a downtime reason, a reject reason or a rework reason. Then the following settings have to be made:

- Choose a reason name.
- Choose a colour to represent the reason.
- Exclude from schedule or not.
- Add additional information about the reason if necessary.
- Forced comment or not - when the reason is used and has *forced comment* activated, the operator must add a comment in free text to give further information about what caused the problem.
- Enter a sorting order - this setting decides in which order the reasons will be shown on the Operator Tools screen.
- Link the reason to relevant RS_categories - RS_categories will be explained further down in this chapter.
- Choose a station if applicable - this is not applicable on injection moulding machines.
- Exclude from OEE or not - for example, not all downtime should be included in the OEE calculations, like *Lack of order* for instance.

To design an intuitive reason structure, folders are of great use. Folders are merely given a name, a colour and a sorting order, in line with what is described above.

The downtime reason structure, reject reason structure or rework reason structure is then connected to a measure point configuration. If one wants to stop using a certain disturbance reason, it is very important to only disconnect it from its reason structure but never delete it completely. Deleting it completely will destroy historic data since all downtime/rejects/reworks categorised with that particular reason will then become uncategorised again. Disconnecting the reason from its reason structure, on the other hand, will preserve historical data while no longer making it possible to categorise upcoming disturbances with that reason.

RS_Categories

There is a function in the CMS called *categories*, which is useful when working with data analysis. Each reason can be assigned one or several RS_categories. One RS_category could for example be *planned*, which should then be linked to all downtime reasons that is considered planned downtime, such as preventive maintenance. It is then possible to filter for the RS_category *planned* in the data analysis tool, visualising all downtime that is considered planned downtime.

RS_categories can be created freely in the software, they are only given a name and a colour.

4.1.12 Reports in the Current Monitoring System

The data analysis tool in the CMS is called *Reports*. It is quite a comprehensive analysis tool which allows the user to look into:

- Trends - displays trends on OEE and its components, as well as amount of downtime, rejects, reworks and totally produced amount of products.
- Loss model - shows a figure similar to 4.3, but with real production data on the bars.
- Production monitoring - displays numbers on amount of products, time parameters and production pace.
- Machine efficiency
  - OEE - overall equipment efficiency with its APQ components.
  - Availability - a more detailed view of the availability component.
  - OEE 24/7 - uses the total available production time as a base for calculations instead of planned production time.
- Downtime losses - downtime reasons shown in total time lost and in number of stops.
- Rejects - number of rejects per reject reason and their share of the totally produced amount of products.
- Reworks - number of reworks per rework reason and their share of the totally produced amount of products.
- Cycle time - compares the average cycle time, and the average cycle time including downtime, to the optimal cycle time.
- Capability report - monitoring of process parameters.
- Maintenance - technical availability, MDT and MTBF.
- Time axis - a timeline where shift team, order availability, downtime, OEE and produced amount is compiled per machine.

In combination with the subjects above, the software also allows the user to filter on time periods, one or several machines, articles, orders, reasons and categories, resulting in many ways to display the information of interest.

Reports can be saved for easy access. For example, if a report displaying OEE over the last seven days is saved in the software, whenever that report is opened it will always display OEE seven days back from the moment you are viewing the report. There is also a software function that allows the user to easily email or print reports. It is also possible to set up automatic printing or emailing of reports, e.g. emailing a certain report on a weekly basis to chosen individuals or print a certain report each morning in a production department. Exporting data from the CMS to e.g. Excel files for further analysis is also possible.

4.1.13 SPA Using the Current Monitoring System

Monitoring Process

The first six entries of the suggested monitoring process to be employed when utilising a PPM presented in section 2.1.5 are dependent on the type of production monitoring employed. Those entries are reiterated below (numbers) along with how the procedure translates if the CMS is used (bullet points).

1. Identification of result parameters.

    - Because of the design of the software, there are three set result parameters available; downtime, number of rejects and reworks, and reduced production rate.

2. Identification of influencing factors for each factor group.

    - The factors are synonymous with the reasons in the software, and the factor groups can be represented by use of folders.

3. Identification of possible connections between result parameters and factors.

    - This is, to a slight extent, done in the previous step. When adding reasons to the software, they are connected to a certain result parameter. Practically, the categorisation of downtime and rejects utilises different reason pools, as explained in section 4.1.11. For a reason to be coupled to downtime, it has to be actively placed in the downtime reason pool.

4. Prioritisation of aforementioned connections.

    - Any form of prioritisation is not possible in the software.

5. Production monitoring where events connected to the result parameters are registered and corresponding factors are identified.

    - Downtime is automatically registered and manually categorised by operators, with the exception of *set-up* and *lack of order*. Rejects are manually registered and categorised by operators. Reduced production rate is automatically registered, but cannot be categorised.

6. Analysis and preparation of collected data.

    - The analysis and preparation is made by the software using the reports tool. The reports tool is highly flexible and enables data to be presented in a multitude of ways with little manual effort, as explained in section 4.1.12.

Data Collection

In section 2.1.6, some common drawbacks of production monitoring systems were presented. They are summarised below and compared with the CMS.

- Insufficient information resolution. Error codes are not sufficiently precise in their nature, making it difficult to identify the real causes of disturbance.
  - The information resolution of the CMS is completely dependent on the expertise of the programmer and his or her knowledge of the process in question, since all error codes are manually added. It therefore has the ability to reach a very high information resolution.
- Lacking use of collected information. The information collected is not used, often because of a lack of time and the complexity of proper analysis. This demotivates operators to continue using the PPM.
  - This is not directly related to the monitoring system, but the organisational drive. It should however be noted that basic production analysis, such as calculation and presentation of OEE, in the CMS does not require any expert knowledge and is subsequently within reach of operators as well as technicians and management.
- The system offers low flexibility. The operators' possibility to describe and input the disturbances in a structured way is limited.
  - This is true for the CMS. It is not convenient to add error codes on the go, which means that they will have to be noted in a separate system before it can be added to the CMS.
- Poor adaptation to current application. The system does not sufficiently represent the reality in which machines and operators operate.
  - The CMS has a good amount of customisation regarding menus and reasons, enabling the program to be properly tailored to the production processes in question.
- Lacking identification of connections. The system lacks ability to connect causes to effects, i.e. the system does not connect factors to result parameters.
  - This is true for the CMS. The system is designed in such a way that downtime and rejects can be connected to one reason only, and reduced production rate cannot be connected to a reason at all. This means that the only result parameters available are the generalised ones, i.e. *downtime*, *rejects* and *reduced production rate*. This problem is exemplified below.

    Depending on the various quality requirements of the product in question, there might be several reasons that a product might be rejected. Burn marks, air bubbles, warping etc. These reasons are the result parameters, i.e. the effect. For each quality issue, or reason of rejection, there is one or more things that has gone wrong with the process, the material etc. These are the factors. For a proper monitoring, each reason of rejection should be connected to the fault in the process, material etc. that caused it. In the CMS, as mentioned above, a reject can only be connected to one error code. Since the error codes are designed manually by the responsible production manager, the error codes can technically be both factors and result parameters.

4.2 Technical Problem Solving

4.2.1 System Monitoring

A spreadsheet was created to systematically track the status of the system. In this spreadsheet problems were noted along with detailed descriptions, if and how they could be solved temporarily or permanently, timestamps, notable events and occasional comments. To obtain a good data resolution, the systems were checked twice per day; once in the morning and once in the afternoon every workday.

To check the status of the systems, Office Tools in the CMS was used. Here, with super user-rights, it can be checked if the server has contact with the terminal (the computer by the machine logged into Operator Tools) and the Black Box. If not, the last time of contact is displayed. If a terminal had lost connection, the last time of contact was noted and the status of the computer was checked physically. When the problem had been identified, it was noted. Depending on the issue, an operator was briefly questioned to investigate whether a certain machine- or production related event could be the cause of the lost connection. Depending on the severity of the issue, different actions were taken to solve it.

4.2.2 Identified Problems

Department A

After four weeks of monitoring, these are the problems that surfaced in department A:

- **Update-related problems.** The terminal on machine IMS1 was stuck in an update loop. This was resolved by the supplier.
- **Connectivity issues.** All terminals connected with WiFi, contrary to Ethernet, except the one on machine IMS6 have experienced varying degrees of spontaneously lost internet connectivity. This results in the terminal not being able to transfer information to the server. The terminal does however save the data properly for a limited amount of time, so when connection is reestablished no data has been lost. Restarting the computer temporarily solves the issue, but also leads to lost time in the production monitoring. However, if the terminal has had no contact with the server for a longer time period, once it connects again and tries to synchronise with the server, problems will arise in the form of inaccurate downtime being displayed for the machine in question.
- **Hardware issues.** The terminal on machine IMS2 was unable to start up. This was due to a faulty hard drive and resulted in no production data being

registered. The terminals on machine IMS7 and IMS8 suffer from periods of degraded performance and are occasionally not responding to user input. This is suspected to lead to the terminal crashing, which results in incorrect logging of production status.

- **Powered down terminals.** In some cases, the terminals where shut down or had been restarted and were not logged in, resulting in lost and/or false production data. This happens as a result of either someone physically shutting the terminal down, or the terminal losing power. The terminal gets its power from the machine, which means that it shuts down if the power to the machine is cut.

- **Login issues.** The terminals on machine IMS6 and IMS9 have a different operating system that requires a physical keyboard to login. No physical keyboard was available, nor is there a convenient space for one at the moment. When consulting the IT-department it turns out that the terminals cannot be updated to a new operating system, since this would cause the screens to lose their functionality. Terminals not logged in results in lost production data.

- **Windows updates.** If the terminal is shut down and started or restarted for some reason, Windows often automatically updates the terminal. This is not really a technical issue, but the updates take quite some time, which might result in lost data since operators do not have time to wait for the update to complete so that they can log in.

- **Machine to Black Box-connection.** On machines IMS1, IMS2 and IMS3, the signal that tells whether the machine is in automatic mode or manual mode is fed into the Black Box and used to determine whether it is in operation or not. This results in degraded monitoring data, since the machines have to be switched into manual mode by an operator when the machine stops automatically. Example: A machine gets an alarm and stops automatically. There are no operators nearby at this time, and the stop isn't noticed until 30 minutes have passed. An operator then puts the machine into manual mode, resolves the problem, and puts it back into automatic mode. This takes ten minutes. Since the machine was in automatic mode for the first 30 minutes of the downtime, this time is not registered as downtime in the CMS. Only the ten minutes of manual operation will be registered.

Department B

The systems in department B exhibited somewhat different behaviours. After four weeks of monitoring, the following problems had been noted.

- **Powered down terminals.** This problem is identical to the one in department A. See identically named item in the list above for further details.

- **Windows updates.** This problem is also identical to the one in department A. See identically named item in the list above for further details.

- **Black Box to terminal-connection.** This issue differs to its department A counterpart. The Black Boxes in machines IMP3 and IMP4, while properly connected to the machine with regards to correct registration of downtime, spontaneously loses connection to the terminal, leading to a complete loss of production monitoring for the duration of the connectivity loss. Restarting the terminal solves the issue temporarily, rarely for longer than a few hours. The problem was investigated with the help of the system supplier and the maintenance department, and the cable between the Black Box and the terminal showed to be slightly faulty.

4.2.3 Action Proposal

After six weeks of tracking the status of the systems, no new or unfamiliar problems had surfaced for approximately one week in either department. An action list was prepared and presented to the factory manager. The list contained descriptions of all encountered problems and their possible solutions, as well as cost estimations of said solutions.

4.3 Reason Collection

4.3.1 Reasons

Due to the nature of the injection moulding process, no reworks are made which makes the monitoring software's rework reasons non-applicable, leaving downtime reasons and reject reasons to be investigated.

Downtime Reasons

A set of downtime reasons already exist in the CMS from the first attempt to use the software a couple of years ago. The same reasons were used for both departments holding injection moulding machines. However, the reasons are very general and do not describe specific root causes for downtime, see appendix B. To avoid being influenced by these existing reasons when investigating possible new reasons, they were not taken into consideration initially.

To find the most common influencing factors, experienced operators and process technicians were interviewed and the production process was researched department wise. Firstly using semi-structured interviews, as explained in section 2.8, to avoid influencing the opinions and answers from operators and process technicians. The semi-structured interviews were based on the following questions:

- What downtime reasons have you experienced due to
  - the machine?
  - the tool?
  - the peripheral equipment?
  - the material?
  - the process?

  - the organisation?

- Is any preventive maintenance done during production?
- How do you handle order switches?

The information gained from these interviews was compiled and a first draft of a downtime reason structure was presented to process technicians at each department. During this presentation more precise questions regarding downtime reasons could be asked and valuable feedback could be collected from the process technicians who helped validate each reason. For downtime reasons concerning preventive maintenance, the maintenance manager was consulted instead.

Reject Reasons

Reject reasons are already used in Nolato MediTechs ERP system, since the reject percentage is currently used as a KPI. For administrative purposes, it is advantageous if the reject reasons in the CMS matches those already in use. Process technicians at each department were consulted about which of these existing reject reasons they were actually using, in order to not add any unnecessary reject reasons to the software.

4.3.2 Reason Structure

Assigning a downtime or reject to a specific reason represents the majority of the interaction with the software. It is for this reason vital that the downtime and reject reasons are logically and effectively structured. In order to conform to systematic production analysis using a PPM, the factors were divided based on the factor groups presented in section 2.1.3. Additional subcategories were introduced as well, to maintain a user-friendly interface according to the theory on HMI. To enable a higher data resolution, it is decided that factors belonging to factor group H, *Unidentified factors*, should be divided and added to every created category and subcategory instead. These factors should be called "XX Unspecified", e.g. *Tool Unspecified* or *Peripheral equipment Unspecified*.

Naming

When it comes to the design of the reason naming format, the authors have identified three different approaches enabled by the software; colour format, letter format and number format. Note that this is complementing the descriptive name of the reason as opposed to replacing it, e.g. "Faulty conveyor" becomes "301 - Faulty conveyor". The idea is that one should be able to relate a reason to a category by only viewing the reason on its own. The different reason formats are exemplified in appendix C.

As can be seen in the first menu level in appendix C, the letter and number formats make it more difficult to distinguish the categories at a glance compared with the colour format. For this reason, colours will be used in accordance with appendix C. However, because of colour blindness, redundancy should be applied. With the number format each reason gets a specific number, as opposed to the letter format where all reasons are identified by the letter of their respective factor group.

HMI Considerations

Following the guidelines of HMI presented in section 2.5, not more than nine reasons will be displayed in the same menu. If more than nine reasons are identified for a certain category, additional partition based on some other identified attribute will take place. Although the guidelines recommend that not more than seven colours should be used to convey information, all major categories will be assigned a colour. This decision is made since no information is conveyed by the colours alone, the main purpose of the colours is differentiation and the number of colours just slightly exceed the suggested number.

Colour

The colours will be selected based on figure 2.6. The ISCC-NBS centroid numbers from the figure were compared with a list of all ISCC-NBS colours [24] in order to obtain the technical name of the colour, e.g. Very_Light_Blue. The technical name was then used to obtain the HEX code of the colour [25], which is used to input the colour in the software. The used colours are presented in table 4.1 along with their respective HEX code. If there are less than nine major categories, all colours will be distinguishable for observers with red-green-deficient vision as well.

Table 4.1: The first nine colours from figure 2.6 along with their respective HEX code.

Colour	**ISCC-NBS Name**	**HEX Code**
White	White	#FFF2F3F4
Black	Black	#FF222222
Yellow	Vivid_Yellow	#FFF3C300
Purple	Strong_Purple	#FF875692
Orange	Vivid_Orange	#FFF38400
Light Blue	Very_Light_Blue	#FFA1CAF1
Red	Vivid_Red	#FFBE0032
Buff	Grayish_Yellow	#FFC2B280
Grey	Medium_Gray	#FF848482

4.3.3 Reason Numbering

Although it is decided that the naming should include some kind of numbering format, multiple approaches of this nature are possible. These will be brought up and assessed below.

Option 1

Every reason is assigned a three-digit number, where the first and second digits represent the category and the subcategory of the reason and the third digit identifies the specific reason, e.g. [100 - Machine], [110 - Cooling] and [111 - Malfunctioning sensor]. The ”Unspecified” reasons, of which there will be one for every folder level, are assigned a number with 9 as the last digit, ensuring that it's always placed last in the menu. All specified reasons will therefore end with a number of one through nine. Numbers ending with a zero represent folders.

This principle limits the amount of reasons for every subcategory to eight. If more than eight reasons are identified, another subcategory in another folder, with a new number and a new "Unspecified" reason will have to me made.

Example

In the category [300 - Peripherals], there are three subcategories; [310 - Robot], [320 - Conveyor] and [330 - Carousel]. One finds ten reasons belonging to the robot subcategory, which means that a new subcategory will have to be made. Since 320 and 330 are already taken, the new subcategory will be numbered 340. Reasons connected to the robot are now numbered 31X and 34X and the inherent structure is lost.

Option 2

This option is very similar to *Option 1*, but a digit or letter representing the department is added. This reduces the risk of a subcategory becoming full and a new subcategory having to be made. This will be explained by an example.

Example

A number of reasons have been identified in department A. In the category [200 - Tooling], subcategory [210 - Cooling] there are six stop codes; 211 - 216. In department B, eight reasons within the same subcategory are identified. Three of them are identical to reasons already added by department A (211, 212, 213), but the rest are new and have to be added. Since each reason needs a unique number, they will be numbered starting from 217, which means that a new subcategory will have to be created even though this subcategory for department B only contains six specified reasons (211, 212, 213, 217 and 218). As the number of departments using the system increase, this approach soon becomes untenable. If the reasons instead are department specific, this problem is avoided since the reasons in every subcategory always will start from XX1.

The drawback of this approach is that there can be several reasons with identical names and meaning but differing numbers. When the system is to be implemented in a new department, no current reasons can be used so all have to be added.

Option 3

This option is based on the same basic principle as *option 1*, but the subcategories are not coupled with specific digits. This enables much simpler and more intuitive numbering of reasons. The "Unspecified" reasons are numbered in a descending manner starting from X99, while the specified reasons are numbered in an ascending manner starting from X01. There is an unspecified reason for every folder level, i.e. for every category and subcategory, so it's therefore unlikely that more than ten exist for every category, which makes up to 90 specified reasons possible for every category.

Using this principle, some of the structure from *option 1* is lost, but coding and design in the CMS is greatly simplified, streamlining possible system expansion.

4.4 Systematic Monitoring of OEE

4.4.1 Visions about the Current Monitoring System

To sort out what expectations and visions the factory manager and the production managers had for using the CMS as a tool for continuous production monitoring, interviews were conducted with them all individually. The interviews were semi-structured according to section 2.8, and based on the following questions:

- What should the information from the CMS be used for?
- How often is information from the CMS needed?
- Which information is the most interesting?
- How should the information from the CMS be presented?

The answers from these interviews are presented below, and a more detailed account can be found in appendix D.

Compilation of Interviews

According to the factory manager, information from the CMS should be used for reporting at the factory pulse meetings, to provide a fact-based analysis to motivate improvement projects and for KPI reporting upwards in the organisation. Therefore the OEE values and especially the causes behind the machine performance is of interest. The information need to be constantly updated on a weekly basis, with a monthly summary as well. The standardised reports from the CMS need to be visualized in a way that gives a good overview, and for pulse meetings a graphic presentation is preferable to make the information easily accessible.

According to the production managers, information from the CMS could be used for highlighting potential improvements, to address the primary causes of downtime and give the operators a hint of where to put their focus during the current shift. Bad delivery status could get an explanation from the CMS. The information could also be used to give a picture of where in the organisation there is need to prioritise, and what, because sometimes it may be relevant to lend personnel between departments. The maintenance department could benefit from using the CMS as well, as they could monitor the machines that are prioritised each shift as well as keep track of how much and what kind of maintenance they do at the different departments and/or machines. The production managers are therefore also interested in the OEE values for the machines with their underlying causes of downtime, considering both the number of stops and the time consumed. The percentage of total downtime that is categorised as planned maintenance is also of interest. The information is needed on a daily basis for use at department pulse meetings and the day-to-day activities, but also on a weekly and monthly basis to provide an overview of the status in each department. The information should be presented as simply as possible to give a good overview and be easily accessible.

To summarise, both the factory manager and the production managers are interested in the performance of each machine and the causes behind that performance. But while the production managers will have a more detailed view of their respective department, the factory manager will have a more holistic view, and this is reflected in the level of information they request as well as how often they need the information the CMS can provide.

4.4.2 Existing Structures for Production Monitoring and Continuous Improvements at Nolato MediTech

To understand the existing structures for production monitoring and continuous improvements at Nolato Meditech, key figures were interviewed and the internally developed continuous improvement program Medical Excellence was studied.

Pulse Meetings

Please note that this report only covers pulse meetings involving production personnel. Nolato MediTech works with daily follow-up on different hierarchical levels as well as crossfunctionally with the use of pulse meetings. These meetings are quite brief, about 10-15 minutes, and as suggested, take place daily. The purpose of the meetings is to shine light on various disturbances and subsequently manage them in a structured way. Depending on the nature and severity of the disturbance, it is either managed locally at the department, or it is brought upwards in the organisation in order to involve other departments and resources in the problem solving process.

Each production department has daily pulse meetings involving the production leader, process technicians and operators. There is also a factory pulse meeting that involves all production leaders, the factory manager as well as representatives with managerial positions from other departments, such as logistics and quality.

Continuous Improvements Meetings

On top of the regular follow-up, the company also works with weekly continuous improvements meetings (CI-meetings). Each department has its own continuous improvements group, and all employees are part of a group. Contrary to pulse meetings, the purpose of CI-meetings is to solve disturbances by e.g. altering physical equipment or organisational instructions to prevent further disturbances of the same nature. The company has through Medical Excellence established a standardised, well-described flow for suggestions related to continuous improvements that are addressed during these meetings, including evaluation, responsibility, timeline etcetera.

4.4.3 Education

Since operators work a 24/7 5-shift schedule, there is no single time slot where more than two out of five shift groups are on-site simultaneously. On Mondays and Thursdays between 13:00 and 14:25, two shifts overlap and it is recommended that education takes place during these time slots, in order to reduce the total number of required education occasions. All members cannot however participate at the same time, since someone has to monitor production. These factors in combination means that education will have to take place over the course of several weeks, unless personnel are called in at specific occasions.

4.4.4 Benchmarking

A semi-structured interview was conducted with the Lean Coordinator at Nolato MediTech Lomma. The interview was based on the following questions:

- How does OEE monitoring with the help from the CMS work at the factory in Lomma?
  - Are pulse meetings and CI-meetings involved?
  - Which time horizon do you work towards? Daily, weekly, monthly follow-up etc.?
- How stable are your monitoring systems and what have you done to ensure stable production monitoring?
- How detailed are your downtime codes and how have you chosen to structure them?
  - How did you decide on a suitable micro stop limit?
- Do you use reject categorisation?
- How did you proceed to educate operators and other personnel in using the CMS?

Compilation of Interview

Follow-up using the CMS:
Initially, the data from the CMS, mostly the biggest stops, was followed up on CI meetings once a week. But since the biggest production disruptions are reviewed daily at pulse meetings, the CI meetings just became a repetition of what had already been said and done during the week, resulting in the weekly follow-up being scrapped. OEE is now compiled on a monthly basis and on these occasions they look into long-term solutions to production problems.

OEE is not addressed at the pulse meetings, only its underlying loss causes are addressed, e.g. downtime and rejects. Many of the operators do not have enough knowledge of what OEE is at the moment. Some education has been held, but the Lean Coordinator states that if you do not encounter what you have been trained in on a regular basis, you forget about it. He also gives the example that if you have many rejects, but very few stops and no rate losses, then OEE only drops very little in value. OEE can therefore be above its target value, while the number of rejects have exceeded its target value. Therefore, it makes more sense to go through the OEE components at pulse meetings instead, e.g. stops and rejects, because they say more about what the situation looks like ”on the floor” and enable faster reaction.

The monthly follow-up is done towards their largest customer and is thus customer-driven. The customer is interested in OEE in conjunction to the tools they own, but since the tools are always in the same machine, it is possible to use data from these machines when reporting to the customer. All the stops during the last month are compiled and then sent to a technician. The technician proceeds to check which machines that did not reach the OEE target value, why they didn't and what actions were taken to solve the problem. If no actions have been initiated, this is done by the technician. This is then summarised and the customer gets information about how much they produce, how much was discarded, the OEE value as well as actions taken if production performance have been subpar.

In Lomma they use reports designed with the help of the system supplier, as of now. Their Lean Coordinator and the above mentioned technician is the only ones working with data analysis at this point, production leaders are yet to be involved. They have also recently introduced a new role in Lomma, Shift Coordinator. The idea is to educate the appointed shift coordinators in OEE in general as well as the CMS so that they can become autonomous regarding OEE follow-up. Shift coordinators have a slightly more administrative role than e.g. process technicians, and the idea is that they should be able to allocate resources to where they are needed. For example, one department on a particular day has zero tool changes and another has several, so the shift coordinator can release some resources from the department with a low workload to the department with a high workload. They should also secure non-production-related resources, e.g. improvement work, which is why it is good that they have knowledge of how to work with OEE.

As of now, Lomma has the CMS installed on 15 % of their machines, which result in the difficulty of not working with follow-up in the same way on all machines in the factory.

System stability

They have ensured stable monitoring by connecting the systems via Ethernet cable. However, they have had a lot of problems with the Black Boxes. Eight of them have broken for no apparent reason. If a Black Box is broken, it may take a few days for a technician to dismantle it, since you do not want to interrupt production. Then it must be sent to the system supplier for repair, which can take up to three weeks. Worst case scenario, 1.5 months of monitoring is missed. In Lomma they now have three extra Black Boxes as backup, as even though they are quite expensive it is still better than missing out on monitoring if one breaks. When the CMS stopped working on one machine, there were certain operators who, because of lacking information, assumed that it did not work on any machine and thus stopped using it completely. It is therefore important to convey the correct information.

Downtime codes

Initially, downtime codes existed in the ERP system. After each stop, you had to open up the ERP system, click through to the right window, fill in the right cause, fill in time, etc. That process was far too complex and time-consuming, so it was scrapped. A 30 second stop could take five minutes to register. With the CMS it is much simpler to categorise downtime. Lommas current downtime reasons in the CMS can be viewed in appendix E. However, the ERP system is still used for major stoppages occurring during production, but stops between batches and many of the shorter stoppages are not registered, which is done in the CMS.

Micro stop limit:
The micro stop limit is set to two minutes for almost all machines. It was chosen initially as it felt as a reasonable time span. After evaluation, this time was adjusted on one particular machine which takes longer to start.
Reject registration
Major rejects during production are addressed at pulse meetings. Rejects are currently not registered in the CMS, only in the ERP system, where rejects are handled in the same way as in Hörby. But the Lean Coordinator points out the advantage of registering rejects in the CMS. In the ERP system, only a lump sum of the rejects is shown, e.g. 3.6 %, while in the CMS you can see precisely how many rejects have happened for every reject reason. But he also suspects that there is a startup period that you have to go through if you begin registering rejects in the CMS. You probably can't really trust the value in the CMS at first since the registration will not be properly done immediately, which also risk reducing the use of rejects in the CMS. There have been discussions with the system supplier about the possibility of automating data collection even more. As of now, each cycle is converted into a number of produced parts as well as a signal that says the machine is running. On some machines though, it is possible to use more machine signals than that. For example, if you want to take a product sample you press a button. This button can be connected to the monitoring system and automatically register a product sample. The first shot that is run after daily cleaning of the tool is automatically discarded, this signal can also be connected to the system for automatic registration. They have briefly discussed trying this on one machine and evaluate the outcome. It would also make it easier for the quality technicians during final reporting of the order, as they then need the exact reject figure.
Education
Lommas Lean Coordinator held the initial training of production personnel. He produced educational material based on cherry-picked material from the system supplier. Since then there has been some turnover of employees, so not everyone has adequate knowledge of how to use the CMS at the moment. The plan is to educate some of the process technicians, who in their turn can train the operators. The ambition is to make process technicians more administratively responsible so that they can add new downtime reasons, new reports etc.

4.5 Special Considerations

4.5.1 Validation Orders

Most of the products produced by Nolato MediTech, and thereby most of the tools, are owned by a different company of which Nolato MediTech is a subcontractor.

When a new tool is to be taken into production, a special validation order is run in order to officially validate the tool and associated process parameters. During the validation, different process parameters such as heating and injection speed are slightly varied in a controlled manner and in different combinations and the resulting products are inspected. This results in a validated window for every process parameter that must be respected during production. If one wishes to use process parameters outside of the validated window, a new validation must take place in consultation with the owner of the product and tool. Note that all products produced during this validation run are rejected.

4.5.2 Current Reject Registration

The reject percentage is currently one of the main KPIs used at Nolato MediTech, and all rejects are therefore registered. However, not all rejects happen during production. When a batch is being produced, some products of sub-par quality are discovered, discarded and registered as rejects right away. When the batch has been produced in full, it is sent to inspection, where all products are inspected. At this stage, additional products are discarded and registered as rejects after which a final number of rejects for that particular batch is obtained. Subsequently, all rejects are not registered during the production run, which has some implications on the way reject registration should be handled in the CMS.

4.5.3 Line Clearance

When the production run of an order has been completed, an activity referred to as *line clearance* is conducted. Line clearance is a standardised process with the intention of readying the production area for upcoming orders by removing any documentation, products and remaining material from the previous order.

5. Results

In this chapter, all final results and deliverables are presented. Software settings for sufficient production monitoring, the performance of the CMS as a tool for SPA, solutions to technical problems, collected reasons, suggested organisational procedures and roles as well as suggested education and training are presented.

5.1 The Current Monitoring System

Software settings that are relevant for OEE monitoring will be accounted for in this chapter. Except for downtime or reject reason-specific settings, which will be accounted for in chapter 5.3. An evaluation of the CMS as a production monitoring software will also be presented in this chapter.

There are a few essential settings in the CMS that can't be made until the organisation is ready for a live implementation of the CMS. These final settings will make the changes previously done by the authors, described in 5.1.1 and 5.1.2 below, appear on the screens by the machines. This is not something that should be done until the technical problems have been fixed and the monitoring systems are stable, or until the education of production personnel are ready to start. The final settings include coupling the new measure point configurations to the right machines, as well as the machine-specific settings regarding which downtime that should automatically be categorised. A step-by-step instruction explaining these final settings and how to make them can be found in appendix F (Swedish).

5.1.1 Machine-specific Settings

Micro Stop Limit

Based on the factors concerning micro stoppages in chapter 4.1.9, the micro stop limit is set to 120 seconds (2 minutes). This applies to all injection moulding machines.

Automatically Categorised Downtime

- Downtime occurring when there is no order available in the CMS will be automatically categorised as [505 - Orderbrist], which translates to *Lack of order*.
- Downtime occurring right from the beginning of an order will be automatically categorised as [701 - Omställning], which translates to *Setup*.

OEE Target Value

As mentioned in 4.1.7, it is possible to manually set an OEE target value linked to each machine which is secondary to the OEE target value for an order. Therefore the OEE target value per machine need to be revised to make sure it is up to date. Doing this has not been part of this project and is therefore left to Nolato MediTech to investigate.

5.1.2 Measure Point Configurations

One measure point configuration was created per production department for department A and B. The difference between these configurations lies in which downtime and reject reasons are linked to each configuration, since these reasons differ between departments. Chapter 5.3 will describe downtime and reject reasons for each production department.

All other settings for the measure point configurations are identical between the production departments and will be accounted for in this chapter.

Main Screen Header

The following three pieces of information where chosen to be displayed on the header of the Operator Tools screen:

- Order number (in Swedish: *ordernummer*)
- Article namne (in Swedish: *artikelbenämning*)
- OEE for current shift (in Swedish: *skift OEE*)

Figure 5.1 shows an Operator Tools screen with the specified header.

Main Screen Menu Items

The following menu items where chosen for the bottom row of the Operator Tools screen:

- Production plan (in Swedish: *Körplan*)
- Downtime coding (in Swedish: *Stoppkodning*)
- Rejects (in Swedish: *Kassation*)
- Main menu (in Swedish: *Huvudmeny*)
  - Momentary production statistics (in Swedish: *Momentant*)
  - Production report (in Swedish: *Produktionsrapport*)
  - Latest article (in Swedish: *Senaste artikel*)
  - Latest stop (in Swedish: *Senaste stopp*)
  - Shift report (in Swedish: *Skiftrapport*)
- Documents (in Swedish: *Dokument*)

Figure 5.1 shows an Operator Tools screen with the menu item *Production plan*, as well as all the specified menu items on the bottom of the screen. Figure 5.2 displays the menu item *Downtime coding* where downtime is categorised. Figure 5.3 shows the menu item *Rejects* where rejects are registered and categorised. Figure 5.4 shows the menu item *Main menu* and its sub menus, which all display different production statistics. Figure 5.5 displays the menu item *Documents* which contain instruction documents.

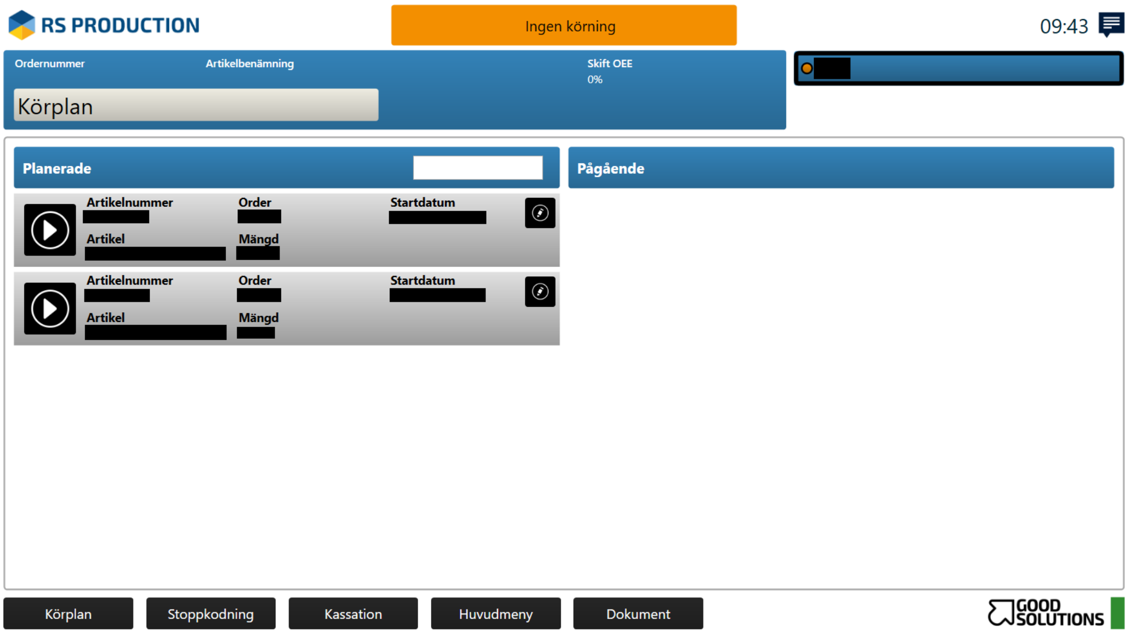


Figure 5.1: Operator Tools - *Production plan*

Production Order

Three specific settings regarding production orders in the production plan-screen are used:

- Article settings should be displayed.
- Planned start of production should be displayed.
- A function that allows operators to search for specific production orders is activated.

APQ Periods

For viewing the current status on each machine, the three APQ periods where chosen as:

- Period 1 = 60 min = 1 hour
- Period 2 = 480 min = 8 hours
- Period 3 = 1440 min = 24 hours

Figure 5.6 shows how it looks when checking the current status on a machine with the set APQ periods.

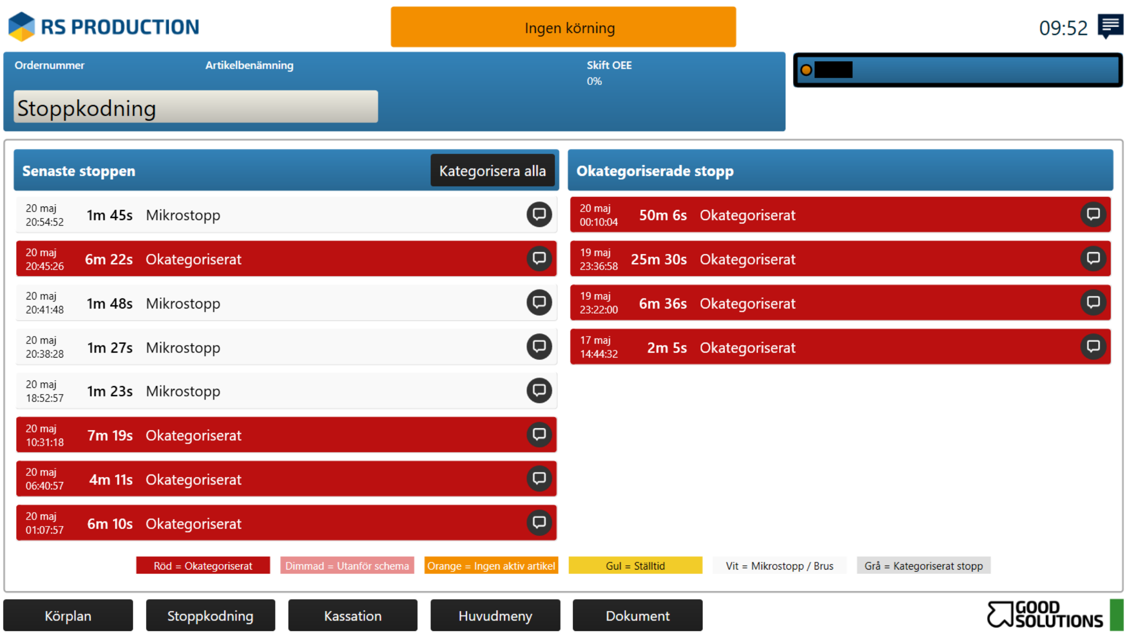


Figure 5.2: Operator Tools screen - *Downtime coding*

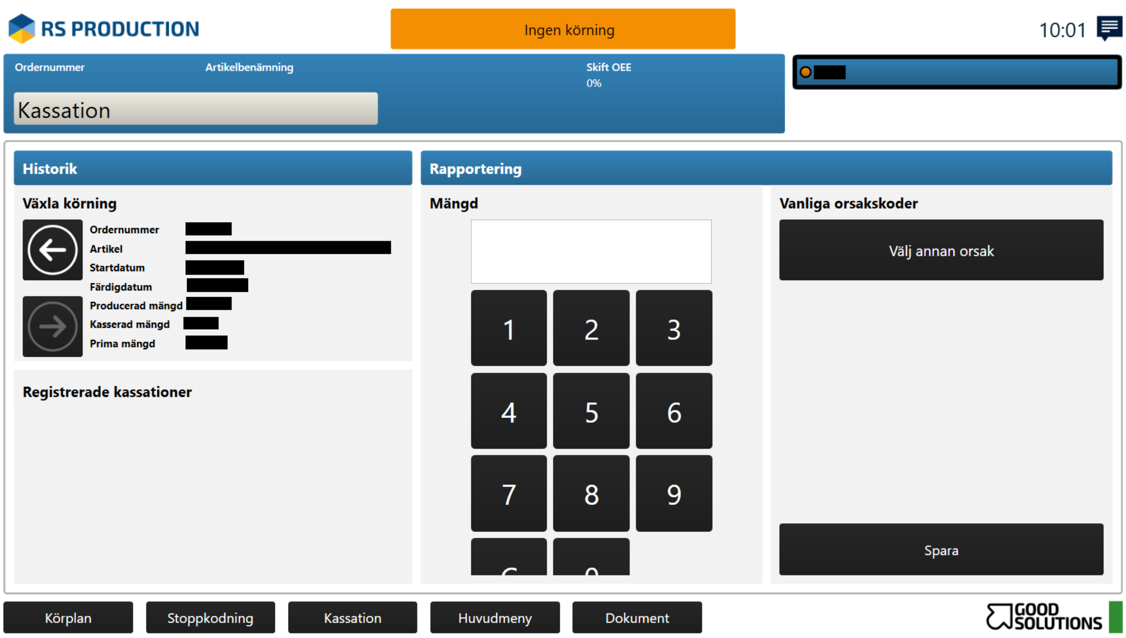


Figure 5.3: Operator Tools screen - *Rejects*

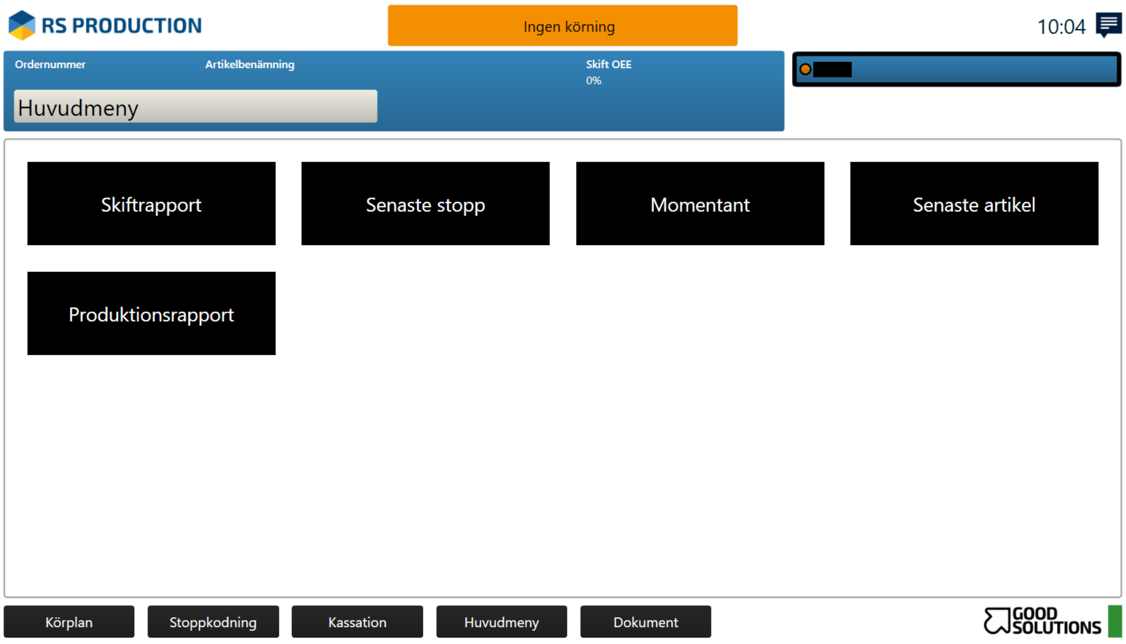


Figure 5.4: Operator Tools screen - *Main menu*

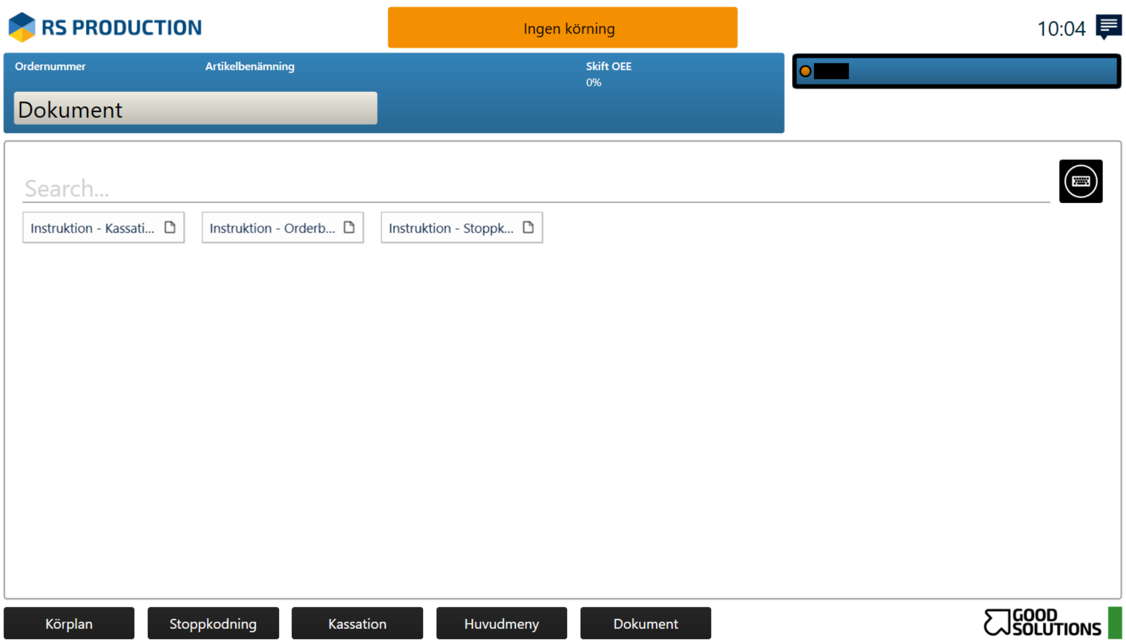


Figure 5.5: Operator Tools screen - *Documents*

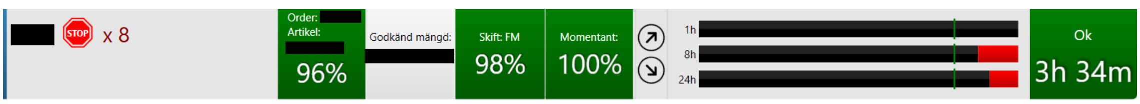


Figure 5.6: The current status of a machine

5.1.3 SPA Using the Current Monitoring System

The performance of the CMS as a system for SPA for Nolato MediTech is evaluated based on SPA with the use of a PPM.

Advantages

- Factors are manually designed and added, meaning that any desired resolution can be achieved.
- Factors can be categorised as desired, meaning that one can utilise the factor groups.
- Downtime and reduced production rate is automatically registered.
- Extensive analysis and preparation of data is handled automatically.

Disadvantages

- Specific result parameters are not available or assignable, only the main result parameter groups downtime, rejects and reduced production rate.
- Reduced production rate cannot be connected to any factor.
- The operators' ability to describe and input disturbances that are previously not added to the system is greatly limited.

5.2 Technical Problems

Based on the problem report presented in section 4.2.2, it is suggested that some actions should be taken to ensure stable operation over longer time periods. These actions, along with cost estimations made by the project supervisor at Nolato MediTech, are presented below.

- All computers should be connected to the network via Ethernet cable to ensure a stable internet connection.
  Affected computers: IMS1, IMS2, IMS3, IMS4, IMS6, IMP2, IMP3, IMP4.
  Estimated cost: 40 000 SEK.
- Power to the computers should be supplied independently of the machine. This is to prevent the lost monitoring and increased hardware wear that sudden power losses contribute to.
  Affected computers: IMS1, IMS2, IMS3, IMS4, IMS6, IMS7, IMS8, IMS9, IMP1, IMP2, IMP3, IMP4.
  Estimated cost: 50 000 SEK.
- Faulty computers should be replaced. All computers in department A are six years old, so when a hard drive breaks or the computer becomes sluggish and freezes frequently, it should be replaced by recommendation of the Nolato IT-department.
  Affected computers: IMS2, IMS7, IMS8.
  Estimated cost: 39 000 SEK (based on an offer from the system supplier).

- Improper machine to Black Box-connections should be corrected. The maintenance department suggests that the red light signal of the machine is fed into the Black Box and subsequently used to trigger a production stop.
  Affected computers: IMS1, IMS2, IMS3.
  Estimated cost: Continuous maintenance expenses.

- Improper Black Box to terminal-connections should be corrected. System supplier suggests replacing the cable between Black Box and terminal.
  Affected computers: IMP3, IMP4.
  Estimated cost: Continuous maintenance expenses.

In addition to the suggestions above it is also recommended that the terminals are updated manually at set intervals to overcome the issue of unwanted updates in the middle of production.

The suggested actions were approved by the management at Nolato MediTech a few weeks before the end of this project. The Lean Coordinator at the Hörby plant will take care of the practicalities and make sure these actions are implemented since the time horizon for the implementation is well beyond this project.

5.3 Reasons

Structure

A combination of colour format and number format, as described in 4.3.2, will be used for all reasons added to the CMS. This makes it possible to relate a reason to a category by only viewing the reason on its own. The colour format makes it possible to distinguish factor categories by a glance. Colouring is applied according to HMI and the colour coding principles in table 4.1. The number format gives each reason its individual identification number, which greatly simplifies the handling of the reasons both in the CMS and in any external database.

Numbering

Numbering of the reasons will be done according to *Option 3* in 4.3.3, which means that every reason is assigned a three-digit number, where the first number represent the category/main folder and the following digits represent the specific reason. All reasons that are "Unspecified" will be numbered in a descending manner, starting from X99. All specified reasons will be numbered in an ascending manner, starting from X01.

5.3.1 Downtime Reasons

All collected downtime reasons are divided into main folders which are based on the PPM factor groups but adapted to this specific case. The main folders are:

- **100 - Machine**, all downtime reasons concerning the machine are placed in this folder and given a number between 101-199.

- **200 - Tool**, all downtime reasons concerning the tool are placed in this folder and given a number between 201-299.

- **300 - Peripheral equipment**, all downtime reasons concerning the peripheral equipment are placed in this folder and given a number between 301-399.
- **400 - Material**, all downtime reasons concerning the material are placed in this folder and given a number between 401-499.
- **500 - Personnel and organisation**, all downtime reasons concerning personnel and organisation are placed in this folder and given a number between 501-599.
- **600 - Preventive maintenance**, all downtime reasons concerning preventive maintenance are placed in this folder and given a number between 601-699.
- **700 - Order switch**, all downtime reasons concerning order switches are placed in this folder and given a number between 701-799.
- **800 - Miscellaneous**, all downtime reasons that can't be placed in folder 100-700 are placed in this folder and given a number between 801-899.

Every category/main folder was assigned a colour and a sorting order based on their identification number, see appendix G for the specific settings. There are sub folders as well, but those are not numbered in any way since their only purpose is to make it easier to navigate on the Operator Tools screen. Therefore the sub folders are merely given a name, without identification number, and a colour matching its main folder.

A total of 62 downtime reasons were created based on the feedback and validation from production personnel, of which 60 are used at department A and 26 are used at department B. 46 of the 62 downtime reasons are specific, the rest are made up of different levels of "Unspecified" since there is an "Unspecified" choice in every folder and sub folder. This enables a higher data resolution than if there were only to be one general "Unspecified" choice, since it is now possible to choose e.g. *Machine unspecified* or *Cooling system unspecified* rather than just *Unspecified*. Appendix H and I show all downtime reasons for department A and B, respectively, as well as the structure of reasons and folders. There is one downtime reason structure for each department and this structure is linked to the measure point configuration belonging to each department.

All specific downtime reason settings for the CMS can be found in appendix G, but they were created according to the following list:

- All collected downtime reasons are named according to the structuring and numbering described at the beginning of chapter 5.3.
- All downtime reasons are given a colour depending on which folder they are assigned to.
- No downtime reasons are excluded from the schedule.
- No additional information about the downtime reasons are entered.
- Forced comments are used on all "Unspecified" downtime reasons as well as on all downtime reasons belonging to the category *Personnel and organisation*.

- The sorting order is the same as the identification number.
- All downtime reasons are linked to at least one RS_category, except [801 - Strömavbrott] (transl. *power failure*).
- Two downtime reasons are excluded from OEE, [505 - Orderbrist] (transl. *Lack of order*) and [608 - Kalibrering formspruta] (transl. *calibration of injection moulding machine*).

There is one RS_category per main folder 100 -700, as well as one called "Unspecified" and one called "Planned". These are created to facilitate data analysis as described in 4.1.11. The RS_categories are:

- **Machine** - assigned to all reasons in folder *100 - Machine*, enabling filtering on downtime that originates from machine problems.
- **Tool** - assigned to all reasons in folder *200 - Tool*, enabling filtering on downtime that originates from tool problems.
- **Peripheral equipment** - assigned to all reasons in folder *300 - Peripheral equipment*, enabling filtering on downtime that originates from problems with the peripheral equipment.
- **Material** - assigned to all reasons in folder *400 - Material*, enabling filtering on downtime that originates from material problems.
- **Personnel and organisation** - assigned to all reasons in folder *500 - Personnel and organisation*, enabling filtering on downtime that originates from organisational problems.
- **Preventive** - assigned to all reasons in folder *600 - Preventive maintenance*, enabling filtering on downtime that originates from performing preventive actions.
- **Order switch** - assigned to all reasons in folder *700 - Order switch*, enabling filtering on downtime that originates from changing orders.
- **Planned** - assigned to all reasons in folder *600 - Preventive maintenance* and *700 - Order switch*, enabling filtering on downtime that is considered planned and does not directly originate from a problem.
- **Unspecified** - assigned to all reasons named "XX Unspecified", enabling filtering on downtime that originates from problems that haven't been possible to categorise.

5.3.2 Reject Reasons

Satisfactory reject reasons already exist at Nolato MediTech. In the CMS these are organised into folders based on their identification code, see appendix J for the main folder settings. The folders are given a colour according to the reason structure explained at the beginning of chapter 5.3, but the reason numbering as explained at the beginning of chapter 5.3 is omitted for reject reasons since they already have identification codes that are in use.

All reject reasons have the following settings in the CMS:

- The reject reasons entered in the CMS carry the same name that is already in use in the ERP system, identification number included.
- All reject reasons are given a colour depending on which folder they are assigned to.
- No reject reasons are excluded from the schedule.
- No additional information about the reject reasons are entered.
- No forced comments are used on any reject reason.
- The sorting order is the same as the identification number.
- No reject reasons are linked to any RS_categories.
- No reject reasons are excluded from OEE.

All reject reason settings can be found in detail in appendix J.

For each department's reject reason structure, only the reject reasons actually used for that production segment is included. See appendix K for department A's reject reason structure and appendix L for department B's reject reason structure. The departments respective reason structure is linked to the measure point configuration belonging to each department.

5.4 Systematic Monitoring of OEE

5.4.1 Downtime Categorisation

Stoppages should be categorised as soon as possible, though handling the problem itself is prioritised to ensure production. If it takes longer than 5 minutes from when the machine stopped until an operator is available to handle the problem, the stoppage should be split into sections describing how much time was spent on actually handing the problem vs. how long it took before the problem could be addressed. This also applies to when there is need for a repairer or spare parts, the goal is to visualise how much time is spent on actively handling the problem and how much time is just waiting.

Order Switch

Order switches entail time spent on line clearance and setup. Downtime due to line clearance should be assigned to the order that have just been produced, while downtime due to setup should be assigned to the following order. Therefore, when a production order is completed, the machine should be stopped and line clearance performed. Then the active order in the CMS should be switched to the upcoming production order and setup should be performed.

5.4.2 Reject Registration and Categorisation

When a reject is discovered during production and noted on the batch documentation, it should be registered in the CMS directly as well.

As soon as all rejects discovered after production are summarised as the order officially closes, they have to be entered retroactively in the CMS as well.

5.4.3 OEE Follow-up

Nolato MediTech, operating in a line of business with stringent requirements on many aspects of delivery such as quality and traceability, in combination with several years of experience with the Medical Excellence program, already has many standardised organisational structures and pathways in place for a sufficient KPI follow-up. Continuous monitoring of OEE will not only help greatly in identifying areas with improvement potential, but it will also assist the daily disturbance handling.

An OEE-section will be added to the continuous improvement boards of the production departments. In this section, the three biggest sources of downtime losses will be displayed, along with monthly trends of the respective losses and of the OEE value for each machine. The losses are to be sorted by time, not frequency. The losses are to be analysed in order to find a sufficient solution, and the suggested solutions will thereafter follow the same procedure as a generic improvement suggestion. The targeted loss should be monitored before, during and after the improvement project. A clear goal and target value for the improvement project should be set, e.g. *The amount of downtime due to malfunctioning robots should be lowered by 10 %*. When evaluating the success of the improvement project the goal of the project should be evaluated as well.

On the pulse boards of the departments, OEE for each machine for the last 24 hours will be presented along with weekly trends. This way, it is quickly spotted if a machine has been performing subpar, and the underlying reason is easy to obtain. By also displaying the OEE values for every day the last week, one is able to spot possible negative trends and act before the OEE target is undershot. Just like how disturbances are handled now, machines not reaching their set OEE target should be brought up at the factory pulse meeting.

5.4.4 Standardised Reports in the Current Monitoring System

To support OEE follow-up at pulse meetings and CI-meetings, a few standardised reports have been created in the CMS. Having these basic reports available will make the information extraction from the software both easier and faster, at the same time it ensures that there is consistency in what is presented at each meeting. If there is need for further investigation, of e.g. root causes, the software easily allows alterations in the reports so that one can choose to display what is needed at the moment without creating a new report. If no active choice is made to save these alterations, the report will once again look as it was originally designed next time it is opened.

The report structure will be the same on all production departments, and the only difference between the reports on every department will be which machines/measure points that are displayed. Figure 5.7 and 5.8 shows the complete report structure in the CMS.

Looking at reports in the software on a screen during meetings is preferable, but printing the reports is also an option. If automatic printing and/or emailing of any of the reports are desired, it is left to Nolato MediTech to implement this part since the systems are not yet in use.

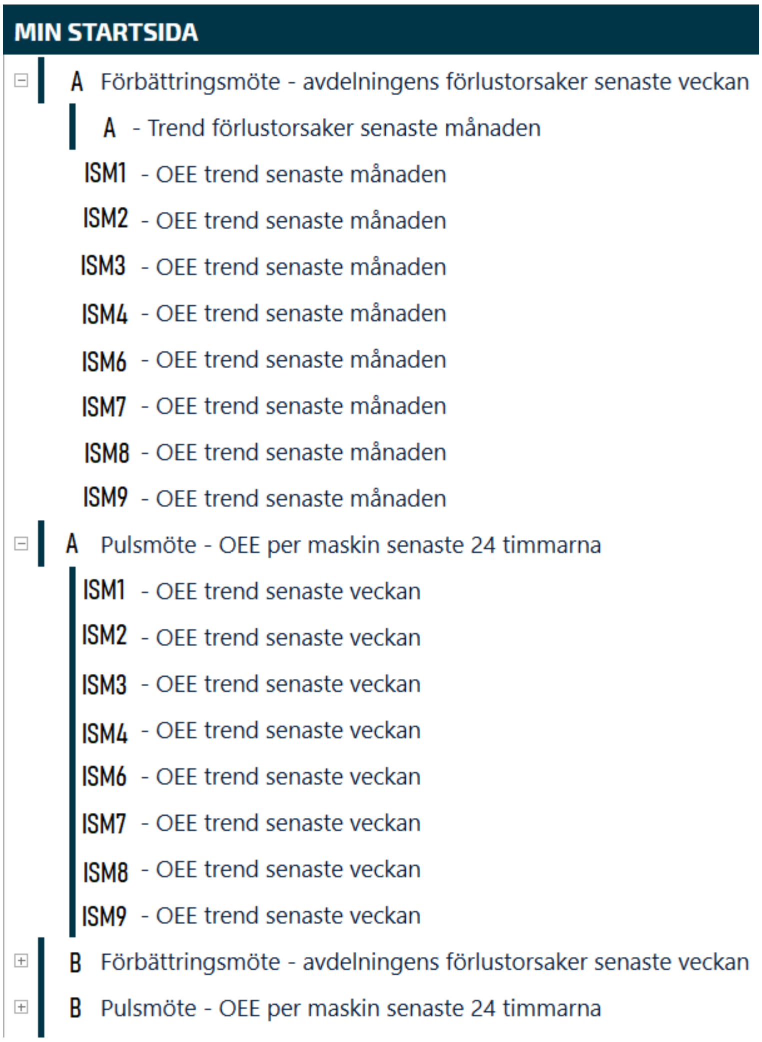


Figure 5.7: Report structure in the CMS (Swedish)

Pulse Meetings

For pulse meetings, the first report gives an overview of the OEE value and its APQ components for all machines in each department during the last 24 hours, see figure 5.9. It makes it easy to spot if any machine has performed below the target value, market by the green line, and if it depends on downtime, rejects or rate losses, which will be represented on the bars as red, grey or yellow segments respectively. The valuable production time is represented as a black segment on the bars. If one wants to investigate further into the underlying causes of a machines OEE value, clicking on the bar of that machine will open a new window with information regarding the biggest downtime losses, reject losses and more

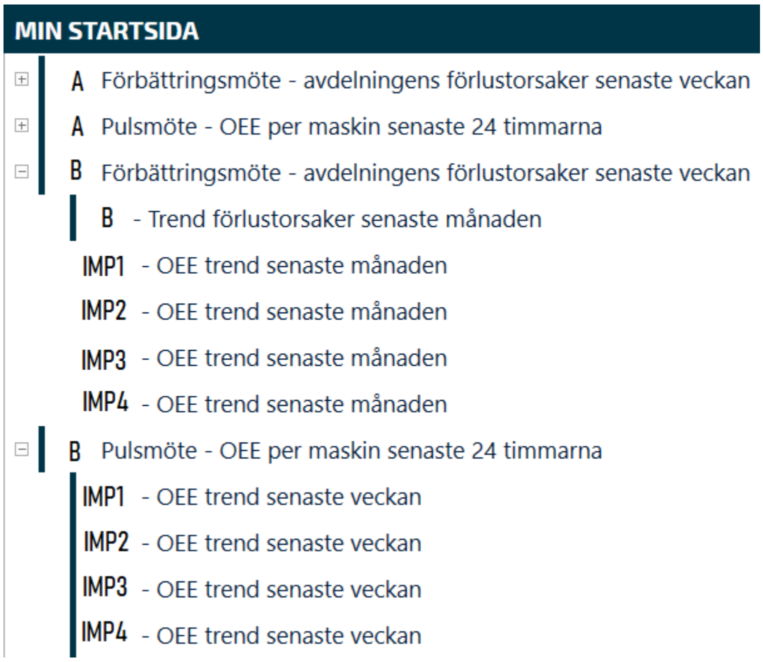


Figure 5.8: Report structure in the CMS (Swedish)

detailed information regarding calculations for that specific machine.

Included in the pulse meeting reports there is also a trend report for each machine which displays OEE and the APQ components for the last week, see figure 5.10 for an example. These trend reports make it possible to intercept if a machine has a downward trend and thereby fix the problem before the OEE value dips below its target value. Seeing an upward trend might inspire to continuing the good work.

CI-meetings

For CI-meetings, the first report shows the three biggest downtime reasons for the department during the last week, both in terms of total time lost and number of stops, see figure 5.11. The total time lost is of most interest and is what should be used as input to the CI-meetings.

A report displaying the trend of downtime reasons for one month back is also included in the CI-meeting reports, see figure 5.12. The standardised report shows all existing downtime causes, but it is easy to filter for one or multiple reasons to display the specific downtime reasons the group is working with at the moment and thereby visualise the result of improvement projects.

Trend reports for each machine displaying OEE and its APQ components one month back is also included in the CI-meeting reports, see figure 5.13 for an example. By viewing these reports those working with continuous improvements can track how the OEE value is affected by improvement projects and thereby get feedback on their efforts.

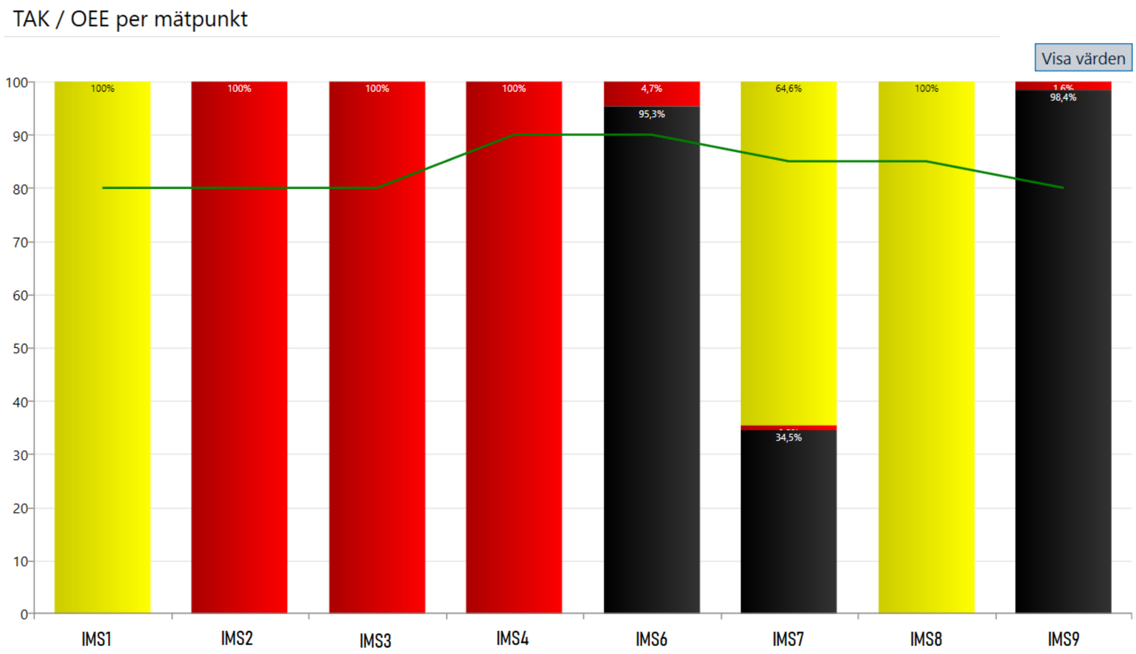


Figure 5.9: OEE per machine the last 24 hours. *Note: the values in this figure are not representative of the actual production at Nolato MediTech since the CMS has not been correctly used up to this point.*

5.4.5 Routine to Collect New Reasons

As stated in section 5.3.1, all unspecified downtime reasons have the option *Forced comment* enabled, meaning that the operators are required to input more precise information on the disturbance. Before the improvement meetings, all commented stoppages should be presented and it will be assessed whether or not one or several new reasons should be added to the software. The reasons are subsequently added to the software according to the procedure described in section 5.3, which is summarised and reiterated here:

1. The appropriate category and, if applicable, subcategory of the reason is identified.
2. The reason is named appropriately and given a number that corresponds to the next available number (low to high) for that particular category.
3. The reason is given a colour matching the category.
4. The reason is given a sorting number that is equal to its number.
5. If the reason prompts the creation of a new subcategory, a new *Unspecified*-reason belonging to that subcategory is created and given the next available number (high to low).

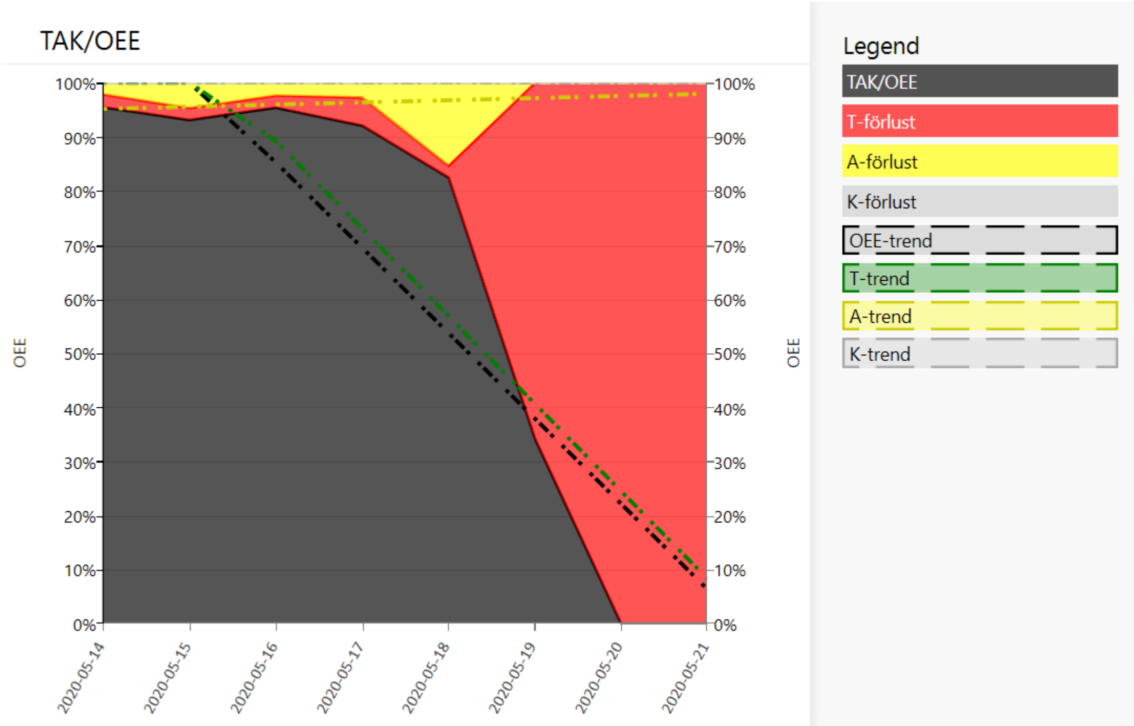


Figure 5.10: OEE trend for one machine the last week. *Note: the values in this figure are not representative of the actual production at Nolato MediTech since the CMS has not been correctly used up to this point.*

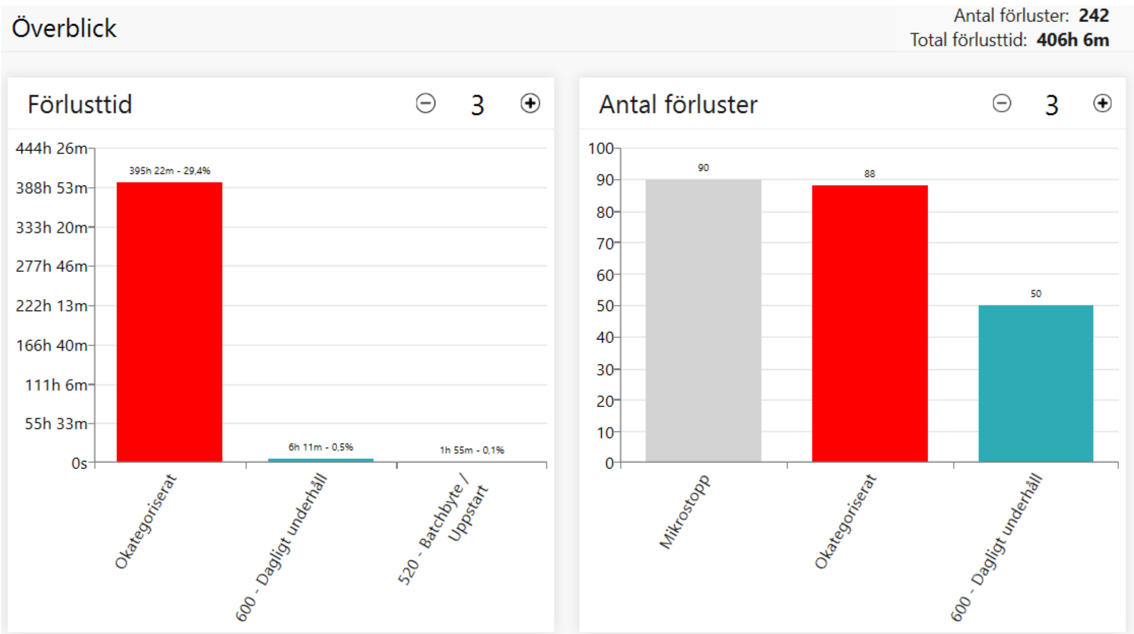


Figure 5.11: Three biggest downtime reasons during the past week. *Note: the data in this figure is not representative of the actual production at Nolato MediTech since the CMS has not been correctly used up to this point.*

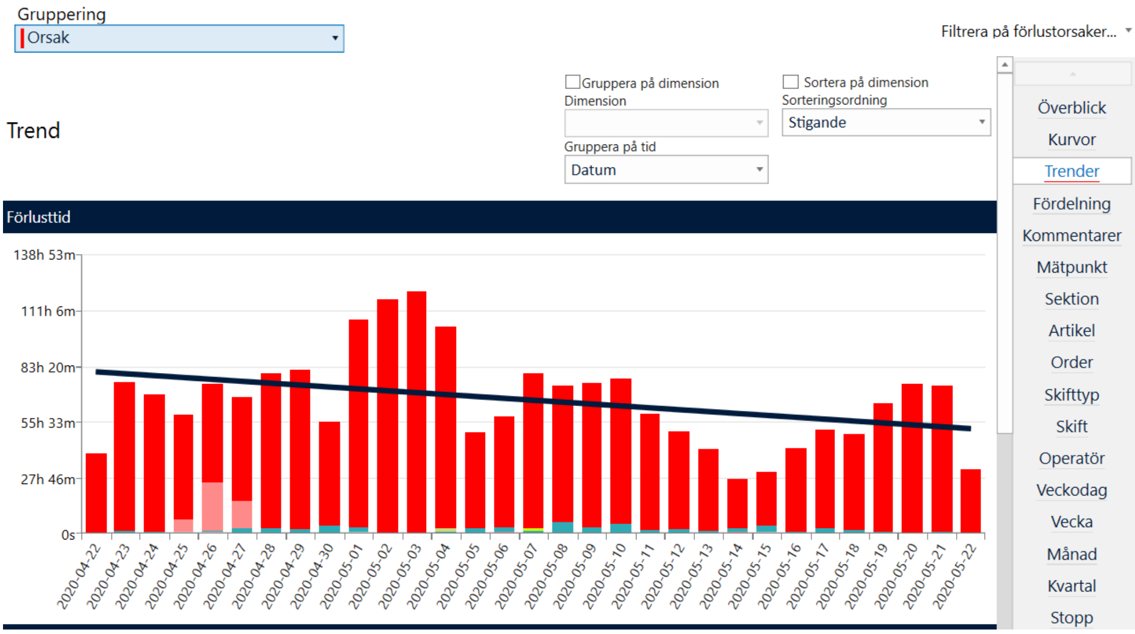


Figure 5.12: Trend of downtime reasons during the past month. *Note: the data in this figure is not representative of the actual production at Nolato MediTech since the CMS has not been correctly used up to this point.*

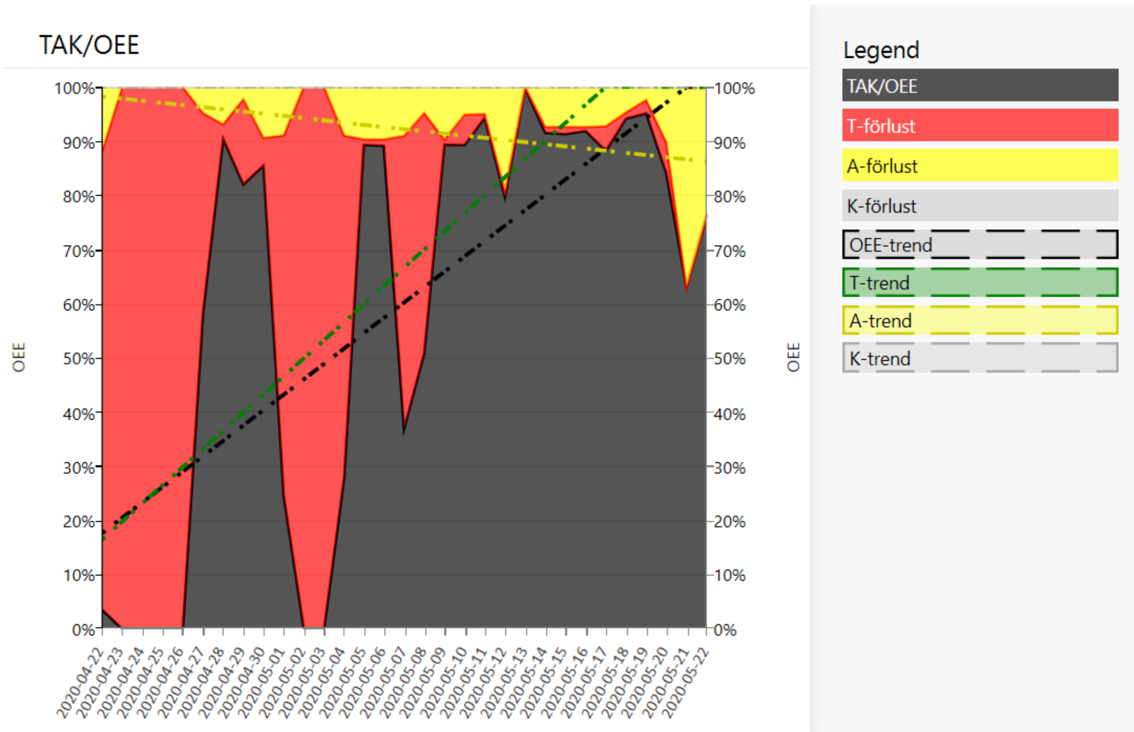


Figure 5.13: OEE trend for one machine one month back. *Note: the values in this figure are not representative of the actual production at Nolato MediTech since the CMS has not been correctly used up to this point.*

5.5 Roles and Responsibilities

Based on the activities concerning use of the software conducted by the authors during this project, three different roles with associated responsibilities have been established; operators, operationally responsible and administratively responsible. General responsibilities are presented below, and a detailed list of software functions that each role requires knowledge of is presented in figure 5.14.

5.5.1 Operators

All operators and process technicians have the following responsibilities:

- Start and end orders in the CMS.
- Categorise downtime in the CMS. This also applies to maintenance staff.
- Add and categorise rejects.

5.5.2 Operationally Responsible

There should be one operationally responsible per department, preferably a process technician or someone who is highly involved in production and does not work on a shift team and subsequently participates on all pulse meetings and CI-meetings. The operationally responsible has the following responsibilities:

- Extract appropriate data from the CMS and add it to the pulse board and the CI-board.
- Check commented stoppages in the CMS and evaluate suggested reasons.
- Alter and add reasons in the CMS.
- Ensure that the defined micro-stop limit is appropriate.
- Retroactively register rejects incurred as a result of post-production inspection.
- Inform coworkers of changes made to the CMS software, e.g. new reasons or altered reason structure.
- Ensure that the CMS is being used by operators.
- Monitor the functionality of the CMS-related equipment.
- Notify the administratively responsible if e.g. any complex problem arises or if an administrative altercation is necessary for some other reason.

5.5.3 Administratively Responsible

The administratively responsible has the following responsibilities:

- Manage communication with the system supplier.
- Manage users.
- Manage advanced software settings.
- Generally have a good understanding of the software, both from a user perspective and a system administrator perspective to be able to support the operationally responsible.

The Lean Coordinator of Hörby has been appointed to Administratively responsible.

	Operators	Operationally responsibe	Administratively responsible
Downtime categorisation	x	x	x
Reject registration and categorisation	x	x	x
Downtime division	x	x	x
End and start of orders	x	x	x
Using the comment function	x	x	x
Reason management		x	x
Altering the micro stop-limit		x	x
Report management		x	x
Understanding the synchronisation indicator		x	x
Configuration of Operator Tools-menus		x	x
Measure point configurations			x
Measure point settings			x
Scheduling			x
Article settings			x
Order management			x
Hardware management			x
System administration			x
User settings			x
Technical system overview			x
Local model			x

Figure 5.14: The program functions that each role require knowledge of.

5.5.4 User Accounts and Software Installations

The user accounts that need to be created are presented in table 5.1. Furthermore, the CMS must be installed on the following computers:

- One stationary computer in department A
- One stationary computer in department B
- The operationally responsible at department A's computer

Table 5.1: Required user accounts and respective user types.

User account	User type
Department A	Report user
Department B	Report user
Operationally responsible dept. A	User
Operationally responsible dept. B	User
Administratively responsible	Super user

- The operationally responsible at department B's computer
- The administratively responsible's computer

5.6 Education and Training

Personnel will have to be educated according to their assigned roles. References to educational material for the respective program functions in figure 5.14 are found in figure 5.15.

As part of the education, it would be preferable to have a learning period where all affected personnel get the chance to become comfortable with using the software, then having a distinct start of production monitoring after which the collected data can be used in a reliable way. It is up to the operationally responsible to assess when all personnel are sufficiently comfortable with using the system.

5.6.1 Operators

The education directed towards operators should include:

1. General presentation of the CMS.
2. General presentation of OEE.
   - Explanation of the effects of a successful production improvement on OEE.
   - Explanation of the OEE target values in relation to a specific machine and order.
3. Clarification that the performance of the machines are measured, not the performance of the operators.
4. General demonstration of interaction with the CMS.
5. Explanation of the current downtime reasons and reason categories.
   - Clarification that the choice of reasons and reason categories is not final and that it can be altered as the use of the software proceeds.

Program functions	Educational material
Downtime categorisation	Digital training P100 - 510
Reject registration and categorisation	Digital training P100 - 530
Downtime division	Digital training P100 - 510
End and start of orders	RS Academy - User training step 2
Using the comment function	Digital training P100 - 510
Reason management	Digital training P100 - 030
	RS Academy - User training step 2
Altering the micro stop-limit	See appendix *Altering the micro stop-limit*
Report management	Digital training P100 - 520
	RS Academy - User training step 1
	The supplier's support-website
Understanding the synchronisation indicator	RS Academy - User training step 2
Configuration of Operator Tools-menus	Digital training P100 - 080
	RS Academy - User training step 2
Measure point configurations	RS Academy - User training step 2
Measure point settings	RS Academy - User training step 2
Scheduling	RS Academy - User training step 2
Article settings	RS Academy - User training step 2
Order management	RS Academy - User training step 2
Hardware management	RS Academy - User training step 2
System administration	RS Academy - User training step 2
User settings	Digital training P100 - 020
	RS Academy - User training step 2
Technical system overview	RS Academy - User training step 2
Local model	*The supplier's support-website*

Figure 5.15: The program functions along with associated educational material.

- Emphasise that if a downtime reason is difficult to categorise the *Unspecified* reasons should be used. They require an additional comment to be made, but operators should be urged to enter only a space if needed.

6. Demonstration of downtime categorisation.
7. Explanation of micro stops.
8. Explanation and demonstration of order switches, including automatic set-up categorisation and automatic lack of order categorisation.
9. Explanation and demonstration of downtime division.
10. Explanation of automatic downtime division by shift group switches.
11. Hands-on downtime handling, where all operators must get a chance to try.
12. Explanation of the current reject reasons.
13. Demonstration of reject registration and categorisation.
14. Hands-on reject handling, where all operators must get a chance to try.

15. Information on the start-up period with less requirements regarding correct categorisation etc.

16. Demonstration of the CMS handling instructions.

17. Demonstration of logging onto the CMS.

18. In department A, machines IMS6 and IMS9 require a physical keyboard to be connected to the computer to enable login.

Handling Instructions as Support During Production

Step-by-step instructions describing downtime categorisation, reject categorisation and order switches will be available as separate documents in Operator Tools. These instructions are found in their original form in appendix N (Swedish).

5.6.2 Operationally Responsible

The operationally responsible must have the same knowledge foundation as operators, and should subsequently attend the same training as a first step.

The education directed towards operationally responsible should include:

1. Procedure of altering the micro stop-limit.

2. Walkthrough of how to create, alter and structure reasons as well as connecting them to measure point configurations.

   - It is very important to note that one should never delete a reason. This will cause stoppages previously categorised with that reason to become uncategorised. Instead, simply disconnect the reason from the measure point configuration.

3. Walkthrough of how to navigate and manage the reports section.

   - How to add, alter and save reports.
   - How to export reports.

4. Procedure of finding commented stoppages.

5. Walkthrough of the synchronisation indicator.

6. Procedure of accessing the advanced menu on the operator terminals.

7. Walkthrough of the user type *User* that is to be assigned to operationally responsible personnel.

8. Access to all educational material, including digital training material and folders provided by the supplier as well as material prepared by the authors.

5.6.3 Administratively Responsible

The administratively responsible should naturally possess all knowledge about the software the operationally responsible do, and should therefore have undergone the same type of training and education. Since the administratively responsible should be familiar with many advanced settings, it is advised that he or she is given access to all available educational material and learns the program functions suggested in figure 5.14 autonomously with the use of a local model.

If the administratively responsible needs further support, it is suggested that he or she contacts the system supplier.

5.6.4 Report Users

Other personnel that might find the data from the CMS useful are advised to contact the administratively responsible for access to material for self-education and software installation.

6. Discussion and conclusion

6.1 The Current Monitoring System

6.1.1 Optimal Cycle Time

The optimal cycle time used in the CMS is currently automatically fetched from the ERP-system. The cycle time registered in the ERP-system is however an average of the real cycle time from past orders. According to a process technician, the characteristics of the material, which varies between material batches, primarily dictate the required cycle time.

Since the data in the ERP-system is mainly used for production planning, it is reasonable that the average cycle time is used here. However, it is not at all appropriate to utilise this data point as the optimal cycle time in the CMS. This ultimately results in many instances of reduced production rate not being captured. Instead, the lowest possible cycle time should be used as the optimal cycle time.

6.1.2 Micro Stop Limit

The micro stop limit is, as described in section 5.1.1, set to 120 seconds for all injection moulding machines. The appropriate limit for a micro stop is highly dependent on which exact type of process it concerns. It is therefore important that this limit is evaluated after some time, when enough data on the accumulated time of micro stops has been collected. For example, if micro stops take up a considerable amount of the total downtime, it is justifiable to lower the micro stop limit and thereby visualise the production problems. It is likely that micro stops will be the most common type of downtime based on frequency, but since it's the accumulated duration of the micro stops that determine if the limit needs to be lowered, the micro stop frequency doesn't need to be taken into account.

6.1.3 The Current Monitoring System Interface

Main Screen Header

None of the pieces of information assignable to the header are necessary for production monitoring. The pieces of information are according to a process technician of no apparent interest to operators.

The pieces of information regarding operators are tied to a function in the program that enables operators to log into the system, connecting a certain time of production to a certain operator. This is not currently used, and since the authors see no benefit in using it, these options are omitted. Since all faulty products are scrapped instead of reworked, the *number of reworks* option does not apply.

Of the remaining pieces of information, the authors decided on three of them that were subjectively deemed the most interesting to have constant access to; order number, article name and OEE for the current shift.

Note that not all information slots were utilised, since the principals of HMI state that excess information should be avoided.

Main Screen Menu Items

The menus that are necessary for production monitoring as well as the documents menu containing operator instructions are naturally included. Furthermore, a main menu button is added that in turn enables access to several screens that might be of interest.

The authors decided that all screens related to production statistics should be accessible via the home screen. These screens present the opportunity to view production statistics directly by the machine, which could be of interest for operators as they are able to view the performance of the machine without having to start the CMS in the department office.

The remaining menu items were deemed uninteresting and were subsequently disregarded.

6.1.4 SPA Using the Current Monitoring System

Currently, the ability to categorise reduced production rate does not exist in the CMS. This is quite a serious flaw from a production analysis standpoint, since one cannot connect reduced production rate to certain factors and thereby loses one of the cornerstones of SPA. Although, because of the validated process window explained in section 4.5.1, major reductions of production rate will not occur. This is because this would result in some process parameters ending up outside of the validated window, requiring production to be halted. However, smaller reductions of production rate are of course possible, and if they go on for long enough it all may amount to considerable losses. Losses that cannot be categorised.

The system also lacks support for use of specific result parameters. When it comes to downtime the problem can be overcome since there are only two suggested result parameters; planned and unplanned downtime. Utilising unplanned and planned as RS_categories, the authors have managed to overcome this particular problem. When it comes to rejects, the same success has not been reached. When designing reject reasons, one has to decide if one wishes to utilise the reasons to register result parameters or factors. This matter is addressed further in section 6.3.4.

The fact that factors cannot be added on-the-go enables them to instead be added in a controlled, systematic fashion, thereby preserving the inherent structure. However, one can imagine some form of suggestion feature in the software, enabling operators to add factors that are not immediately added to the interface, but must be actively evaluated and added at a later stage. Such a feature does not currently exist, which is why the authors have decided to utilise the forced comment-feature as a rudimentary substitute.

When it comes to continuous registration of production disturbances, the system is very intuitive and user friendly, making it easy to learn.

The reports-section of the software that handles analysis and preparation of data is highly potent and can present data in a multitude of ways and formats, enabling the user to fulfill their need with ease. The user does not have to have particular knowledge on KPIs or OEE to be able to obtain well compiled data. A big advantage of the system is that all data can be accessed from any computer, as long as the correct software is installed and a user account is added.

All in all, the CMS is deemed sufficient for systematic monitoring of OEE at Nolato MediTech, although not optimal.

6.2 Technical Problems

The technical problems encountered during this project were more extensive and took longer time to find solutions to than expected. It did however provide the valuable insight that it is never as easy as to "just collect the data", as well as that making sure that one has a stable monitoring system is of upmost importance. Otherwise the collected data is useless.

6.3 Reasons

6.3.1 Reason Resolution

The gathered reasons, or factors, are overall rather general in nature. Ideally, all reasons should be very specific. Which would result in every loss being connected to a very specific reason without the need of further investigation. However, the authors have discovered incentives to keep the reasons more general.

- *Operator knowledge.* To find the root cause of every possible production related problem, one needs to have an exceptional understanding of the production process and its underlying physical and chemical mechanisms. This is not something that can be expected of an operator without further specific education.

- *Process variations.* Sometimes finding the exact root cause of e.g. a defect would require extensive investigation. During production it is not viable to allocate that much time to an investigation of this sort if it is not absolutely necessary. A much faster and thereby cheaper way to deal with the problem is to instead, in a structured way, manipulate process variables in a trial and error-manner until the defect in question is ironed out, making it difficult to place in a specific reason. This procedure will result in some rejections, but the nature of the current manufacturing makes it economically viable. This is certainly not true for all types of manufacturing and all kinds of products. In this case however, with injection moulding of polymer and silicone rubber products in big batches with low cycle times, it is indeed true.

- *Data quality.* To ensure a high quality of data, it is important that the selection of a reason is quick and logical. If it's too much of a hassle, e.g. because of too many reasons or an unintuitive categorisation, there is a chance operators won't take the time to find the right reason and subsequently data is either tainted or lost.
- *Existing reject reasons* In the company's ERP-system, reject codes already exist. For administrative purposes, it is an advantage if the reasons in the CMS matches those in the ERP-system.

6.3.2 The Difference in Reason Resolution Between Departments

Something that came as a surprise during the project, which the authors found quite interesting, was just how different department A and B turned out to be when it came to reason resolution. During interviews and discussions with production personnel, it became apparent that department B had more interest in keeping the downtime reasons general and the operators could not pinpoint as many specific things as they could in department A. It's hard to speculate in what this depends on, but it could be partly due to a difference in competence between departments. Or, perhaps more likely, due to the fact that department B produce many different kinds of products, while department A only produce products from the same product family.

Even though there probably are some downtime reasons found in department A which also applies to department B, it would not at all be beneficial to add these reasons to department B if they don't know how to identify them. It is much more reasonable to start off with a more general reason resolution and add more reasons as the need arises in the department.

6.3.3 Reason Structure and Numbering

Deciding how the downtime and reject reasons should be structured and numbered was something that the authors put a lot of thought into. Balancing the need for a structure that felt intuitive and was easy to follow, with the usefulness of the structure when it came to adding more reasons to the software or setting up monitoring at new departments, as well as to being able to identify which group a single reason belonged to by just looking at its identification number was no easy feat. It is quite possible that it could have been done better, but from the authors' perspective the resulting structure is the best compromise. The reason the identification number is limited to three digits is simply because it is easier to grasp and less cluttered than four or more digits. Having more than three digits would otherwise have opened up for more ways to structure and number the collected reasons.

6.3.4 Reject Reasons

The rejects that are currently registered in the company's ERP-system are registered based on why the product did not meet the quality requirements, e.g. unfilled, burn-marks, bubbles, etc., instead of what caused the product to not meet the quality requirements, e.g. varied material properties, wrong temperature etc.

This means that the result parameters are registered, not the factors. The decision to register rejects in the CMS using the same principle is based on the following considerations:

- It would most likely create confusion to register the result parameters in one system and factors in another.
- Many operators most likely lack sufficient knowledge of the process to be able to correctly connect a reject to one or several factors. Sometimes it can be difficult to pinpoint the exact factor even with sufficient knowledge of the process.
- To obtain a correct OEE-value, it is very important to register all rejects. Registration in the CMS that's identical to the one currently carried out facilitates this.
- Since some of the rejects are registered after the inspection by personnel not necessarily connected with production, estimating reasonable factors can be difficult.

6.4 Systematic Monitoring of OEE

Something that is highlighted in the literature regarding systematic production analysis and KPIs is that all personnel working with the monitoring system must get feedback on their efforts and see that the data they collect is actually being used. The reverse might demotivate the use of the monitoring system. By incorporating OEE follow-up, together with follow-up regarding its underlying causes, into the daily work at each department, it is the authors' hope that seeing the direct result of the data collection will contribute to continued use of the monitoring system.

An important thing that everyone involved with OEE monitoring should be aware of is that improvements done to the input of the production process can have a negative affect on the OEE value, but still lead to productivity improvements. It is important to have a good understanding of the underlying components and their respective influence on the OEE value in order to be able to relate input and output. Studying the underlying components might also be more intuitive and descriptive than just studying the compiled OEE value.

6.4.1 Standardised Reports in the Current Monitoring System

The reason behind choosing a few standardised reports for pulse meetings and CI-meetings, when the software offers so many different options to display production data, was founded in the idea that it is better to keep it simple and brief at first. Then, if there is need for a more thorough investigation, users could themselves choose to display what is of interest to them at the moment. Another incentive to keep the standardised reports brief is the fact that one cannot predict exactly what kind of data is needed at every occasion.

6.4.2 Planned Downtime in OEE Calculations

Depending on what downtime that's included in the OEE calculation, different variants of the KPI can be obtained. According to the original definition by Nakajima, planned downtime should not be included. However, as described in section 2.4.1, what's considered planned is not unambiguous. The authors have therefore decided that downtime is considered planned if it's registered in the production plan, i.e. if it shows up as an order in the CMS interface. *Lack of orders* and *machine calibration* are therefore excluded from the OEE calculation, but *preventive maintenance* is not. The setting to include a certain type of downtime in the OEE-calculations or not is very simple to alter. The Nolato MediTech management will have to make an unambiguous decision regarding this matter. The authors do however recommend that preventive maintenance is included in the calculations if the time could have been used to produce. On the other hand, if preventive maintenance is carried out during a period where the machine would not have produced anyway, e.g. because of lack of orders, it should not be included.

6.4.3 Existing Structures for Production Monitoring and Continuous Improvements at Nolato MediTech

It was of the authors' opinion that the most natural way of setting up a standardised follow-up of OEE is to incorporate it suitably into existing structures. The drawback of this approach is that it is not necessarily possible to design the follow-up in such a way that it completely matches what is suggested in the literature. However, what is possibly lost in quality of the follow-up is gained in ease of implementation. An implementation that requires little effort is more likely to be positively received by various affected members of the organisation and thereby enables a shorter transitional period with a higher chance of success. It was then up to the authors to compromise in the configuration of the follow-up to ensure that the implementation requires little effort without the follow-up becoming sub optimal.

6.4.4 Benchmarking towards the Lomma factory

System Stability

The CMS is currently stable in Lomma, largely due to the use of Ethernet instead of wireless connection, which reinforces the suggestion that all computers should be connected using Ethernet. However, they have had major problems with several Black Boxes, which has not been the case in Hörby. As of now, there is no reason to believe that the same problems will occur in Hörby.

Micro stop limit

The micro stop limit in Lomma is set to two minutes for all machines but one. Since the production is similar to the one in Hörby, this is believed to be a good initial micro stop limit that may not have to be altered much.

Reject Registration

Currently, rejects are not registered in the CMS in Lomma. This amounts to the OEE value presented by the systems being higher than it should, and the Lean Coordinator did not specify a particular reason as to why it is not registered. He did however mention that he believes that beginning to register rejects would lead to a start-up period where the registrations will not be properly done and the OEE cannot be trusted. This is expected by the authors as well, hence the suggested start-up period.

Roles and Education

Up until now, the Lean Coordinator in Lomma has single-handedly handled everything regarding the CMS. Initially, this understandably required heaps of time. However, the newly appointed shift coordinators combined with the Lean Coordinator seem to correspond pretty well to the authors' suggestions regarding operationally and administratively responsible.

All training of production personnel regarding the CMS was held by the Lean Coordinator, utilising educational material from the system supplier. The plan is to educate some of the process technicians so that they can handle some more administrative parts of the software, such as adding new downtime reasons etcetera. Yet again, this resembles the operationally responsible position suggested by the authors.

Downtime Reasons

Part of the downtime reasons used in Lomma are categorised in a manner similar to the one suggested by the authors, with the use of folders and sub folders. The major categories differ, as do most sub categories, but the biggest difference lies in folders and reasons being mixed at the highest menu level. Most reasons at this level are identical to the ones initially used in Hörby. The reason resolution seems comparable, but *unspecified*-reasons or corresponding ones are not utilised. Furthermore, numbering and colouring of reasons are inconsistent.

Follow-up Using the CMS

In Lomma, the main components of OEE, mainly downtime and rejects, are addressed on daily pulse meetings. However, the actual OEE value is not used. This approach is however quite similar to the one suggested by the authors, with the exception that OEE is not used as an indicator to prompt further investigation of specific losses. Instead, the losses are looked at right away. The reason that OEE is not used this way, according to the Lean Coordinator, is two-fold; many operators do not have enough knowledge of OEE, and the number of rejects is the main KPI used since before the implementation of the CMS. If there has been very little downtime and no production rate losses, the reject percentage can be unacceptable even if the OEE is above its target value. Practically, a component of the KPI is more important than the KPI itself. Since the reject percentage is the main KPI in Hörby as well, there is a high likelihood that the reporting of OEE during pulse meetings sooner or later is dropped.

Initially, the biggest stoppages were addressed on CI meetings. Since this practically became a repetition of what had already been addressed on pulse meetings, it was scrapped. The procedures to be employed during pulse meetings and CI meetings suggested by the authors are of different natures. The daily follow-up is intended to manage disturbances, much like how production is monitored and reported on today, but with the added data and information that comes with the CMS. The purpose is, to put it bluntly, to temporarily solve disturbances and explain why the situation looks like it does. The procedure during CI meetings, on the other hand, is meant to solve disturbances permanently by developing long term solutions to the biggest production problems. The authors believe it to be an advantage that not the exact same information is presented on both pulse meetings and CI meetings, as this will differentiate them and hopefully retain the right focus regarding managing vs solving disturbances.

The CMS is utilised for monthly follow-up. This follow-up is however customer driven, but somewhat resembles the follow-up suggested by the authors for the CI meetings in it that action plans are derived if a machine does not reach its OEE target.

Bibliography

[1] Nolato AB. URL: https://www.nolato.com (visited on 03/04/2020).

[2] Nolato AB. *Medical Solutions business area*. URL: https://www.nolato.com/en/nolato-group/medical-solutions-business-area (visited on 03/04/2020).

[3] Nolato AB. *Integrated Solutions business area*. URL: https://www.nolato.com/en/nolato-group/integrated-solutions-business-area (visited on 03/04/2020).

[4] Nolato AB. *Industrial Solutions business area*. URL: https://www.nolato.com/en/nolato-group/industrial-solutions-business-area (visited on 03/04/2020).

[5] Nolato. *Nolato, 2019 annual report*. https://mb.cision.com/Main/966/3081288/1224284.pdf. Apr. 2020.

[6] J.-E. Ståhl. *Industriella Tillverkningssystem del II - Länken mellan teknik och ekonomi*. Lund, Sweden, 2016.

[7] T. Ohno. *Toyota Production System: Beyond Large-Scale Production*. Portland, Oregon: Productivity Press, 1988.

[8] Toyota Motor Corporation. *The "thinking" production system: TPS as a winning strategy for developing people in the global manufacturing environment*. https://media.toyota.co.uk/wp-content/files_mf/1323862732essenceTPS.pdf. Oct. 2003.

[9] K. Ishikawa. *Introduction to Quality Control*. Tokyo, Japan: 3A Corporation, 1990.

[10] P. Almström et al. *Sustainable and resource efficient business performance measurement systems – The handbook*. ISBN 978-91-639-5272-2: SuREBPMS, 2017.

[11] C. Andersson and M. Bellgran. "On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity". In: *Journal of Manufacturing Systems* 35 (2015), pp. 144–154. DOI: https://doi.org/10.1016/j.jmsy.2014.12.003.

[12] G. T. Doran. "There's a S.M.A.R.T. way to write management's goals and objectives." In: *AMA FORUM* 70.11 (1981), pp. 35–36.

[13] S. Nakajima. *Introduction to TPM - Total Productive Maintenance*. ISBN: 0-915299-23-2: Productivity Press, Inc, 1988.

[14] C. Andersson and M. Bellgran. "Combining Overall Equipment Efficiency (OEE) and productivity measures as drivers for production improvements". In: *Swedish Production Symposium 2011* 4 (2011), pp. 20–29. DOI: https://portal.research.lu.se/portal/files/6184392/2224805.pdf.

[15] G. A. Miller. "The magical number seven, plus or minus two: Some limits on our capacity for processing information". In: *Psychological Review* 63.2 (1956), pp. 81–97. DOI: https://doi.org/10.1037/h0043158.

[16] K. L. Kelly. "Twenty-Two Colors of Maximum Contrast". In: *Color Engineering* 3.6 (1965), pp. 26–27.

[17] P. Green-Armytage. "A Colour Alphabet and the Limits of Colour Coding". In: *Colour: Design & Creativity* 10.5 (2010), pp. 1–23.

[18] AV Plastics. URL: https://www.avplastics.co.uk/what-is-injection-moulding/injection_moulding (visited on 03/04/2020).

[19] Omnexus. URL: https://omnexus.specialchem.com/selection-guide/silicone-rubber-elastomer#LSR (visited on 05/11/2020).

[20] Dow. *Liquid injection molding: Processing guide for SILASTIC^{TM} Liquid Silicone Rubber (LSR) and SILASTIC^{TM} Fluoro Liquid Silicone Rubber (F-LSR)*. URL: https://www.dow.com/en-us/document-viewer.html?ramdomVar=1736152743811030603&docPath=/content/dam/dcc/documents/en-us/app-tech-guide/45/45-10/45-1014-01-liquid-injection-molding-processing-guide.pdf (visited on 05/11/2020).

[21] Plastics Technology. *Getting Into LSR: Part II - Choosing an Injection Machine*. URL: https://www.ptonline.com/articles/getting-into-lsr (visited on 05/27/2020).

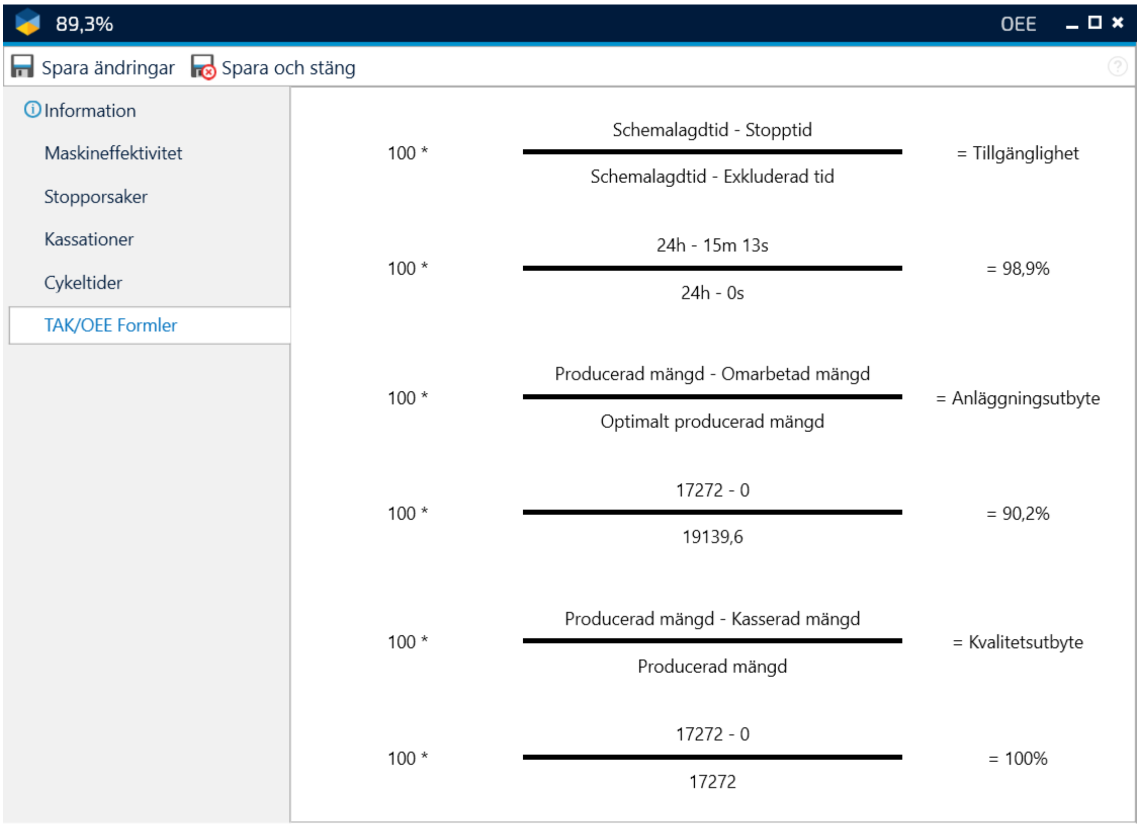
[22] J. Dudovskiy. *Interviews*. URL: https://research-methodology.net/research-methods/qualitative-research/interviews/ (visited on 05/23/2020).

[23] Good Solutions AB. *Internal training material*. 2020.

[24] P. Centore. *sRGB Centroids for the ISCC-NBS Colour System*. 2016.

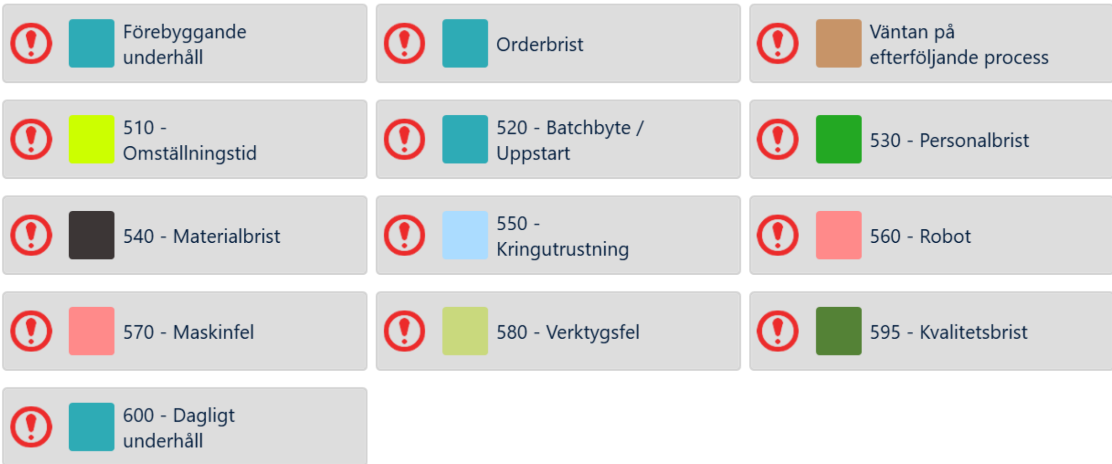
[25] Voluntocracy. URL: https://www.w3schools.com/colors/w3-nbs.txt (visited on 04/17/2020).

A. APQ-components as Defined in the Current Monitoring System



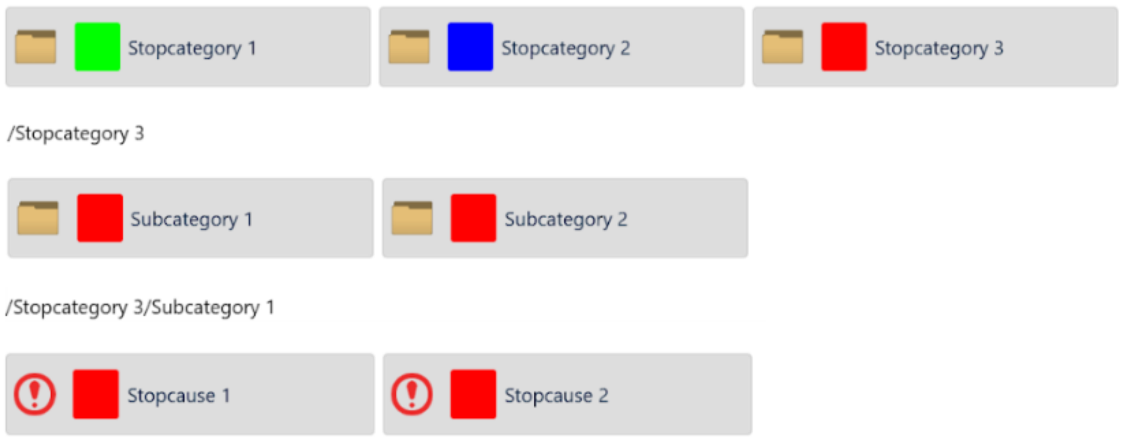
Note: the data in this figure is not representative of the actual production at Nolato MediTech since the CMS has not been correctly used up to this point.

B. Previous Downtime Reasons Nolato MediTech Hörby



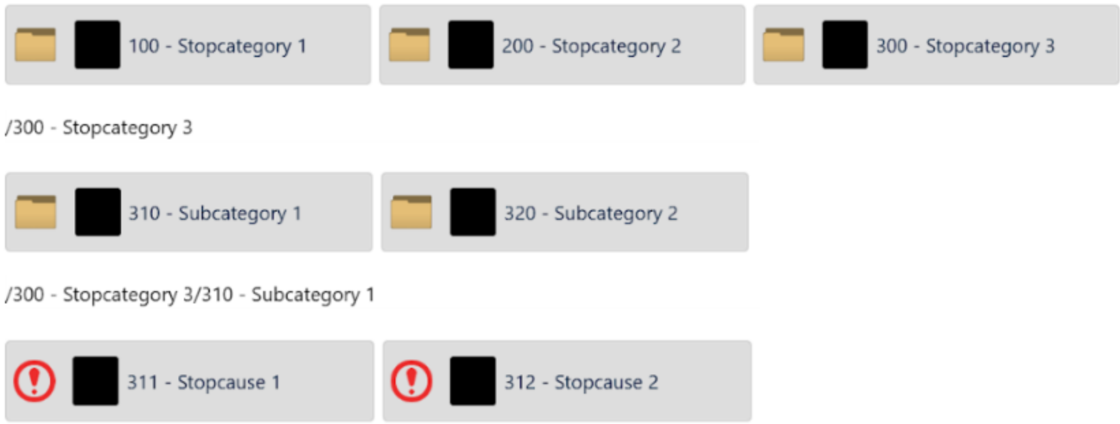
C. Different Reason Formats

Colour format:



Letter format:

Number format:



D. Interview Summary - Visions about the Current Monitoring System

What should the information from the CMS be used for?

- Production managers
  - It could be used for highlighting potential improvements in the production, for example where there is need for modernisation and what kind of renovation should be done.
  - To be able to address the primary causes of downtime, to number of stops and to time consumed. This information could be relevant on a daily basis to see where machine operators need to lay their focus during a particular shift. It could also be used to summarize over a certain period of time in the past to see where bigger improvement projects should be done.
  - Give a picture of where in the organisation there is need to prioritise, and what. It is not always the production managers own department that is in focus and it may be relevant to lend personnel to other departments.
  - Bad delivery status can get an explanation by going back and check the CMS.
  - Involve the Maintenance department. They can monitor the machines that are prioritised at the moment via the CMS. It is also possible to create detailed downtime coding in the CMS to enable the Maintenance department to keep track of what kind of maintenance they do at different machines and how much time they spend on it.
- Factory manager
  - Reporting at factory pulse meetings, showing OEE data and the underlying downtime causes.
  - Improvement projects originated from a fact-based analysis.
  - KPI reporting higher up in the organisation.

How often is information from the CMS needed?

- Production managers

  - On a daily basis for use at the pulse meetings at each department. Mostly to report the most frequent and/or time consuming causes of downtime.
  - On a monthly basis to provide an overview and the possibility to look further into areas of interest.
- Factory manager
  - On a weekly and a monthly basis to get an overview of how every department is doing.

Which information is most interesting?

- Production managers
  - The primary causes of downtime considering the number of stoppages.
  - The primary causes of downtime considering the time consumed by the stoppages.
  - The percentage of total downtime that is planned maintenance.
  - The utilization of the machines.
- Factory manager
  - Causes behind machine performance.
  - An overview of downtime causes that indicates where improvement should be done.

How should the information from the CMS be presented?

- Production managers
  - As simple as possible to give a good overview.
- Factory manager
  - Visualized in a way that gives a good overview.
  - Graphic presentation at pulse meetings to make the information easily accessible.

E. Downtime Reasons Nolato MediTech Lomma


/Service och underhåll
Maskin underhåll
Robot
B underhåll
C underhåll
/Service och underhåll/Maskin underhåll
FU Maskinunderhåll
Årservice av maskin
/Service och underhåll/Robot
Veckounderhåll robot
Månadsunderhåll robot
Kvartalsunderhåll robot
Halvårsunderhåll robot
Årservice av robot


/Robot
6-axlad stopp
Produkt X stopp
PnP stopp
/Robot/6-axlad stopp
Skrivare
Vacuum
Brätteshantering
TPU hantering
Robot axlar
Vändstation / Fixtursystem
Provtagning
Övriga stopp i cellen
/Robot/Produkt X stopp
Vacuum fel 1
Vacuum fel 2
Robot 1
Robot 2
Transportband
Fixtur
/Robot/PnP stopp
Hg1 axel
Hg2 axel
Hg1 vac
Hg2 vac
Centrering
MPi fel
TPU Krock
Vändstation / Fixtursystem
Provtagning


/Kringutrustning
RS-production - påverkar
Delta kontroller
Styrskåp / varmkanaler
RS-production - påverkar ej
Formvärmare
Färgblandare
Transportband
Tejpmaskin
/Administration
Flexternalsystem
/Fastighet
Planerat stopp Fastighet
Oplanerat stopp. Fastighet
/Övriga stopp
RS-production - påverkar
TPU brist - kund
710 - Validering / Testkörning
Kundrelaterat
RS-production - påverkar ej

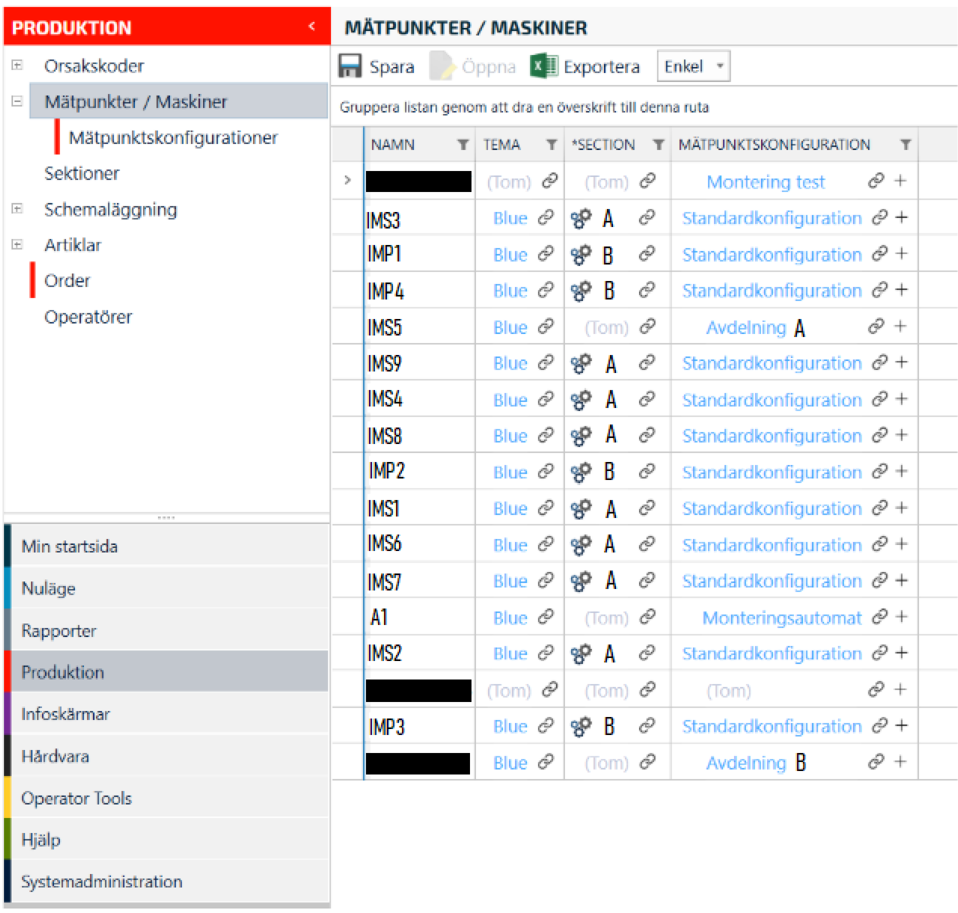
F. Final Settings in the Current Monitoring System

Lansering av den uppdaterade versionen av RS Production

När åtgärdsförslagen är på plats och systemen är redo att tas i bruk behöver några sista inställningar göras i RS Production för att de uppdaterade stopp- och kassationskoderna ska läggas upp på alla terminaler. Nedan följer en instruktion för de saker som behöver göras.

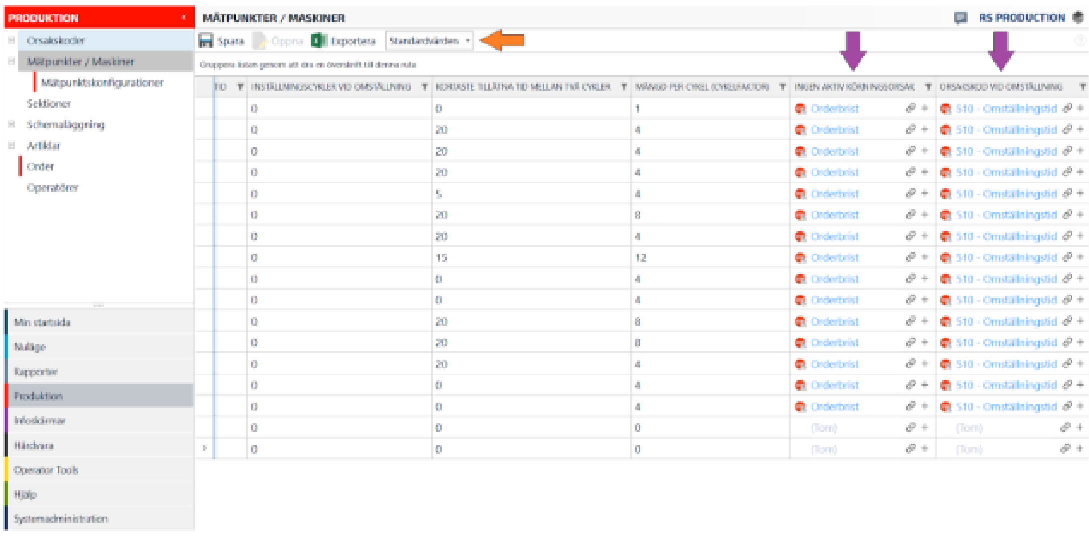
Koppla de nya mätpunktskonfigurationerna till rätt maskiner.

1. I menyn till vänster, välj *Produktion → Mätpunkter / Maskiner*.
2. Under *Mätpunktskonfiguration*, koppla mätpunktskonfigurationen *Avdelning A* till alla mätpunkter (maskiner) tillhörande avdelning A
3. Under *Mätpunktskonfiguration*, koppla mätpunktskonfigurationen *Avdelning B* till alla mätpunkter (maskiner) tillhörande avdelning B



Lägg till de orsaker som ska kodas automatiskt.

1. I menyn till vänster, välj *Produktion → Mätpunkter / Maskiner*.
2. Växla från *Enkel* till *Standardvärden*, se orange pil i bilden nedan.
3. Skrolla längst till höger för att se kolumnerna markerade med lila pil i bilden nedan.
4. För alla mätpunkter (maskiner) tillhörande avdelning `A` och `B` koppla
    a. stoppkoden *[505 - Orderbrist]* till kolumnen *Ingen aktiv körningsorsak*.
    b. stoppkoden *[701 - Omställning]* till kolumnen *Orsakskod vid omställning*.



G. Downtime Reason Settings

RS_Categories:

Kategorier i RS Production
Maskin
Verktyg
Kringutrustning
Material
Personal & Organisation
Förebyggande
Orderbyte
Planerat
Ospecificerat

Main folders for downtime reasons:

Namn	Sorteringsnummer	Färg	Kommentar
100 - Maskin	100	Vit #FFF2F3F4	Alla stoppkoder rörande maskin läggs i denna mapp och får ett nummer mellan 101 - 199
200 - Verktyg	200	Svart #FF222222	Alla stoppkoder rörande verktyg läggs i denna mapp och får ett nummer mellan 201 - 299
300 - Kringutrustning	300	Gul #FFF3C300	Alla stoppkoder rörande kringutrustning läggs i denna mapp och får ett nummer mellan 301 - 399
400 - Material	400	Lila #FF875692	Alla stoppkoder rörande material läggs i denna mapp och får ett nummer mellan 401 - 499
500 - Personal & Organisation	500	Orange #FFF38400	Alla stoppkoder rörande personal och organisation läggs i denna mapp och får ett nummer mellan 501 - 599
600 - Förebyggande underhåll	600	Ljusblå #FFA1CAF1	Alla stoppkoder rörande förebyggande underhåll läggs i denna mapp och får ett nummer mellan 601 - 699
700 - Orderbyte	700	Röd #FFBE0032	Alla stoppkoder rörande orderbyte läggs i denna mapp och får ett nummer mellan 701 - 799
800 - Diverse	800	Grågul #FFC2B280	Alla stoppkoder som inte passar in i mapp 100 - 700 läggs i denna mapp och får ett nummer mellan 801 - 899

Downtime reasons:

Namn	Sorterings-ordning	Färg	Kategori (orsaksmapp)	Exkludera från OEE	Tvingande kommentar	Används på avd. A	Används på avd. B	Kommentar
101 - Givarfel/signalfel maskin	101	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
102 - Fel på maskingrind	102	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
103 - Slut på köldmedium	103	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
104 - Igensatt vattenfilter	104	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
105 - Läckage kylning	105	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
106 - Igensatt sil vid materialintag	106	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
107 - Givarfel sprutenhet	107	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
108- Materialstyrning	109	Vit #FFF2F3F4	Maskin	-	-	Ja	-	
109 - Tom materialpotta	110	Vit #FFF2F3F4	Maskin	-	-	-	Ja	
196 - Materialförsörjning plast ospecificerat	195	Vit #FFF2F3F4	Maskin, Ospecificerat	-	Ja	-	Ja	
197 - Sprutenhet ospecificerat	197	Vit #FFF2F3F4	Maskin, Ospecificerat	-	Ja	Ja	-	
198 - Kylning ospecificerat	198	Vit #FFF2F3F4	Maskin, Ospecificerat	-	Ja	Ja	-	
199 - Maskin ospecificerat	199	Vit #FFF2F3F4	Maskin, Ospecificerat	-	Ja	Ja	Ja	
201 - Vulkat verktyg	201	Svart #FF222222	Verktyg	-	-	Ja	-	
202 - Igensatt sil verktyg	202	Svart #FF222222	Verktyg	-	-	Ja	-	
203 - Fel på kärna	203	Svart #FF222222	Verktyg	-	-	Ja	-	
204 - Beläggning på verktyget	204	Svart #FF222222	Verktyg	-	-	Ja	-	
205 - Igensatt vattenfilter	205	Svart #FF222222	Verktyg	-	-	Ja	-	
206 - Givarfel värmezon	206	Svart #FF222222	Verktyg	-	-	Ja	-	
207 - Fel på värmeelement	207	Svart #FF222222	Verktyg	-	-	Ja	-	
208 - Avluftningsskruv/kolv har fastnat	208	Svart #FF222222	Verktyg	-	-	Ja	-	
209 - Givarfel avluftning	209	Svart #FF222222	Verktyg	-	-	Ja	-	
210 - Kvalitetsproblem verktyg	210	Svart #FF222222	Verktyg	-	-	Ja	Ja	
211 - Läckage kylning	211	Svart #FF222222	Verktyg	-	-	Ja	-	
296 - Avluftning ospecificerat	296	Svart #FF222222	Verktyg, Ospecificerat	-	Ja	Ja	-	
297 - Värmezon ospecificerat	297	Svart #FF222222	Verktyg, Ospecificerat	-	Ja	Ja	-	
298 - Kylning ospecificerat	298	Svart #FF222222	Verktyg, Ospecificerat	-	Ja	Ja	-	
299 - Verktyg ospecificerat	299	Svart #FF222222	Verktyg, Ospecificerat	-	Ja	Ja	Ja	

Namn	Sorterings-ordning	Färg	Kategori (orsaksmapp)	Exkludera från OEE	Tvingande kommentar	Används på avd. A	Används på avd. B	Kommentar
301 - Pneumatikfel robotsystem	301	Gul #FFF3C300	Kringutrustning	-	-	Ja	-	
302 - Givarfel robotsystem	302	Gul #FFF3C300	Kringutrustning	-	-	Ja	-	
303 - Fel på gripare	303	Gul #FFF3C300	Kringutrustning	-	-	Ja	-	
304 - Fel på WEMO-robot	304	Gul #FFF3C300	Kringutrustning	-	-	Ja	-	
305 - Fel på grind till robotbur	305	Gul #FFF3C300	Kringutrustning	-	-	Ja	-	
306 - Pumpsläpp materialpump	306	Gul #FFF3C300	Kringutrustning	-	-	Ja	-	
307 - Brist på lådor	307	Gul #FFF3C300	Kringutrustning	-	-	-	Ja	
395 - Materialpump silikon ospecificerat	395	Gul #FFF3C300	Kringutrustning, Ospecificerat	-	Ja	Ja	-	
396 - Robotsystem ospecificerat	396	Gul #FFF3C300	Kringutrustning, Ospecificerat	-	Ja	Ja	-	
397 - Karusell ospecificerat	397	Gul #FFF3C300	Kringutrustning, Ospecificerat	-	Ja	Ja	Ja	
398 - Transportband ospecificerat	398	Gul #FFF3C300	Kringutrustning, Ospecificerat	-	Ja	Ja	Ja	
399 - Kringutrustning ospecificerat	399	Gul #FFF3C300	Kringutrustning, Ospecificerat	-	Ja	Ja	Ja	
401 - Byte av lotnummer	401	Lila #FF875692	Material	-	-	Ja	-	
402 - Materialbrist på lager	402	Lila #FF875692	Material	-	-	Ja	Ja	
499 - Material ospecificerat	499	Lila #FF875692	Material, Ospecificerat	-	Ja	Ja	Ja	
501 - Personalbrist	501	Orange #FFF38400	Personal & Organisation	-	Ja	Ja	Ja	
502 - Väntan på intern reperatör	502	Orange #FFF38400	Personal & Organisation	-	Ja	Ja	Ja	
503 - Väntan på extern reperatör	503	Orange #FFF38400	Personal & Organisation	-	Ja	Ja	Ja	
504 - Väntan på reservdel	504	Orange #FFF38400	Personal & Organisation	-	Ja	Ja	Ja	
505 - Orderbrist	505	Orange #FFF38400	Personal & Organisation	Ja	Ja	Ja	Ja	Anges automatiskt när det inte finns någon aktiv körningsorsak.
506 - Väntan på mätresultat	506	Orange #FFF38400	Personal & Organisation	-	Ja	-	Ja	
599 - Personal & Organisation ospecificerat	599	Orange #FFF38400	Personal & Organisation, Ospecificerat	-	Ja	Ja	Ja	

Namn	Sorterings-ordning	Färg	Kategori (orsaksmapp)	Exkludera från OEE	Tvingande kommentar	Används på avd. A	Används på avd. B	Kommentar
601 - Smörjning av verktyg A1	601	Ljusblå #FFA1CAF1	Förebyggande, Planerat	-	-	-	Ja	
602 - Smörjning av verktyg A2	602	Ljusblå #FFA1CAF1	Förebyggande, Planerat	-	-	Ja	-	
603 - Smörjning av avluftningsskruv A4	603	Ljusblå #FFA1CAF1	Förebyggande, Planerat	-	-	Ja	-	
604 - Förebyggande underhåll verktyg B0	604	Ljusblå #FFA1CAF1	Förebyggande, Planerat	-	-	Ja	-	
605 - Förebyggande underhåll formspruta	605	Ljusblå #FFA1CAF1	Förebyggande, Planerat	-	-	Ja	Ja	
606 - Förebyggande underhåll robot	606	Ljusblå #FFA1CAF1	Förebyggande, Planerat	-	-	Ja	-	
607 - Förebyggande underhåll verktyg	607	Ljusblå #FFA1CAF1	Förebyggande, Planerat	-	-	Ja	Ja	
608 - Kalibrering formspruta	608	Ljusblå #FFA1CAF1	Förebyggande, Planerat	Ja	-	Ja	Ja	
701 - Omställning	701	Röd #FFBE0032	Orderbyte, Planerat	-	-	Ja	Ja	Anges automatiskt vid omställning i början av varje order.
702 - Line Clearance	702	Röd #FFBE0032	Orderbyte, Planerat	-	-	Ja	Ja	
801 - Strömavbrott	801	Grågul #FFC2B280		-	-	Ja	Ja	
899 - Ospecificerat	899	Grågul #FFC2B280	Ospecificerat	-	Ja	Ja	Ja	

H. Downtime Reasons Department A

- 100 - Maskin
- 200 - Verktyg
- 300 - Kringutrustning
- 400 - Material
- 500 - Personal & organisation
- 600 - Förebyggande underhåll
- 700 - Orderbyte
- 800 - Diverse

/100 - Maskin

- Sprutenhet
- Kylning
- 101 - Givarfel/ signalfel maskin
- 102 - Fel på maskingrind
- 108 - Materialstyrning
- 199 - Maskin ospecificerat

/100 - Maskin/Sprutenhet

- 106 - Igensatt sil vid materialintag
- 107 - Givarfel sprutenhet
- 197 - Sprutenhet ospecificerat

/100 - Maskin/Kylning

- 103 - Slut på köldmedium
- 104 - Igensatt vattenfilter
- 105 - Läckage kylning
- 198 - Kylning ospecificerat

/200 - Verktyg

Kylning	Värmezon	Avluftning
201 - Vulkat verktyg	202 - Igensatt sil verktyg	203 - Fel på kärna
204 - Beläggning på verktyget	210 - Kvalitetsproblem verktyg	299 - Verktyg ospecificerat

/200 - Verktyg/Kylning

205 - Igensatt vattenfilter	211 - Läckage kylning	298 - Kylning ospecificerat

/200 - Verktyg/Värmezon

206 - Givarfel värmezon	207 - Fel på värmeelement	297 - Värmezon ospecificerat

/200 - Verktyg/Avluftning

208 - Avluftningsskruv/ kolv har fastnat	209 - Givarfel avluftning	296 - Avluftning ospecificerat

/300 - Kringutrustning

- Materialpump
- Transportband
- Karusell
- Robotsystem
- 399 - Kringutrustning ospecificerat

/300 - Kringutrustning/Materialpump

- 306 - Pumpsläpp materialpump
- 395 - Materialpump silikon ospecificerat

/300 - Kringutrustning/Transportband

- 398 - Transportband ospecificerat

/300 - Kringutrustning/Karusell

- 397 - Karusell ospecificerat

/300 - Kringutrustning/Robotsystem

- 301 - Pneumatikfel robotsystem
- 302 - Givarfel robotsystem
- 303 - Fel på gripare
- 304 - Fel på WEMO-robot
- 305 - Fel på grind till robotbur
- 396 - Robotsystem ospecificerat

/400 - Material

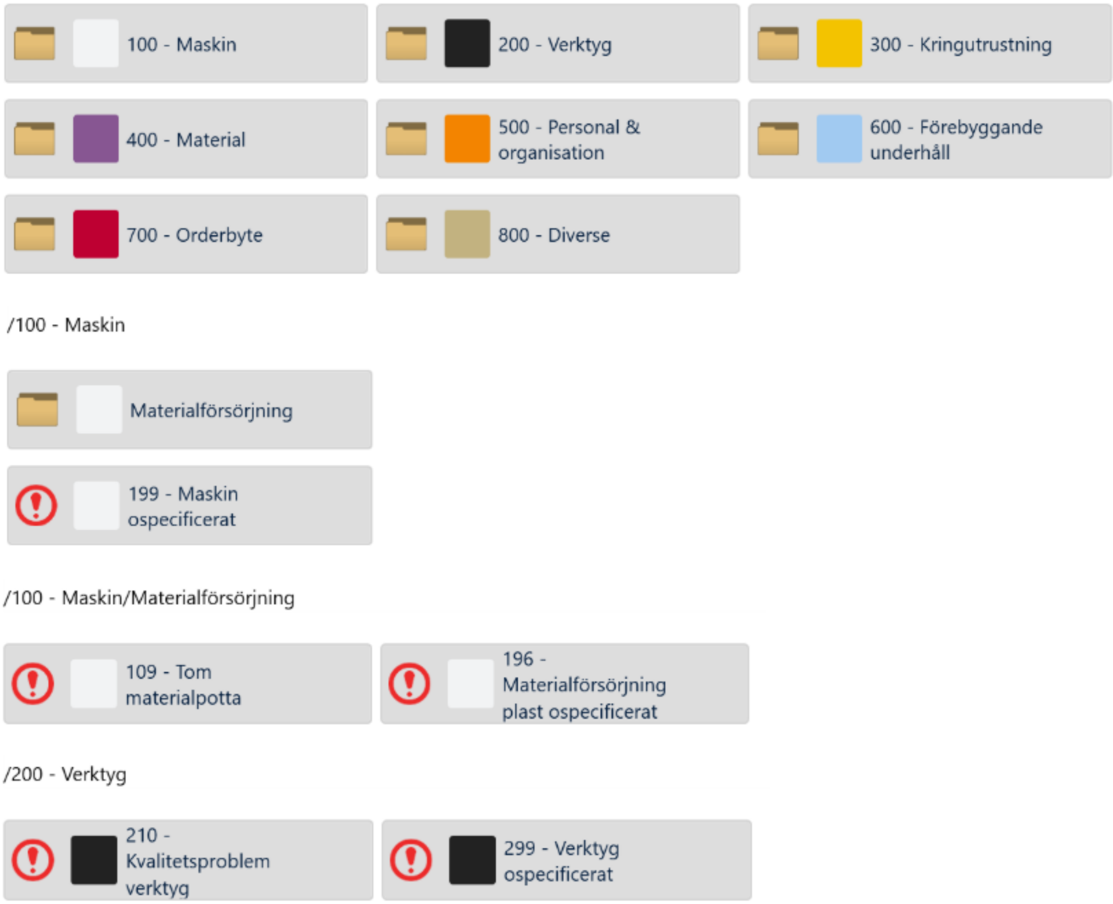
- 401 - Byte av lotnummer
- 402 - Materialbrist på lager
- 499 - Material ospecificerat

/500 - Personal & organisation

- 501 - Personalbrist
- 502 - Väntan på intern reparatör
- 503 - Väntan på extern reparatör
- 504 - Väntan på reservdel
- 505 - Orderbrist
- 599 - P&O ospecificerat


/600 - Förebyggande underhåll
Förebyggande underhåll S&U
602 - Smörjning av verktyg A2
603 - Smörjning av avluftningsskruv A4
604 - Förebyggande underhåll verktyg B0
/600 - Förebyggande underhåll/Förebyggande underhåll S&U
605 - Förebyggande underhåll formspruta
606 - Förebyggande underhåll robot
607 - Förebyggande underhåll verktyg
608 - Kalibrering formspruta
/700 - Orderbyte
701 - Omställning
702 - Line clearance
/800 - Diverse
801 - Strömavbrott
899 - Ospecificerat

I. Downtime Reasons Department B



/300 - Kringutrustning

- 307 - Brist på lådor
- 397 - Karusell ospecificerat
- 398 - Transportband ospecificerat
- 399 - Kringutrustning ospecificerat

/400 - Material

- 402 - Materialbrist på lager
- 499 - Material ospecificerat

/500 - Personal & Organisation

- 501 - Personalbrist
- 502 - Väntan på intern reparatör
- 503 - Väntan på extern reparatör
- 504 - Väntan på reservdel
- 505 - Orderbrist
- 506 - Väntan på mätresultat
- 599 - P&O ospecificerat

/600 - Förebyggande underhåll

- Förebyggande underhåll S&U
- 601 - Smörjning av verktyg A1

/600 - Förebyggande underhåll/Förebyggande underhåll S&U

- 605 - Förebyggande underhåll formspruta
- 607 - Förebyggande underhåll verktyg
- 608 - Kalibrering formspruta

/700 - Orderbyte

- 701 - Omställning
- 702 - Line clearance

/800 - Diverse

- 801 - Strömavbrott
- 899 - Ospecificerat

J. Reject Reason Settings

Main folders for reject reasons:

Namn	Sorteringordning (RS Production)	Färg	Kommentar
B100 - B106	100	Vit #FFF2F3F4	Kassationskoderna delas in utifrån sin IFS-kod. Detta eftersom operatörerna är vana att använda koderna och när man ska logga kassationen i RS Production har man precis noterat den i batchdokumentationen och vet den exakta koden. Därför hittar man orsaken snabbare om de är sorterade efter nummerkod.
B107 - B113	107	Svart #FF222222	
B114 - B120	114	Gul #FFF3C300	
B121 - B127	121	Lila #FF875692	

Reject reasons:

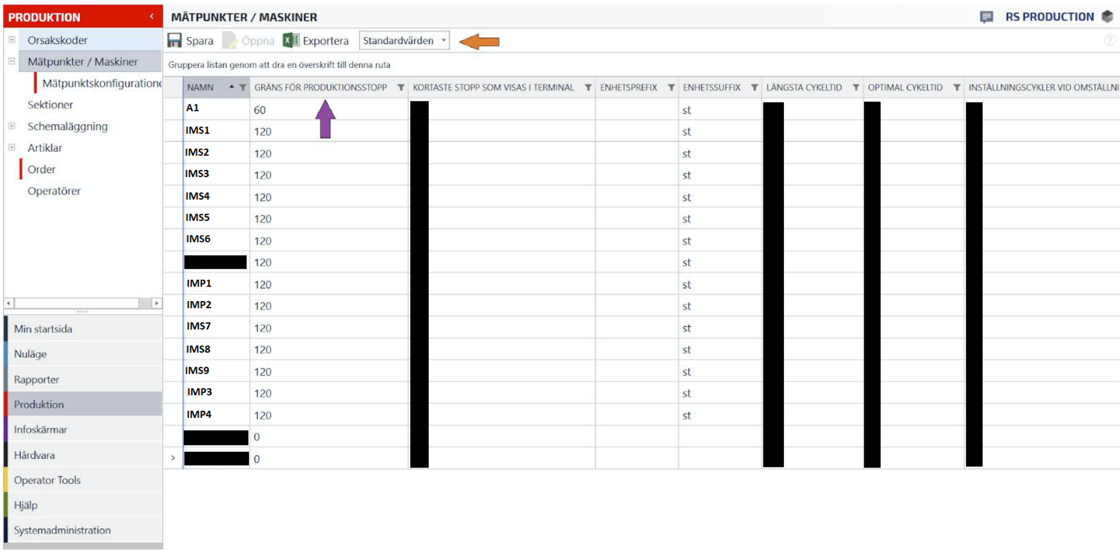
Namn (från IFS)	Sorteringsordning (RS Production)	Färg	Orsaksmapp	Används på avd. A	Används på avd. B	Kommentar
B100 - Planerad uppstart	100	Vit #FFF2F3F4	B100 - B106	Ja	Ja	
B101 - Oplanerad uppstart	101	Vit #FFF2F3F4	B100 - B106	Ja	Ja	
B102 - Deformation	102	Vit #FFF2F3F4	B100 - B106	Ja	Ja	
B103 - Färgfel	103	Vit #FFF2F3F4	B100 - B106	-	Ja	
B104 - Grad	104	Vit #FFF2F3F4	B100 - B106	Ja	Ja	
B105 - Ingöt	105	Vit #FFF2F3F4	B100 - B106	Ja	-	
B106 - Missfärgning	106	Vit #FFF2F3F4	B100 - B106	Ja	Ja	
B107 - Mått/vikt	107	Svart #FF222222	B107 - B113	Ja	Ja	
B108 - Ofylld	108	Svart #FF222222	B107 - B113	Ja	Ja	
B109 - Mixup	109	Svart #FF222222	B107 - B113	Ja	-	
B110 - Tryckfel	-			-	-	Ej inlagd i RS Production
B111 - Spill	111	Svart #FF222222	B107 - B113	Ja	Ja	
B112 - Produktionskontroll/mätdetaljer	112	Svart #FF222222	B107 - B113	Ja	Ja	
B113 - Luft	113	Svart #FF222222	B107 - B113	Ja	-	
B114 - Bränningar	114	Gul #FFF3C300	B114 - B120	-	Ja	
B115 - Vulkfel	115	Gul #FFF3C300	B114 - B120	Ja	-	
B116 - Hack	116	Gul #FFF3C300	B114 - B120	Ja	-	
B117 - Märke	117	Gul #FFF3C300	B114 - B120	Ja	Ja	
B118 - Beläggning	118	Gul #FFF3C300	B114 - B120	Ja	Ja	
B119 - Ytfel	119	Gul #FFF3C300	B114 - B120	Ja	Ja	
B120 - Partförskjutning	120	Gul #FFF3C300	B114 - B120	Ja	Ja	
B121 - Utgånget datum	121	Lila #FF875692	B121 - B127	Ja	-	
B122 - Kasserat Material Lager	122	Lila #FF875692	B121 - B127	-	Ja	
B123 - Felaktigt monterad	-	-	-	-	-	Ej inlagd i RS Production
B125 - Detaljer saknas	-	-	-	-	-	Ej inlagd i RS Production
B127 - Förorening	127	Lila #FF875692	B121 - B127	Ja	Ja	
B128 - Felaktigt antal i påsar	-	-	-	-	-	Ej inlagd i RS Production
B129 - Detaljer/påsar hopsvetsade	-	-	-	-	-	Ej inlagd i RS Production
B130 - Ej korrekt svetsade, singelpack	-	-	-	-	-	Ej inlagd i RS Production
B131 - Ej korrekt svetsade, multipack	-	-	-	-	-	Ej inlagd i RS Production
B132 - Svarta prickar/ingjutna partiklar – förpackning	-	-	-	-	-	Ej inlagd i RS Production
B133 - Små hål ("pinholes") i singelpack	-	-	-	-	-	Ej inlagd i RS Production
B134 - Applikator översvetsad	-	-	-	-	-	Ej inlagd i RS Production
B135 - Vassa kanter	-	-	-	-	-	Ej inlagd i RS Production

K. Reject Reasons Department A

L. Reject Reasons Department B

M. Altering the Micro Stop-limit (Swedish)

1. Gå in i menyn *Produktion* → *Mätpunkter / Maskiner*
2. Växla från *Enkel* till *Standardvärden*, se orange pil i bilden nedan.
3. Nu kommer man åt kolumnen *Gräns för produktionsstopp*, se lila pil i bilden nedan. Här anges längden för ett mikrostopp i sekunder, inställningen görs per maskin.



N. Step-by-step Handling Instructions

Stoppkodning

Maskinen har larmat och stannat automatiskt

1. Se till att menyn **Stoppkodning** är aktiv. Klicka annars på knappen **[Stoppkodning]**
2. Notera hur länge maskinen stått still innan larmet uppmärksammats, alltså varaktigheten på det nuvarande okategoriserade stoppet.
    a. Om det är *mindre än 5 minuter*, hantera felet, få igång maskinen och hoppa till *steg 7*.
    b. Om det är *mer än 5 minuter*, gå till *steg 3.*
3. Hantera larmet och få igång maskinen. Om reparatör behövs, gå till rubriken *Vid behov av reparatör* längre ned i dokumentet.
4. Klicka på det okategoriserade stoppet.
5. Klicka på **[Dela upp]**.
6. Uppskatta hur stor del av stoppet som bestod av aktiv hantering av problemet och dela upp stoppet enligt uppskattningen.
7. Kategorisera stoppet/stoppen.
    a. Om uppdelat stopp, klicka på första okategoriserade stoppet och ange **[501 - Personalbrist]**. Klicka sedan på det andra okategoriserade stoppet och ange lämplig stopporsak.
    b. Om ej uppdelat stopp, klicka på det okategoriserade stoppet och ange lämplig stopporsak.
8. Använd kommentarsfunktionen för utökad information, om behov uppstår.

Maskinen stannas manuellt

1. Se till att menyn **Stoppkodning** är aktiv. Klicka annars på knappen **[Stoppkodning]**
2. Hantera anledningen till stoppet och få igång maskinen. Om reparatör behövs, gå till rubriken *Vid behov av reparatör* längre ned i dokumentet. Gå annars vidare till *steg 3*.
3. Klicka på det okategoriserade stoppet och ange lämplig stopporsak.
4. Använd kommentarsfunktionen för utökad information, om behov uppstår.

Vid behov av reparatör

1. När problemet har hanterats, klicka på det okategoriserade stoppet.
2. Klicka på **[Dela upp]**.
3. Uppskatta hur stor del av stoppet som bestod av väntan på reparatör/reservdel jämfört med aktiv hantering av problemet och dela upp stoppet i två eller flera delar enligt uppskattningen.
4. Kategorisera det/de första okategoriserade stoppet/stoppen och ange det som är lämpligt utav **[501 - Personalbrist]**, **[502 - Väntan på intern reparatör]**, **[503 - Väntan på extern reparatör]** och **[504 - Väntan på reservdel]**, . Klicka sedan på det sista okategoriserade stoppet och ange lämplig stopporsak som beskriver det faktiska problemet.
5. Använd kommentarsfunktionen för utökad information, om behov uppstår.

Kassationskodning

1. Se till att menyn **Kassation** är aktiv. Klicka annars på knappen **[Kassation]**
2. Dubbelkolla att rätt order visas till vänster på skärmen.
3. Ange antalet kasserade detaljer under **Mängd**.
4. Klicka på knappen **[Välj annan orsak]**, om inte den relevanta orsaken redan ligger under **Vanliga orsakskoder** till höger på skärmen.
5. Välj lämplig kassationsorsak.
6. Klicka sedan på knappen **[Spara]**. Nu visas de registrerade kassationerna till vänster på skärmen.
    a. Använd kommentarsfunktionen för utökad information, om behov uppstår. Ange kommentar på en registrerad kassation genom att trycka på symbolen **[T]** på gällande kassation.
7. För att redigera en kassation behöver man först ta bort den registrerade kassationen man vill redigera, för att sedan lägga till en helt ny.
    a. För att ta bort en registrerad kassation, tryck på gällande kassation under **Registrerade kassationer**, bekräfta sedan frågan om att ta bort kassationen.

Orderbyte

1. Stoppa maskinen och genomför Line Clearance när ordern är slutförd.
2. Klicka på knappen **[Körplan]**.
3. Klicka på knappen **[Stoppa]** under rubriken **Pågående** för att avsluta ordern.
4. Starta genast nästkommande order i RS Production genom att klicka på ▸-knappen på rätt order under rubriken **Planerade**.
5. Nuvarande stoppet registreras som omställning automatiskt.
6. Ställ maskinen för den nya ordern.
7. Starta maskinen och börja producera.