Using production data for improved planning and control

by

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Project degree (20 credits)

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Abstract

With the purpose of coping with the global competitiveness between lead companies there is a need for systematic methods to provide shorter production time and higher quality of the resulting system. Currently, there is a tendency to focus on the solution instead of looking for the requirements and the production management don´t realize the severe consequences it has. According to the PPA studies of Swedish manufacturing companies, and some other studies, there is a significant gap between operation times in reality and in the planning systems. In order to solve this, it is installed a new level in the structure of MPCS (Manufacturing Planning and Control Systems) between the ERP/APS system and the shop floor level, called MES (Manufacturing Execution System). Through that, it is provided real-time information to the managers that help them to take decisions based on facts.

The objective of the study is to analyze the present software existing in the MES level in the company *Good Solutions* and the corresponding model of disturbances and production times in order to improve the planning and control. That is developed with real production data and it is checked what can be modified and improved on it. A model for production disturbances is given as well as some proposals with the intention of automating the decision process.

Keywords: Manufacturing process, Production System, MES, Production disturbances.

Acknowledgment

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I thank to so many people in Spain with whom I have spent my life, the ones from six years old and the others, especially to my ETSII friends that supported me in the hard moments and also for the unforgettable experiences that we have lived together.

Finally, thanks to my family because they help me in my entire life and they made this real. For your eternal encourage to develop the best from me. I love you!

Göteborg, in June 2011

Clara Díez Montes

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- MPCS: Manufacturing Planning and Control Systems
- PPA: Productivity Potential Assessment
- MES: Manufacturing Execution System
- VSM: Viable System model
- TEAM: Task Evaluation Analysis Methodology
- KPIs: Key Performance Indicators
- OEE : Overall Equipment Effectiveness
- TaGS: Tacticus and Good Solutions
- TEEP: Total Effective Equipment Performance
- APS: Advanced Planning Systems
- ERP: Enterprise Resource Planning
- HRM: Human Resource Management
- FRM: Finance Resource Management
- SCM :Supply Chain Management
- MRP :Manufacturing Resource Planning
- CRM: Customer Relationship Management
- MESA: Manufacturing Enterprise Solution Association
- RFID: Radio Frequency Identification
- OCR: Optical Character Recognition

1. Introduction

This chapter describes the background and the purpose of the project work as well as the research questions, the delimitations and the method used for developing the master thesis.

1.1 Background

There is often a mismatch between data in operation times in reality on the shop-floor level and the equivalent times in the manufacturing planning and control systems (MPCS) (Almström and Winroth, 2009). This has critical consequences for the company in order to use efficiently the existing resources and have knowledge about the delivery dates, achieving a sustainable production system. Manufacturing companies have to know about what the prerequisites are for efficient control of their own manufacturing system. For the understanding of what an ideal real-time control system is we should be able to identify the controlled system, the controller and the relationships between them (Almström and Murgau, 2008). In next figure it is represented the hierarchical pyramid between the enterprise resource planning or advanced planning systems (ERP/APS), the shop floor control and the physical system. Also the mismatch of information between the different levels is shown.

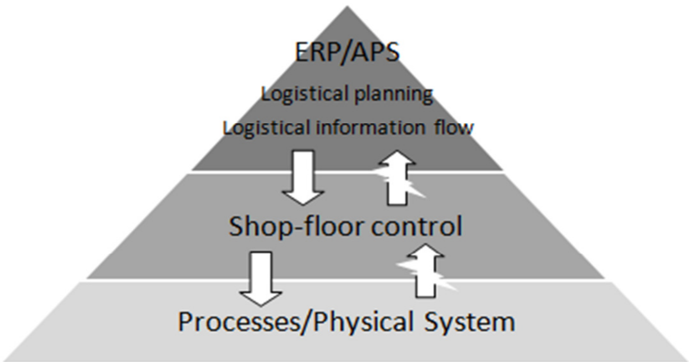


Figure 1: Mismatch between ERP, shop floor control and processes.

The studies carried out in Swedish manufacturing industry based on PPA (Productivity Potential Assessment) have revealed similar situations in the inability for real-time control. This method was developed during 2005-2006 by the Institute for Management of Innovation and Technology at Chalmers University. It is very useful from a company perspective but also from a consultant perspective, showing that there is a great deal of uncertainty of what to measure at shop floor level and how to measure it. The studies done with PPA also prove that there generally is a huge potential for improving the productivity by utilizing resources better (Almström and Winroth, 2009).

The weakness of business planning systems such as ERP and APS is the method of collecting and updating data. In order to avoid of manual adjustments that leads to missing accuracy of data and also losing the functionality of these systems, it is necessary to introduce a solution for integrating ERP/APS systems with shop floor data acquisition and collection systems (Huang, 2002). The next step after taking data in the shop-floor level is to implement them by the MES (Manufacturing Execution System), term that typically includes the management of product definitions, resources, scheduling, execution of production orders, collection of production data, etc. The integration of MES helps manufacturing managers to get real-time information about production schedules, financial issues and operation performance data. Moreover, it supports to make decision based on production problems.

In order to provide software for the management of production, there is a swedish company called *Good Solutions* that installs smart touch screens in the working area where the operator introduces all the information related to disturbances, times in the process, etc. That information moves seamlessly between TaGS and ERP system. TaGS stand for the product RS-Production with Movex integration. *Good Solutions* develop, sell and deliver it together with a company named *Tacticus*. The letters "Ta" are for their partner *Tacticus* who are specialized in Movex/ERP and the letters "GS" are for *Good Solutions*.

1.2 Purpose

The master thesis is developed in Chalmers University of Technology. Chalmers has been performing some research programs in a close collaboration with manufacturing, industrial software and consulting companies in order to find the main reasons for this mismatch and also give some suggestions for solving the gap. The divisions of Manufacturing technology and Operations management are involved in some researches to realize real-time control with a high level of automation in decisions and planning on all levels. They have proposed the viable production system model (VSM) that provides a mean to evaluate whether the existing or a planned organization and management system can control the manufacturing system in real-time or not (Almström and Murgau, 2008).

The purpose of the thesis is to test the model itself in reality through the software RS-Production used by the company *Good Solutions.* For that, it is studied the manufacturing planning and control in a customer company through touch screens installed in the shop floor level next to the operator´s area of work. Then it is analyzed how the data is measured by the software, which works in the MES level.

1.3 Research questions

This study analyzes where the lost of information and misunderstandings are when an event in the shop floor level occurs. This can be summarized by asking the following questions:

1. What are the advantages in MES implementation?
2. How does RS-Production work and are there any possible improvements of the present version?
3. What are the reasons for deviations in the operation times, batch times and scrap rate?
4. How can data collected from production be used to update and change the planning system?

1.4 Delimitations

The focus of the project is to evaluate incoming data and analyzing it with help of the software used in *Good Solutions* and to develop a Real-time control model. There are some limitations regarding the access to the data, specifically the real time status of the data and the private information in the company.

1.5 Method

The method followed consists on literature review, where a list of useful and related sources has been used in order to get the basic and necessary background about the topic. For that, there were helpful some papers about the subject and the database available at Chalmers university library website. After, a model for disturbances was formulated and then it was learnt how the software RS-Production runs with help of *Good Solutions*. Subsequently, it has been evaluated what is missing in the model, and finally research is carried out by analyzing the data and making some research questions to one of the managers of the company. It should have been interesting spend sometime in the shop-floor level of the customer company that is located in the south of Sweden to see how they do it and where can be the mismatch between operation times and the one set in the planning system.

The methodology is based on the TEAM (Task Evaluation Analysis Methodology) (Johansson 1999; Harlin 2000), but here it is applied a shorter version:

ACTIVITIES	RESULTS
Learn how RS-production and TAGS work	Understanding of MES implementation
Figure out causes for different disturbances in the company	Understanding stop causes and production disturbance handling
Formulate a model for disturbances based on the one existing in the company	Identified problem areas related to production disturbance handling
Analyze production data	Understanding stop causes and production disturbance handling
Discuss with Mikael Persson what is missing (management interviews)	Improvement suggestions: measures, implementations, etc.
Formulate methodology (including strategy, data model, collection methods and technology, procedures, practical guideline)	Suggest a new functionality in RS-Production to manage new automated solutions to handle disturbances in the production

Table 1: Description of the methodology applied.

2. Theoretical framework

This chapter introduces the general definition of production system and then the objectives, the measure and the OEE factor as a way of measurement is described. After it is defined the Manufacturing Planning and Control Systems (MPCS) and the different levels belonging to that concept. It has been focused on the MES level as the study that will come later is developed with software in that level.

2.1 Production System

A production system usually employs a series of value-adding manufacturing processes to convert raw materials into useful forms and eventually into finished products putting into practice the customer´s demands regarding price, quality, reliability, flexibility, etc. (Öhrström, 1997). To produce added value, the raw materials are used as a resource in addition to the human and mechanical resources in order to convert the demand information into products. Otherwise it can be produced products that nobody needs what implies that they have no value added (Sato, 2008).

The three main concepts in the production system that are shown in the next figure have to be controlled. The end result of an effective control of the production system is the ability to produce products at lower cost, faster and with fewer defects (Ingram, 2011).

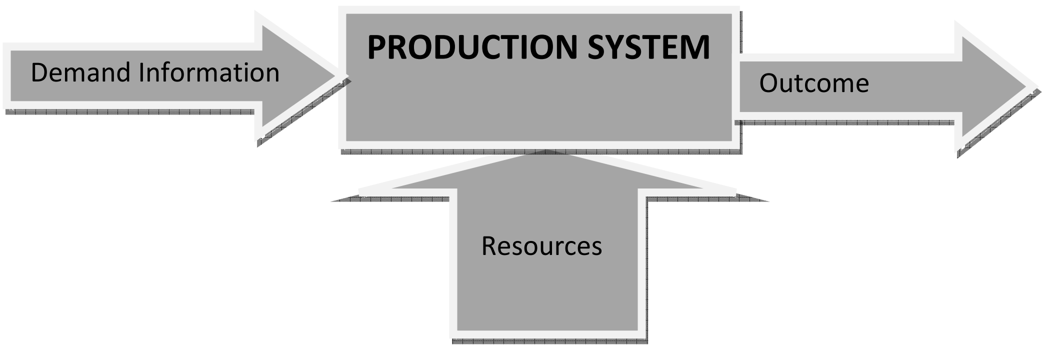


Figure 2: View of production system.

2.1.1 Objectives of the control

There are a set of objectives for the control of the system that must be met in order to cope the goals of the production; minimize the production time to ensure that the processes are completed in as little time as possible; meet the production goals and overall deadline; minimize the costs; use efficiently the resources decreasing raw materials and ensuring that each production department has exactly the right materials at the right time; customer satisfaction in terms of quality and security (Ingram, 2011).

2.1.2 Measure

The measurement in the performance of the objectives in the control is often expressed with KPIs (Key Performance Indicators). The KPIs will differ depending on the organization but they must reflect the organization´s goals, also must be the key to its success and they must be quantifiable. One example of the KPIs that includes a lot of others indicators, what should mean a good measurement, is the OEE (Overall Equipment Effectiveness) that is explained in following.

2.1.3 OEE

OEE are the stands for Overall Equipment Effectiveness. It is a framework for measuring the efficiency and effectiveness of a process, by breaking it down into three constituent components, called the OEE Factors: availability, efficiency and quality.

It is a data that evaluates how effectively a manufacturing process is utilized and is used to improve the performance of the process. It is not an absolute measure and allows making a comparison between manufacturing units. It measures effectiveness based on scheduled hours but not against calendar hours as it is done in TEEP (Total Effective Equipment Performance).

The objective of the manufacturing automation should be a higher OEE, not just localized improvement.

2.1.3.1 How to calculate OEE

OEE = Availability * Performance (Efficiency) * Quality rate

$$Availability = \frac{Scheduled\ production\ time - Total\ stop\ time}{Scheduled\ production\ time}$$

$$Efficiency = \frac{Theoretical\ cycle\ time \times Produced\ amount}{Scheduled\ production\ time - Total\ stop\ time}$$

$$Quality = \frac{Produced\ amount - Discarded}{Produced\ amount}$$

Simplifying the expression for the OEE it is obtained the following formula:

$$OEE = A \times E \times Q = \frac{Theoretical\ cycle\ time\ \times (Produced\ amount - Discarded)}{Scheduled\ production\ time - Total\ stop\ time}$$

The theoretical cycle time is the summation of cycle times of individual value-added operations at the minimum known process time for a single unit of product for a manufacturing sequence (SEMATECH, 2011). This definition includes the load time and also the process and unload time but does not include transportation, set up, queue, downtime, metrology, or production test, which would be considered process inefficiencies. The theoretical cycle time is taken from the machine´s data but the problem comes up with the manual work theoretical cycle time because it depends in many factors as the ability of the operator, the ergonomic to performance the action, etc. Cycle-time improvement will be also significantly aid in improving product quality.

The planned (scheduled) production time is the total time that equipment is expected to produce and the total stop time is the time that there is not production; it is not value added time. The produced amount includes the good pieces as well as the discarded ones.

Adding the term “Method” in the definition of OEE it is obtained the concept called productivity:

$$Productivity = M \times OEE$$

In the graph below it is explained visually how the planned production time is divided in the availability loss where are included the planned and unplanned stops, the efficiency loss that is produced by the slower speed as well as the rework and the quality loss what includes the scrap rate.

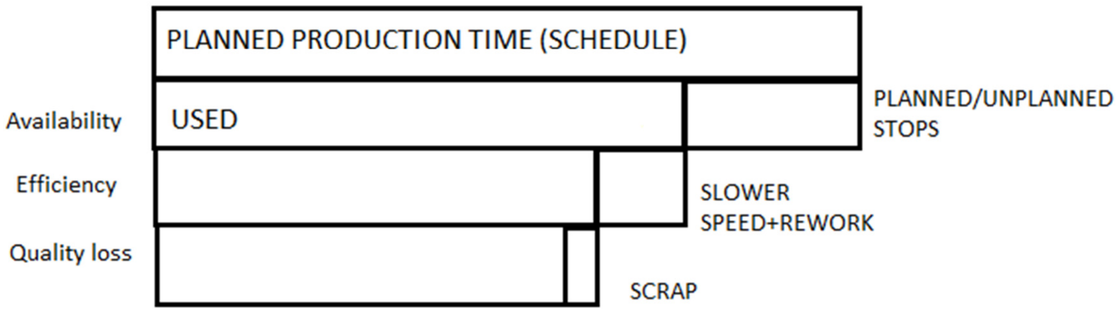


Figure 3: Planned production time in terms of availability, efficiency and quality loss.

2.1.3.2 Factors in the OEE

Availability loss

All stoppages that are produced by availability and accessibility in the scheduled production count as failure. The two problem areas that cause availability to be less than 100% are setup and equipment breakdowns.

At a measurement point, if a total of 20 minutes stop time during a 60 minute period is measured, the availability loss is 33.3% and the accessibility component of OEE is 67.7%.

Performance (efficiency)

It describes the manufactured quantity in relation to the optimal one, to the number of pieces expected. The calculation ignores the amount that could be produced during the stopping time. The problem areas that cut into performance are lower speed and minor stoppages.

If the optimal cycle time for one article at a measurement point is 60 seconds it can optimally be produced 40 units in 40 minutes but if it is only managed to produce 30 units, the performance component of OEE is 75%.

Quality

It is the number of good pieces as a percentage of the number of pieces produced. It occurs when the rejections are registered.

If 5 units of 30 made don´t move forward in the process, the quality loss is 16.7% and the quality component of OEE is 83.3%.

2.1.4 Control System

Manufacturing planning and control systems (MPCS) is traditionally developed to plan and monitor manufacturing plant performance and is considered as a significant element for plant performance improvement (Vollmann T. E., 2005).

In the past, 2-level structure was defined for MPCS (ERP/APS and shop floor), but at end of 1990s, a new structure was developed by introducing the term “Manufacturing Execution Systems (MES)”. According to the ISA S 95 standard, 3-level structure, known as ISA level model, is offered for planning systems. ISA S 95 standard is defined by a committee of 200 users and manufacturers. Each level that includes some modules operates within indicated time horizon (Kletti, 2007) as shown in the figure below.

There are no exact boundaries between these three levels and they have overlap areas. It can be said that MES functionalities are in real time with a technological orientation and ERP functionalities are in a medium and long term with a commercial orientation. In addition, there is an unclear border between MES level and automation level and because of some functions like data acquisition and the transfer of machine settings; a tight connection between two levels is generated (Naraghi, 2011).

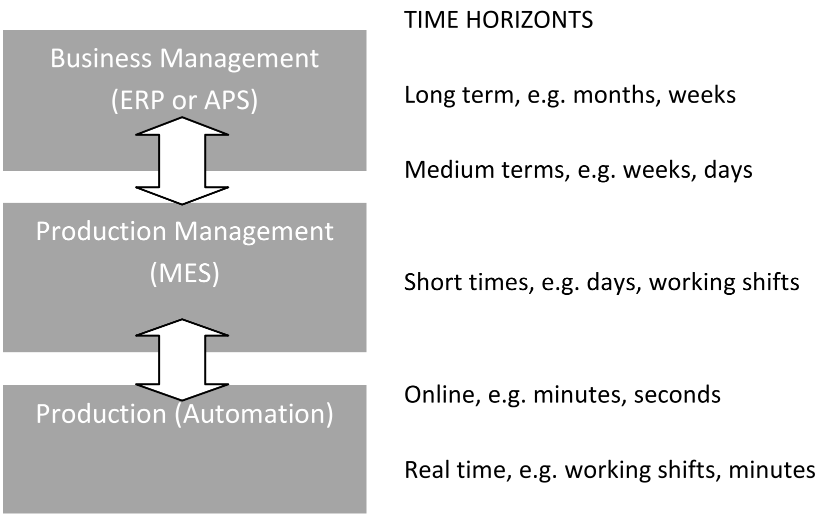


Figure 4: Three-level architecture (Kletti, 2007).

2.1.4.1 ERP / APS

The upper level (3rd level) is called business management (ERP/APS). It contains these function modules; Human Resource Management (HRM), Finance Resource Management (FRM), Supply Chain Management (SCM), Manufacturing Resource Planning (MRP) and Customer Relationship Management (CRM). They are shown in Figure 5. Although these modules are separate from each other, they have common points. Some of them like CRM and SCM modules can be used as integrated part of ERP or APS systems or as an independent function. ERP and APS systems comprise a planning period that generally is considered for a medium and long term period.

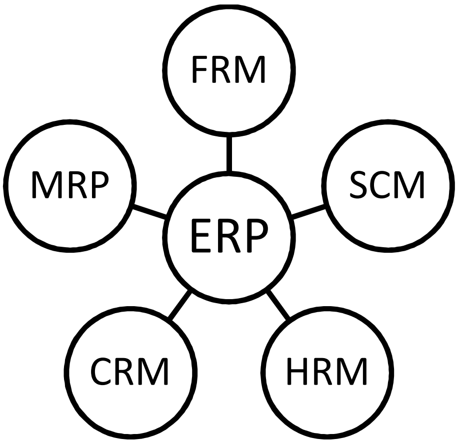


Figure 5: Information integration through ERP system.

2.1.4.2 MES

At the end of 1990s the 2nd level was developed by Manufacturing Enterprise Solution Association (MESA), which is production management level or MES when the need for accurate data in production information systems became necessary (Meyer, et al., 2009). A time horizon that is specified in MES level is short term and real-time. The term "MES" contains 11 functions that make possible the integration between automation level and enterprise scheduling level (Meyer, et al., 2009):

1- Operations / detailed sequencing
2- Dispatching production units
3- Product and tracking genealogy
4- Labour management
5- Quality management
6- Maintenance management
7- Data collection and acquisition
8- Process management
9- Performance analysis
10- Document control
11- Resource allocation and status

2.1.4.3 Automation

The 1st level, known as production (automation) level, is relevant to shop floor data acquisition and collection. There are some different technologies and methodologies that can be used to collect data on the shop floor and to transform the collected data from shop floor to higher level (MES). The choice of technology depends on the circumstances of each company as type of business, complexity of operations, annual revenue, company policies and etc. Some of them are:

- Barcode system
- Radio Frequency Identification (RFID)
- Optical Character Recognition (OCR)

Barcode system is one of the first technologies, used to automate data collection where hand recording is neither timely or cost effective. A one-dimensional (1D) barcode consists of several rectangular bars with varied width that are located beside each other in different distances. 1D barcode labels usually have a serial number that is used to provide extra information about product such as name or price. It can record shop floor data with high rate but the negative points of this technology are that improper environment can damage barcode labels or data capacity of barcodes are usually less than 20 characters. Also, distance limitation for the scanning process is another disadvantage (Cecelja, 2002). The new generation of barcodes are the two dimensional barcodes (2D), which have more data representation capability.

RFID is a technology that allows information is transferred between identified objects. These objects can be products, people, production materials and etc. The RFID system usually contains three parts; a tag including one or more electronic chips/labels, a reader (interrogator with antenna) and a data processing system. In some cases a RFID reader and a data processing unit are the same such as mobile phones with RFID reader. The RFID function can be explained as follow: In a transmission field, the tag that is powered up by the RF (for a passive tag) or by its own power (for an active tag) responds to a radio signal received and sends all own encoded data. And then the data will be decoded by the reader itself or by the data processing unit (Cecelja, 2002).

In an OCR system, the data are read from standard printed text and converted into ASCII characters. Data encoded in OCR, in opposite of bar code technology, is machine-readable as well as human readable. The function of this technology is based on recognition of patterns which include letters, numbers and some symbols e.g. commas and question marks. Because of high error rate during recognition process, this technology is not reliable compared to barcode system. In addition, application of this system in manufacturing companies is still restricted (Cecelja, 2002).

2.1.4.4 Information flow between business management level and MES level

As it is shown in the next figure, there is bidirectional information flow between MES level and ERP/APS level.

Work orders (including due dates, required processes and part numbers) as well as staff off/on-duty plans that are provided by business management level are used as input data in the MES level. The information keep in MES data storage and in the moment that it is necessary the detailed work orders respecting to equipments, tools, manpower in the production level are planned. From the other direction, the event messages such as alarm messages that may result from shortage of raw materials or a machine break down are sent from production management level to business management level. These messages support real time (re) planning of activities in the ERP/APS level. Attendance reports for preparing payroll are sent to ERP/APS level as well (Huang, 2002).

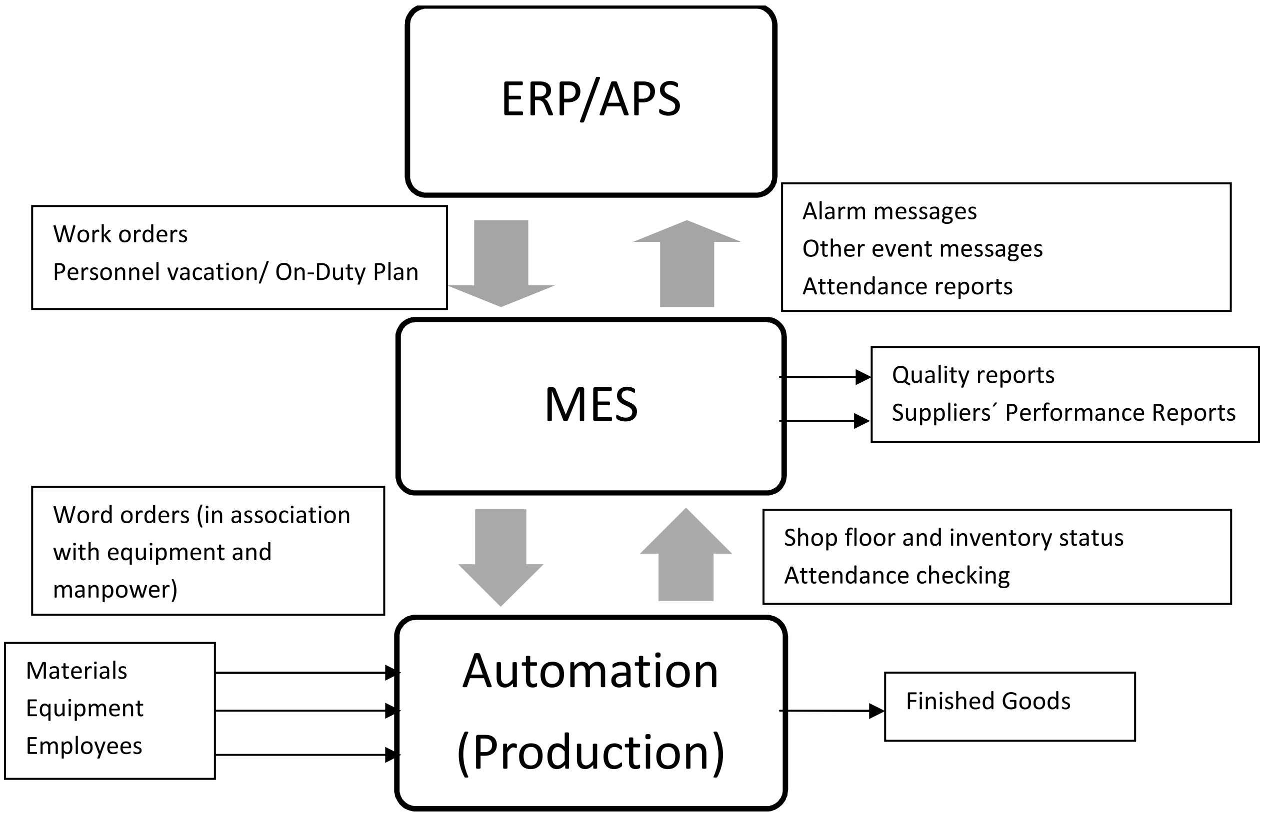


Figure 6: Information flow between different levels of MPCS (Huang, 2002).

2.1.4.5 Information flow between MES level and automation (production) level

As shown in the previous figure, MES can transmit detailed work orders including daily work schedule for each machine and employee to automation level. Moreover, maintenance timetables are sent to maintenance staff in order to carry out equipment maintenance in a right time. In the other direction, shop floor facts including the status of job, operation, operator, machine, tool, material, and material handling system, are transmitted from production level to MES level. For data collecting on the shop floor there are used some different electronic devices such as barcode reader, magnetic strip reader and RFID.

2.1.5 Disturbances

An important characteristic of any manufacturing system is the manufacturing "responsiveness"; its ability to maintain an immutable performance under changing operating conditions, the disturbances or unpredictable events that can influence the system's ability to achieve its performance objectives (Saad and Gindy, 1998).

A manufacturing system´s efficiency is depending on how well it fulfils the customers´ demand and how well it can cope with all ongoing changes. To achieve and maintain high productivity, the consequences of all kinds of disturbances have to be minimized. Disturbances occur for various reasons, human erroneous actions as well as technical malfunctions (Johansson, 1999). Many research publications list machine breakdowns as the most important factor that can influence shop floor performance. Additional types of disturbances identified are: variations in production demand patterns and volume, unavailability of cutting tools and catastrophic tool breakdowns, transport system failures, etc.

One way of regarding disturbances is shown in the Figure 7figure 7. The system disturbances are caused by small failures that can be introduced either at the development site or in the production site. In both sites the reason may originate from the technology, the humans involved, or the way they are organized. It can also be something that remains from an earlier failure that has left the system in a bad state.

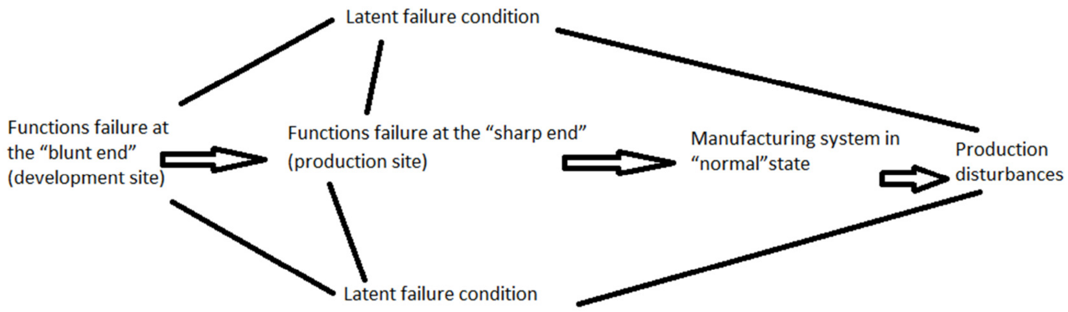


Figure 7: A contemporary model of system disturbances (adapted from Hollnagel, 1998).

A disturbance is defined (Lindau and Lumsden, 1994) as an event which affects a planned resource movement in such a way that a deviation from plan occurs. Actions taken to prevent the propagation of disturbances can be classified as formal and informal actions. Formal actions are such actions which are defined in a computer system, and informal actions are such that are executed manually.

In a holistic evaluation it is difficult to say that one of the actions is efficient. Some actions are, however, better than others. Partial delivery is a suitable action when materials shortages occur, subcontracting when machines break down and moving personnel when absenteeism occurs.

The main objective of safety actions is to guard against unforeseen events, i.e. disturbances. What is not known about these actions is how well they contribute to the overall system performance. An action can be used successfully to prevent a material shortage, but at the same time incur a cost or generate disturbances in other activities in the material flow. The safety actions are those used in manufacturing companies with a material flow consisting of a work shop and a final assembly area, i.e. companies working solely as assembly plants are not included. These actions are identified on a tactical level, i.e. actions used by planning. Safety actions used to prevent the propagation of disturbances are (Lindau and Lumsden, 1994):

- **Safety stock and buffers** are stocks kept as a reserve to guard against materials shortage because of uncertainty in supply and demand.
- **Safety capacity** is defined as the planning or reservation of extra personnel and/or equipment besides known demands to guard against unforeseen events.
- **Safety lead-time** is a time added to the normal lead-time in order to finish an order before its due date.
- **Over planning** results in components for a complete end-product being available instead of different quantities of different components being kept in safety stock.
- **Expediting** consists principally of finding and rushing "hot" jobs through the manufacturing facility.
- **Subcontracting** can be an effective method of balancing supply and demand.

There is no efficient way of preventing the propagation of disturbances (Lindau and Lumsden, 1994); an action which incurs a high cost or which upsets the system is not preferable. The action used is either expensive, but has a low impact on the system upset, or cheap but upsets the system considerably.

2.1.5.1 A model for disturbances

According to Saad and Gindy (1998) disturbances are classified based upon their sources of origination; first they are divided by internal and external.

Internal disturbances	**External disturbances**
Machines: (1) Unavailability (breakdown, corrective maintenance, preventive maintenance). (2) Availability, but with limitations on machine capacity.	Demand related: (1) Unexpected orders (variety). (2) Expected orders with time delay. (3) Expected orders arriving early. (4) Change in order priority. (5) Quantity variation lower/higher than planned.
Tools/fixtures: (1) Unavailability (not requested, not earmarked for job, shared and used by resources). (2) Available, but with constraints.	Supplier related: (1) Delivery at the wrong time. (2) Non-delivery of the required parts.
Transport: (1) Unavailability (e.g. breakdown, etc.). (2) Available with limited capacity.	
Operators: (1) Unavailability (e.g. sickness, holiday, disputes, etc). (2) Available with constraints (e.g. lack of appropriate skills).	

Table 2: Classification of disturbances (Saad and Gindy, 1998).

3. Present state analysis of RS-Production/TaGS

3.1 About the software

This software provides a screen interface to the machine operators in which they perform their work. They are the best experts that know how their machine works, why it is frozen or why some production must be discarded. The operator terminal displays are constantly update with information such as route plans, when production will start, the availability of the machine, the causes of the stop, how much should be produced and what materials to use. The operator receives all this information with clear graphics directly at the workplace.

TaGS take care of error handling and have fair consideration of the data entered, also if the network connection temporarily disappears it buffers information and transfer it when communications come up again. It has an interface against industrial equipment, meaning that the system via electrical signals is constantly updated on current rates of production and it has a direct perception of a stop in the machine.

The operation reports offer:

- Correct amount produced
- Discarded amount with a cause code
- Used machine time
- Stop time/break time with a cause code
- Set up times
- Manned time

It has follow-up reports that describe the efficiency of production and the loss that occurred. In addition, it provides a graphical interface in a web environment where managers can easily build up shifts; the planning can be done daily or weekly.

3.1.1 Modules

The office tools in RS-Production are the office portion, where the managers set the settings and pick up reports. There, the features are divided into six groups or categories: instantaneous real time information from production; reports analytical and smart follow-up reports; register/edit article index and correction of manufacturing data; scheduling system preferences and stop causes; machine interfaces settings for touch screens; help manual.

In the instantaneous real time information from production it is possible to follow the scheduled orders, the late orders (marked with a red border), the stops, the amount of product discarded for each time slot, the machinery efficiency, the tools and the materials used. In the produced quantity bar is checked visually with the colours if the quantity produced was less or more than the desired target value for the time unit. It is the same with the scrap; it is determined the causes of the discarded product by the colour of the bar.

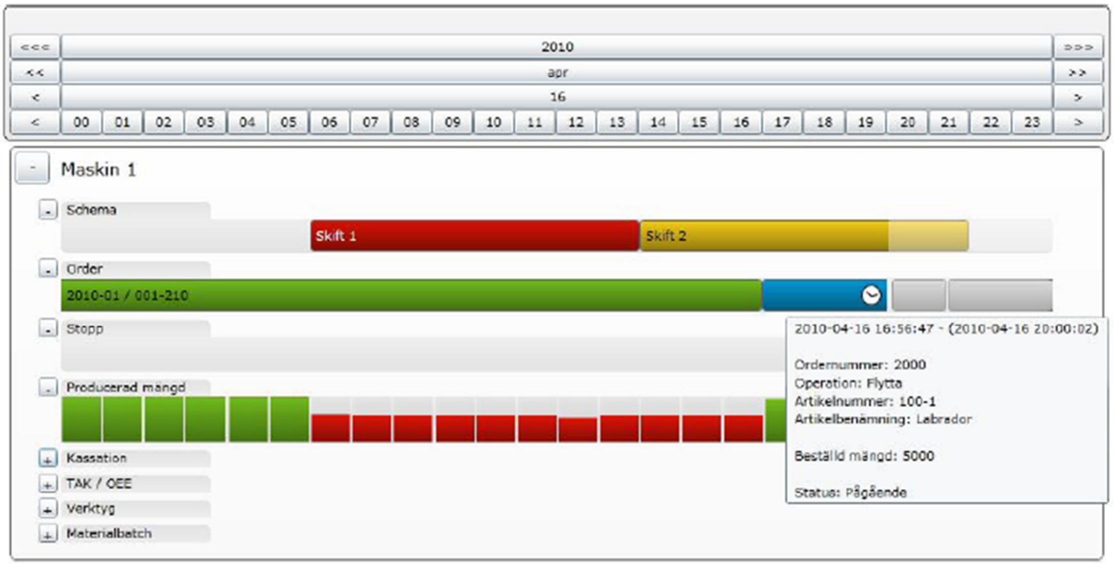


Figure 8: Example of current general production in a customer company (*Good Solutions* manual).

In the software RS-Production the OEE is translated to the Swedish stands TAK, where availability is represented by T (Tillgänglighet), efficiency by A (Anläggningsutbyte) and the quality loss by K (Kvalitetsutbyte).

In the availability loss, downtime includes both micro-stop and production stoppages. Even a stop that is shorter than the limit for how long stopped to be displayed in the operator's touch screens counted as downtime.

The exception is the stop categorized by stopping the causes that are marked as “Exclude from T”. They will not be charged to access the component. In the customer company where they are working now they don’t have the option “Exclude from T” in any of the stops but normally here are included stop codes like “No planned production” and “Education”. They are production disturbances that a machine operator or production leader cannot influence.

It is possible the measurement in real time for instantaneous OEE in the current machine showing if the measuring point is below or above its target value for the OEE and also it indicates that there is production at the measurement point by "Ok". The two arrows indicate OEE-trend for a time interval. In the example, the first arrow is red because is going from 81% to 70% and the second is green because is going from 58% to 81%. In the second machine both arrows are green because it is positive in both cases (74% to 84% on top and 68% to 74% on bottom).

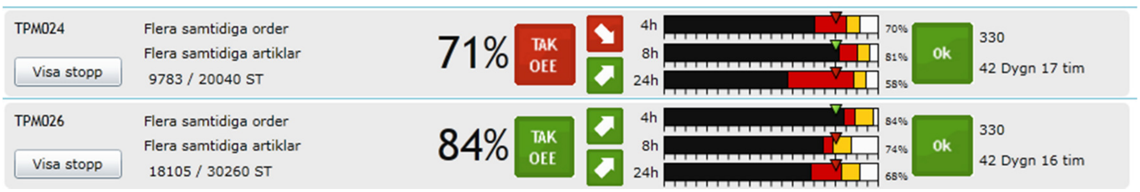


Figure 9: In real time status of the working machines (*Good Solutions* manual).

Also it is followed in real time each machine cycle, what is different for each machine implementations, and checked how to relate to the optimal cycle time which is the reference of 100% efficiency. There are described the cycle time in seconds (the time that has passed since the previous cycle signal), the exact timing of cycle signal, the orders that are running on that machine, and the article description and part number. The red and the blue line show the maximum allowable cycle time and the optimal cycle time (100% efficiency) respectively.

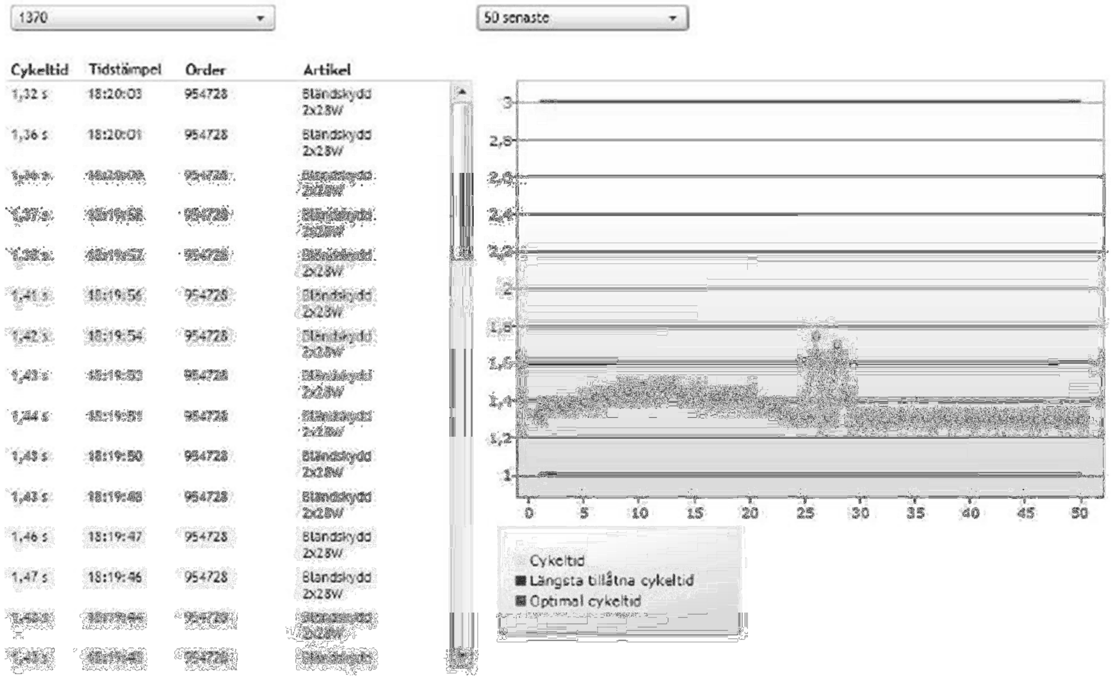
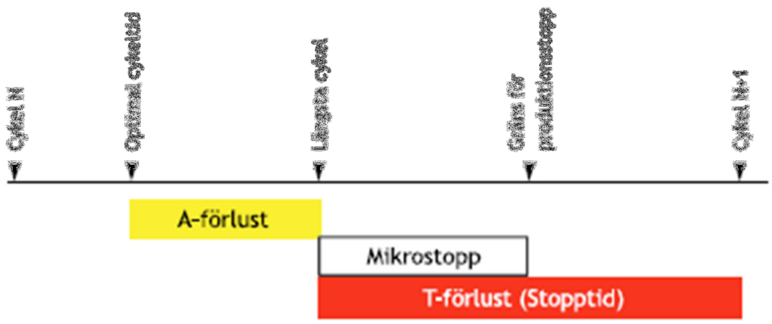


Figure 10: Example of cycle time monitoring.

In the reports analytical and smart follow-up reports there are presented the stop causes, the discarded amount and causes, the produced amount, the relevant times in the process, etc. Regarding to the stop times it is important to consider the boundaries; the limit of time for efficiency loss goes from optimal cycle to longest cycle; from longest cycle to the beginning of the next cycle it belongs to availability loss.

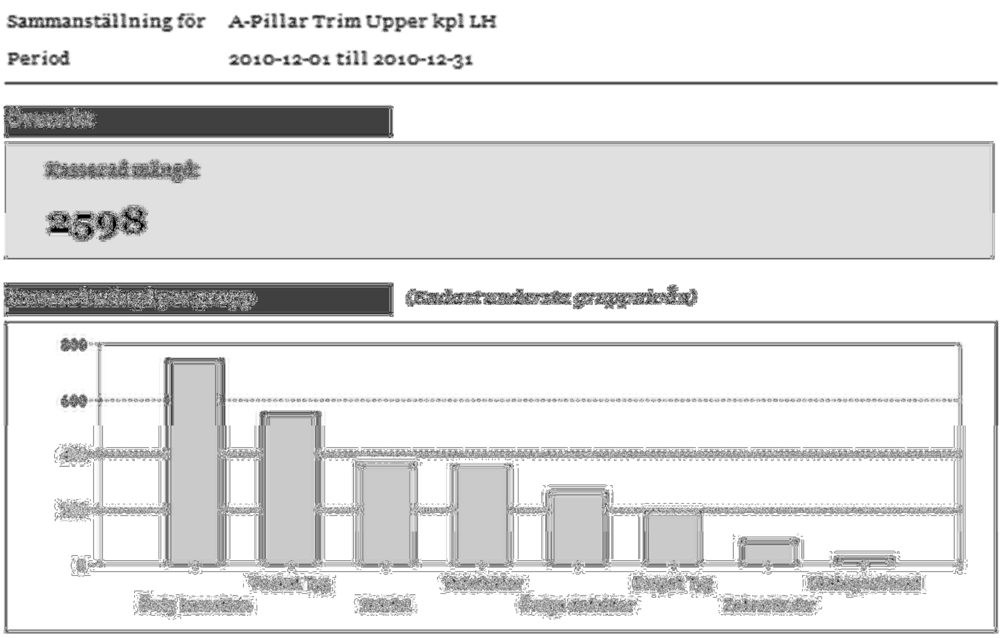


The optimal cycle, the longest cycle and the limit for the micro stop is established specifically for every combination of article/machine. This is made different from each customer (Mikael Persson, *Good Solutions* AB):

- In some cases the machines really have a “fixed” speed. It is either producing 0 or 10 000 per hour. Milk production is an example.
- Some customers have very few articles or types of articles (up to 10 or 20) and it is relatively easy for them to have detailed knowledge about the optimal cycle times.
- Some customers have very poor control of the setting of those times. They can have many articles with different cycle times. In this case it is recommended one of the following: do not use speed loss in the daily efficiency measurement; update the optimal cycle time from the shortest measured cycle time; or use “default” optimal cycle times like importing “time per unit”-x% from ERP system (normally this last option is not recommended).

3.1.2 Deficiencies

During the understanding of the running of RS-Production there were found some deficiencies in the software. Regarding to the discarded amount there were some mismatches between the total number of discarded items in a period for the manufacturing of a product, for example “A-Pillar Trim Upper kpl LH”, and the summation of the number from every order made in that product belonging to the same period. It is maybe produced because they were taken into account in the next order but it is not really clear. In the example, the total number of discarded items is 2598 and the sum from the different orders in that period is 504 + 1002 + 1378 = 2884 that is not consistent.



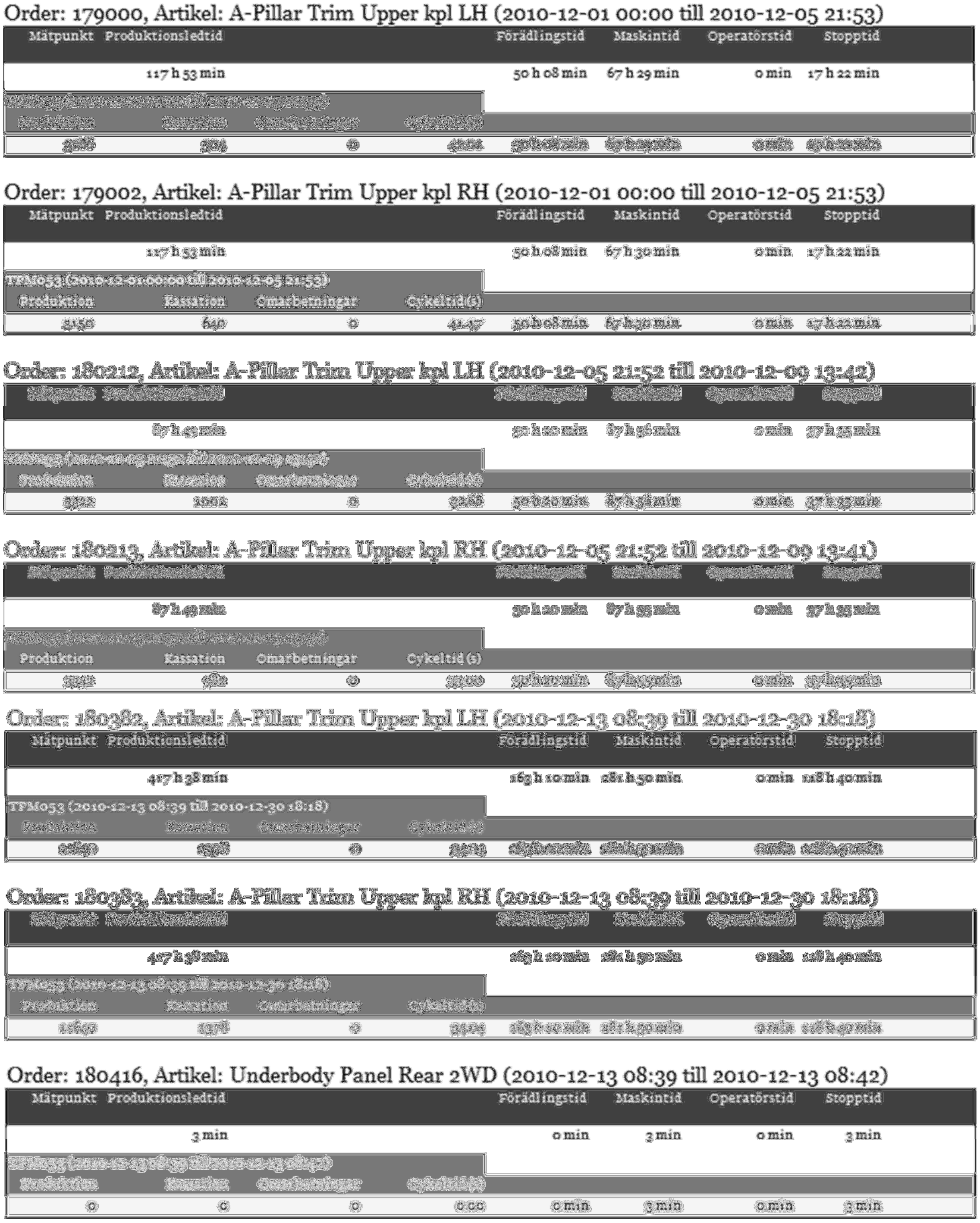


Figure 11: Mismatch between discarded amounts for "A-Pillar Trim upper kpl LH" in December 2010.

In addition, the value of the factors in the OEE according with the formulas sometimes do not correspond what the one written in the reports. For example in January 2011, in the production of "B-pillar kpl LH Off Bl", the quality factor is 90% but introducing the data for that period (Produced amount= 3476; Discarded= 494) in the formula:

$$Quality = \frac{Produced\ amount - Discarded}{Produced\ amount}$$

, the K factor should be 86% what does not correspond.

3.1.3 Development potential and improvements

The implementation of the software has an enormous potential. If every data is taken with the maximum accuracy it can be controlled all the manufacturing process with the information taken from the shop-floor level. But for that, all the figures involved in the process should work perfectly. The workers should know how it works perfectly and should be concentrated at every data that is introduced in order to not forgetting anything. The screens should be always running with the latest technology and the managers should be aware of the different problems continuously.

The improvements can be made in order to solve the deficiencies mentioned. The numbers in the different parts of the whole report have to be consistent and for that it has to be good communication between the workers set in the different shifts. Also there can be some improvements regarding to the available model of disturbances with the aim of minimizing the mismatch between reality and the information in the reports, as it was explained before.

4. Disturbance handling at a company

In order to analyze the disturbances, it was selected one of the customer company set in the south of Sweden that provides technical products in plastic as overhead consoles, fuel tank, engine covers, under body panels, pillars, housing for headlights, airbag covers, multi trap cartridge, fuel tanks, instrument cluster, etc. At the moment *Good Solutions* AB is implementing the software; by the database it is possible to select a period and then a machine, a section, an article by the name or the number, a production order or a shift. It is likely to combine even three of those dimensions. It was compared the data belonging to three different months, November 2010, December 2010, and January 2011 for some products; “A-Pillar trim upper kpl LH”, “B-Pillar kpl Off Bl” (right and left) and “Hinge net big LHD”. The version for the right instead of left of the first and the third product had almost the same data so the comparison was not worthy.

4.1 OEE

To start guessing what are the reasons for deviations in the times and data it is analyzed each concept inside the definition of OEE: availability, efficiency and quality. Average OEE is always calculated based on the total scheduled time.

The percentage in the right of each component is the average for the selected period and the second percentage is the lost. The colour code used is black for OEE, red for availability loss, yellow for efficiency loss and white for quality loss. Multiplying the three components it is obtained the OEE percentage as it was explained in the theoretical framework.

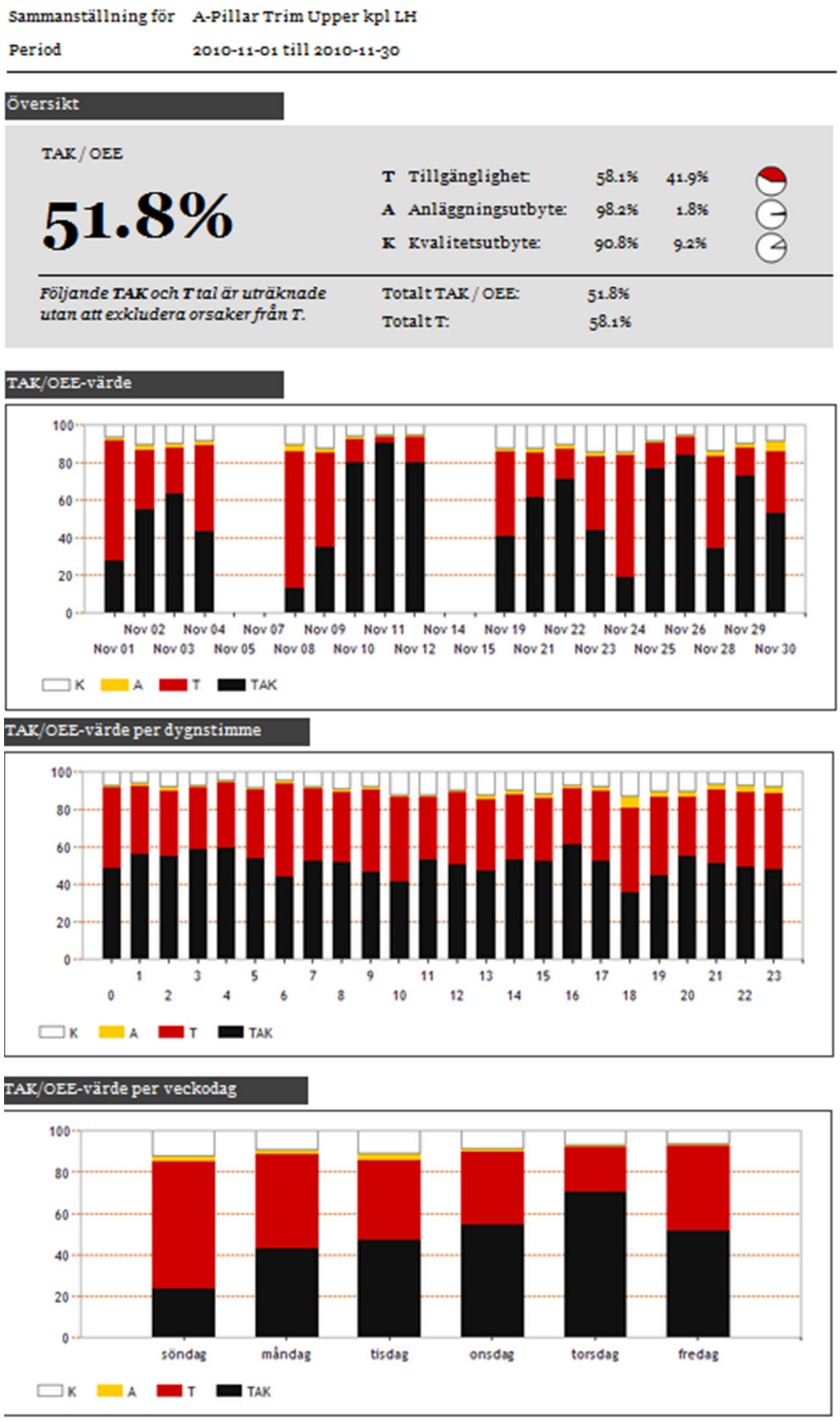


Figure 12: OEE in November 2010 for "A-Pillar Trim upper LH".

According to the formulas, the variables that can be modified aiming to modify the components of the OEE are: Scheduled production time, total stop time, theoretical cycle time, produced amount and discarded amount. In Appendix 1 there is the table with all the data belonging to the products in the selected periods. There are marked in red the lowest numbers in comparison between the three months and the subsequently times and amounts that affect the numbers.

Comparing the data of the three different months it can be said that the OEE in January for "B-Pillar LH" was smaller due to the reduction in the percentage of both availability and quality. It was the same in November for "B-Pillar RH" due to the efficiency and also in "Hinge Net Big" in November because of the availability loss. What can generate this?

Regarding to the **availability** loss there are included the planned and unplanned stops that refer to the breakdowns and the set-ups. Among the planned stops are the time to have lunch, the rest periods, the change of pallets, the maintenance, etc. In the unplanned stops are integrated the tool failures, the machines disturbance, etc. All of those planned and unplanned stops have been classified before. In addition, it has to be included the external disturbances both regarding to the demand and the supplier.

In the **efficiency** loss there are taken into account reasons like the slower speed due to new employees or the different ability to do the work between operators and also some short stops. Some other reasons included in both availability and efficiency losses are called allowances and they are explained and classified in Appendix 2.

Within the **quality** loss there are counted the scrap rate that means the discarded amount in that period and also the rework of the products if necessary.

4.2 Stop reasons

In order to minimize the consequences of any kind of disturbance it was done a compilation about the ones existing in the customer company. The different disturbances that the operator can select are set in a main menu and sub-menus. The reason codes are grouped in schedules to use a different set of reason codes on different data points.

- Set up
    - Start up
    - Test run
    - Start up after weekend
    - Start up after longer stops
- Maintenance
    - Preventive machine maintenance
    - Preventive robot maintenance
    - Lubrication
    - Cleaning
- Disturbance
    - Auxiliary equipment
    - Lack of material
    - Lack of packing material

  - Lack of supplementary components
  - Lack of operator (operator not present)
  - Machine disturbance
  - Tool failure
  - Planned stop
  - Weekend (or holiday) stop
  - Process monitoring
  - Stop at coffee break
  - Break at set up
- ❖ Process of adjustment
  - Robot programming
  - Vision programming
  - Process optimization
- ❖ Response
- ❖ Uncategorized
- ❖ Network management (disturbance)
- ❖ Cylinder heating (specific disturbance for this machine)
- ❖ Stuck component
- ❖ Change of pallets (in semiautomatic driving)

With the intention of checking whether that classification was correct or there were some reasons missing, it was compared with the model of Saad and Gindy (1998) that was explained in the theoretical framework. They are first classified as internal and external disturbances, depending on whether the origin of the disturbance is from within or outside the boundary of the manufacturing system.

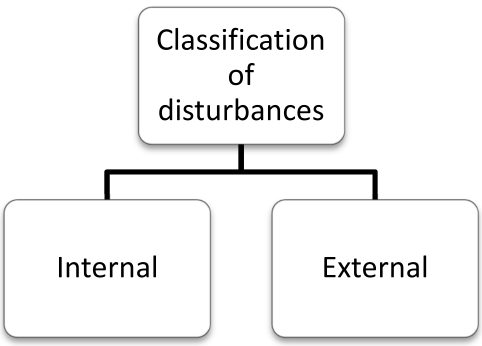


Figure 13: Classification of disturbances.

All the internal disturbances are related to resources as machines, tool/fixtures, transport, operators, etc. As a general classification of the internal disturbances, they are divided by planned or unplanned, depending on if they were in the scheduled time or not.

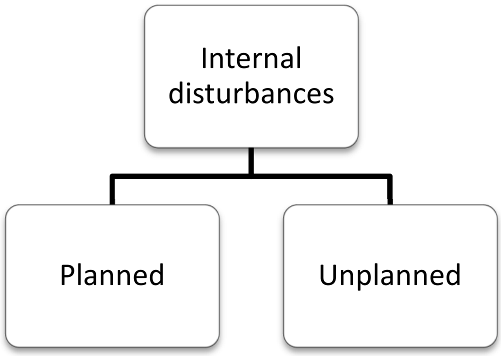


Figure 14: Classification of internal disturbances.

Belonging to the internal and planned disturbances there are included some main reasons as the auxiliary equipment disturbance, maintenance, weekend or holiday stop, set up, stop at coffee break, process of adjustment, process monitoring and uncategorized and the correspondent sub-classes that are shown in the following figure. Furthermore, the reasons for the internal and unplanned disturbances are classified (machine disturbance, tool failure, etc).

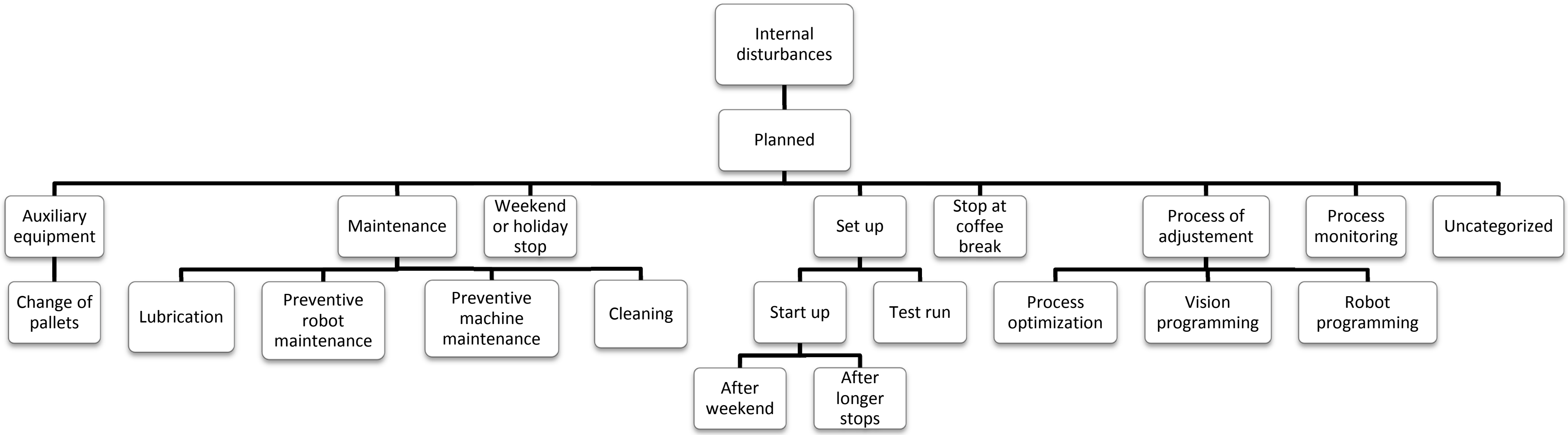


Figure 15: Classification of internal and planned disturbances.

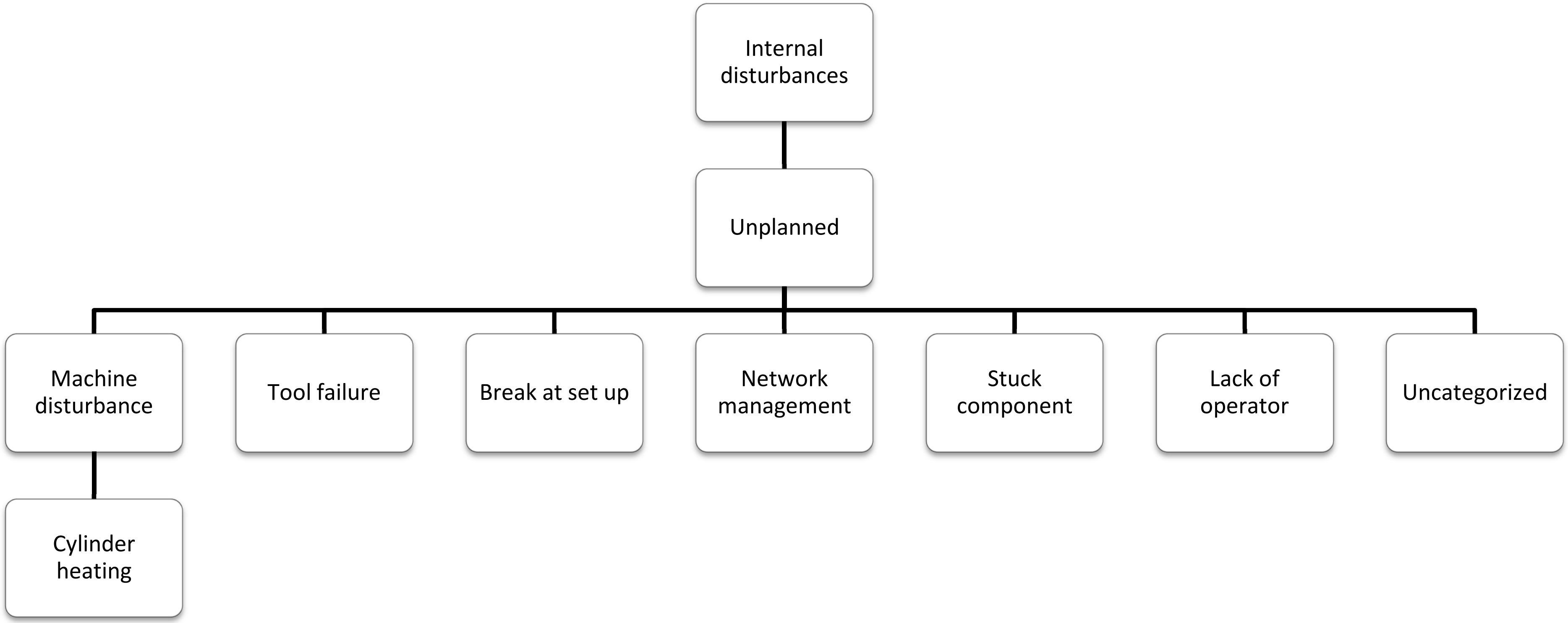


Figure 16: Classification of internal and unplanned disturbances.

On the other hand, the external disturbances are separated depending on whether they are related to the demand or the supplier.

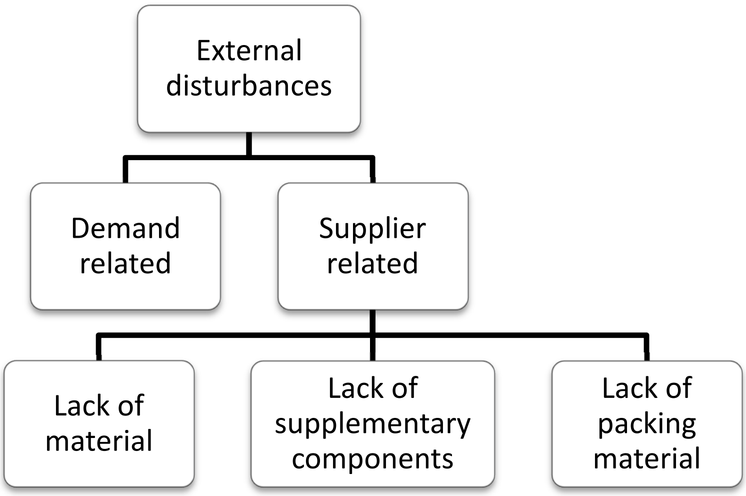


Figure 17: Classification of external disturbances.

Comparing this new model with the classification before, the changes that can be done about the internal disturbances are:

- "Machine disturbance" can be divided by breakdown of the machine and limitation in the machine capacity.
- "Tool failure" can be divided by breakdown of the tool, not earmarked for job, shared (not full capacity of the tool).
- It can be added "Transport breakdown" and "limited capacity" of the transport between stations in the manufacturing process (this is not necessary if the process is completely automated).

Regarding to the external disturbances, the operator can´t know if the orders are expected or not or if they are arriving earlier or with time delay, also about changes in order priority that are managed by the engineers so this type of disturbances cannot be included in the options.

In the disturbances related to the supplier it can be subdivided "Lack of material" by "No material" and "Material in wrong time" in order to specify the reason of that. It can be done the same for "Lack of supplementary components" and "Lack of packing material".

The graphs about stop causes are shown in following. In the first graph there are the number of stops (number of micro-stop and stop production during the search period) per group, as micro-stop, operational engineers, uncategorized, stand, response, process of adjustment, maintenance, no planned production, clamping, etc. In the second graph it is analyzed the stop-time in hours per group.

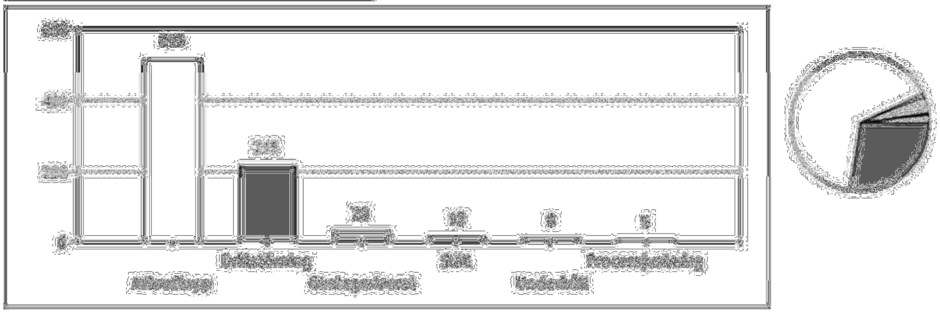
Here is not only important the number of stops but the total stop time because is what affects in the T and A factors. The total stop time is the cumulative time of the micro-stop and production stops during the search period. The time between stops is the average time between each stop ("Meantime between failures"); it is the total production divided by the number of stops. The production between stops is the average amount of output for each stop. There are follow-up reports for the stop cause and the graphics group the stops by the cause but also by the total number of stops and by the downtime in hours. Also it is possible to order them by weekday and hour in the selected period.

Sammanställning för	A-Pillar Trim Upper kpl LH
Period	2010-11-01 till 2010-11-30

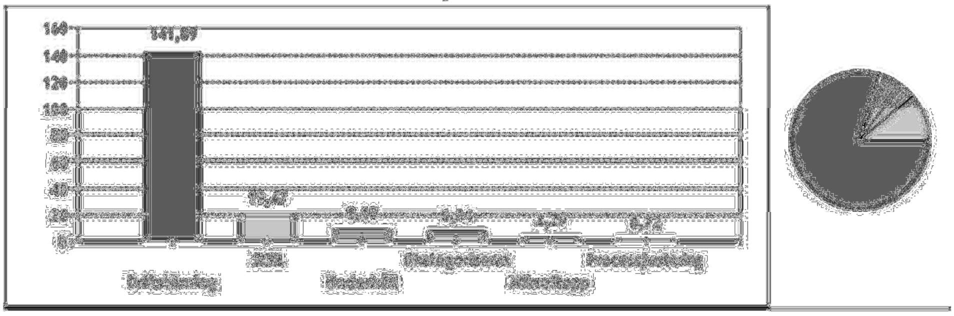
[illegible]

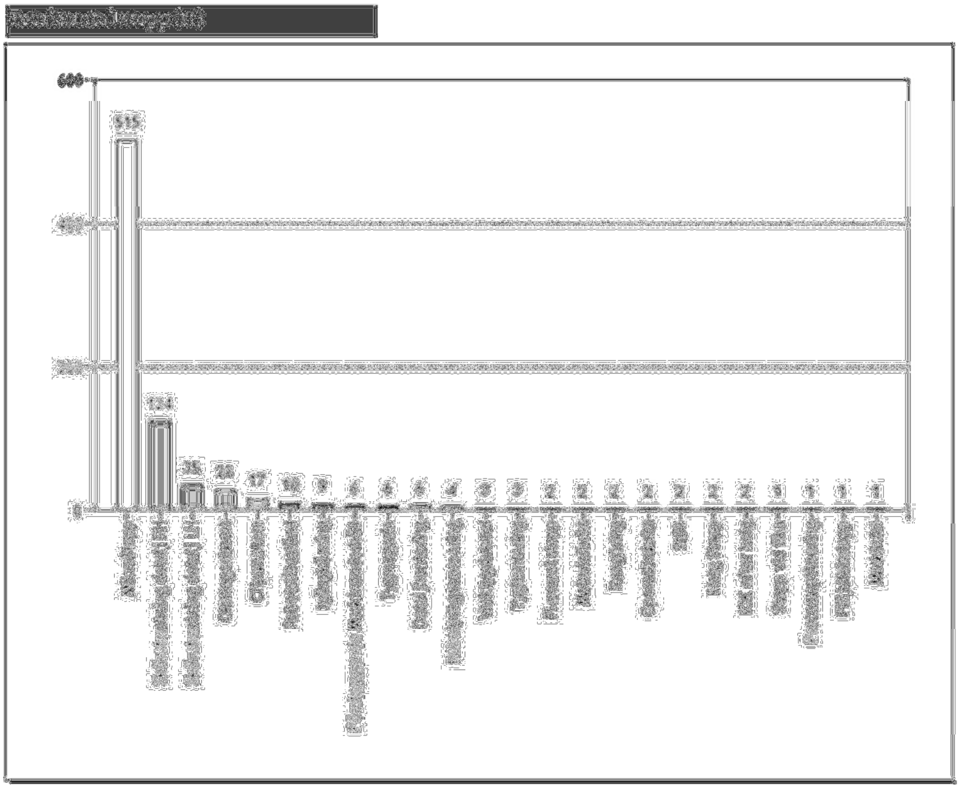
Antal stopp	Total stopptid	Tid mellan stopp	Snittlängd mellan stopp	Kommentarer
783	178 h 35 min	47 min	44	Länk

[illegible] ([illegible])



[illegible] ([illegible])





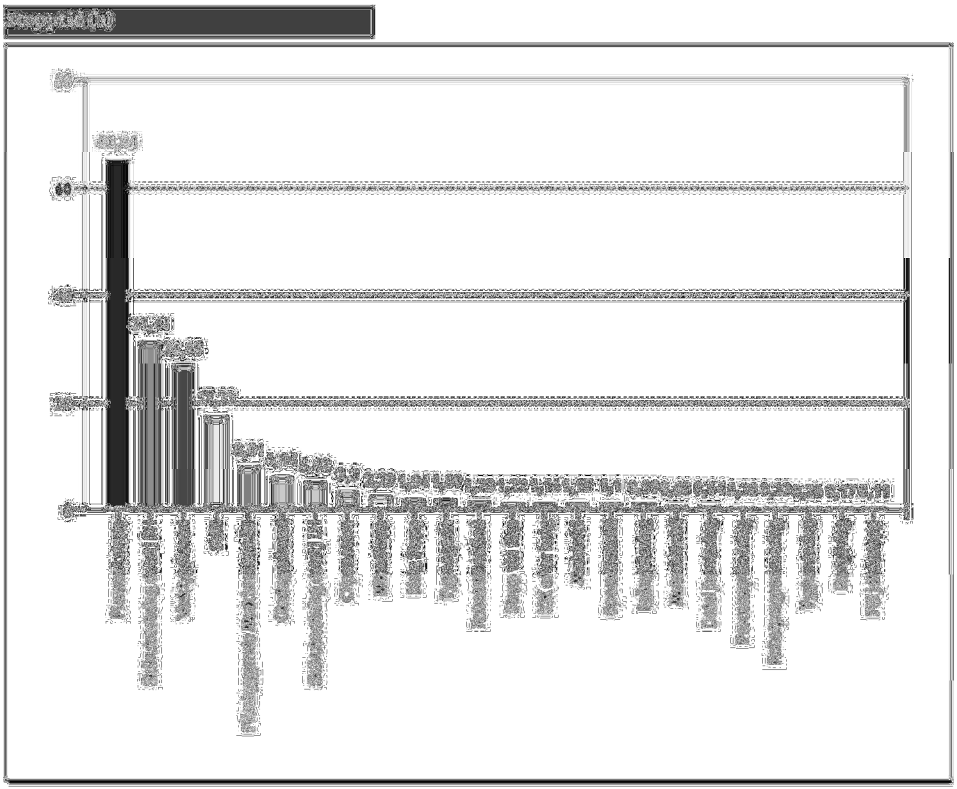


Figure 18: Stop causes in November 2010 for “A-Pillar Trim upper LH”.

In this point, it is useful to check the value adding time (scheduled time - stops time) compared with the scheduled time and it can be said that in January the “B-Pillar kpl LH” had the smallest percentage.

4.3 Discarded amount

Regarding to the quality loss, the discarded amount for "A-Pillar trim upper LH" in December is the biggest that means higher quality loss and smaller OEE number. That happens also for the "B-Pillar kpl LH" in January. Some of the reasons are: scrap box (the sum of scrap collected in some box), start-up scrap, surface defects, problems with added textile, closure orders, cutting errors, pleated fabric, incomplete cast, dimensional errors, black dots, deformed, tensile specimens, vesicles, zebra stripes, cut off mark, cracks, visible network, feature fabrics, test, shade tolerance, etc.

It is important to know in which part of the process it is taken into account of the defective units. The operator normally registers the defective (scrap) units continuously during the job; if it not "fits" with the work procedure it is allow to register them when the job have finished. In Office Tools items can even be registered after the production order had finished.

The discarded items are grouped as it is shown in the next graphic:

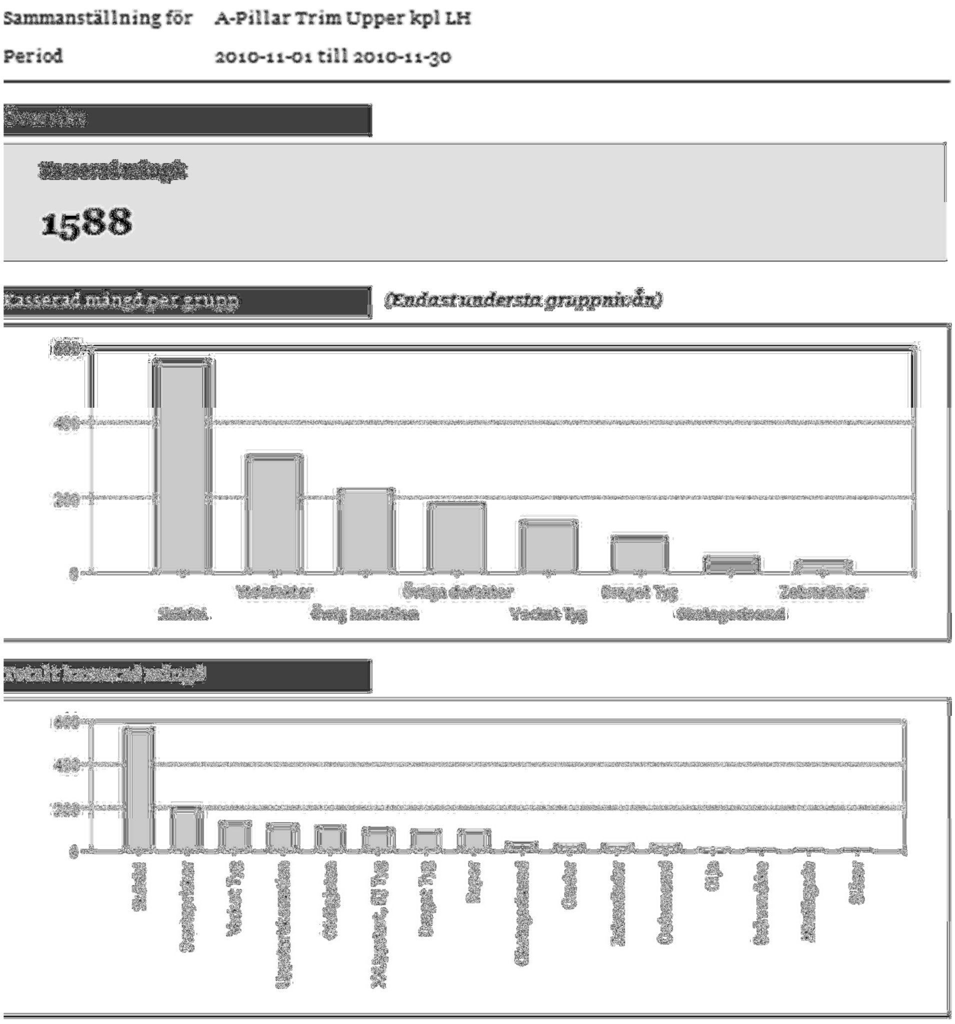


Figure 19: Discarded amount in November 2010 for "A-Pillar Trim upper LH".

4.4 Production monitoring

As a general overview, it is possible to monitor the production during the periods selected. The bottom graph shows the quantity produced in comparison with what would be produced if all the processing expected lifetime was used for the production of the optimal pace. The white bar shows the optimal quantity produced outside the stop time and the black bar indicates the measured quantity produced. The first graph is referred to the efficiency losses and the second one to the availability losses.

The scheduled production time is the sum of the time that is scheduled during the search period. The scheduled time with active order is the sum of the time that had no active orders in the search period. This line contains information of interest only if there are actively change orders in the RS-Production. The value adding time is the total of the value-added time in a scheduled production time during the search period, what means the time that operation was active without stops.

The bar "Produced quantity" always shows the maximum using only T-licensing at the measuring point because that do not follow up losses.

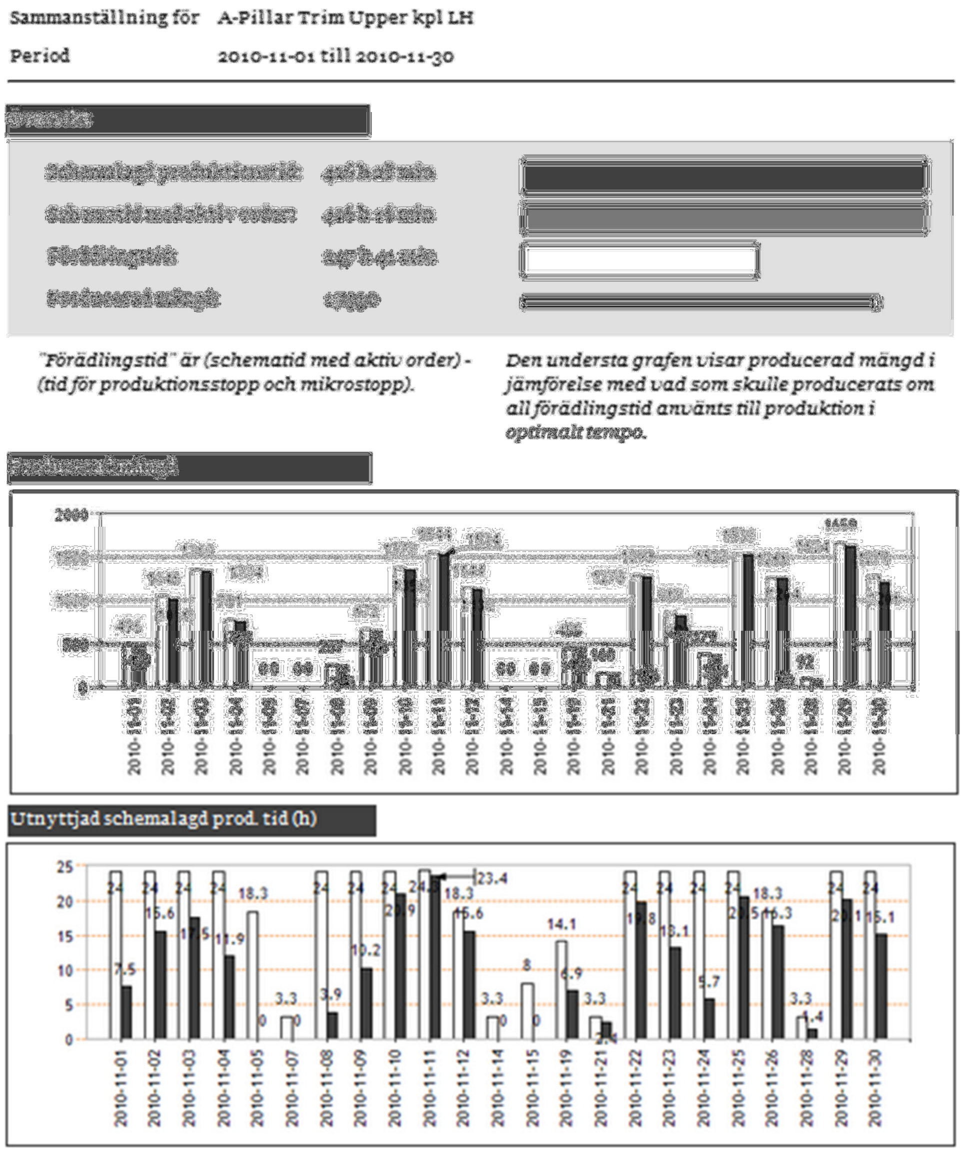


Figure 20: Production monitoring in November 2010 for "A-Pillar Trim Upper kpl LH".

4.5 Order summary

The orders are summarized with the following times:

- Production Lead time: Production Order's total time from first operation stage start-up to the last stage operation closure.
- Value adding time: total of the value-added time in a scheduled production time during the search period. That means the time that operation was active without stops.
- Machine time: sum of the active time and the detailed operation steps in the production order. It is the sum of time that the machine has been switched on and active with an order, but not necessarily producing anything.
- Operator time: the sum of the order's operator time (manual time) that was reported on the touch screen.
- Stop Time: sum of stoppage time in a scheduled production time in the production order.

- Cycle time: average cycle time of each operation step. This uses the same data to estimate the efficiency/plant exchange what means that all stop time is excluded and only the actual cycle is counted.

Calculations:
Value adding time + Stop Time = Machine time.
Production Lead time - Machine time = Waiting time in buffers.

Order: 179000, Artikel: A-Pillar Trim Upper kpl LH (2010-12-01 00:00 till 2010-12-05 21:53)

Mätpunkt	Produktionsledtid			Förädlingstid	Maskintid	Operatörstid	Stopptid
	117 h 53 min			50 h 08 min	67 h 29 min	0 min	17 h 22 min

TPM053 (2010-12-01 00:00 till 2010-12-05 21:53)

[illegible]	[illegible]	[illegible]	Cykeltid (s)				
[illegible]	504	0	42.01	50 h 08 min	67 h 29 min	0 min	17 h 22 min

Figure 21: Example of order summary for “A-Pillar Trim Upper kpl LH”.

5. Proposal/solution

5.1 Method

“The viable production system model (VSM)” consists on the relation between different fields in order to realize real-time control and higher level of automation in the planning and decision process (Almström and Murgau, 2008). Critical parameters in the production system need to be measured and monitored continuously both to produce a real-time measure, through some kind of filtering, as well as to provide data for statistical analysis. The arrows indicate the logical relation between entities as well as information transfer. For testing the model, RS-Production can contribute with the concepts “Continuous measurement”, “Real time measure”, “Statistical evaluation” and “Continuous improvements”; specifically to solve the gap between “Production system” and “Continuous measurement”. There, disturbances in the shop-floor level and the number of products are the most important issues to measure.

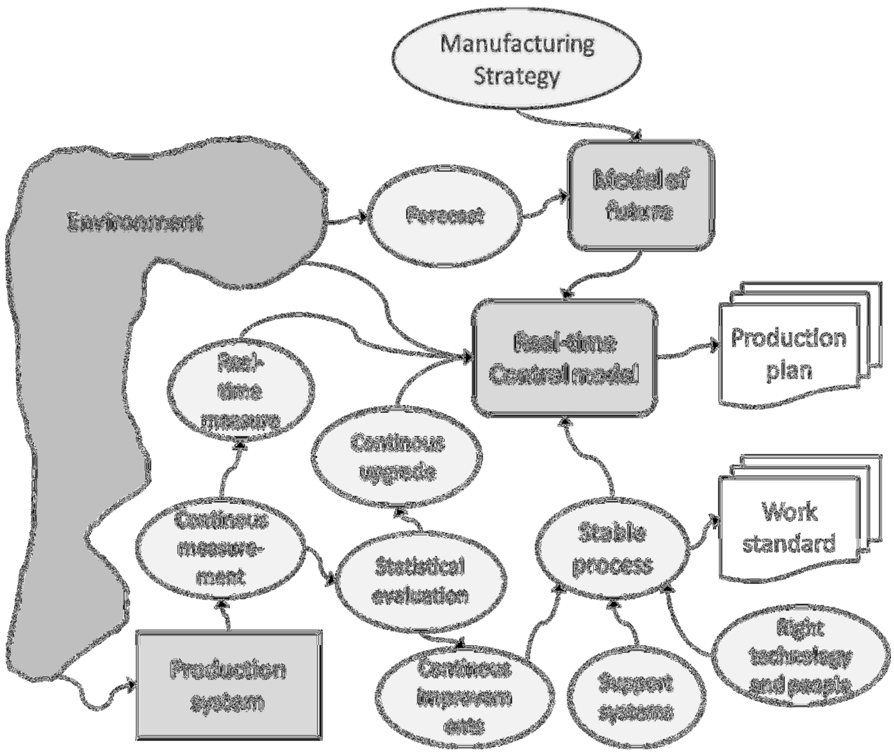


Figure 22: System model of the prerequisites for real time control (Almström and Murgau, 2008).

Figure 23 describes the most important concepts that need to be in place to achieve efficient real-time control in a practical industrial setting, and the relation between these concepts and functions. It is based on the VSM model in Figure 22. In order to improve the planning and control of the manufacturing process the theoretical graphic in the production system is compared with the flow of information that is used in RS-Production and it is studied what is missing and what should be improved.

Starting from the sensor devices like the ones explained in the shop floor data acquisition section as buttons or keys in the machines and robots, sensors in the conveyor belt, cameras along the manufacturing process, etc, the next step is the sensory processing. That task belongs to the MES level and after using the appropriate software, the managers have to decide about the necessary disturbances to consider. Furthermore, there is carried out both the statistical processing of the data and the decision making by the managers and engineers where the main focus is the automation growth instead of the manual processing of the information to optimize it. Directly related to that issue, a knowledge base as a database is needed, with all the information of typical disturbances coming from the statistical processing and also the procedures to solve them. This idea is not really well developed in most of the companies due to the thought that after solving a problem nothing else is important and they will not need the right procedure anymore.

One of the main focuses of the decision making should be the initiation of improvements in the projects. In order to take the correct determinations, the decision making is continually compared with the system model; the theoretical times and the ideal procedures in which the managers base their judgments. The schedule that will be installed in the factory is set by the decision making in cooperation with the order planning and the system model. This will influence the main actors, the workers in the shop-floor level.

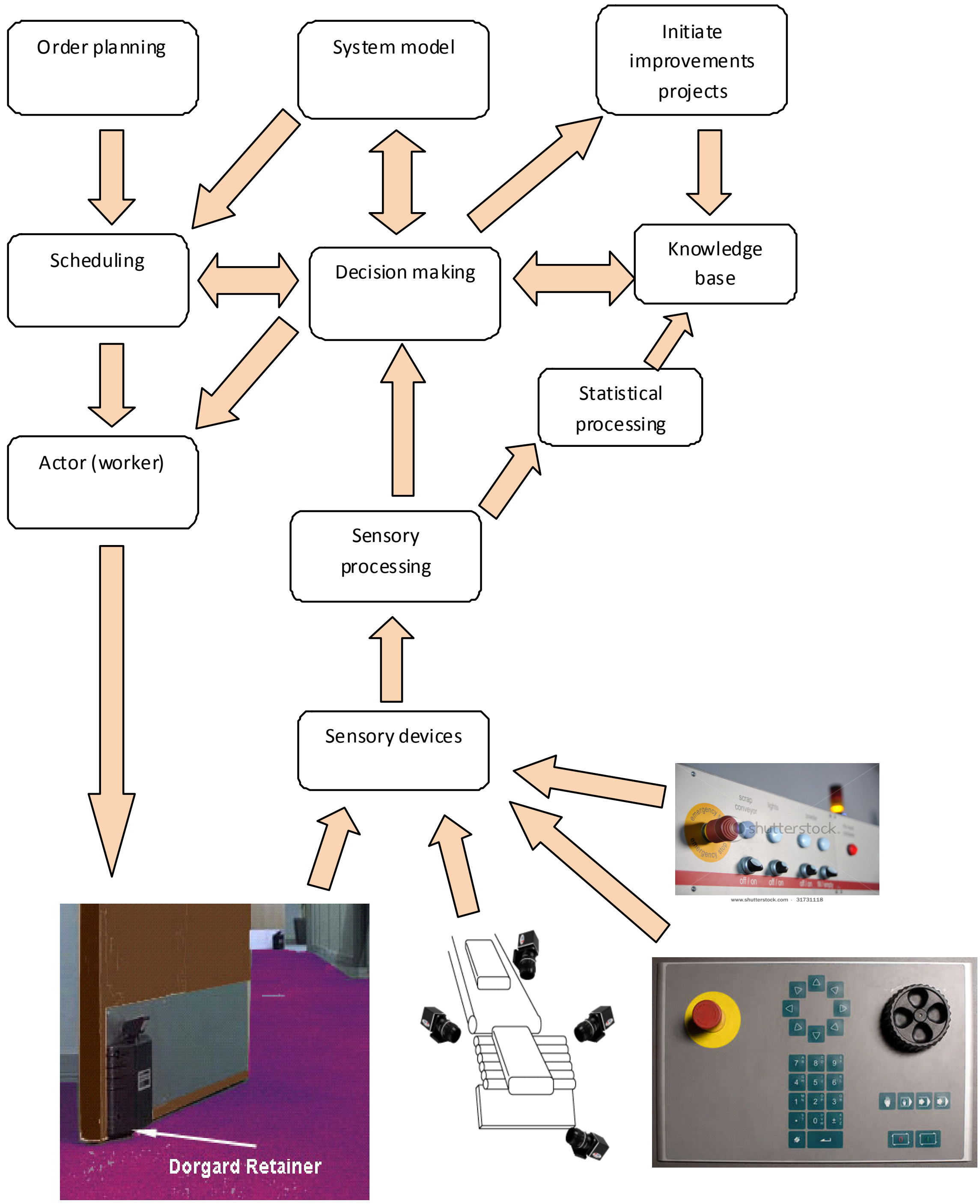


Figure 23: Flow of information in an "ideal" model of organization.

Comparing this ideal model with the one existing in *Good Solutions* there are three main fields that can be improved: the decision making, the knowledge base and the system model. RS-Production is taking part in some of those modules as the sensory processing, system model, knowledge base, statistical processing, order planning and scheduling but it is not done in the most efficient way.

Regarding to the knowledge base there is not a database or worksheet with the disturbances taken place in the shop floor level and the procedure needed to follow in order to solve it. This should be very useful to improve the efficiency in fixing it. Moreover, if the system model, the theoretical information in which is based the decision making, is more accurate, more near to the reality; the decisions will be closer to the real problem. Those two modules that affect the decision making can be handled with new automated solutions.

5.2 Example using data

Concerning with the components in the Production system there were involved three main figures: the resources (machines and operators handling the machines), the outcome (final products) and the control of the flow in each part of the production line (organization). All of them are measured by the software RS-Production so the next step is to analyze the flow of information in order to implement it. Taking into account the levels of information, the software available and how the failures are analyzed; the following graphic illustrates the connection between them.

There is a 3-level structure consisting in the shop-floor level, MES level and ERP level. In the first level, the machine control and production data are introduced in the touch screens by the workers. Then this information is transferred to the database in the MES level where the managers and engineers are controlling it from the office tools; checking the reports, making the schedules and adding new products or machines if it is the case. From the database it is obtained two concepts, the 'Real time status' and the 'Reports with Statistical Evaluation'. If there is something wrong or unusual in the first one the two possible choices are either 'Prioritize the improvements' what is made by the workers in the shop floor level or 'Change the planning model' in the ERP system. What will decide what the best option is? According to Mikael Persson (*Good Solutions* AB), improvements should be listening carefully where they make be largest result. An easy way to see it is that the largest possible improvement results are where the disturbance is the biggest. However, all the disturbances cannot be fully removed; some can only be reduced (set up time for example). In this case change the planning model cannot be redone and the improvements are prioritized. On the other hand, if there is something wrong or unusual with the real time status the options are either 'Change the schedule' what is done in the ERP level or 'Change machine, operator, etc.', what is done in the shop floor level.

In this model there are two different types of changes, ones that are based on some unusual data from the database and others that don´t depend on the information from the database; there are other reasons than efficiency for improvements, for example making improvements to gain safety margin. That type of very important improvements cannot be traced back to disturbance codes.

It was not possible to access to the 'Real time status' module from the account provided by *Good Solutions* AB, so the data analyzed in the disturbance handling section was focused on the 'Report Statistical Evaluation'.

After understanding how the software works and the flow of information needed around the process, the next task is to analyze how to manage new automated solutions in order to handle disturbances in the production. Regarding to the option of prioritize the improvements, it could be possible to install a device that analyzes in real time the cycle time and if the pace changes in a continuous flow of data in cycle times (not in exceptional reasons), automatically it would change the pace of the process to a new one. That avoids the fact that the manager has to check the cycle times and then change the pace if necessary, gaining time. Also regarding to machines, if there is an extra flow of discarded amount of products, it could be possible to install an alarm to call the operators and change the wrong machine to a different one. In the operators is a questionable issue due to the different skills but it could be possible to automate the breaks in the periods that the efficiency starts to go down or relocate some of them if the manned time increases a lot and it is not due to a fail in the machines. Also if the operator is not in the workplace with repeated frequency it has to be taken a solution. This is determined by the managers so the decision cannot be automated completely. About the total stop time there are already graphics with the statistical data of the reasons and they check it with some frequency but it could be possible to install a database that automatically finds an improvement or solution if the stop time increases or the value added time decreases based on the historical causes of disturbance.

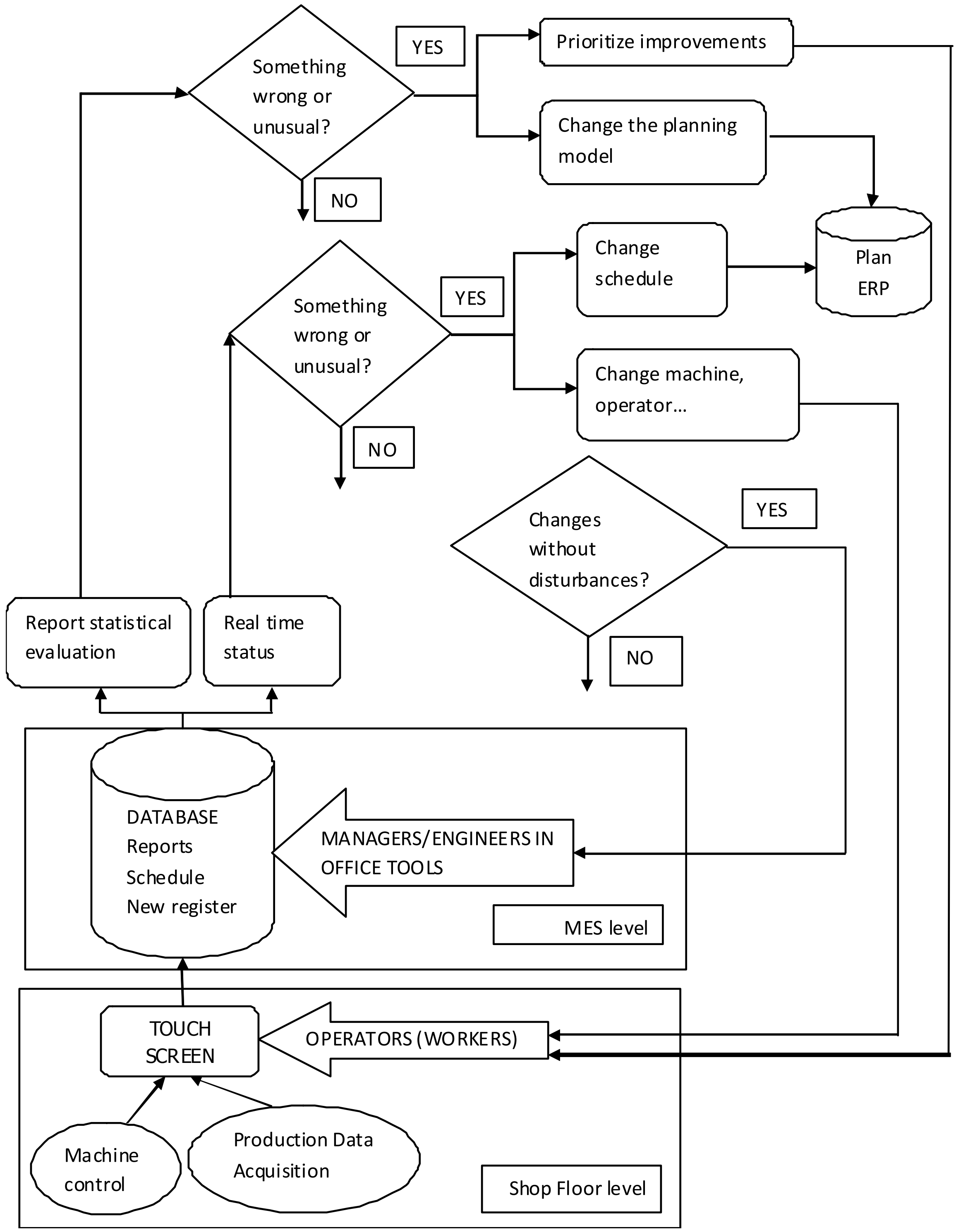


Figure 24: Flow of information used in RS-Production.

6. Discussion

6.1 Difficulties

The main difficulty in the development of this project was the language due to the software was Swedish and it was spent a lot of time translating every key and understanding the different modules. In addition, it was planned to go to the customer company in order to check the way of catching the shop-floor data, also to ask for some questions to the workers and managers and to validate the model but they were not interested for some reason and it was not possible.

From the account provided by *Good Solutions* AB there was not access to the real time information from production module, so the data analyzed in the disturbance handling section was focused on the analytical and smart follow-up reports.

Also it is questionable if the method used is the right one or not. It was compared some theoretical points with the process used in the company and checked the differences. Also there were studied the missing points and the possible improvements but it was not implemented in the company what does not allow to prove any conclusion; there have been just developed some guidelines.

6.2 Suggestions for further research

Further research must be done in order to confirm the capabilities of MES software due to it is a field that is not yet really well set in most of companies.

Also, it should be implemented the ideas said about guiding the software to the maximum level of automation and it should be improved the current software with the model that has been developed about disturbances. It can be studied where are the bottlenecks in the implementation process and how to solve them. It should be checked the wrong data concerning the OEE percentages between the different orders and the discarded products.

In addition, it can be studied what the customer companies expect about the MES solution and develop the specialization of the software for each one.

7. Conclusions

1. What are the advantages in MES implementation?

In order to bridge the gap between operation times in reality and in the planning systems MES solutions are developed. They provide accurate and real-time information for making decisions and solving problems. Companies are helped to improve utilization of their resources with a proper integration of MES software with existing applications from other levels as business management level including ERP/APS software and automation level along with bar code systems, RFID, OCR and PLCs.

There are some studies regarding the advantages of MES implementation, most of them related to American industries, and they illustrate that companies with MES solutions can improve faster than firms not using MES.

2. How does RS-Production work and are there any possible improvements of the present version?

It works though smart touch screens set next to the working position where the operators introduce the data coming from the shop floor level about times, discarded products, production disturbances, stops, etc. They also receive the information about how much should be produced, the materials needed, when the shifts start and finish, etc. The software is updating the information in real time and it generates analytical and follow-up reports with graphics of the periods needed, comparison between the amount produced and the one that would be produced with the optimum pace, etc. If it is required to change some schedule, some machine, operator, etc. o register a new component that is done from the Office Tools where the managers can make the proper corrections.

The improvements concern the disturbances missing like “Machine disturbance” that can be divided by breakdown of the machine and limitation in the machine capacity; “Tool failure” can be divided by breakdown of the tool, not earmarked for job, shared (not full capacity of the tool); it can be added “Transport breakdown” and “limited capacity” of the transport between stations in the manufacturing process (this is not necessary if the process is completely automated); it can be subdivided “Lack of material” by “No material” and “Material in wrong time” in order to specify the reason of that; and also it can be done the same for “Lack of supplementary components” and “Lack of packing material”.

Also it can be fixed the mistakes between the times and amount of discarded products in a period or in different orders and also the mismatch between the percentages in OEE.

3. What are the reasons for deviations in the operation times, batch times and scrap rate?

There are disturbances in the shop floor level. The times and amounts can be affected by some different factors. One of them is the lack of experience of the operator with the software or the carelessness to implement it and the misunderstandings between operators from different shifts. Also the manually work that can have some variations between workers. Other reasons for that are the disturbances during the production process, especially the unplanned stops, as the unplanned machine stops, tool failure, break at set-up, network management, etc.

4. How can data collected from production be used to update and change the planning system?

It can be used in order to check what is wrong and what can be improved. The changes in the schedule can be done before than the disturbance increases to avoid bigger mistakes in the manufacturing process.

The modern perspective in MPCS includes 3-level structure formed by ERP/APS, MES and shop floor level in order to fill the gap between the operation times in the planning systems and in reality. From the MES level it is possible to adjust the production plan to the demand with the purpose of having the right amount in each moment. In RS-Production the information is constantly updated and through that the managers take the decisions about changes in the production planning, in the machines, operators, etc. Using some indicators like OEE it is possible to measure the efficiency in the production process of the company. It is break down into the constituents: availability, efficiency and quality and includes a lot of some other factors as scheduled production time, total stop time, theoretical cycle time, produced amount and discarded amount

There are given some proposals for a new functionality in RS-Production to manage new automated solutions to handle disturbances in the production. It could be possible to install a device that analyzes in real time the cycle time and if the pace changes in a continuous flow of data about cycle time (not in exceptional reasons), automatically it would change the pace of the process to a new one. That avoids the fact that the manager has to check the cycle times and then change the pace if necessary, gaining time. Also regarding to machines, if there is an extra flow of discarded amount of products, it could be possible to install an alarm to call the operators with the purpose of changing the wrong machine to a different one. In the operators is a questionable issue due to the different skills and preferences but it could be possible to automate the breaks in the periods that the efficiency starts to decrease or relocate some of them if the manned time increases a lot and it is not due to a fail in the machines. Also if the operator is not in the workplace with repeated frequency it has to be taken a solution. This is determined by the managers so it cannot be automated completely. Concerning the total stop time there are already graphics with the statistical data of the reasons and they check it with some frequency but it could be possible to install a database that automatically finds an improvement or solution if the stop time increases or the value added time decreases based on the historical causes of disturbance.

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Appendix 1

	Machine	TAK/OEE	T (Availability)	A (Efficiency)	K (Quality)	Stops	Total stop time	Discarded amount	Scheduled production time	Value adding time(scheduled time-stops time)	Theoretical cycle time(s)	Produced amount
A-pillar trim upper kpl LH	TPM053											
November-10		51,80%	58,10%	98,20%	90,80%	783	178h35m	1588	426h28m	247h41m (58,07%)	110	17330
December-10		49,30%	60,30%	93,20%	87,70%	5468	173h37m	2598	437h27m	263h38m (60,26%)	110	21132
January-11		48%	59%	89,60%	90,80%	5949	152h59m	1616	373h17m	220h25m (59,04%)	110	17489
B-pillar kpl LH Off Bl UPEJGK	TPM014											
November-10		82,20%	88,10%	95%	98,20%	84	8h23m	98	70h42m	62h19m (88,1%)	45	5405
December-10		70,70%	78,50%	95,80%	94%	75	19h21m	325	90h05m	70h44m (78,5%)	45	5420
January-11		60,10%	69,50%	96,20%	90%	61	19h50m	494	64h51m	45h01m (69,4%)	45	3476
B-pillar kpl RH Off Bl UPEJGK	TPM014											
November-10		61,40%	84,80%	74,60%	97,10%	100	16h28m	210	108h31m	92h04m (84,84%)	45	7147
December-10		68,00%	72,60%	97,40%	96,10%	91	28h45m	232	105h02m	76h16m (72,61%)	45	5944
January-11		77,90%	83,00%	98,20%	95,60%	65	11h1m	203	64h59m	53h58m (83,04%)	45	4621
Hinge Net Big LHD UPEJGK	TPM026											
November-10		43,40%	55,10%	89%	88,60%	3353	226h34m	4657	504h50m	278h15m (55,1%)	4	32778
December-10		52,90%	64,60%	95,20%	86%	756	115h56m	3692	322h51m	208h36m (64,6%)	4	25086
January-11		50,50%	59,40%	94,10%	90,90%	724	170h45m	2881	421h	250h15m (59,44%)	4	29756

Table 3: Example of OEE for three months.

Appendix 2

The following list of allowances is included in the availability and efficiency loss:

- Constant allowances
  - Personal needs: trips to drink water/restroom
  - Basic fatigue: account for the energy expended, is a way to alleviate monotony, it depend on the need for concentration and repetitiveness
- Variable fatigue allowances

  Working conditions: noise, heat, humidity; nature of the work: posture, muscular exertion, tediousness; general health of the worker
- Special allowances
  - Unavoidable delays: interruptions from the supervisor, irregularities from the material, difficulties in maintaining tolerances and specifications, interference delays…
  - Avoidable delays: idleness
- Extra allowances: account for an unduly high number of rejects, manually handling the work…
- Policy allowances: new employees, the differently able…

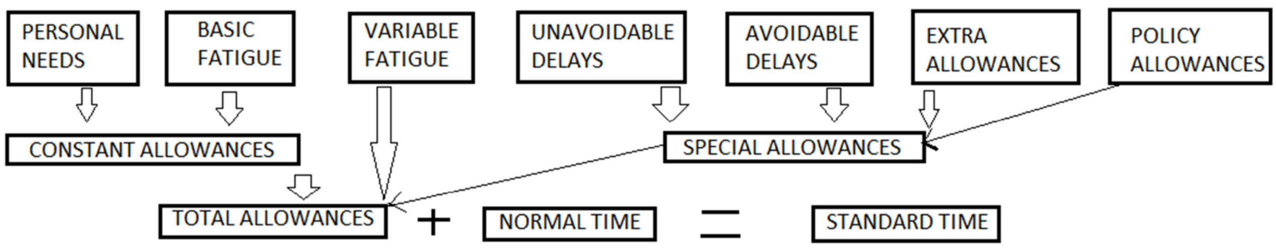

Figure 25: Allowances