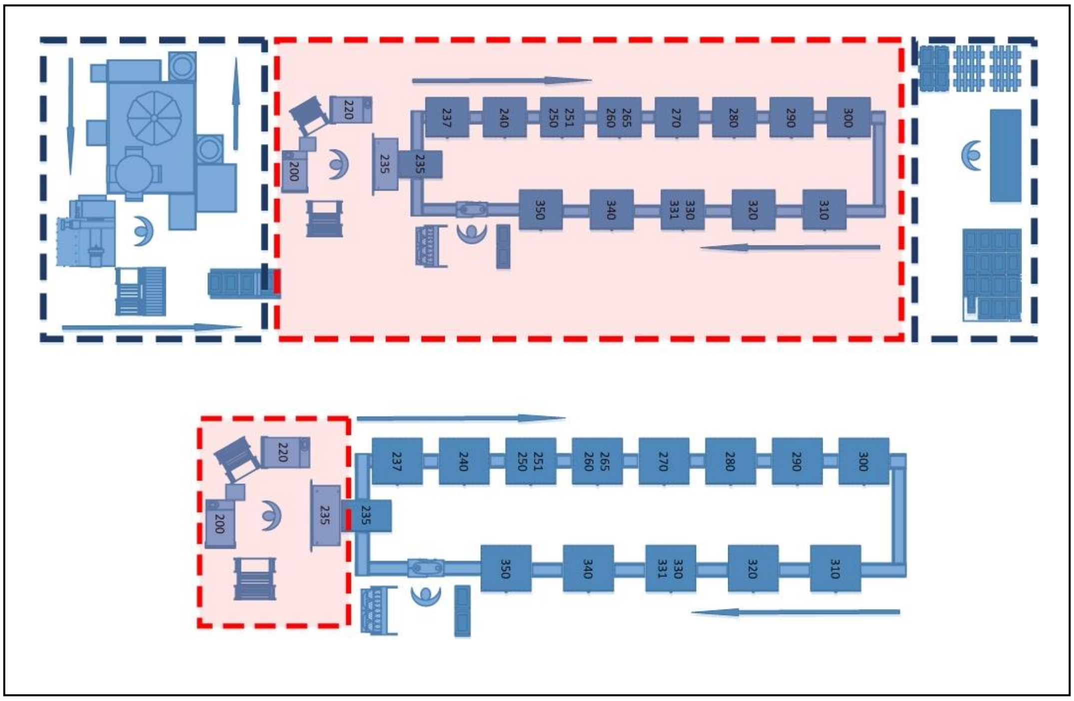

Multiple level flow analysis

Autoliv Sweden AB – Inflators

Master of Science Thesis

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Department of Product and Production Development
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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2014

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Cover:
The cover picture shows the multiple production flow levels of a line at AutolivSverige AB – Inflators.

Chalmers Reproservice
Gothenburg, Sweden 2014

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ABSTRACT

This thesis attempted to increase the robustness and flow efficiency of a production line at the automotive security supplierAutoliv AB. The theory of constraints was applied in order to take as much advantaged as possible of the existing resources. It was preceded by thorough data collection, data validation and analysis. Correct measurement together with accurate system design was a prerequisite to acquire credible performance results.

Standardization and support of the bottleneck were found to be enhancing the robustness of the line. Communication through workshop was also found to have an influence on the robustness as it improved the work methods and reduced the variation of performance of the line. The flow efficiency was increased by improved work methods, optimizing bottleneck processes and through the coordination of the different flow levels of the line. It was concluded that production system robustness and flow efficiency require coordinated support functions. It was further realized that visualization could increase the awareness and incentivize employee performance.

The thesis also attempted to relate suitable production flow measures to a hierarchy of production levels. Theory concluded that a production flow measure must consider all relevant factors, be valid in different production formats, provide analytical data and be a standard in an organization. Historical flow indicators (throughput and utilization) had already been considered insufficient to fulfill these criteria as they did not include all relevant factors; they did not indicate the origin of waste nor did they address factors that will improve the production flow.

OEE (Overall Equipment Effectiveness) was investigated as a replacement to throughput and utilization. A limiting factor of OEE was that it did not consider dependency on other equipment in a continuous production line. In order to measure production flow on multiple levels where equipment depends upon each other, other measurements had to be considered. The thesis regarded seven flow measures and related them to the hierarchy of production system of the G1 line. System flow was preferably measured through Process OEE since it gave indication of availability and performance improvements of the bottleneck of the production system.

KEYWORDS:Multiple levels, measure, production, improvement, efficiency, effectiveness, OEE

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Vårgårda, June 2014
Johannes Torstensson & Emanuel Mosquera

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NOTATIONS

TERMINOLOGY

Alert	In-house data collection system for shift results, longer stops and OEE
APG	Autoliv Passenger-inflator Gas. The product producedon the G1 production line.
APS	Autoliv Production System. APS-time is used for 5S in the production area
Automated production system	Production system that only comprises automatic work
Availability	The degree to which a process is serviceable
Batch	The quantity of products produced in one operation
Blocked	When a process is unable to pass on any processed material due to a halt or problem in the upstream process
Buffer	Storage between two processes that helps to reduce the variation between the processes
Constraint	Anything in the production system that restricts the maximum output
Cycle time	Time required for a process to complete the processing of one product
Disturbance	Any interruption to an ideal process
Down time	The period during which a process is unavailable
Downstream resource	Succeeding resource in a production system
Effectiveness	The appropriateness of a method to accomplish a purpose
Efficiency	The level of performance with regard to time and effort i.e. the ratio between standard hours of work produced and hours actually worked

FLAI	In-house data system for scrap rate, station errors, shift results and OEE
Fictive study	A study of an imaginary but possible scenario
FIFO	First in first out
G1 line	The production line of investigation. The G1 line produces the APG
Inertia welding	A friction welding process that joins two parts through the use of kinetic energy
Kanban	A logistic system that reduces waste of material flow by providing only the right amount of material at the right point in time
Idle	The state of a process being either blocked or starved
Lead time	The time required for a product to pass through a production system
Lean production	A philosophy which aims to reduce waste in production. It focuses on eliminating factors that do not add any value to the customer
Long stops	A stop due to machine breakdown that takes more than 5 minutes to solve
Manual production system	Production system that only comprises manual work
MAG welding	Short for Metal Active Gas welding. The active gases prevents the weld from oxidizing
Material handling	Refers to how the material in a production system is handled e.g. material flow and material supply
Palette	Fixture which transports the APG through the processes on the main assembly line
Performance	The actual production rate compared to the designed
Planned production time	Shift time scheduled for production

Process	Refers to how technologies and methods are used to transform an input to an output
Production system	A system in which resources such as material labor, machinery and other equipment are used to create useful goods or services
Production system flow	The transfer of material, information or labor within a production system
Scrap	Parts with insufficient quality that are thrown away
Semi-automatic production system	Production system that comprises both manual and automated work
Set-up time	Time spent preparing machines or devices for production
Short stops	A stop due to a machine breakdown that takes less than 5 minutes to solve
Support activity	Activities which supports the core activity, e.g. material handling, preventive maintenance or cleaning
Starved	When a process is unable to function due to lack of materials. It is usually due to a halt in the upstream process
Tact time	Customer demand divided by available production time
Toyota production system	Precursor of lean production
Upstream resource	Preceding resource in a production system
Utilization	The ratio between hours active through available hours
Work in process	Refers to all materials that have started but still not completed the production cycle

1 INTRODUCTION

The following master thesis work has been carried out at Autoliv Sverige AB – Inflators. The work has been performed on site in Vårgårda, Sweden in close contact to the process. This has created allowance for continuous observation and evaluation of the production system. The goal of the thesis was to improve the robustness and flow efficiency of the system.

1.1 Company information

Autoliv AB is a well-known company within the automotive security sector which operates within both active and passive security. Within the passiveis presently a new generation of inflators gaining ground, denoted APG (Autoliv Passenger-inflator Gas), which uses oxygen and hydrogen in the inflation process. This is the third generation where the first used powder, the second a combination of gas and powder, and the third (APG) utilizes active gas. Compared to the previous techniques, it has an improved level of purity with less smoke and toxic substances. The new innovation have enabled a new, more slimmed, product design due to that no internal pressure is built up inside the inflator when it is deployed.

1.2 Background

The production process at Autoliv is characterized by large volumes and short tact times. This implies that several competitive advantages could be strengthened by increased robustness and stability, together with high flow efficiency. The system would benefit from improvements which secure a smooth, efficient and stable flow.

System performance measures allow companies to continuously keep track of the performance and by that achieve desired results. The most production systems consist of flows on different levels, i.e. system, line and cell flows. In order to direct improvement actions it is important to evaluate the efficiency and effectiveness correctly on each respective level.

1.3 Production line G1

The APG is produced at a semi-automated production line denoted G1. The production system consists of three subsystems: the pre-assembly line, the main assembly line and the 24H leak tester. The two lines consist of separate line-flows where the pre-assembly feeds the main assembly with a buffer in between. The products are then sent to the 24h leak tester before being packed in transport boxes ready to be shipped to the customers. The production processes consist of several different processes and employ four operators.

The pre-assembly line (see Figure 2) manufactures the two compression chambers that can be seen on both sides of the APG in Figure 1. The production process consists of laser welding, resistance welding and inertia (friction) welding and has several built-in quality checks. The parts are moved through the process using rotating tables and other automated equipment. The single operator is positioned close by and feeds the inertia-weld operation which is the final operation on this line. Automated machines undertake the rest of the operations. Cleanliness is important for a fully functional process.

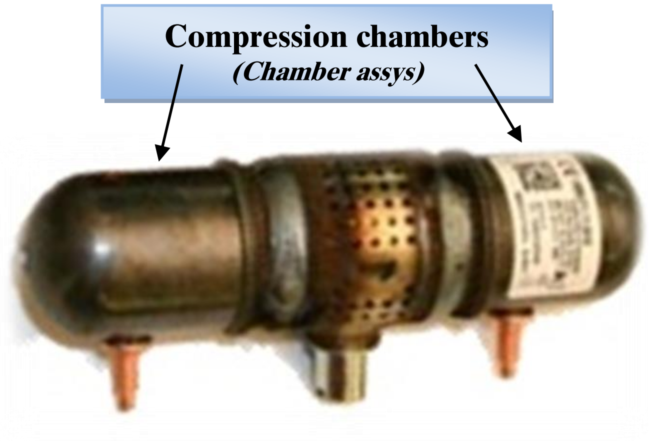


Figure 1 – Autoliv Passenger-inflator Gas (APG)
© Autoliv Sverige AB, 2014

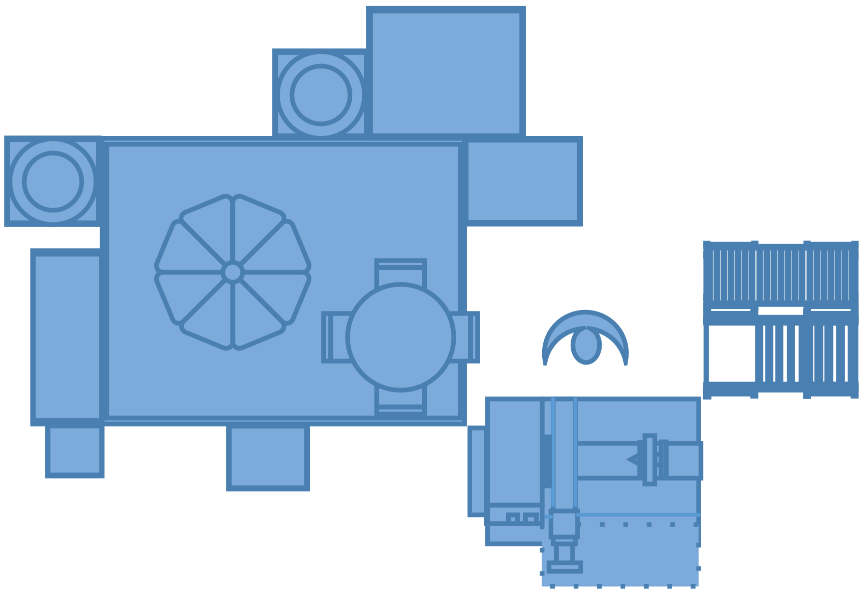


Figure 2 – Pre-assembly line

The main assembly line (see Figure 3) starts with the pre-assembled compression chambers and ends with the final product. The production process in this line consists of MAG welding, friction welding, crimping and gas filling. The pre-assembly consists of several built-in quality controls to assure functionality of the final product. One operator works in the semi-automated MAG-cell, which feeds the line after processing. The other operator is placed at the end of the line and is responsible for unloading and a final check. The flow starts with the MAG welding operation and then proceeds clockwise.

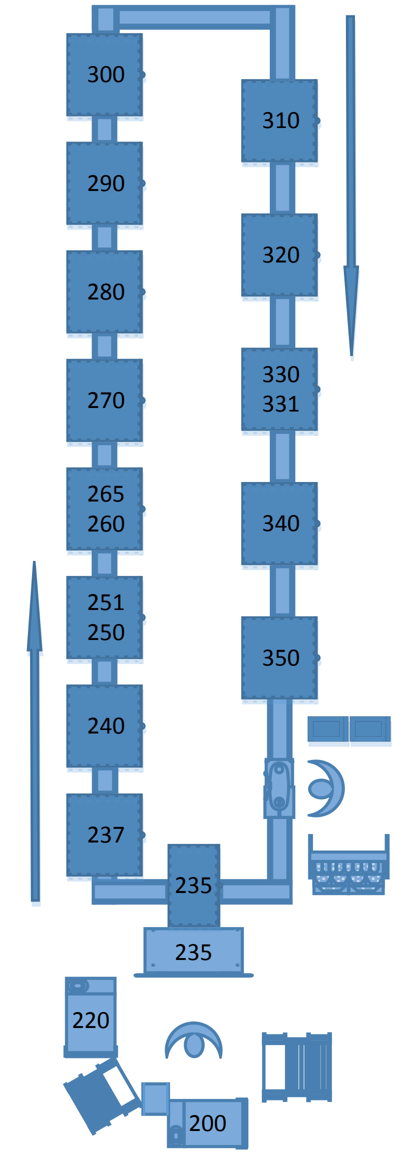


Figure 3 – Main assembly line

The 24h leak tester (see Figure 4) is a final quality check, assuring that the product remains fully functional 24 hours after it has passed through the line. The equipment requires one operator and is fed by a high-capacity FIFO lane. The tester is utilized on an irregular basis when a sufficient number of products are ready to be processed.

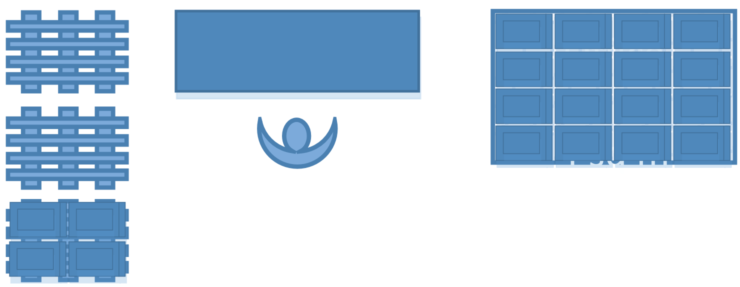


Figure 4– 24hleak tester

1.4 Purpose

The information that Autoliv obtains from measuring the OEE-value is not sufficient to explain why the performance of the line has reduced over time. Increased volumes are expected in the near future and the potential for improvement must therefore be investigated. Autoliv is also facing difficulties when it comes to determining the potential of possible improvements. This makes it hard to identify problem areas and provide a means for maintaining a smooth and stable flow.

In order to redirect focus the system awareness needs to be enhanced using appropriate measures. Without substantial and sufficiently documented system measurements it is difficult to qualify any observed improvements. Several types of measures exist for the evaluation of a production system. The system improvement work was intended to achieve:

- Main purpose: Increase robustness
- Secondary purpose: Increase flow efficiency

1.5 Objectives

The evaluation of measures performed during the thesis work was designed to serve as a guide for the usage of the measures in different flow levels. Some specific objectives for the project were to:

- Analyze and map the production line G1
- Identify areas of improvement
- Recommend improvement actions to enhance the system robustness and performance
- Evaluate and recommend usage of measures on the three different flow levels

1.6 Scope

To create a reasonable scope the thesis work has been limited to:

- Only provide proposals on solutions on a conceptual level
- Only include the G1 line from the first pre assembly station till the APG is leak tested and packed in final transportation box to customer
- Only consider the production of the model APG-1 which implies:
    - No model changes
    - No setup times
    - Only performance for this product

2 THEORY

Different concepts related to production engineering were collected from different sources, mainly academic books and scientific articles.Almost all literature had been written during the last ten years and most of them contained a few practical examples that facilitated the comprehension.

2.1 Measures in production

A flow measure must consider all relevant factors, be valid in different production formats, provide analytical data and be a standard in an organization (Beamon, B.M., 1999).

Throughput and utilization have historically been used in industry for measuring production flow much because the simplicity. Once they were considered being insufficient, they were replaced by OEE (Overall Equipment Effectiveness) which is nowadays frequently applied in industry and on multiple production flow levels. (Braglia, M. et al., 2007)

Overall Equipment Effectiveness (OEE)

OEE is a method for measuring the effectiveness and efficiency of production equipment. It is used to monitor equipment productivity and as an indicator of where the process and performance of the individual machine can be improved. The OEE is based on the system factors: availability (A), performance (P) and quality (Q). 'A' relates to production uptime and is affected by breakdowns, set-up, adjustment periods and other interruptions. It is calculated by uptime divided by available time. The second factor, 'P', relates to the actual operational pace i.e. the ideal pace minus speed losses due to minor interruptions. It is calculated as ideal cycle time times the number of products produced, divided by total operating time. The third factor, 'Q', accounts for the number of defects. It is calculated to be the number of flawless products divided by the total number of products produced. (Garza-Reyes J.A. et al., 2010)

$$\boldsymbol{OEE = Availability * Performance * Quality}$$ Equation 1

Process OEE

Process OEE can be applied to measure the performance of a production line. The value is calculated by multiplying the availability and performance of the bottleneck, respectively A_{BN} and P_{BN}, as a quality factor, Q_{tot}t. Q_{tot} is the ratio of the total output from the bottleneck subtracted from the total amount of defective products from downstream processes(DSD)).

$$\boldsymbol{Process\ OEE = A_{BN} * P_{BN} * Q_{tot}}$$ Equation 2

$$\boldsymbol{Q_{tot} = \frac{Output_{BN} - DSD}{Output_{BN}}}$$ Equation 3

(Braglia 2007)

Overall Line Effectiveness (OLE)

Another proposed method for evaluating the performance of the entire line is overall line effectiveness, OLE. OLE is obtained from multiplying the factors LA and $LPQP$. $LPQP$ stands for line production quality performance and is a combination of the line performance LP and the line quality LQ. No distinction is made between the performance and quality as it is assumed that a defective product from a machine will not be transferred to the next. LA represents the ratio between the operational time of the last machine (OT_{LM}) and the planned production time (LT).

$$\boldsymbol{OLE = LA * LPQP}$$ Equation 4

$$\boldsymbol{LA = \frac{OT_{LM}}{LT}}$$ Equation 5

(Nachiappan & Anantharam 2005)

Overall Equipment Effectiveness of a Manufacturing Line (OEEML)

OEEML is a method for estimating the actual efficiency of a production line where the machines are not operating separately but affects one another's performance. OEEML takes into account that buffers could be added between the machines. It is the ratio of the cycle time of the bottleneck (CT_{BN}) to the cycle time of the last machine of the line (CT_{LM}) and the ratio of the station value time of the last machine (SVT_{LM}) to the line loading time (LT). The OEEML can exceed the value 1 due to CT_{BN} being greater than CT_{LM}.

$$\boldsymbol{OEEML = \frac{CT_{BN}}{CT_{LM}} * \frac{SVT_{LM}}{LT}}$$ Equation 6

(Braglia 2007)

Time Per Unit (TPU)

TPU is the same as labor content which is defined as the accumulative labor minutes(T_{ALM}), that is required for producing a unit. In a production system, the labor content can be used to analyze how much labor that is invested into one unit as well as an indication of the production flow. The TPU is calculated as the ratio of measured TPU ($TPU_{Measured}$) to ideal TPU (TPU_{Ideal}). TPU_{Ideal} considers operating time and ideal bottleneck cycle time.

$$\boldsymbol{TPU_{Measured} = \frac{T_{ALM}}{O_{LM}}}$$ Equation 7

$$\boldsymbol{TPU_{Ideal} = \frac{OT_{Line}}{CT_{BN}}}$$ Equation 8

$$TPU = \frac{TPU_{Measured}}{TPU_{Ideal}}$$ Equation 9

(Cachon, G. & Terwiesch, C., 2012)

Line Efficiency (LE)

Line efficiency represents how efficient the operators of a line are utilized during a time period. It consists of two parameters: the total operative time of the line(OT_{Line}), and the total time that the operators have been present (T_{LM}).

$$LE = \frac{OT_{Line}}{T_{LM}}$$ Equation 10

(Online Clothing Study, 2014)

Manual Assembly Efficiency (MAE)

MAE is used to complement OEE by measuring the efficiency of manual stations. MAE considers the following factors: rework, number of operators that are part of the product assembly and waiting time. The components are: the quantity of products (t_{Iai}), time for rework per product (t_{Rai}), the quantity of operators (N_A), the full amount of available time (t_{TOT}), the planned stop time (t_{PS}) and the inefficient time due to shortage of work for the operators (t_{UN}).

$$MAE = \frac{\sum_{I=1}^{N}(t_{Iai} - t_{Rai})}{N_A(t_{TOT} - t_{PS} - t_{UN})}$$ Equation 11

(Bellgran, M., Säfsten,K. 2010)

Productivity

Productivity is an engineering method for analyzing and measuring total productivity improvement.Productivity has many definitions. One proposed method for analysis is to separate productivity in three dimensions: Method (M), Performance (P) and Utilization (U) that, when multiplied together represent the magnitude of the overall productivity. The M dimension corresponds to the productivity effectiveness whereas the P dimension reflects the efficiency. Both method and performance have an impact on the U dimension.

The dimension M is by far the most significant dimension. A stable method with less interruption, it results in more utilization of machines and personnel. M is divided into two groups: “hardware” and “software”. Hardware consists of methods for machines, tools, layout and such. Software is comprised of motion patterns, education, supportive functions and organization.

The P dimension refers to the performance of the employees or the pace of the machines. The P dimension is comparing actual working pace to standard time. Even though P has an impact on the other two dimensions, it does not exclusively represent the productivity.

The U dimension is applicable to labor as well as machines; however the U dimension is of less importance compared to the other dimensions. It is defined as the ratio of value-adding activities to available time. Losses for this dimension are often due to technical volatility; stable processes and aligned maintenance enhance the U. It is also dependent on the flow of goods and material. Variation of these flows makes it difficult to efficiently allocate labor.(Sakamoto, 2010)

$$\boldsymbol{Productivity = M * P * U} \qquad \text{Equation 12}$$

2.2 Data collection

There are two types of research data: quantitative and qualitative. Quantitative data is numerical, whereas qualitative data is descriptive in nature. Quantitative data collection is preferred for data that can be measured and qualitative data collection for data that is descriptive and cannot be measured numerically. The parameters for quantitative data collection are thus much easier to define than those for qualitative data collection. (Ostrom & Wilhelmsen, 2012)

Quantitative data collection consists of gathering and organizing numbers into statistics. In order to acquire representative statistics, the sample size should be reasonably large and samples should be well distributed. Two common methods for quantitative data collection are: retrospective studies involving historical data and direct measurement methods e.g. time study. (Ostrom & Wilhelmsen, 2012)

Qualitative data collection does not involve statistics. It refers to interpreting phenomena or numerical results based on people's perceptions, opinions and beliefs. It is therefore important to obtain perspectives from multiple sources. Three common methods for qualitative data collection are: focus groups e.g. workshops; interviews; and observations. The interviews are mostly semi-structured. The optimal sample size of people or observations depends on saturation. (Botti & Endacott, 2008)

As they are complementary, it can be beneficial to concurrently conduct both types of data collection in order to properly validate data. After data collection, data must be analyzed to ensure that it is both reliable and valid for the intended application. (Sargent, 2013)

2.3 System constraints

Every production system has constraints. More accurately can this be narrowed down to that the output of an entire system often is limited by one single machine or cell, called the system constraint. (Cauwenberghe & Tung, 2009)

The capacity of a manufacturing system is restricted by the capacity of one or more constraining stations, called 'bottlenecks'. An increase in the capacity of these bottleneck stations will result in an increase in the capacity of the whole system, which is why it is important to identify them when attempting to improve system capacity. Locating the bottlenecks in a manufacturing system can be difficult, but one common method is Theory of Constraints which focuses on gradually increasing the bottleneck capacity.(Roser C. et al., 2003)

2.3.1 Indicators

There are various factors that may indicate the existence of a system constraint.

- The lowest production rate of a station, where it can be isolated from other stations.Production rate includes losses in time due to scrap (Lin. L. et al., 2007)
- Largesbuffers indicate that the immediatedownstream process of the buffer could be a bottleneck. In order to draw this conclusion, the buffer storage capacity must be unlimited. If the buffer levels are limited, the bottleneck could be located to the station immediately after the station with the highest level of blockage. (Lin. L. et al., 2007)
- Alternatively, smallbuffers may indicate that the immediate upstream process of the buffer is the system bottleneck. If the buffer levels are limited, the bottleneck could be located to the station immediately downstream to the station with the highest level of starvation. (Lin. L. et al., 2007)
- The bottleneck can be defined as the station with the largest percentage of utilization. Both processing and maintenance time must then be considered as components of the utilization, since both are possible sources of system constraints.
  (Roser C. et al., 2003)

2.4 Improvement tools

The purpose of improvement tools is to enhance effectiveness and efficiency in an organization. They aim at reducing waste and ensuring that the right processes are applied in the right way. There are numerous improvement tools for different fields of applications. The appropriate improvement tools for this project included standardization, standard times, incentives, visualization and communication.

2.4.1 Standardization

Standardized work is defined as the most desirable work method in terms of safety, efficiency and quality. Standardized work is a basic production philosophy that should facilitate the conditions for continuous improvement. Continuous improvement implies change, which means that even if the current process seems to be optimal, the standard work methods should still continue to evolve.
(Martin & Bell, 2011)

2.4.2 Standard time

In production engineering, the level of productivity is beneficial to measure. There are different ways of measuring.An accurate measureshould be objective and not include variations due to individual worker's performance. Measuring the physical time taken for two different methods of completing a task is unsuitable, as it is dependent on the worker's performance. Standard times are based on standard performance and take objectivity into consideration.

A standard time is defined as the time it takes for a worker to complete a task. The time is based on specific methods and equipment whilst working under the conditions of predetermined globally approved common pace standards such asSAM standards (Sequential Activity Method). The definition implies that the worker is physically capable and suitably qualified to perform the measured task. (Sakamoto, 2010)

2.4.3 Incentives

Incentives exist to create a positive motivational influence on performance and thus productivity. From the employees' point of view, incentives help them to understand what is expected of them and provide motivation. From an employer's point of view, a reduced labor cost and operational cycle time lead to improved competitiveness and customer service. There are different classifications of incentives: remuneration and financial (in particular money), moral, coercive and natural.(Zandin, K., 2001)

2.4.4 Visualization

Visualization refers to visually monitoring summaries of recorded data. It is often used to highlight results and potential areas for improvement of a process by comparing actual to expected performance. Visualization is intended to enhance awareness and engagement, and incentivize people to achieve better results. There are several methods and tools for visually monitoring a process. Day-to-day tracking charts are commonly used for monitoring the daily expected and actual performance, ideally in terms of units produced, and numbers and type of stops in the process. Thorough documentation of interruptions can be used to indicate the root causes of issues.

In order for the visualization to function, all participants must be genuinely involved and continuously documenting. Furthermore, it is important for the initiators of the process to continue monitoring after implementation, and to provide participants with feedback. In this sense visualization also works as a means for enforcing discipline.
(Sakamoto, 2010)

2.4.5 Communication

Communication is a central part of running a company. It enables company strategy, mobilizes employee efforts and facilitates the problem solving. Communication within a company also enhances competitiveness and creativity, and results in more satisfied personnel leading to lower costs, better efficiency and higher profitability.

Internal communication can be conducted in many ways; some companies are communicating through standards and visualization. No matter how the communication is conducted, it is important that it represents the company values.(Quirke, B., 2008)

3 METHOD

The overall method was to break down the G1 line into three different levels: system level, line level and cell level. Divers data collection provided a picture of the line and conclusions could be drawn of where to encounter the line bottleneck. Bottleneck improvements were analyzed and implemented through the theory of constraints. A redesign of the system level was thereafter regarded. The data was also used in several flow measurements that would indicate the degree of production flow efficiency of each level. The suitability of each flow measurement was evaluated.

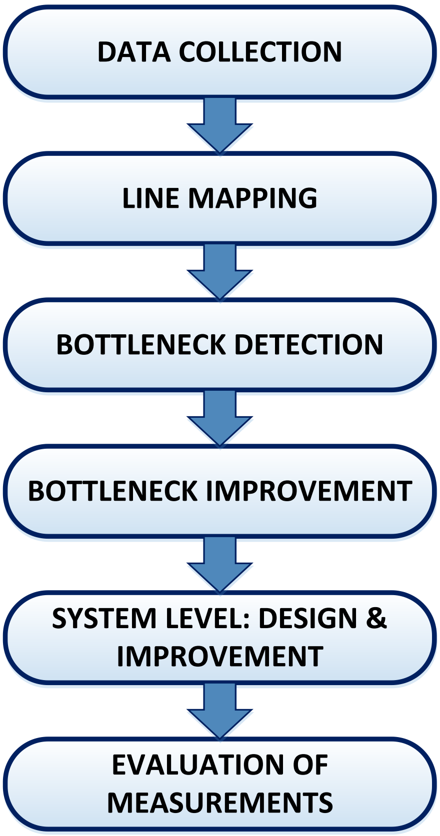


Figure 5– Methodology

3.1 Data collection

The overall goal of the data collection was to detect the bottleneck of the production line and thus calculate the flow efficiency on a production line level, sub-production line level and station bottleneck level. The data collection began at the production line level and was then broken down into stations. Quantitative and qualitative assessments were undertaken simultaneously: observations and interviews were compared and contrasted to the direct measurements. Retrospective studies demonstrated the production history and were used to verify the direct measurements.

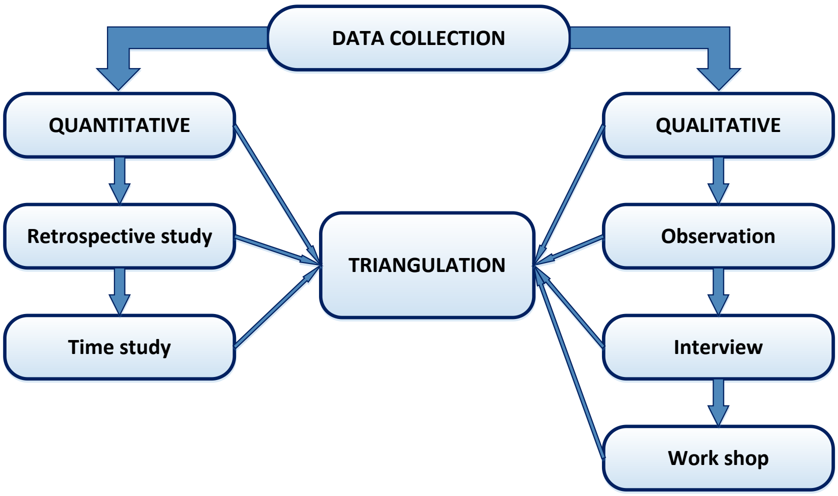


Figure 6 – Data collection methodology

3.1.1 Quantitative data

Aside from sample size and variation of the sampling, it is important to consider the following:

- Key variables and measurement tools must be defined
- Variance of data should be dependent on the key variable itself and not on the measurement method
- Data collection, data analysis and measurement tools should not be subjective
- It should be possible for others to obtain similar results through replication

Once the data collection is completed, the data must be organized so that it may be visualized in terms of descriptive statistics, e.g. as data charts. These statistics will show which numbers are representative and which are not.
(Botti & Endacott, 2008)

Retrospective studies

Retrospective studies are used to find dependencies between factors or correlations between independent factors and the dependent factor. Retrospective studies can also be used to verify direct measurement and eliminate non-representative current values. (Powers B.A. et al., 2011)

The aim of the retrospective studies was to acquire information on the performance of the production line and verify the results of the time studies. There were two in-house data collection systems from which data was extracted, named FLAI and ALERT. ALERT had recently been installed, as the production line had undergone a change of its in-house data collection systems at the beginning of 2014. The installation of ALERT resulted in difficulties in correlating data from before and after the installation. It was therefore decided to focus exclusively on the time period during which ALERT had been in use i.e. the months of January and February 2014.

FLAI and ALERT provided information about shift results: station errors, scrap rate, long stops and OEE. Both systems organized the shift results by date and subsystem. The results were however sometimes difficult to interpret as they were partially lacking in information and sometimes inaccurate.

Through interviews it was discovered that the station errors were divided into two categories: short and long stops. Long stops referred to stops longer than five minutes and were supposed to be directly registered in ALERT as they occurred.

Time study

Time study is a work measurement technique for measuring the time taken to complete operations, and determining the time distribution. It is used when the operational cycles are repetitive and include a variety of disparate tasks. The study involves constant observations and time measurements using a stopwatch or recording equipment. Two factors of deviation are randomly incorporated into time systems: the deviation of the system (the result of clustering many variables) and the applicator deviation (dependent on the human factor). The applicator deviation is considered to be the more severe of the two factors because it has a stronger impact on the reliability of the data. (Sakamoto, 2010)

A time study was undertaken to determine various process times of the production line, such as cycle and lead times. The measurement tool for collecting the different time measurements was a stop watch. Each measurement started by clarifying the parameters and ensuring that the data collection was not going to be selective. The boundaries for each variable had to be defined so that similar results would be obtained from different replications throughout the study. Differences in cycle times indicated where the production line was unbalanced and where the bottleneck could be found. The time study was also used to measure different activities in the manual stations.

Early observations complemented by interviews showed that the cycle times of the automatic stations varied significantly less than those for the manual stations. The cycle times of the manual stations varied due to differences of work methods and performances among the operatorsi.e.variation dependent on an applicator variation in the system. The cycle times of the manual stations thus required larger sample sizes as well as samples from several operators.

Through observations and test measurements it became clear that ten cycle times would satisfyingly represent the cycle times of the automatic station and that twenty cycle times per operator and station would give a fair result of the manual stations. A comparison between the cycle times of the manual stations and SAM times would later expose any improvement potential of the manual work methods and performance.

Frequency study

A sample survey is used for obtaining an estimation of the frequency of different activities during an operation. The study is conducted during a set time period, through momentary observations and measurements of a section of a production system. The object for observation can be either a machine a human or a process. The study is preceded by calculations of the time component of each activity,

which is then multiplied by the frequency. The cumulative time for each activity in relation to the total observation time gives a representation of the real distribution of activities. Conclusions can then be drawn about which interventions are most suitable to improve the operation efficiency.
(Grahm, Å. & Mellander, K., 1973)

The logging of the activities in the manual stations resulted in a list of occurring events. Out of this several points of interest could be collected such as produced quantity, number of events, quantity between events etc.

3.1.2 Qualitative data

In order to increase the reliability of the data, it is important to:

- Carry out the observations at different times, due to event variation
- Carry out persistent observations to ensure all events are being captured
- Overlap the data collection with the data analysis, even at an early stage, and emphasize the qualitative data collection. This will provide the researcher with feedback on whether the data collection should be retargeted or not. It will also help the researcher to understand when the data collection has reached the point of saturation.

Once the data collection has concluded, the data must be is validated and verified by the participants and other sources.(Botti & Endacott, 2008)

Observation aims to compare stated to actual actions. It seeks to identify issues of which the participants were previously unaware. Observation can be conducted concurrently with or consecutively to the interviews.(Botti & Endacott, 2008)

The constant access to the production line implied that all data collection could be done freely and with no time restrictions as long as the production line was actually running. Consequently, observations and interviews were obtained during different times and were of varying duration. They could also be performed with high persistency and analyzed immediately.

Genchi Genbutsu

In Japanese, Genchi Genbutsu means “go and see for yourself”, referring to undertaking an observational study of production processes. Genchi Genbutsu is the second most important ground rule in the Toyota production system. It may involve one or more participants and emphasizes that problem solving is most effective when undertaken by someone who is directly experiencing the problem. According to the Toyota production system, remote problem solving tends to results in delayed or inappropriate solutions because of the lack of information. The lack of direct understanding of the problem will produce an inferior analysis. However, in practice it is very common for an error encountered on the shop floor to be passed on to someone remote for analysis.(Marksberry P, 2011)

The Genchi Genbutsu approach provided an initial idea of the production process and ongoing improvement ideas. It was also an approach of confirming issues that had arisen from interviews and retrospective studies. The Genchi Genbutsu resulted in a direct understanding of how processes could be improved, and provided an objective view of issues on which operators, maintenance, the industrial engineers, etc. had different viewpoints.

Practical experience

The researcher's ability to interpret the qualitative data is strengthened through the researcher's practical experience in the investigated area.
(Botti & Endacott, 2008)

For this reason, several days were spent working at the manual stations. The practical experience enriched the understanding of the improvement potentials that had been developed through the Genchi Genbutsu approach. The practical experiences were undertaken to facilitate the comprehension of the work methods and which working performance that was feasible. As the practical experiences were carried out with the assistant of an operator, they also resulted in an informal form of interviewing the operator.

Interviews

Interviewing is a very common approach for collecting and analyzing data when changing and improving an organization. The results from the interviews provide a clear picture of the employees' desires. Interviewing is suitable for quickly gathering information about the current situation, and facilitates a systematic approach. Interviews can be conducted with a group of people or individuals. The interviewees may be directed by certain subjective questions or not. Two common types of interviews are semi-structured and unstructured interviews.
(Gilley,A. et al., 2009)

A semi-structured interview is guided by a set of predetermined open questions that allow the interview to deviate from an intended direction, when the interviewer feels the necessity. (Botti & Endacott, 2008)

An unstructured interview is an informal form of interviewing and is not guided by predetermined questions. The informality tends to affect the behavior of the interviewee and result in more honest answers. In comparison to structured interviews, it is harder to draw conclusions between the responses of the various interviewees. Another disadvantage of the unstructured interview is that the lack of predetermined questions makes it more time consuming.
(Jones, K.D., 2010)

It became clear that semi-structured interviews required interruptions in peoples' work, which is why these were more difficult to achieve. The free passage and unconditional communication with the process engineers, the operators, the maintenance staff and computer engineers resulted in unstructured interviews most of the times. The interviews had many benefits; complementary information to the quantitative data collection, identification of weaknesses of the production line and passing on reflections between the interviewees. A list of performed interviews is presented in Table 1.

Table 1 – Qualitative data – Interviews

Interviewees	Interview
Process Engineers	Numerous semi-structured interviews regarding documentation, historical changes and events, line problems, future, reconstruction and general expert knowledge.
IT department	Numerous unstructured interviews regarding data communication. One semi-structured interview to discuss general data communication solutions.
Maintenance	Numerous unstructured interviews regarding larger scale problems, longer stop, historical repairs. Two semi-structured interviews to discuss general improvement solutions and disturbance handling.
Production shift leader	Numerous unstructured interviews regarding general process improvements. One semi-structured interview during a workshop to discuss the suggestions and ideas that would facilitate and improve the work on the production line.
Operators	Numerous unstructured interviews regarding general process improvements. One semi-structured interview during a workshop to discuss the suggestions and ideas that would facilitate and improve the work on the production line.
Product developer	Unstructured interview regarding design and function of the product as well as ideas about process improvements

Workshop

The semi-constructed interview was part of a workshop with the operators. A workshop is a meeting for discussions between people related to the relevant areas. The workshop aims to analyze the current situation, exchange information amongst the participants, educate, and to create solutions and generate implementation plans. The number of participants should be limited to ensure active involvement. The ambience of the workshop should be designed to create a sense of the importance of everyone's participation, not only for the discussion but also for any implementation plans and future improvements.

The activities should preferably be action-oriented to enhance the level of engagement of the participants. It is important that the facilitator provides the participant with information of what is expected to come out of the workshop, including an overall goal and the strategies to be used. In order to establish a dynamic and efficient workshop, this information should be provided in advance. The facilitator should furthermore establish clear goals, to assist with the design and sequencing of the workshop activities. The more instructive and detailed the activities are, the easier is becomes to evaluate their results in terms of the overall goal. (Ritz, W.C. 1970)

The workshop was conducted in a conference room with a two of operators and one shift leader during the early phase of the project. The overall goal was to complement the previous unstructured interviews and collect suggestions and ideas that would facilitate and improve the work on the production line. The work methods of the operators had been found to be greatly disparate, so the key result of the workshop was to determine the best work method and set a standard. The suggestions from the workshop were later forwarded to interested parties.

Some pre-determined questions were leading the discussion forward. It was important to encourage creativity during the workshop so the questions did allow a free discussion. The questions were focusing on cell design, ergonomics, work load, education, supportive functions, and different disturbances that could appear. The work methods of the manual stations were compiled in a hierarchical task analysis, HTA (see 3.3.2.1).

3.1.3 Data validation

The data was validated in accordance to the initial criteria: quantitative must be objective, the key variable must rigorously defined and the variations dependent on the key variable itself and not the measurement method. The historical data must not contain any outliers and not be lacking crucial information. To validate qualitative data, observations must be carried out persistently and at different times. The information from interviews must be confirmed by alternative sources.

The second step of validation was to perform triangulation. This method was particularly useful when different viewpoint from different employees did not coincide or when separating subjective information from objective. Triangulation was useful for both types of data collection.

3.2 Present state

When the data collection were finished and a satisfying system understanding were evolved the system were analyzed. An overall system mapping was visualized using a VSM. Gathered data were consolidated the OEE factors, which wasthe company’s way of monitoring production effectiveness.

3.2.1 Production system

The production system depends of several different support functions to operate successfully. These are production control, material filling, maintenance etc. A value stream map was created with purpose to gain further understanding and visualize the system with its affecting factors.

Value stream map

Value stream mapping is a method for identifying and reducing non-value adding activities in a system. Non value adding activities refer to overproduction, waiting, transportation, inappropriate processing, unnecessary inventory, unnecessary motions and defects. The VSM covers the beginning through to the customer in a production system. The approach is to map the current state in terms of material and information flow and compare it to a future state where non-value adding activities have been removed. VSM is a good tool for visualizing waste and is used for internal benchmarking rather than external. (Hines P., 1999)

Component value

The appreciation in value was of interest to understand the scrap cost in the different production steps. This was collected from Autoliv's material withdrawal system, Movex.

3.2.2 System performance

A variant of OEE (see2.1), has historically been used to monitor the production effectiveness in the different subsystems. The recent introduction of a new data logging system has resulted in that the data was being logged in different systems. Therefore there was a need to gather data from multiple sources to calculate the values. This analysis was primarily made to determine the productivity of the present state, but also to find sources of losses. The value was calculated as:

$$\boldsymbol{Autoliv\ OEE = Availability * Performance * Quality} \quad \text{Equation 13}$$

3.3 Evaluation and identification of improvement areas

The evaluation and improvement work was performed following the methodology corresponding to the theory of constraints. This section is structured according to these steps to clearly present the methodology used while working with system improvements.

Theory of constraints

Theory of constraints is a convenient tool when assessing and improving a production system. The methodology is based on five steps which help the user to improve the systems performance by directing the attention to the right part, i.e. the constraint. The five steps to follow are:

1. Identify
2. Exploit
3. Subordinate
4. Elevate
5. Iterate

(Rahman, 1998)

3.3.1 Bottleneck detection

The localization of the constraint can be more or less easy dependent of the system complexity. There are a few common indicators to look for and these are:

- Resources which constantly are under pressure and are characterized of a high utilization
- Resources with a large downstream buffer and no upstream buffers
- Resources which seldom are starved or blocked

- And finally, do the resources after the probable constraint have a low utilization rate?

(Cauwenberghe & Tung, 2009)

In this thesis work this was done in two stages on two different flow levels. The first was to find which subsystem that was constraining the system and later on to find which part of the subsystem that was the final bottleneck. In this case was both the capacity and scrap rate of interest due to the time loss and cost which is the result of the latter.

3.3.1.1 First flow level: System constraint

As mentioned, the APG production consists of three subsystems with buffers in between (Figure 7). These are the pre-assembly line, main assembly line and the final 24H-leak tester. All of these subsystems can be separated and operated independently of each other as long as there is enough material to feed the next. The first thing to be done was to determine which of the three that limited the system.

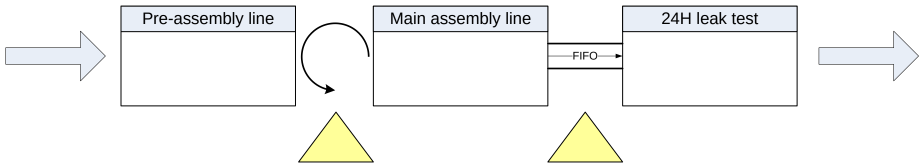


Figure 7 – APG production system

In order to calculate the occupancy, cycle times was measures and compared to the designed times. Further on wereold shift reports analyzed, buffer levels observed, utilization rates calculated and the distribution of scrap parsed to enable the detection described in5.1.

3.3.1.2 Second flow level: Line constraint

When the system constraint had been found to be the main line amore in depth analysis was needed to determine the lineconstraint. This subsystem consists of semi-automatic station for welding and loading, 18 completely automated stations connected by an accumulating conveyor followed by a manual station for unloading and final check (Figure 8).

The APG is, when the MAG-cell cycle is finished, loaded into the cooling tower which in turn loads a palette on the conveyor. No buffers exist in between except from the products are in the conveyor between the stations.Disturbances on the line do not affect the manual station as long as the problem is fixed before the MAG-cell isbeing blocked. The automated stations are dependent of each other due to that they easily blocks/starves the adjacent stations.

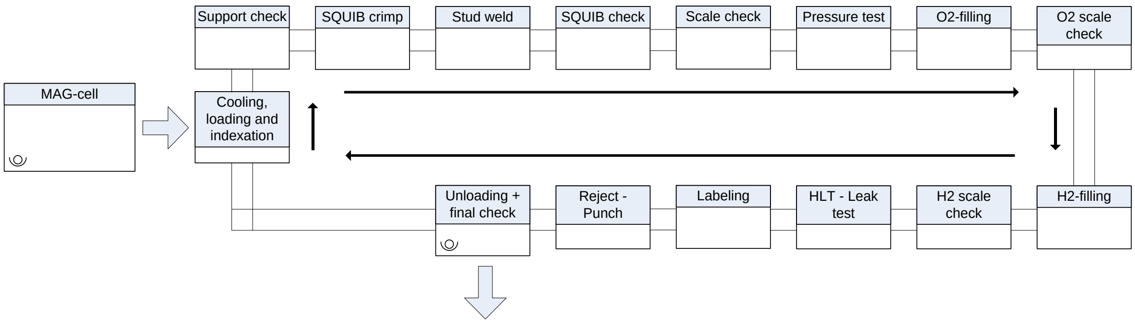


Figure 8 – Main assembly line

Cycle times

The line-bottleneck detection required several time measurements of both automated and manual stations. The cycle times of the automated stations were defined as the time from when the palette stops in the station until it starts moving again. For the manual it was set from when one cycle starts until the next one starts. See AppendixIfor templates and more detailed definitions.

Buffers

The flow on the conveyor was observed to find potential constraints among the automated stations.

Utilization

Based on the cycle time measurements and the average shift result (collected from FLAI) the average utilization of the automated stations could be calculated. This was done based on equation 14 below.

$$Utilization = \frac{Station\ cycle\ time * Average\ shift\ result}{Avaliable\ operation\ time/day} \quad \text{Equation 14}$$

Short and long stops

Disturbances in production can have a significant impact on the output. An old system for handling short stops existed but was not presently used properly and therefore not of relevance on this stage. Long stops were collected and aggregated from ALERT.

Scrap

One unit in the scrap container means both a loss of production time and unit costs. The line computer keeps track and logs occurring errors which results in a scrapped part. By extracting all station errors from the computer system the biggest scrap sources could be revealed. Errors with code "Wrong station order" on the line were moved to the preceding station because this was found to be the correct origin. This was done by programming a script in Visual Basic (AppendixA)which compiled the results in MS Excel. The station error log was also compared to another list of scrapped products in order to validate the result.

3.3.1.3 Final detection

After finished data collection and analysis the result was collocated from the different parts. This allowed the final detection and focus was then directed to the bottleneck for further improvement work.

3.3.2 Bottleneck exploitation – Third flow level: Cell constraint(s)

Exploitation in general terms means to make something more useful, productive and profitable (Park & Allaby, 2013). Within TOC it implies to find every lost source of capability in the process and bring the most out of it, and this without costly investments (Dettmer, 1997). The principle is simply to first make the best with what you already got since current equipment is already paid for (Cauwenberghe & Tung, 2009). Things to have in mind in this stage are to:

- Assure that the bottleneck only are working with the most important things by removing non-productive work
- Remove potential obstacles and disturbances which limits the capability
- Assure that the bottleneck never is starved nor blocked

(Cauwenberghe & Tung, 2009)

Semi-automatic work cells enables improvements in both machine processes and manual work methods. Methods used for the exploitation work in this project are described in below.

3.3.2.1 Method improvement

The first area to be investigated was the work method in the bottleneck. The procedure is described in section below.

Hierarchical Task Analysis (HTA)

HTA is a type of task breakdown that aims to determine the optimal sequence of operations for attaining the overall goal. When breaking down a task into its elements, certain questions will naturally arise. How is the sub-task performed? What is required to perform the sub-task? Most importantly, the question of why the task is performed the way it is might appear. HTA incorporates hierarchical relationships between the sub-tasks, where each sub-task represents a sub-goal. The contribution of each sub-goal to the overall goal is analyzed to determine its priority and necessity. Each operation of the sub-goals is analyzed to find improvements in the areas of: ergonomics; time, motion and cognition. HTA may also be suitable for educational purposes, if conducted thoroughly.
(Stanton, N.A., 2006)

The method was at first performed to analyze the manual work cycle and later in a workshop with operators to stand base for a standardized work instruction.

Cell flow

Based on the finalHTA the cell flow was analyzed and compared to the original. The importance of traceability within this industry requires a failsafe traceable one piece flow with zero buffers.This flow is mainly controlled by the computer system, why also the control signals were evaluated.

Working performance

The working pace of a manual operation consists of two aspects: skill and effort. It is important to separate these aspects when conducting a work measurement, as the level of skill is more or less constant whilst the effort varies with time. (Sakamoto, 2010)

In this situation it was more feasible to be focusing on the skills instead of efforts e.g. to approach working performance improvement through standardization and education.

Time analysis – Sequential Activity Method

The SAM system is a predetermined motion time system which is used to set feasible standard times for completing basic manual motions or tasks (Zandin, 2001). SAM is most commonly used for work method optimization and line balancing. The SAM system evolves from the basic predetermined motion system MTM (Methods-time measurement) whose standard motions are based on average skill and effort. SAM was developed from MTM to improve the speed of analysis, increase the usage of standard times in industry, and lower human-dependent variation, i.e. the applicator deviation.

The manual motions or tasks are represented in a sequence of activities of which there are three types in the SAM system. These are: basic activities e.g. get-motion and put-motion; supplementary activities such as applying a force to the motion and repetitive tasks like screwing and hammering. The activities have one or more variables that vary depending on weight, distance and level of precision. The activities the sequence, plus variables, for performing a motion or task correspond to a standard time.
(Sakamoto, 2010)

The current system design was based on time estimations of the different subtasks. To correctly be able to evaluate the future performance, a standard time was calculated, using the SAM-system.This was based on the workflow developed in the HTA. The process times for the welding equipment were measured using a stopwatch.

Time and frequency study

The production cell was observed with purpose of gaining additional knowledge about how the available time was distributed. The study went on for 416 minutes and during that time the following was found of interest:

- Occurring activities and deviations from the main task with corresponding deviation time
- Quantity produced
- Number of parts produced between each occurring activity

After the study the distribution of time was calculated to reveal the percentage of time which actually was put on the main task. Other result of interest was the average activity time and the average quantity units in between. The activities that were found during these studies and previous observations was listed and classified.

Standardization of support activities

The bottleneck was designed to perform several support activities in the work cell. Conducted studied demonstrated to what extent these had an impact on the cell performance. Intervals and deviation times was analyzed and potential sources of improvement recorded. These activities were then standardized by execution and interval based on practical experience and in-house expertise.

Buffers
Tactically positioned buffers helps reducing the dependability between different operating equipments (Rahman, 1998). The possibility to create buffers without jeopardizing the traceability was therefore investigated with purpose to reduce the risk of finding the bottleneck blocked or starved.

3.3.2.2 Process improvements
As previously mentioned are this step first of all about improving the available system with its equipment before costly investments are made (Dettmer, 1997). Large improvements can thou be achieved by using small means. Potential minor process improvements were therefore developed, collected and conceptually evaluated.

3.3.2.3 Disturbance handling and prevention
Production systems which are running flawlessly in optimal conditions might experience a significant reduction in performance by frequent disturbances. To prevent these,investigations were made to find probable sources and if possible eliminate them.

Scrap reduction
In order to diminish the scrap rate in the bottleneck the MAG-cell was observed during several occasions. As soonas a product was scrapped the underlying cause was investigated. The analysis included control system errors, welding process errors and manual work errors. Input was collected from the IT department and maintenance personnel to make use of their expertise within the area.

3.3.3 Subordination of non-bottleneck
After finished exploitation the next step is to subordinate every other resource to the bottleneck. By facilitating for the bottleneck the overall system performance can be enhanced, even though the performance of the affected elements is diminished. (Rahman, 1998)

Actions to be taken are for example to:

- Separate and move possible activities
- Assist the bottleneck where it is applicable
- Always feed the bottleneck with input of high quality
- Assure that the bottleneck output is threatened cautiously to prevent damages
- Let the bottleneck set the pace of the system

(Cauwenberghe & Tung, 2009)

In this thesis work it mainly implied that the possibility to separate occurring activitieswas investigated. This was done by interviews, estimations, testing etc. A system design was also created where the activities were dedicated to specific work stations. As a part of this the up- and downstream resource was investigated by time distribution, SAM-time and disturbance. The purpose of this was to prevent that the bottleneck was blocked or starved.

3.3.4 Elevation of bottleneck

If found bottleneck still, after finished exploitation and subordination, limits the desired output further actions are needed. The next step is to elevate the bottleneck by investing additional resources. These improvements are in general of a larger character and require time and money. (Rahman, 1998)

Potential sources of improvements are:

- Education and exercising
- New machines and tools
- Additional human resources

(Cauwenberghe & Tung, 2009)

Interviews and brainstorming activities stood base for finding potential investments on a conceptual level. The effect of the hardware investments was where applicable estimated and measured by performing fictive studies where one of the thesis writers acted as supportive equipment, i.e. performed the supposed task. The effect of additional human resources was calculated using the SAM system, (see3.3.2.1).

3.4 Conceptualization of future system

Solutions found in the TOC-cycle were then aggregated into conceptual systems. Complementary to the bottleneck improvements were improvements on other flow levels. These are of a supportive nature and contributed to the overall system enhancement.

3.4.1 Bottleneck improvements

The bottleneck improvement work ended up with several, more or less costly, possible improvements to implement. These were combined into two possible future states; one without elevation and one with all suggested elevations.

3.4.2 System improvements

The system performance has to do with several support functions for planning, awareness and control. Several different areas were dealt with during the improvement work and these are presented below.

Run chart

A wish from the company was to develop run chart with different gears for the G1-line. The theoretical capacity in ideal conditions was calculated on the three manual stations corresponding to the pre- and main assembly line. The 24H-leak tester was excluded due to that it holds excess capacity and mostly is driven independently of the other. The calculation was based on the SAM-time for manual operations, the measured process times, the time neededfor support activities and 5 % for operator allowance (see equation 15).

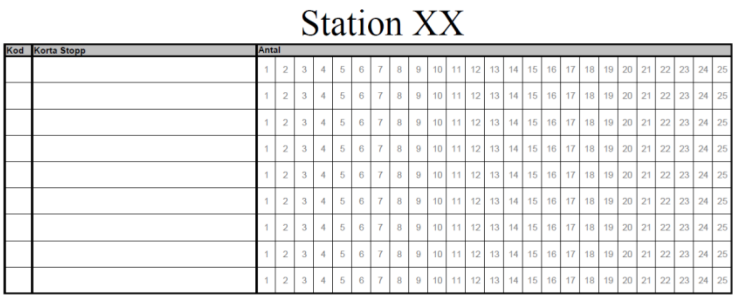
$$\boldsymbol{Quantity\ per\ hour} = \frac{\mathbf{3600}}{(\boldsymbol{Cycle\ time} + \boldsymbol{Support\ time} + \boldsymbol{Allowances})} \quad \text{Equation 15}$$

The time needed for the support activities was calculated by listing all occurring activities, estimating their time consumption, divide by their interval of occurrence and then finally distribute the time on every produced unit (equation 16). This was then done for two, three and four operators to create three different gears to be able to meet different hourly customer demands. The credibility of the result was validated by practical experience and additional measurements.

$$Support\ time = \sum_{i=0}^{n} \frac{\text{Support activity}_i}{\text{Intervall between events}} \qquad \text{Equation 16}$$

Short stops

An old system for logging and handling of short stops existedbut the problem was that it was not used nor updated. The system was refreshed by updating the tic sheets templates (see Figure 9) and creating a new report for visualization using MS Excel. Common errors were collected by interviewing line operators and were then added as possible errors on the tic sheets. The stops was then logged on a daily basis and used to analyze disturbances and the correlation to the origin of scrap.



Station XX

Kod	Korta Stopp	Antal																								
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		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Figure 9 – Autoliv's tic sheettemplate for short stops

Computer systems& shift reports

The use of the different computer system was evaluated and recommendation of usage developed. This was based on interviews and further investigations about the system potential. Until ALERT was introduced in December 2013 a shift report was printed and used for daily evaluation. To keep track of the performance during the thesis work was another shift report created and visualized.

Startup sequence

The company experienced production time losses due to variations in the startup sequence. The sequence was observed at numerous occasions to reveal the root cause of the variations. Complementary to this was the maintenance personnel consulted to verify the different possibilities. The method was then optimized based on gained understanding and a standardized instruction was created.

3.5 Evaluation of measures

This project took into consideration how to analyze production flows in terms of effectiveness, efficiency and productivity.An attempted to relate suitable production flow measures to a hierarchy of production levels was conducted. The methodology used for the evaluation work is visualized in Figure 10 below.

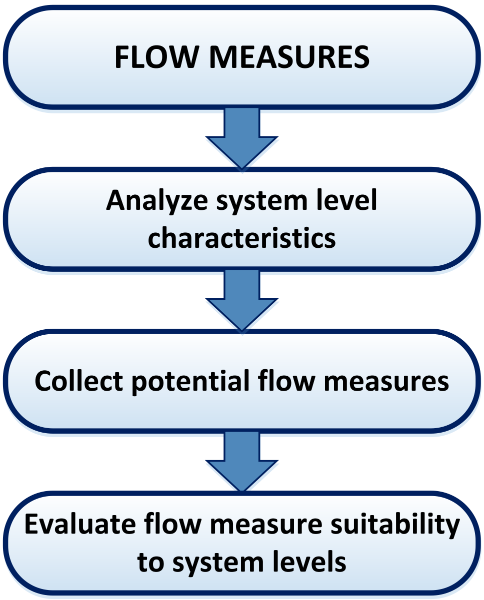

Figure 10 – Methodology: Evaluation of measures

The first step in attempting to describe the flow of the G1 line was to understand the characteristics of it on three levels: system level, line level and cell level. There are some significant differences in characteristics between the levels.

The second step was to analyze several different flow measurements and try to relate them to the characteristics of the levels. The aim was to connect two measurements, preferably of different kind, to each level. The suitability of each measurement to the different levels was analyzed by investigating the correspondence of parameters.

The third step was to calculate the flow measures and to compare them to each other and allocate the most suitable measure. Data was collected and calculated from three occasions. These represented time intervals where the production was observed and all events denoted. They were also chosen because of their inequalities, where the first occasion was during "normal" production, the second occasion included long stops and the thirdwas logged during a performance test on the line. A lot of data collection was required in order to complete the calculations. Most data concerned the availability, performance, quality rate and output of the bottleneck as well as the last station of the G1 line. The measurements were presented and compared in percentage.

4 PRESENT STATE ANALYSIS

The preformed investigations resulted in enhanced understanding about the system and its complexity. System characteristics, production planning, component value and the current performance values are presented in the section below.

4.1 Production system overview

The G1-line is a complex system with a lot of people involved in the process. Except from the operators, the line got support from logistics and maintenance personnel. The production rate are controlled and leveled by production control cards from the Heijunka-board. The overall production view is presented in the value stream map found in Figure 11.

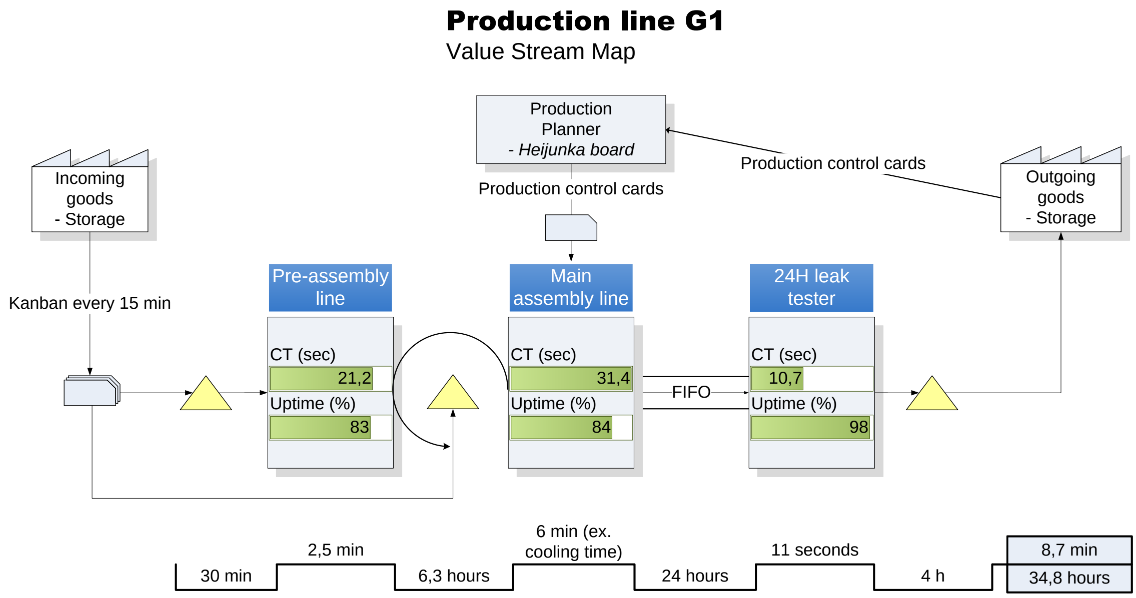

Figure 11 – Value stream map

Shift times

In an ordinary morning shift the available shift time for productionwas 425 minutes. Exceptions from this are Tuesdays and Fridays where 40 minutes were scheduled for APS-time and every second Monday where 120 minutes were scheduled for preventive maintenance.

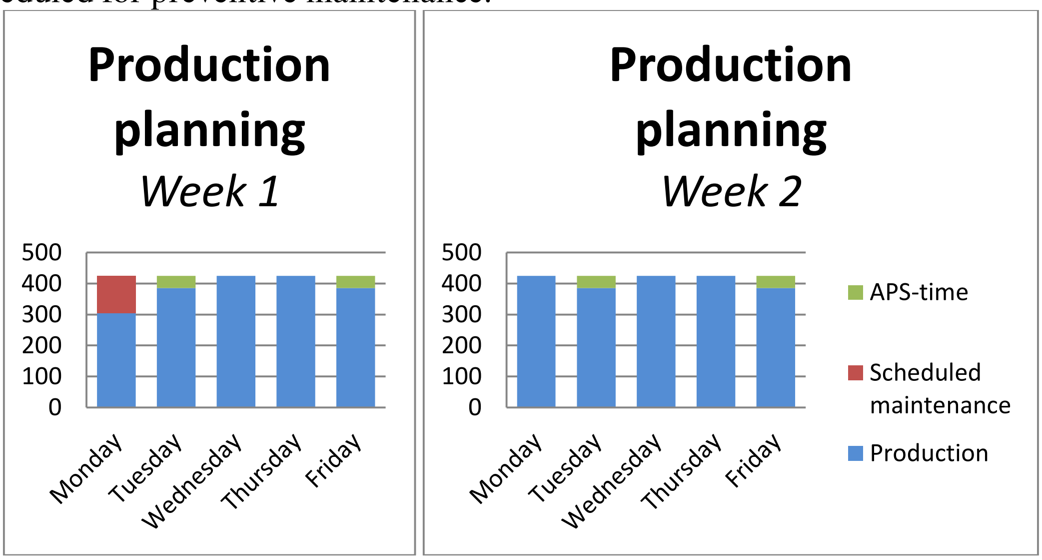

Figure 12 – Production planning

Component value

The component value was calculated by adding up the component value when the components are assembled. This does not take the operator or station running cost into account. 100 % corresponds to the value of an approvedAPG.

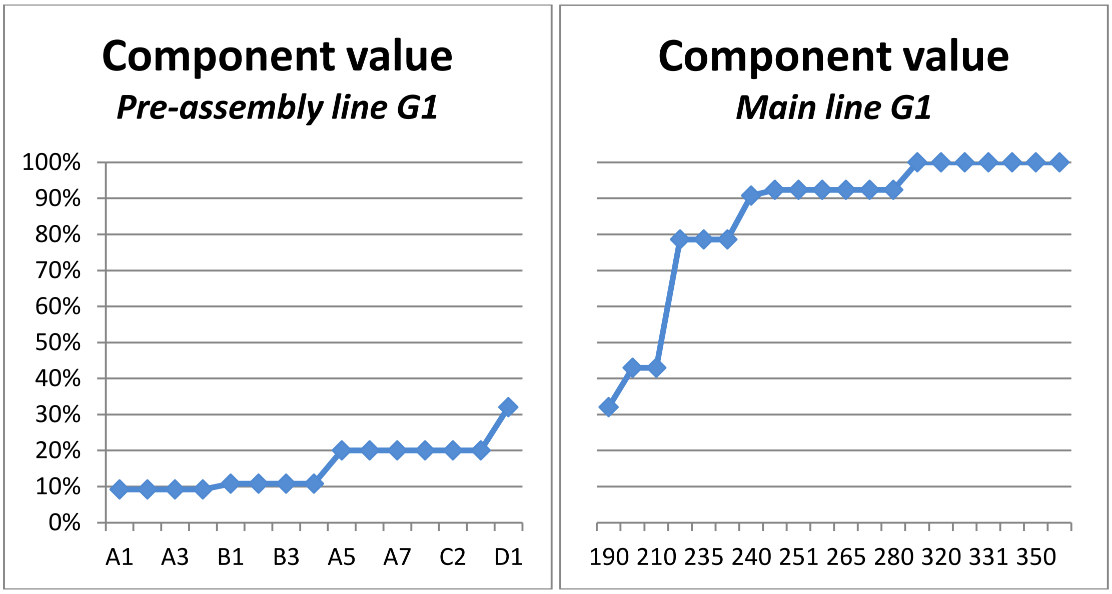

Figure 13 – Component value increase in process chain

4.2 System performance

The system effectiveness was as mentioned monitored using a custom variant of OEE, which generally are used to monitor single equipment effectiveness. Customizations, of the three different, at Autoliv are described below. The historical values for January and February were calculated and are presented in Figure 14. The company's target value was 80 % and corresponds to the red line below. The historical values for the three factors were also plotted separately to find the ones with the largest impact.

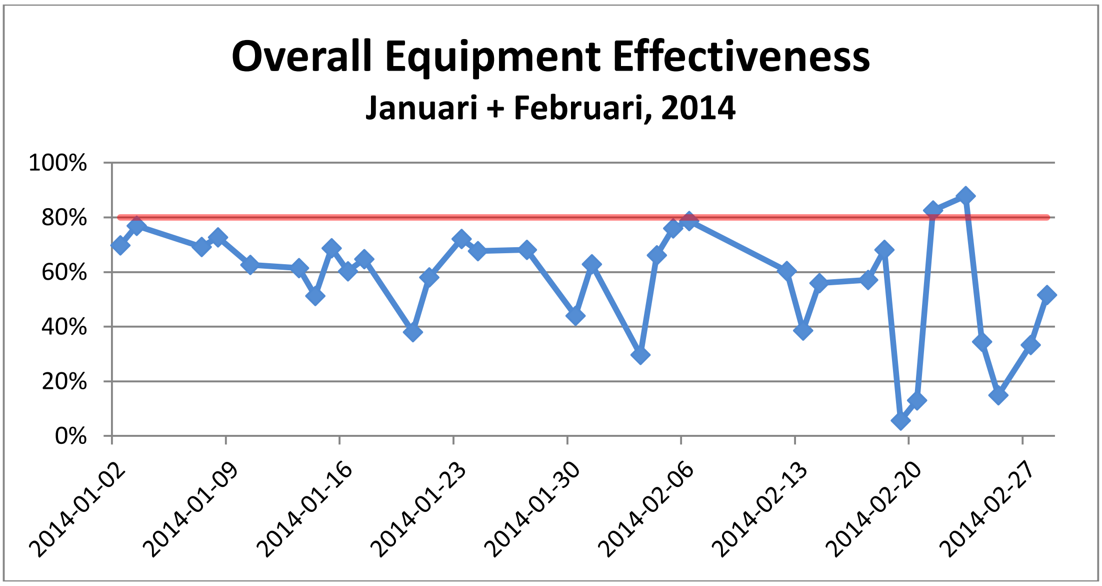

Figure 14 – Historical OEE values, Main assembly line

Availability

The availability factor was affected by long stops and planned stop time. The long stops were collected from ALERT and additional information by interviews. The value was customized to represent an entire subsystem by defining that a long stop in any of the stations affected the utilization of the whole line. Long stops on the pre-assembly line do not affect the availability main assembly line as long as it is not starved.

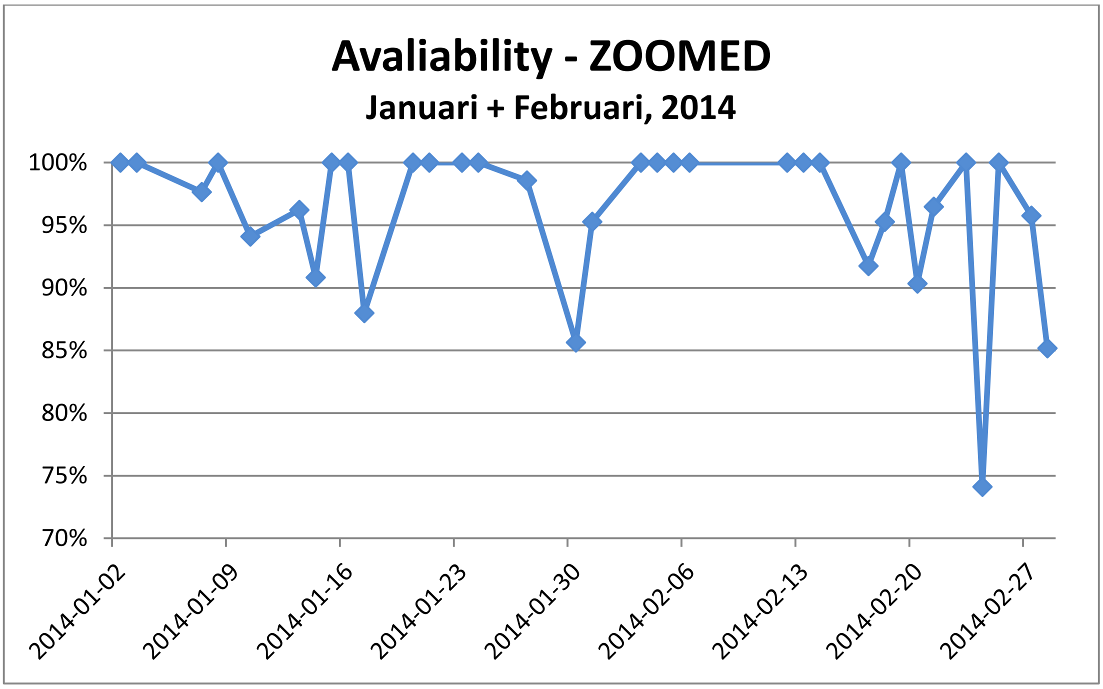

Figure 15 – Historical availability values – Main assembly line

Interviews and observations revealed an inconsistent logging of the long stops. Sometimes it was forgotten and sometimes the maintenance staff did not have time. The general opinion was also that the new computer system was ineffective. The indication was though that the main cause did not lie to the occurrence of long stops and the focus was therefore directed to the other parts.

Performance

The performance factor at Autoliv corresponds to the actual shift cycle time though the designed cycle time (26 seconds). This implies that the value further on is affected by short stops and other variations caused by the operators. Historical shift result data of finished products was collected from FLAI was then divided by the designed capacity based on available production time.

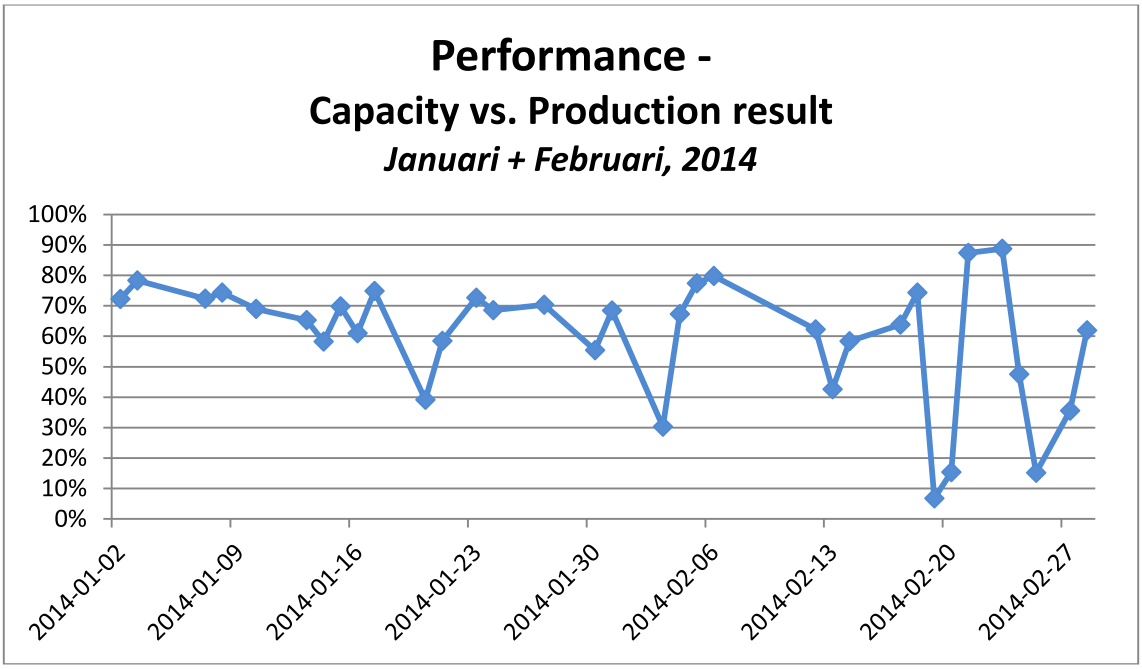

Figure 16 – Historical performance values, Main assembly line

Analysis reveals the close correlation between the performance plot and the final OEE plot. From this the assumption was drawn that the main issue behind the low OEE values was the robustness in the constraining operations, i.e. variations manual work, short stops etc. In general the line produce less than desired. Another problem was that the line was designed to run at a cycle time of 26 seconds (performance in FLAI), while the leveled contract requires a pace of 36(performance in ALERT).

Quality

Products of bad quality are getting more expensive the longer they travel through the production chain. A quality factor was calculated by dividing the scrapped quantity collected from FLAI with the total number of produced part the corresponding day.The numbers are therefore only valid for products with assigned serial number, i.e. after the cooling tower on the main assembly line. Excluded are thus scrap from the pre-assembly line and the MAG-cell. These are thought of lower value and of slightly less interest.

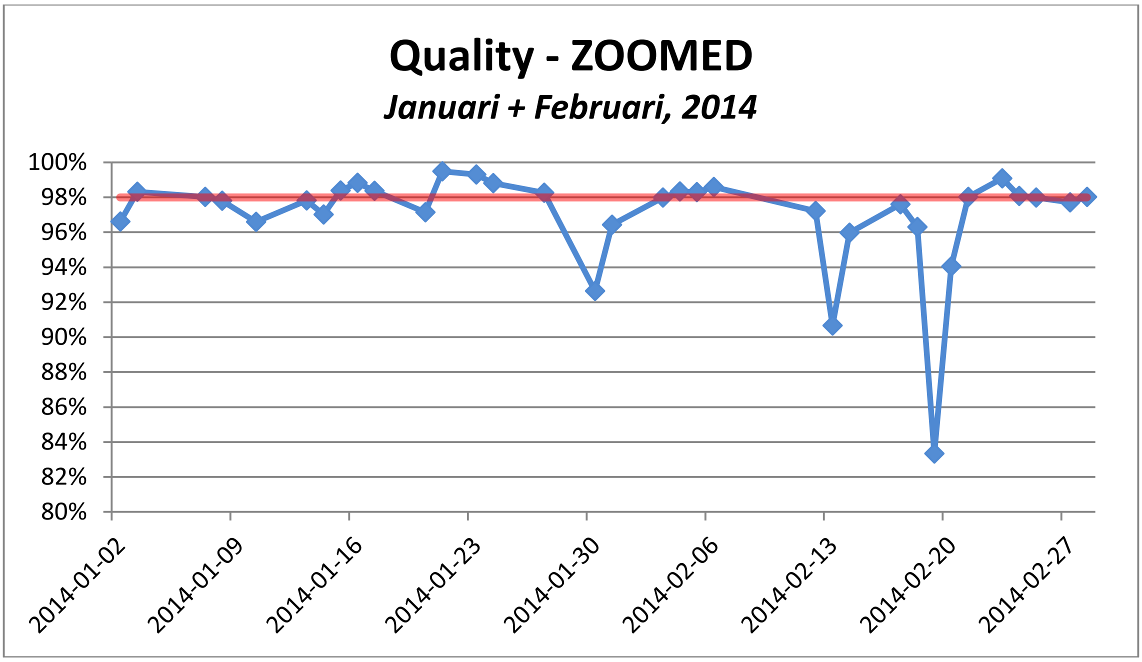

Figure 17 – Historical quality values, Main assembly line

5 EVALUATION AND IDENTIFICATION OF IMPROVEMENT AREAS

The TOC cycle implied several measurements, analyses and improvements. The detection and improvement started on the system flow level and was then narrowed down to system level, followed by the cell level. The result from the different steps in the cycle is presented below.

5.1 Bottleneck detection

The two step detection directed focus early in project. The analysis was initiated at the system flow level and the final detection done at the line flow level. The results are presented separately in the following section.

5.1.1 First stage: System constraint

The first stage detection was made by observing and performing measurements on the different subsystems. This resulted in quickly enhanced understanding of the system characteristics.

Cycle times

The production rate was investigated at the different subsystem by measuring the time between each finished unit. Ideal cycles, without disturbance or support activities, were measured on each subsystem output and put in relation to the designed. The designed cycle times were supposed to include all support activities which implied that the measure times should be lower to handle the designed rate.

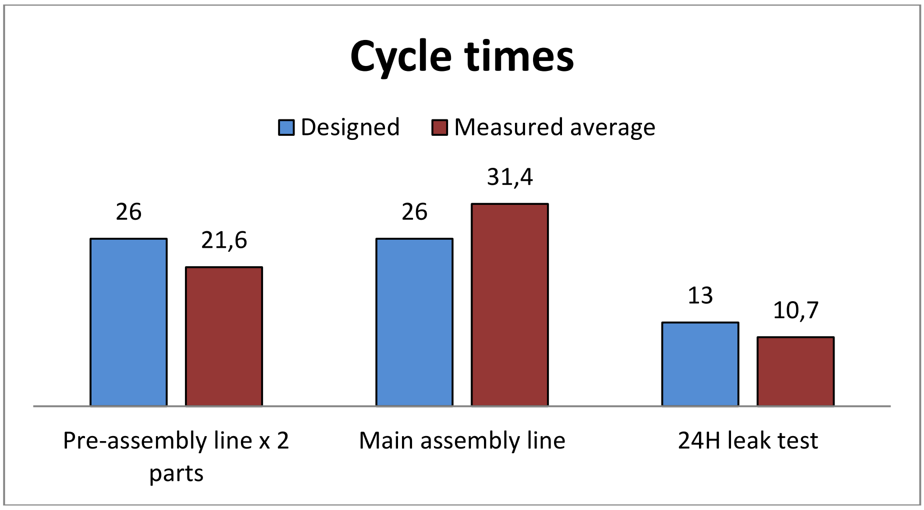

Figure 18 – Designed versus measured cycle times

A time study was also made to investigate the time distribution. The result showed that only slightly above 80 % of the time was spent on the core activity in the manual work cells. This was complemented by interviews estimate the values for the different subsystems. The "other"-part includes material handling, disturbances etc.

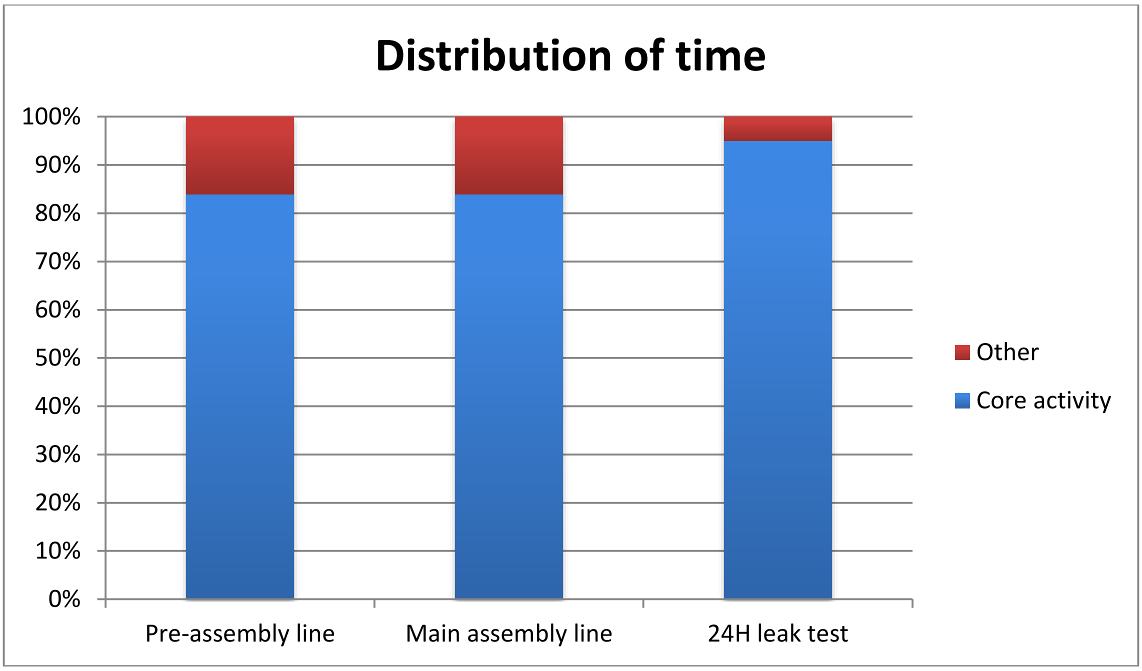

Figure 19 – Distribution of time in manual stations

Buffer levels
Buffers existed between all of the three subsystems. Observations indicated that the buffer levels were large enough for the three to operate independently, and especially for before the 24h leak tester which only was irregularly driven when needed. To strengthen the observations was the buffer level between the pre- and main assembly line logged during a few days. The buffer was built up from zero to maximum during a few days and the conclusion was drawn that the pre-assembly did not limit the flow.

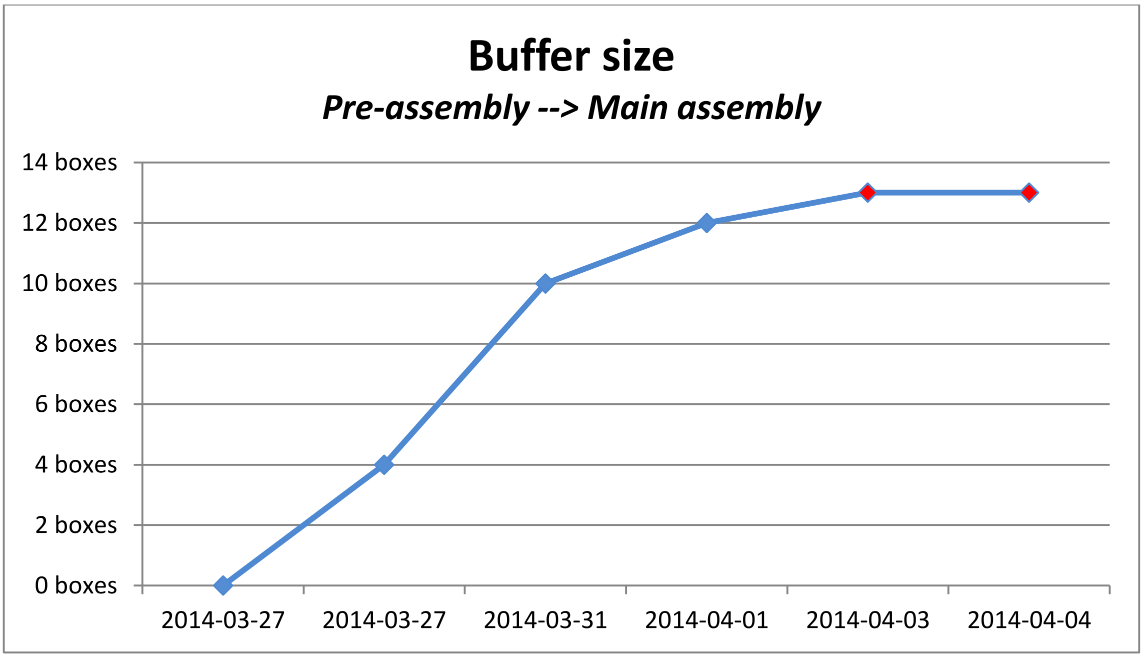

Figure 20 – Observed buffer size between the pre- and main assembly line

Utilization
The utilization in the different subsystems was determined by the utilization in the manual work cells, i.e. when the operator is working. The reason for this was the operator needed to be present to feed and unload the different subsystems. Observations indicated utilization close to 100 % of the main line, a bit below 100 % for the pre-assembly line and finally a low utilization below 50 % on the 24h leak tester.

Scrap
The average scrap cost and quantity from the different subsystems pointed out the main line as the overall largest source. The 24h leak tester was of less interest since errors found there must have been caused in previous processes.

Final system constraint detection
The result of the finalized detection is summarized in Table 2 below.

Table 2 – Final system constraint detection

Element	Indicated bottleneck
Cycle times	Main assembly line
Distribution of time	Pre- or main assembly line
Buffer levels	Main assembly line
Utilization	Main assembly line
Scrap	Main assembly line
System Constraint	**Main assembly line**

5.1.2 Second stage: Line constraint

When the main line had been found as the subsystem constraint the next step was to determine where on the main assembly line the bottleneck could be found. The result of the detection work made on the main assembly line is presented below.

Cycle times
The measured ideal cycle times for both the manual and automated system was compiled into the diagram in Figure 21 below. The measurements unfolded the significantly longer cycle times in the MAG-cell (station 200) compared to the other stations. For further details about the measurements see AppendixI&J.

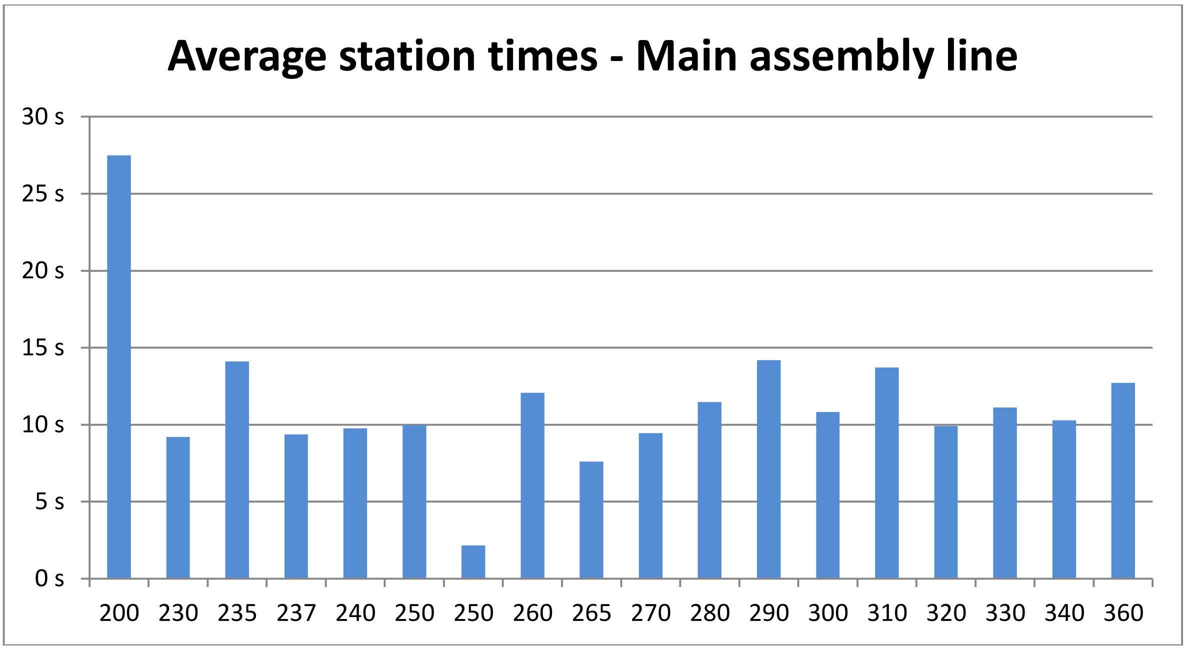

Figure 21 – Average station times, Main assembly line

Buffers

One-piece-flow in the manual cells and a conveyor connecting the automated stations implies that no real buffers exist on the line. The exception is of course parts that are waiting on the conveyor. During the observation which was made was no notable stockings revealed which indicates that all stations on the line operate faster than the MAG-cell.

Utilization

Analysis of the measured station times in relation to the old shift results unfolded the low average utilization on the downstream resources from the MAG. All stations were holding excess capacity, which was supported by the top value of 33 %. These calculations were simplified by only using the standard shift time, i.e. no adjustments were made for APS- and maintenance time, long stops etc. The result was though still considered sufficiently accurate due to the low values.

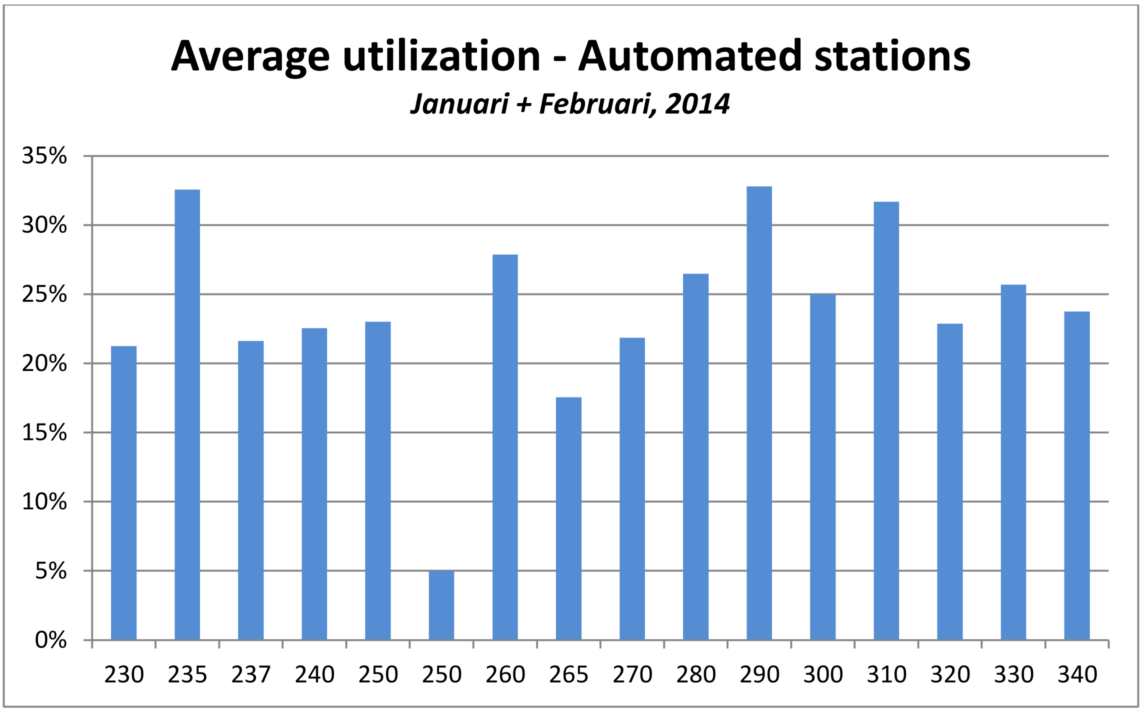

Figure 22 – Average utilization of automated stations

Short and long stops

The long stops that affected the availability factor (see section 4.2) were separated into the different stations. This indicated that the cooling tower (station 230) had the longest total stop time during the period. Errors in the cooling tower are blocking the MAG-cell immediately and the production is forced to stop.

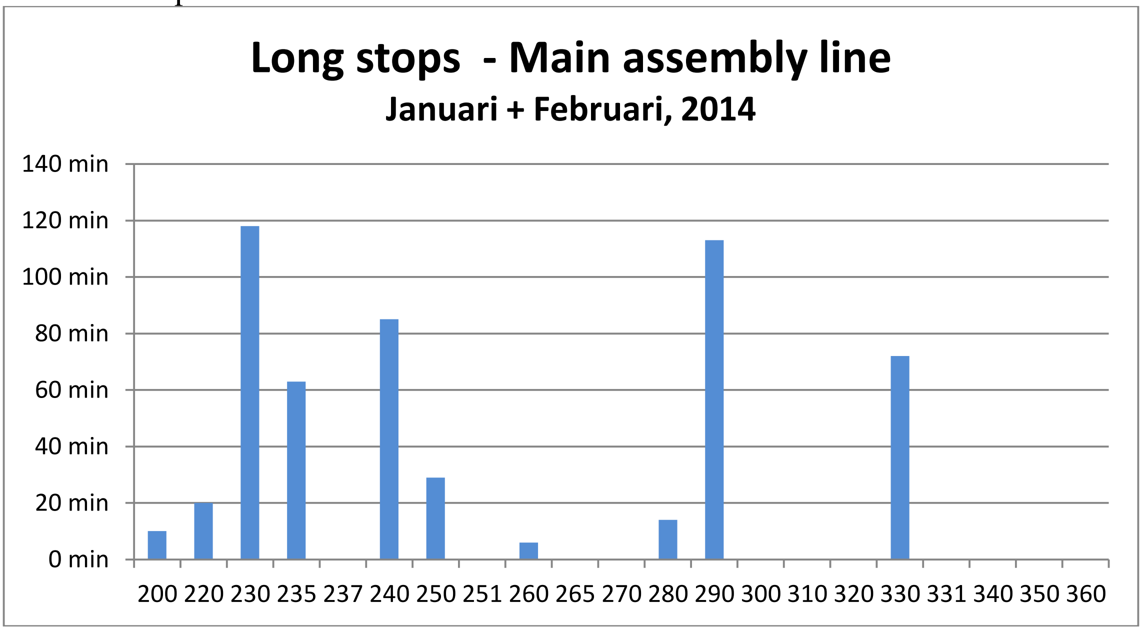

Figure 23 – Long stops, Main assembly line

Scrap

The final investigation was the largest sources of scrap. The result of the origin analysis and error code adjustments is presented in Figure 24 below. The two MAG weld machines in the MAG-cell were found to be the largest sources whichindicated the MAG-cell as the scrap constraint. As visualized in Figure 13 the product value were close to the final after the last MAG-weld operation.

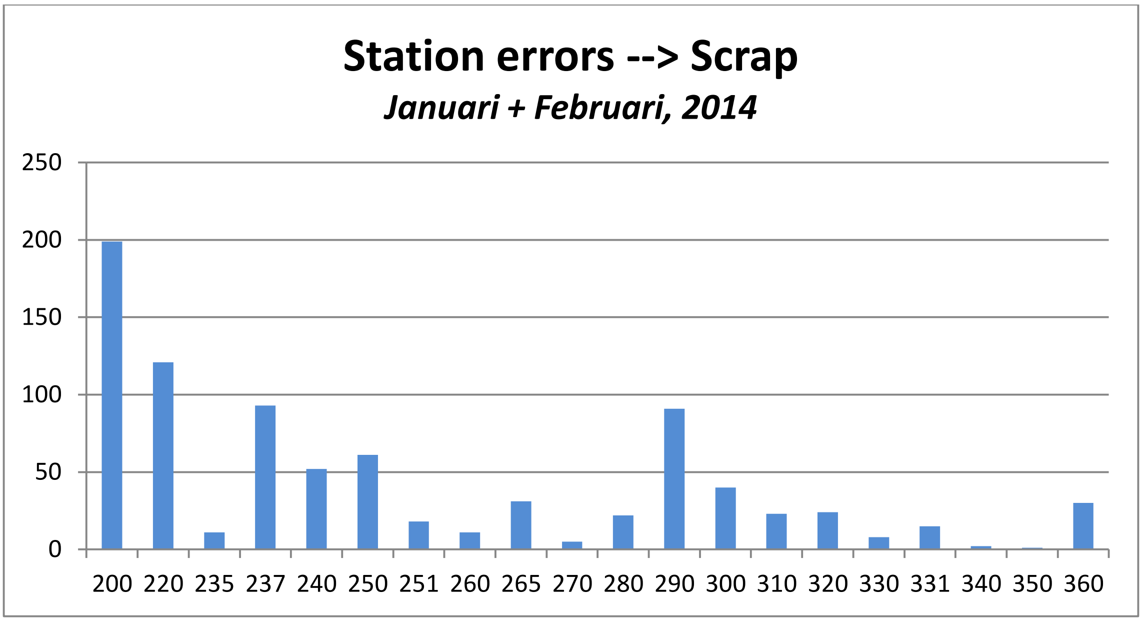

Figure 24 – Station errors, Main assembly line

Final detection – Line constraint
The result from the bottleneck detection is summarized in Table 3 below.

Table 3 – Final line constraint detection

Element	Indicated bottleneck
Cycle times	MAG-cell
Buffer levels	MAG-cell
Utilization	MAG-cell
Long stops	Cooling tower
Scrap	MAG-cell
Final bottleneck	**MAG-cell**

5.2 Bottleneck exploitation

The exploitation work resulted in several potential bottleneck improvements. These were separated into three different areas and are presented below. The areas of improvements were method, process and disturbance improvements.

5.2.1 Method improvement

The main task was performed differently by different operators. The differences were small, due to the control system, but still considerable due to the short cycle time. The discussion during the workshop ended, after analysis, up as the task breakdown presented in Figure 25. An additional outcome from the HTA exercise in the workshop was to improve ergonomics by loweringtwo material racks in the work cell.

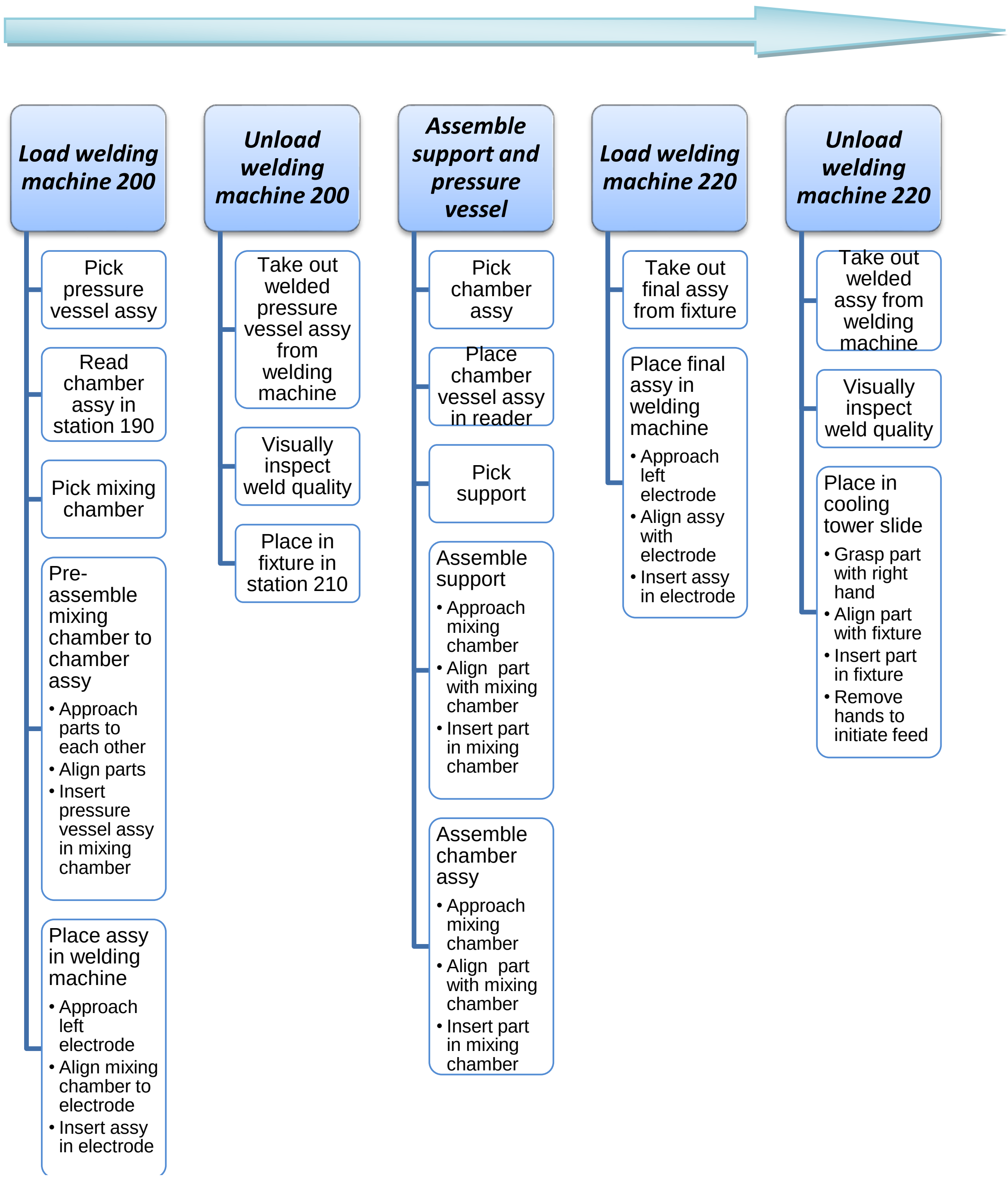

Figure 25 – Hierarchal task analysis, MAG-cell

Operator work flow

The requirements of traceability forced a certain flow with minor exceptions. The blue arrows visualize the ordinary, designed flow in the cell which entails a circular movement. The dashed arrows representswhen the operator moves from the cooling tower (230) to the assembly station 210 and prepares the parts to be assembled before the first welding machine (200) is loaded and unloaded.The circular path was found as the preferable choice for the designed work cycle. The evaluation was made based on operator opinions, work cycle analysis and process engineer expertise.

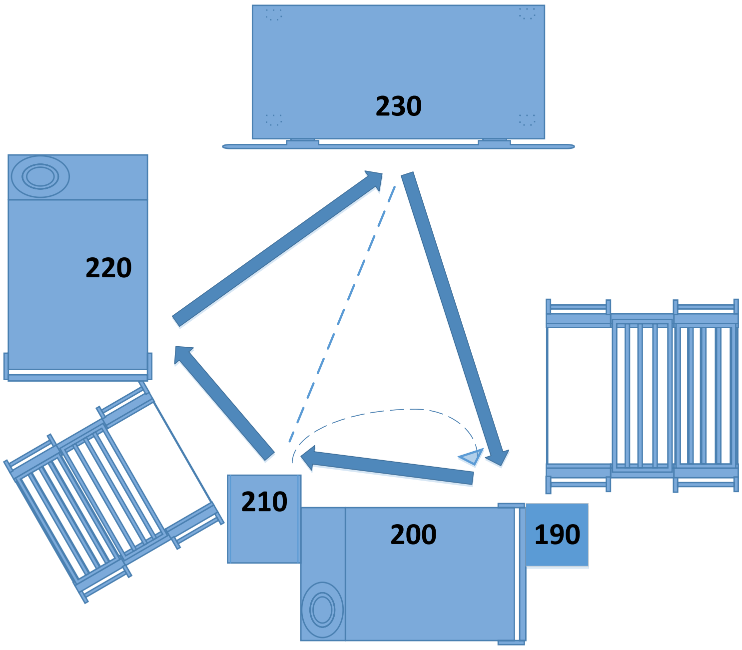

Figure 26 – Work flow in MAG-cell

Standard time
The previous system design was based on estimations of time to perform the designated task. In order to get a more relevant evaluation of the performance was standard times calculated, using the SAM-system. Complementary to this was the process times measured. All times was then summarized in Autoliv's Man Machine Schedule (AppendixD) which was used for cell design. The time for the core task ended up to be 21.5 seconds

Time and frequency study
The variation in performance brought forth the curiosity to investigate the distribution of time and activities. The study showed that only 84 % of the observed time was spent performing the core task (see Figure 27). The rest of the time was spent on cleaning of the welding equipment, material handling, waiting for the blocked cooling tower and handling errors.

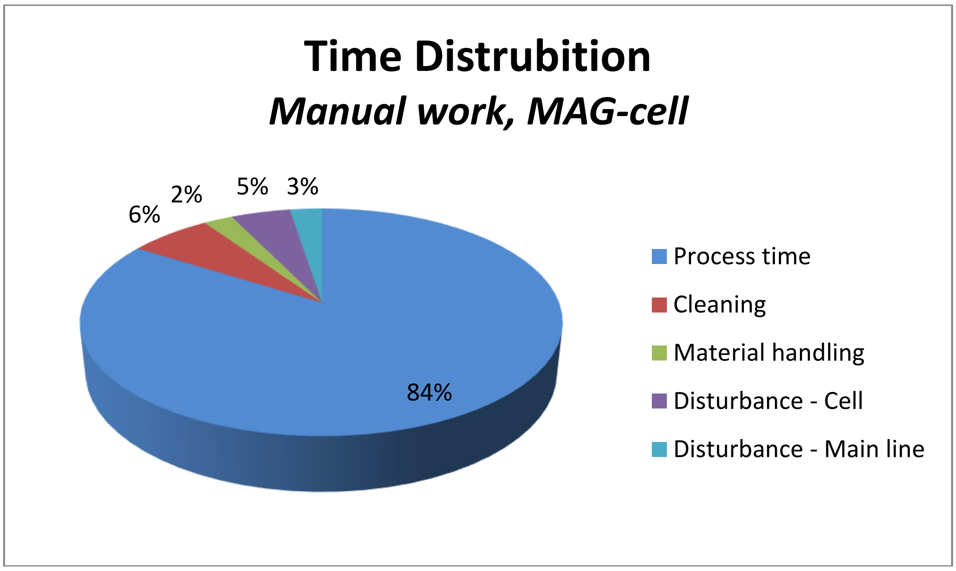

Figure 27 – Result time study MAG-cell

The investigation of occurring activities and theirfrequencyindicated that the production cell suffered significant time losses due to designed activities and disturbances. The total average time added to each cycle was calculated by measuring the time of all occurring events and dividing it with the total quantity of produced parts during the period. Optimization and prevention of activities was needed enhance the cell performance.

Table 4 – Result frequency study MAG

RESULT - Frequency study MAG				416 min (20/2-4/3)
Total produced quantity:	606			
Activity	**Occasions**	**Average**	**Average event time**	**Extra time/unit**
Cleaning	49	Every 12 pcs	29,2 s	2,4 s
Material handling	43	Every 14 pcs	11,8 s	0,8 s
Disturbance - Cell	24	Every 25 pcs	42,8 s	1,7 s
Disturbance - Line	13	Every 47 pcs	43,2 s	0,9 s
				5,8 s

Cleaning

Since cleaning was the most frequent activity was this investigated further. This task was designed to be performed by the operators by an interval of 50 units but the task was performed after an average of just 12 units.

The method and time consumption used for cleaning varied between the operators, and so did also the frequency in between. The different procedures were investigated and evaluated using practical experience in the work cell. As a part of the procedures different protective chemicals were tested. An improvement was experienced using MAG-spray on the fixtures and protective oil on the tip of the nozzle.

The cleaning could be performed either fast and frequent or accurate and more seldom. The idea was to use optimized fixed intervals for full-scale cleaning to reduce the need of extra cleaning in between, and by that save time. All small disturbances should be diminished due to their negative impact on performance. The activity could e.g. be performed after each break (three times daily). Investigations pointed out that the approach diminished the need of extra cleaning if it was done with care. The analysis was later on complemented by an interview of the maintenance personnel. Finally a standardized instruction was put together which is presented in Figure 28 below.

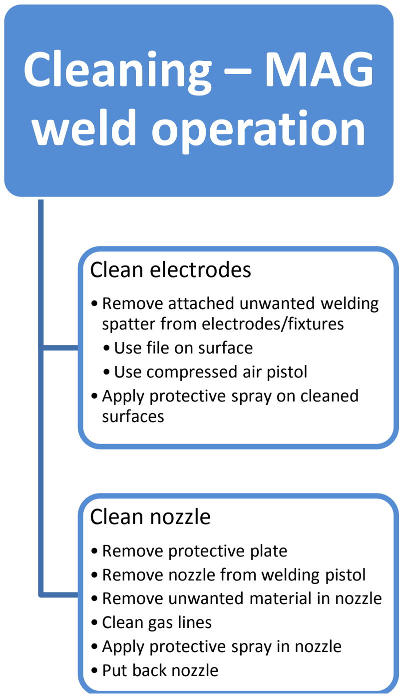

Figure 28– HTA of cleaning activity

Material handling

The second most frequent activity was the material handling which included material changes, barcode scanning, sample running etc. By changing to larger batch sizes the number of necessary switches would decrease, but it would also result in heavier boxes and require longer reaches for parts. Therefore was no resources spent on investigating this further.

A recommendation was still to install barcode scanners in the material racks. Doing this would enable automated scanning and the time consumption for the scanning activity would be eliminated. It could also help the error proofing by continuously scanning the presently used batches.

5.2.2 Process improvements

During the exploitation phase, small scale process improvements were also investigated. Several ideas were found and are presented below.

Change reading position

As seen in the HTA (seen in Figure 25) the chamber assys are read before they are loaded in the welding machines. The designated readers read the 2D laser mark which is printed on the end cup in the pre-assembly line. The SAM-time for the reading the part in station 190 in the MAG-cell adds 2.5 seconds to the work cycle which directly affects the output. An alternative solution would be to read the part when they are placed upside down, after the first weld process, in the assembly station 210 in the MAG-cell. The opportunity to read the code from above was therefore investigated by Autoliv's process engineers with purpose of moving the reading position and lowering the cycle times.

Control system

The control system in the MAG-cell was as mentioned the very strict due to the importance of traceability. The present cycle was investigated and a new developed which is visualized inFigure 29 below. This suggestion is based on a system with changed reading position and would diminish the waiting times created by the control system. The solution was developed by the thesis writers through observations and system analysis. Other potential improvements found were to install a display in the cell to provide to provide performance feedback to the operator.

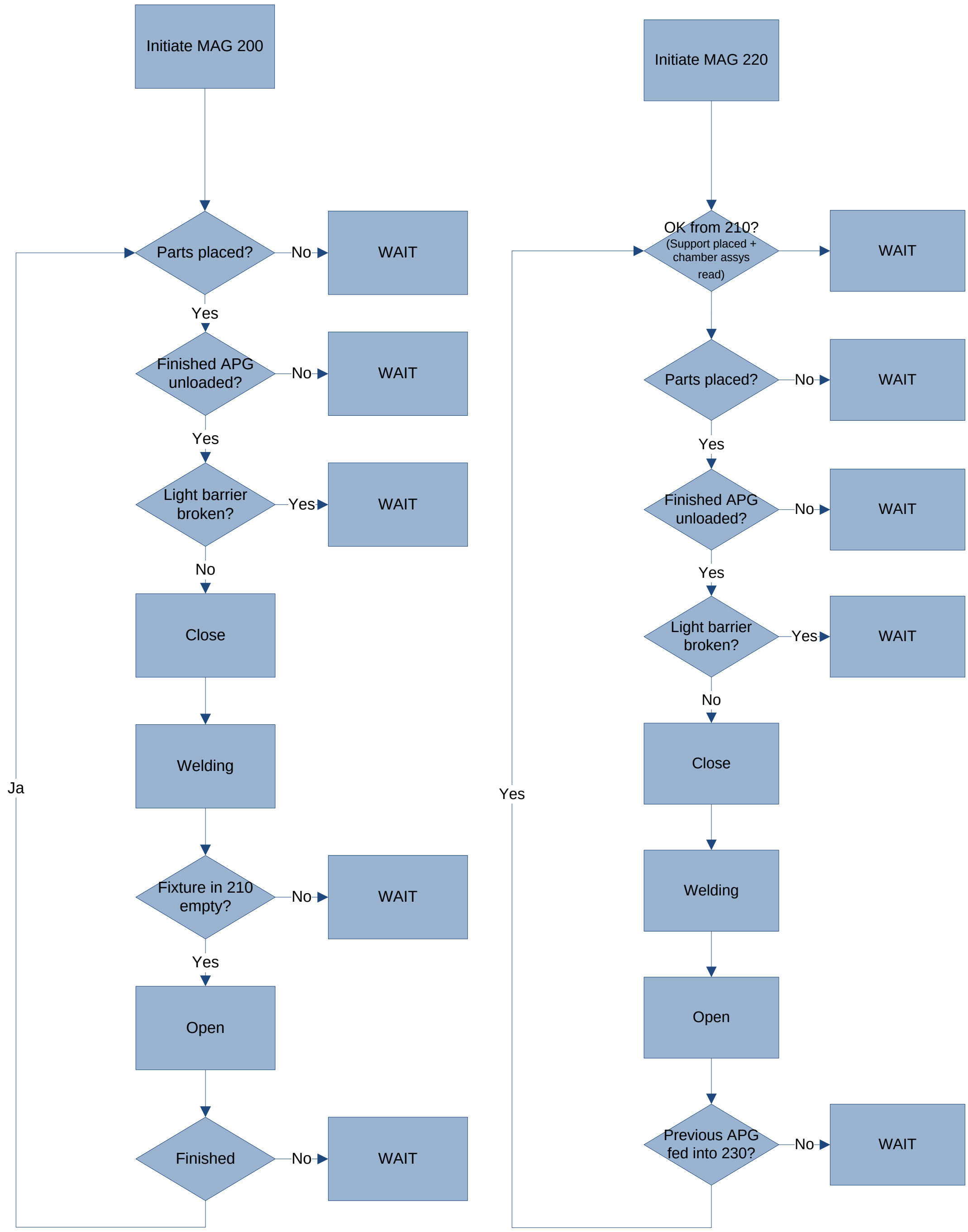

Figure 29 – Control system suggestion, MAG 200 & 220

Weld spatter
The need for the previously described cleaning is the created by the weld spatter which is produced by the process. This cases disturbances and interruptions and should therefore be diminished.

On this level a potential improvement could be to investigate different surface treatments which would prevent the spatter from adhering on the fixtures. Another would be to install closer protective shields which would prevent the spatter from reaching the fixtures. This could for example be a plate which tightly encloses the APG during the process.

Speed up processes
Complementary to the control system suggestion minor hardware investments could be beneficial in order to diminish waiting times experiences by fast operators. This could be achieved by replacing the pneumatic cylinders, which closes and opens the welding process, with new smaller ones. The result would be a faster movement with the same, desired force.

5.2.3 Disturbance handling and prevention
Several interruptions were also caused by disturbances which the system was not designed for. Observations revealed a major system loss due to micro stoppages, disturbances and deviations. In the time and frequency study these were separated into disturbance in the work cell and disturbances on the main line which blocks the work cell (Figure 27&Table 4). The result is summarized below.

Table 5 – Bottleneck disturbance

Disturbance	Probable source	Action
Part cannot be inserted to fixture	Insufficient cleaning	Improve cleaning (see 5.2.1 for recommendations)
Part stuck in fixture	Insufficient cleaning	Improve cleaning (see 5.2.1 for recommendations)
Manual grinding required on welded part	Old weld equipment	See 5.4.1 for possible solutions
Unsuccessfully feeding into cooling tower	Cooling tower	Adjust cooling tower and slide
Part skew in V-block slide to cooling tower	Human error	Assure more accurate placement of parts, rebuild slide or educate operators
Part falls out of fixture	Fixtures	Measure and examine fixtures
Out of material	System	Add alarms which signal to the final check operator that the stations soon will be out of material
Work cell blocked by main line	System	Complement alarm signals to the final check operator which enables the problem to be solved before the cell is blocked
Restore disturbance on line	Education	Educate and instruct the operators in error handling

Scrap analysis

The scrap analysis of the MAG-cell concluded that the operators were scrapping an excessive amount of products. Almost half of the scrap from the MAG-cell was due to lack of knowledge of how to solve an error related to the control system. Products were also partly scrapped due to misinterpretation of the alarm messages. The rest of the scrap derived from welding process errors.

An instruction was made that displayed different scenarios of control system errors and how to handle these errors without scrapping the product. The alarm messages were rewritten to clearly inform the operator whether the product needed to be scrapped or not. Scrap related to welding processes errors were discussed with the maintenance.

5.3 Subordination of non-bottlenecks

The semi-automatic work cell which was the system bottleneck had a direct impact on the shift result. More specifically the output was directly correlated to theoperator'spresence and contributionto the core activity in the bottleneck.In order to dedicate and distribute activities were the other manual stations analyzed by measurements, SAM and utilization. Analysis of the other manual stations occurring activities revealed that there was time available for additional tasks.

Table 6 – Occupancy of manual work cells

Station	Standard time	Estimated utilization
Pre-assembly line – Inertia	10.2 seconds (AppendixE)	~ 90 %
Unloading & final check	9.5 seconds(AppendixF)	~ 50 %

Separation and dedication of activities

A part of the optimization was to investigate the occurring tasks and dedicate the to the specific work stations. The goal was to offload and help the bottleneck where applicable. The denoted occurring activities in the bottleneck were analyzed and possibility of separation investigated. The result is presented in Table 7 where a few activities were found as potential targets of separation.

Table 7 – Additional work activities, MAG-cell

Additional work activities, MAG-cell	Designed	Separation applicable	Suitable task dedication
Open boxes of material	Yes	Yes	Kanban
Change material batch	Yes	No	
Barcode scanning of new batch	Yes	No	
Restore disturbance in cell	No	No	
Manual grinding on APG	No	Yes	Final check
Scrap handling in cell	No	No	
Scheduled cleaning	Yes	Yes	Maintenance (during breaks)

The first activity appropriate for separation was the unsealing of new material batches delivered in cartons. The boxes was loaded by the Kanban personnel into the material racks where they sometimes were left open and sometimes not. The activity was therefore to be standardized to assure that the boxes always are left with truncated paper edges and removed plastics. This time couldinstead be used for the core activity in the bottleneck.

The manual grinding activity was performed in the cell when the there was an overlap in the MAG-weld. Instead of performing this activity directly it could be moved to the final check station, after all processes have been completed on the main line. The final check operator is not constraining the flow in any way and should therefore have plenty of time to perform the adjustments.

From a performance point of view it would be beneficial to perform the previously described full-scaled cleaning out of scheduled production hours. The preferable choice would be to dedicate the task to the maintenance due to their expertise within the field. The activity could then be performed three times daily, at 08:30, 10:42 and 12:42, and the output would increase.

Additional tasks such as material filling, disturbance handling etc. should continuously be dedicated to the operator present at the final check station. Remaining time for the final check operator should be spent in the in the MAG-cell supporting the bottleneck.

Method improvement
Method analysis, using the HTA, resulted in a breakdown of the core activity. The chamber assys which are welded together in the MAG-cell are oriented by two occasions in the work cycle.

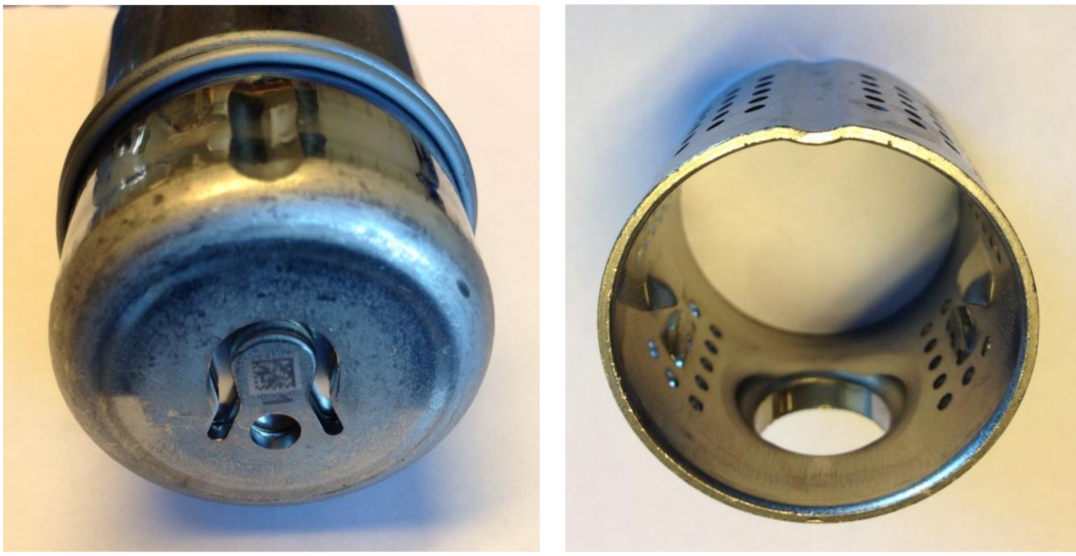

Figure 30 – Index mark on parts

The chamber assys arrived from the pre-assembly line in boxes of 48 units. The units were placed with random rotation and once the boxes were filled they were moved to the buffer before they were loaded on the material racks belonging to the MAG-cell.

The implemented change was to move the indexation part to the pre-assembly operator and by that alleviate the pressure on the bottleneck. This was done by letting the pre-assembly orient all parts before they were placed in the box. The index was to be placed towards the label side of the box. The effect of this became that the cycle time was reduced in the bottleneck by approximately one second, because the parts was already oriented and could be inserted directly in station 210. Another benefit was that the cycle time in the pre-assembly line was not increased due to that it was performed during the machine waiting times (see MMS-chart in AppendixE).

Priorities
To further provide support for the bottleneck all other resources should obey the bottleneck if the bottleneck requests support. Improvements found suitable for this situation was to instate maintenance priority for the bottleneck.

5.4 Elevation of bottleneck

With unlimited resources available the possibilities are wide. Unfortunately that is not the case in reality. The limitation of only dealing with investments on a conceptual level resulted in that less time was spent on examining investments. Several possible solutions was though collected and brainstormed and these are lined up in short below.

5.4.1 Process improvements

First of all the process investments were considered. These are summarized in Table 8 below. The presented benefits are anticipated based on own experiences and discussions with the company personnel.

Table 8 – Process improvements on elevation level

Investment	Benefits
Digital weld equipment	Less weld spatter, higher quality (no gaps/overlap), more stable
Feeders for support and mixing chamber	Parts arrived close and oriented, less material handling
Built in buffers before cooling tower	Diminished dependability towards cooling tower and main line errors
Accumulating cooling tower	Diminished dependability towards main line, possibility to optimize cooling time, products can be fed and unloaded independently
Welding robot	Replace operator in the bottleneck, increase speed and robustness

5.4.2 Human resources

The next step which was done was to evaluate the use of additional human resources. Investments with potential benefits are presented in Table 9.

Table 9 – Human resource investments

Investment	Benefits
Additional operators	Lower cycle time, more bottleneck support
Education	Higher motivation, lower cycle time, improved disturbance handling
Additional workshops	Increased operator participation, overall improvements, higher motivation
Bottleneck occupation during breaks	Prolonged shift times, higher output

6 CONCEPTUALIZATION OF FUTURE SYSTEM

The developed suggestions could then be combined into several different combinations for the future system. Complementary to the bottleneck improvement work was the additional system improvements performed. The results of these are presented in section 6.2 below.

6.1 Future state - Bottleneck

The TOC methodology resulted in several improvement opportunities which are presented in chapter 0. The limitation to only work with solutions on conceptual levels made that the potential improvements were left for Autoliv to consider further. The recommendation is however to implement all suggested change from the exploitation and subordination step, and then investigate the more expensive investments further in terms of potential, pay-off etc.

6.2 System improvements

Several supportive improvements were found and suggested. These affected both the bottleneck and the overall system performance.

Run chart

The developed run chart was designed to support the company in terms of planning and performance evaluation. The different pace-levels allowed the system to run at tact of 111-150 units per hour. The result is presented inTable 10below. For the whole run chart see AppendixG.

Table 10 – Summary of run chart

Operators	Tact time	Hourly capacity
2 *	23,9 sec	150 pcs
3	25,9 sec	139 pcs
4	32,4 sec	111 pcs

When the line is driven by two operators the idea is that one operator runs the pre-assembly line while the other is alternating between the MAG-cell and the final check station. When the buffers are filled the operator moves and helps the other at the main line until the buffers are low again.

The time required for designed activities was calculated based on interval and event times (see AppendixH). Cleaning time in MAG was based on the result from the frequency study and should be updated if anyimprovements are implemented. When the line is driven by three or four operators the utilization are low on the final check operator. By that the operator has time to handle disturbances, fill material, support the other etc.

Short stops

The prepared tic sheets were placed by each station out by the pre- and main assembly line. In order to get the operators on board a part of the APS-time was used for briefing, motivation and education of the new system during the introduction week. The logged stops were then used to direct maintenance actions, perform scrap root cause analysis and create awareness about the lost production time.The idea was to standardize error limits for when the operator should perform actions, contact maintenance and in worst cases stop the line. The interface for handling of the shorts stops is visualized in AppendixL.

From a time and effort point it would be beneficial to install a system for automated logging of stations errors and small stops. The IT department indicated that an initiated solution existed but required further resources before it was fully functional.The recommendation is still to install this system because it would enhance the system awareness and direct maintenance actions with precision.

Computer systems and shift reports

Several computer systems existed which were used partly at the company. The problem was that none were to the full extent and they could therefore not utilize its full potential. The different computer systems caused confusions between Autoliv's different departments and it was clear that they were not satisfied with the functionality. The investigation of where the different data were logged is presented in Table 11.

Table 11 – Data system collocation

DATA	FLAI	ALERT
OK quantity	X	X
Scrapped quantity	X	
Station errors	X	
Long stops		X
Short stops		
Real shift time		
Performance	X (based on system design)	X (based on contract)

The most of the functionalities seemed to exist in ALERT in some adaptation. The recommendation was therefore to log all available data in ALERT and create a new shift report in MS Excel with the desired presentation. By requesting a "global management" account in ALERT subscriptions could be created to ease the future daily evaluation.

The new shift report that was developed during this thesis work was a simplified version which evaluated the daily production against the designed capacity(see AppendixM). The shift results were, together with the short stops, visualized for the operators on a daily basis using a board close to the line. The board was dedicated to the thesis work and provided by the company personnel (see Figure 31). Complementary to the daily evaluation was some additional information presented to increase the curiosity of the operators.

Figure 31 – Visualization board

Startup sequence

The observations and investigations showed that all operators performed the sequence differently. Interview revealed that no proper training had been provided to the operators who instead had to learn from each other. Their method was analyzed in terms of flow and skill, and later complemented by interviewing the maintenance personnel. The result was a standardized work methodology and visualization of the flow.

The highest task complexity, and also the largest variations, was found in the pre-assembly line. The startup sequence also varied dependent on how the line was shutdown the day before. Therefore it was a need of standardizing both the shutdown and startup sequence in order to improve the process. Potential improvements for recommended implementation were:

- Program a shortcut in the inertia display which automatically sets the speed target to 5200 rpm and initiates the warm up sequence
- Place a dedicated end cup (painted) to eliminate the need of collecting one each morning
- Stop emptying the tables in the end of the shift to eliminate unnecessary actions each day

The standardized methodswere collocated and structured to later be transformed to Autoliv work instructions. Things to have in mind when the activity was designed were:

- The inertia weld needs to be started before the laser weld equipment due to shared cooling
- The line equipment needs to be started before the leak tester due to air pressure
- The warm up sequence for inertia takes approximately 5.5 min
- The initiation of the leak-tester takes approximately 2.5 min

With the presented circumstances taken into consideration was the sequence optimized and designed.The result is presented below.

Table 12 – Startup and shutdown sequence, Pre-assembly line

Standardized sequence – Pre-assembly line

1. Startup

1.1 Initiate warm up sequence – Inertia weld
1.2 Activate air condition
1.3 Initiate line equipment
1.4 Turn on illumination for C-table
1.5 Activate leak tester
1.6 Turn on illumination for station C3
1.7 Turn on protective gas
1.8 Initiate A-table
1.9 Initiate B-table
1.10 Initiate laser welding equipment
1.11 Reset resistance welding equipment (B3)
1.12 Reset resistance welding equipment (A5)
1.13 Run sample
1.14 Start of production

2. Shutdown

2.1 Empty tables (if needed)
2.2 Terminate inertia on display
2.3 Turn off illumination for station C3
2.4 Turn off protective gas
2.5 Terminate laser weld equipment
2.6 Terminate line equipment
2.7 Turn off illumination for C-table
2.8 Turn off air condition

Table 13 – Startup and shutdown sequence, Main assembly line

Standardized sequence – Main assembly line

1. Startup

1.1 Turn on illumination
1.2 Turn on protective gas
1.3 Run sample
1.4 Start of production

2. Shutdown

2.1 Turn off protective gas
2.2 Turn off illumination

7 EVALUATION OF MEASURES

The suitability of a flow measurement is dependent on the production level. It is determined by different factors such as production continuity, automatic or manual work, and buffers. This chapter shows how the connection of production flow measures to the three production levels was conducted. The evaluation work is thoroughly described and real numbers are put into practice at Autoliv. Results from calculating the equations of the flow measures are presented.The evaluation is summarized in Table 1414 and is analyzed for each level.

Table 14 – Flow measure evaluation

System level	Line level	Cell level	Type of measurement
OEEML	OLE and Process OEE		Effectiveness
TPU, Line Efficiency		MAE	Efficiency
		Productivity	Effectiveness & efficiency

7.1 Third flow level: Cell flow

There are some disadvantages to using OEE as a cell flow measurement since it only determines the efficiency of semiautomatic or automatic production systems.

MAE is used to determine the efficiency of manual or semiautomatic production systems. Variation of maximal pace as well as the different number of operators is considered in the MAE. Figure 32 shows the fields of application of OEE and MAE. (Bellgran, M., Säfsten,K. 2010)

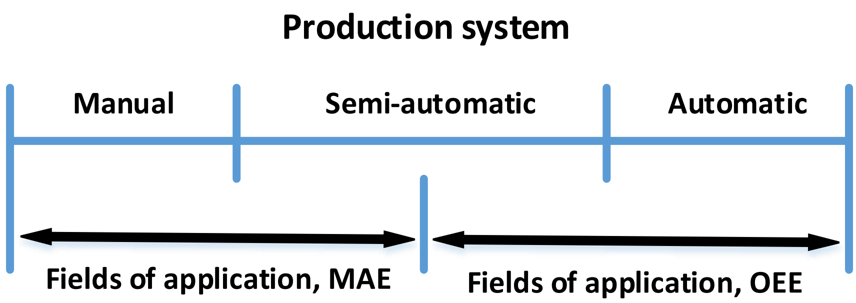

Figure 32 – Fields of application, OEE & MAE

Another disadvantage of OEE is that it does not include any method-dependent factors. A measurement that would be more suitable for cell flow in terms of method is MPU. OEE is related to the MPU as follows:

$$M * OEE = M * P * U * Q$$ Equation 17

(Almström, P., 2012)

The MAG-cell consists of manual and semi-automatic stations that make MAE a more suitable cell flow measurement than OEE. MAE measures not only the output of the MAG-cell but also the work in the cell. MPU is also a suitable cell flow measurement as it considers the manual work methods which are important components in the MAG-cell.

7.2 Second flow level: Line flow

OEE is an index used to evaluate the performance of an individual machine. However, it cannot be used when the machine is part of a continuous production line. A continuous production line consists of a sequence of machines that are dependent on one another; the operational time of the first machine is the available time of the second and so on. The performance of one individual machine is thus affected by the performance of all of the other machines. (Nachiappan & Anantharam 2005)

When evaluating the overall performance of the continuous production line, one cannot simply multiply the OEE values of the individual machines together. If the overall line effectiveness were to be calculated as the product of the availability, performance and quality of the individual machines, the dependency between the machines would not be considered. It is therefore necessary to use a method that looks at the overall line effectiveness, rather than concentrating on the effectiveness of an individual machine. (Nachiappan & Anantharam 2005)

In the case of the G1 line, where stations still can be processing even though one of them is down and where conveyors between the stations can accumulate minor buffers, a more appropriate measure than OEE has to be applied.

One proposed measurement for evaluating the performance of the entire line is overall line effectiveness, OLE. It takes into account the dependencies between the stations in a continuous line. No distinction is made between the performance and quality as it is assumed that a defective product from a machine will not be transferred to the next.(Braglia 2007)

Another measurement is the process OEE that is based on the assumption that the performance P and availability A of a production line can be calculated from the P and A of the bottleneck. The quality Q only includes defective products from processes downstream from the bottleneck. The process OEE assumes that defects ahead of the bottleneck in the production line do not have any impact on the output of the line unless they hinder the bottleneck from operating. To facilitate the counting of Q, the process OEE proposes that the latter defects are left out.(Braglia 2007)

Both OLE and process OEE are suitable line flow measurements for the main line i.e. a continuous line without disconnections. The difference between them is that the process OEE has a stronger focus on the bottleneck and the OLE on the output of the last station.

7.3 First flow level: System flow

A downside with OLE and OEE is that they are not applicable for production lines with buffers between machines. They are calculated with the assumption that a machine’s availability is directly impacted by the performance of the preceding machine. The process OEE and OLE-value would then not be representative of the real overall line, since a machine immediately after a buffer can still be operating even when the previous machine is down (Nachiappan & Anantharam 2005). OEEML has one major benefit compared to other methods, concerning production lines where buffers are linking the machines. OEEML does not undervalue the actual efficiency of those systems (Braglia 2007).

The G1 line has one buffer between continuous lines. OEEML is thus suitable as a system level flow measurement since it takes into account the disconnection between machines i.e. buffer. An alternative measure is the line efficiency which considers operator attendance. TPU is another measure that is focused on all labor minutes to output which makes it an alternative system flow measurement. Since the operators are rotating between the stations, the line efficiency and TPU are not applicable on lower levels.

7.4 Evaluation at Autoliv

The flow measures were evaluated on the G1 line in accordance to the appropriate flow levels. This chapter describes the method of the evaluation and which modifications were required. It also explains how the data was collected and implemented in the measures. A table of the pertinent parameters compares the measures to each other.

Table 15 – Parameter definition and collection

Parameters	Definition and data collection
Operative time	Loading time minus failures, set and adjustment
Output last station	The amount of units produced by the G1 line during the time of data collection. The output was collected from the in-house data collection system
Output bottleneck	The amount of units produced by the MAG-cell during the operative time. The output was collected from the in-house data collection system
Station value time last station	Net operating time for the last station, 90 %. Equals the average of short stops subtracted from operating time.
Designed bottleneck cycle time	The expected cycle time of the MAG-cell. The designed bottleneck cycle time was determined through interviews
Measured bottleneck cycle time	The average cycle time of the MAG-cell. The cycle time was measured with a stop watch
SAM bottleneck cycle time	The theoretically suitable cycle time of the MAG-cell. The SAM cycle time was obtained by relating distances and task complexity to standard times
Scrap bottleneck	The number of products that were scrapped by the MAG-cell
Scrap downstream from bottleneck	The number of products that were scrapped by stations downstream from the MAG-cell
Designed cycle time last machine	The expected cycle time of the last station. The designed cycle time last machine was collected through interview
Availability bottleneck	Process Time + Cleaning + Material Handling of bottleneck
Performance bottleneck	Designed bottleneck cycle time / The number of units produced during the time of measurement
Defects downstream bottleneck	On average 15 a day or 2.6 % of the output from the last machines

In Table 16, the parameters of flow measures for the G1 line are compared. As can be seen, TPU and the line efficiency use the same parameters and should thus not be of any difference. The availability, performance and utilization are indirectly affected by the amount of operating time but are mentioned separately since the MAG-cell is able to produce even though the rest of the main line is temporarily not functioning.

Table 16 – Alignment of parameters to flow measurements

Parameters	OEEML	TPU	LE	PROCESS OEE	OLE	MPU	MAE
Operating time	■	■	■	■	■	■	■
Output last station	■	■	■		■		
Output bottleneck				■		■	■
Station value	■				■		■

time last station							
Designed cycle time bottleneck							
SAM-time cycle time bottleneck							
Measured cycle time bottleneck							
Designed cycle time last machine							
Availability bottleneck							
Performance bottleneck							
Defects in bottleneck							
Defects downstream bottleneck							
Utilization bottleneck							

Due to the continuity of the G1 line, all station operating times where consider equal. The operating time was only calculated with regards to work rotations that occurred each 30 minutes. Line loading time was defined as loading time (calendar time minus planned production stop). The availability and performance of the bottleneck was determined from time studies. Station value time of the last station was calculated based on the reduction of the average percentage of short stops on the main line. The defects downstream from the bottleneck were calculated on data from a 15-day period.

7.5 Results of measure evaluation

The results from the flow measure evaluation are presented in the following two tables. Table 17 presents the parameter values for each parameter and occasion. Table 18 presents the results from calculating the equations of the flow measures.

Parameter values

Table 17 shows the result from the data collection and calculated values from the three occasions. During the first and third occasions the time study did not account for planned production stops and long stops, instead only referring to the net operating time.

The average number of scrapped units downstream of the bottleneck during those days was 15 units. The average output of the G1 line was 570 which signified that the scrap downstream from the bottleneck could be calculated as 2.6 % of the output of the last station. The average stoppage of the main line during 20 days (10 %) was considered when calculating the last station value time.The utilization of the bottleneck was calculated as operating time through loading time.

Table 17 – Calculated parameter values of the G1 line

Parameter	2014-01-21	2014-02-28	2014-05-05 PPR
Planned production stop (min)	0	36	0
Long stop (min)	0	42	0
Operating time (min)	102	173	161
Output last station (units)	210	220	319
Output bottleneck (units)	204	213	309
Station value time last station	93.84	159.16	148.12
Designed cycle time bottleneck (sec)	26	26	26
SAM-time cycle time bottleneck (sec)	21,50	21,50	19
Measured cycle time bottleneck (sec)	27.20	27.20	18.40
Designed cycle time last machine (sec)	13	13	13
Availability bottleneck (ratio)	0.92	0.92	0.87
Performance bottleneck (ratio)	0.92	0,57	0.88
Defects downstream bottleneck (units)	6	7	10
Utilization bottleneck (ratio)	0.97	0.97	0.97

Flow measure values

The values of the parameters were implemented in each flow measure equations. The outcome is shown in table 18. It should be pointed out that the third occasion during the PPR is an indication of the improvement potential of the line when working at its highest pace.

Table 18 – Calculated flow measures of the G1 line

Production level	Flow measures	2014-02-21	2014-02-28	2014-05-05 PPR
System	OEEML	149%	120%	132%
System	Line Efficiency	97%	97%	97%
System	TPU	89%	55%	86%
Line	OLE	89%	38%	86%
Line	Process OEE	82%	51%	75%
Cell	MPU	63%	63%	73%
Cell	MAE	85%	50%	75%

8 DISCUSSION

The lack of sufficient information flow between the different departments and workers was obvious. This was both expressed in interviews and realized in the system analysis. By improving the communication it would probably contribute to enhanced motivation, spread knowledge, bring forth improvements suggestions and also diminish the suffered losses due to imprecise information. A clear example was the production planning where interviews revealed that everyone kept track of their own planned stops, but no one seemed to be aware of the whole situation. This was something that should have been visualized on the company's CPC-board but was not handled satisfactory.

One way of improving the communication would be to hold additional workshops and educations. This would spread on the company expertise and facilitate further collaboration between e.g. operators, maintenance and the process engineers. Almost every operator expressed a positive attitude towards further developed understanding. This was for example stated by one of the operator as "knowledge is never heavy to carry".

The unsatisfactory data logging and handling of computer system caused confusion and annoyance at the company. The issue aroused from when the company was more or less forced to leave the useful old system in favor of ALERT. As mentioned, did a lot of the functionalities exist in ALERT but was not used due to ignorance. Education and standardization of the system use would most likely be beneficial in the long run. Increased understanding would also probably increase the motivation to use the system properly which then would enhance the trustworthiness of the logged data (e.g. the long stops).

One of the largest challenges during the improvement work has been to deal with the large variation in operator performance, which had a direct impact on the performance. The issues aroused when the potential of different improvements was to be evaluated. Was the improvement a result of the change or was it just a difference in operator skill or effort? The goal has been to standardize and provide the bottleneck workers with as much support as possible in order to reduce the variability. Another possible improvement would be to provide real time feedback about the operator performance. This could preferably be done using the previously mentioned display for visualization of the current cycle times in the manual MAG-cell. The shift performance had been low for quite a while which had created some kind of accepted everyday performance.

Another influence which was hard to measure and quantify was the effect of disturbances. Except the different performance efforts was the main reason behind the prolonged cycle times most likely all occurring small events that disturbed the bottleneck work cycle. These were caused by process disturbances, human errors, computer notifications, batch changes, scanning etc. Except from the time loss that the event caused they put the operator out of rhythm which affected a few of the upcoming cycles. A future recommendation is to diminish these small events to create more harmony and stability in the manual work cycles.

The component CT_{BN}/CT_{LM} of the OEEML during the first two occasions was 1.65 and 1.46, so the cycle time of the last station was 1.65, and 1.46 times faster than the constraining station (see table 16). This means that it should have been enough for the last station to be working 60 % (1/1.65) of the available time during the first two occasions and 64 % (1/1.46) during the third. However, the ratio SVT_{LM}/ LT shows that the machine value time was working 90 % of the available time during the first and third occasion and 72 % during the second (due to longer stops included during the second occasion). The last station was thus working with an inefficiency of 30% and redundant time during the first occasion, 12 % during the second and 26 % during the third. The OEEML thus gives a valuable recommendation of directing approximately 23 % of the workforce to assist the MAG-cell based on these three occasions (see equation 6).OEEML seeks to be 100% which occur when the cycle time of the bottleneck is the same as the cycle time of the last machine, assuming that SVT_{LM}/ LT is 100 %. OEEML can therefore be a bit contradictive as a higher percentage does not correspond to a better flow.

The line efficiency is only referring to the inefficiency of working rotations between operators and is consistent during the three occasions i.e. 97 %. The utilization of the operators was very high. Line efficiency shows that the operators are almost fully occupied but does not reveal indications how to rebalance the workforce. Line efficiency is affected by the attendance of operators and does not provide much information about the flow efficiency.

The TPU differs between the occasions due to the different output. The lowest value is found during the second occasion.The TPU only determines the performance of the work force but does not point out where to improve and is therefore quite a weak measure for determining flow.

The OLE is impacted by the ratio output to operating time just like the TPU. Since the first machine of the main line is considered to have the same operating time as the last station in this case (the operator in the MAG-cell and the operator in the last station are equally occupied), the OLE is not affected by that difference. The OLE is similar to the TPU even though they are applied on different system levels of the G1 line.OLE is focused on the operating time of the last machine in a continuous line as well as on a couple of summed up values of the line availability, line performance and quality. It does not specify where to improve the flow as opposed to the process OEE that focuses on how to elevate the bottleneck.

The process OEE which focuses on the pace of the bottleneck station, bottleneck availability and performance, (subtracting only defective products downstream from the bottleneck) appears to be representing the line flow well. However, the process OEE would, in the case of the G1 line, have given the same results even if applied on a system level. It shows the efficiency of the bottleneck and adds waste time due to defective products after the bottleneck. Since the process OEE is referring to the bottleneck it is easy to see the improvement potential of the line (of which the outcome is restricted by the bottleneck). In order for the process OEE to indicate the bottleneck potential, it is important to assure that not too many defective products have been affecting the value and that the measurements and stoppages did not influence the value. It is recommended to conduct measurements on at least five separate occasions. Process OEE determines the flow from a constraining process point of view and indicates how to elevate the overall flow of a production system.

The productivity was increased during the third occasion as the performance went up during the PPR. Three components indicate that the method has between 17-27 % improvement-potential and that the performance could be increased by 20 % referring to the SAM-time. The utilization however is close to perfect. To measure productivity in terms of method and performance on the G1 line targets deficiencies of the MAG-cell indirectly in an approach for improving the line flow. The productivity measure indicates on method improvements and is therefore suitable especially for improving the flow at manual stations.

The MAE does just provide a value that compares output from the bottleneck to the operating time. The waste of time due to defective products in the MAG-cell is negligible. Hence it is not possible to propose any concrete improvement proposals through MAE.MAE considers multiple operators working at one manual station and is therefore appropriate in those cases.

The flow analyses with corresponding improvement actions were performed methodologically through the project. The lack of theoretical equivalent in multiple level flows implied that no relevant comparison to previous studies could be performed. Therefore were results from the three occasions analyzed independently while waiting for additional case studies.

9 CONCLUSION

During the studies of the production line G1 it was concluded that the G1 line constituted a complex multi level production system that required a lot of coordinated support functions to be fully functional. It was found that the different flow levels had to collaborate in order to contribute to the overall system performance.

The studies showed that conflicts between the in-house data systems of the line caused a lot of problems as they impacted the visualization of reliable data. The studies also showed that short stops of the G1 line often make up longer accumulative downtime than long stops, and have a tendency to interrupt work flow which clearly affects the performance.

It is recommended to use visualize line performance data since it creates incentives for greater employee performance. In-house data conflicts must be adjusted to visualize reliable data. Robustness of the G1 line is enhanced by standardizing and supporting the bottleneck. Standardization will also, together with workshops, create a common understanding and will also be beneficial for educational purposes. Communication on a more frequent basis between employees working on the G1 line will have the effect to align employee effort and bring up further improvement possibilities. Furthermore, it is recommended to reintroduce the short stop data collection. An automated system for collecting stops would be preferable as it provides more accurate data no matter short or long stops.

Based on the three studies, OEEML is a suitable flow measurement for the G1 line. OEEML can be useful for the G1 line as it could balance the work force of the operators and determine whether the last station operator can offload work from the bottleneck.

Process OEE is suitable as a flow measure for both system and line level of the G1 line. It shows how to augment the system performance through bottleneck improvements. In production systems like the G1 line, where the process OEE is applicable on system level, it is to prefer to the OEEML since it gives indication of availability and performance improvements of the bottleneck which is more useful than the OEEML that only considers cycle time in terms of bottleneck.

The productivity measurement (method times performance times utilization) is preferred from a cell level point of view includes as the method related parameter facilitates the identification of improvement areas.

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11 APPENDIX

A. VBA script – Station error adjustments

```
Sub Justera_stn_nr_och_summera_fel_2014()
Sheets("Jan+Feb-2014").Select
   Dim station(1 To 20) As Integer

   station(1) = 200
   station(2) = 220
   station(3) = 235
   station(4) = 237
   station(5) = 240
   station(6) = 250
   station(7) = 251
   station(8) = 260
   station(9) = 265
   station(10) = 270
   station(11) = 280
   station(12) = 290
   station(13) = 300
   station(14) = 310
   station(15) = 320
   station(16) = 330
   station(17) = 331
   station(18) = 340
   station(19) = 350
   station(20) = 360
Range("C2:C21").Value = 0                    'Nollställ tabellen

For t = 29 To Cells(Rows.Count, "C").End(xlUp).Row          'Sök igenom tabellen

      For s = 1 To 20
         If station(s) = Cells(t, "C") And Cells(t, "D") = 11022 Then   'Rätt plats hittad i vektorn + stationsbyte nödvändigt?
            station_number = station(s - 1)
         ElseIf station(s) = Cells(t, "C") And Cells(t, "D") <> 11022 Then 'Rätt plats hittad i vektorn + stationsnummer korrekt?
            station_number = station(s)
         End If
Next s
      For rad = 2 To 21       'Lägg till felet i rätt rad i sammanställningstabellen
If Cells(rad, "B") = station_number Then
            Cells(rad, "C") = Cells(rad, "C") + Cells(t, "F")
         End If
      Next rad
'         End If
   Next t
End Sub
```

B. HTA – Work cycle MAG-cell

1. Load welding machine 200

- 1.1 Pick chamber assy
  - 1.1.1 Locate part
  - 1.1.2 Approach part
  - 1.1.3 Grasp part with right hand
- 1.2 Read 2D-code on chamber assy
  - 1.2.1 Approach fixture in 190
  - 1.2.2 Align to fixture
  - 1.2.3 Insert in fixture
- 1.3 Pick mixing chamber
  - 1.3.1 Locate part
  - 1.3.2 Approach part
  - 1.3.3 Grasp part with left hand
- 1.4 Pre-assemble mixing chamber to chamber assy
  - 1.4.1 Extract chamber assy from fixture in 190
  - 1.4.2 Approach parts to each other
  - 1.4.3 Align parts
  - 1.4.4 Insert chamber assy in mixing chamber
- 1.5 Place assy in welding machine
  - 1.5.1 Approach left electrode
  - 1.5.2 Align mixing chamber to electrode
  - 1.5.3 Insert assy in electrode

2. Unload welding machine 200

- 2.1 Take out welded chamber assy from welding machine
  - 2.1.1 Approach part
  - 2.1.2 Grasp part with left hand
  - 2.1.3 Extract part from electrode
  - 2.1.4 Remove hands to initiate process
- 2.2 Visually inspect weld quality
  - 2.2.1 Look at part
  - 2.2.2 Rotate part
  - 2.2.3 Assess weld
- 2.3 Place in fixture in station 210
  - 2.3.1 Grasp part with right hand
  - 2.3.2 Approach fixture
  - 2.3.3 Align part with fixture
  - 2.3.4 Insert part in fixture

3. Assemble support and pressure vessel

- 3.1 Pick chamber assy
  - 3.1.1 Locate part
  - 3.1.2 Approach part
  - 3.1.3 Grasp part with left hand

3.2 Read 2D-code on chamber assy
3.2.1 Approach fixture in 210
3.2.2 Align to fixture
3.2.3 Insert in fixture
3.3 Pick support
3.3.1 Locate part
3.3.2 Approach part
3.3.3 Orient part for correct grip
3.3.4 Grasp part with right hand
3.4 Assemble support
3.4.1 Approach mixing chamber
3.4.2 Align part with mixing chamber
3.4.3 Insert part in mixing chamber
3.5 Assemble chamber assy
3.5.1 Extract chamber assy from fixture in 210
3.5.2 Approach mixing chamber
3.5.3 Align part with mixing chamber
3.5.4 Insert part in mixing chamber

4. Load welding machine 220
4.1 Take out final assy from fixture
4.1.1 Approach part
4.1.2 Grasp part with right hand
4.1.3 Extract part
4.2 Place final assy in welding machine
4.2.1 Approach left electrode
4.2.2 Align assy with electrode
4.2.3 Insert assy in electrode

5. Unload welding machine 220
5.1 Take out welded assy from welding machine
5.1.1 Approach assy
5.1.2 Grasp part with left hand
5.1.3 Extract part from electrode
5.1.4 Remove hands to initiate process
5.2 Visually inspect weld quality
5.2.1 Look at part
5.2.2 Rotate part
5.2.3 Assess weld
5.3 Place in cooling tower slide
5.3.1 Approach slide
5.3.2 Align part with slide
5.3.3 Insert part in slide
5.3.4 Remove hands to initiate feed
5.4 Return to first station

C. HTA – Cleaning in MAG-cell

1. Clean electrodes

- 1.1 Remove attached unwanted welding spatter from electrodes/fixtures
  - 1.1.1 Use file on surface
  - 1.1.2 Use compressed air pistol
- 1.2 Apply protective spray on cleaned surfaces

2. Clean nozzle

- 2.1 Remove protective plate
- 2.2 Remove nozzle from welding pistol
- 2.3 Remove unwanted material in nozzle
- 2.4 Clean gas lines
- 2.5 Apply protective spray in nozzle
- 2.6 Put back nozzle

D. Man Machine Schedule – MAG-cell

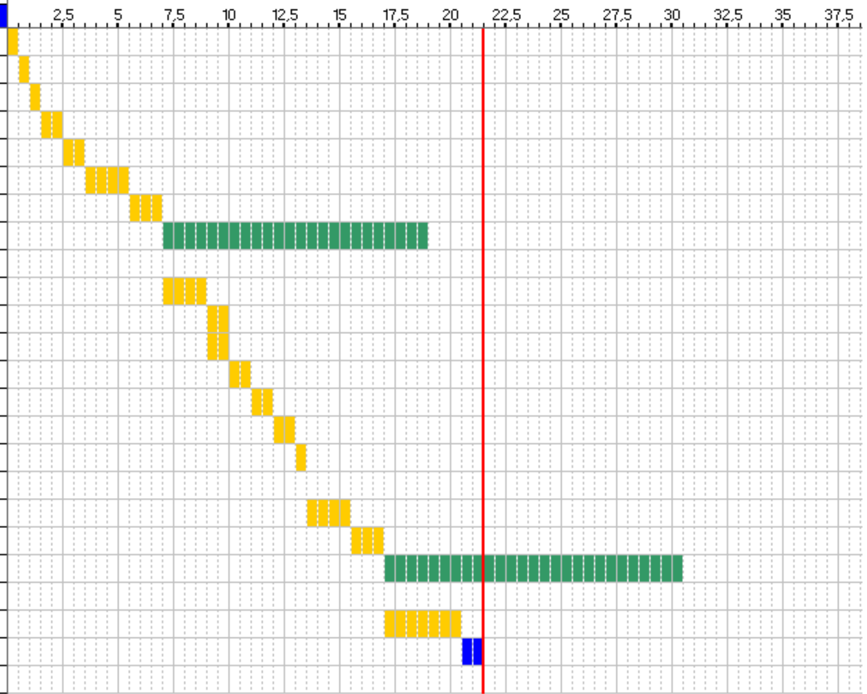
Process:

MAG-cell G1 line (APG)

Insert Row | Delete Row

1 cell = 0,5 sec Max = 115 sec Product: APG-1 Shift Working Time:
Change resolution-> No. of Operator(s): 1 Takt Time: 21,5 Mark Takt Time

Start Time	Work Seq Number	Operation	Time: Manual	Time: Auto	Time: Walk
0,0	190	Ta pressure vessel assy från låda (GS45)	0,7		
	190	Placera pressure vessel assy i läsfixtur (PD45)	0,7		
	190	Ta pressure vessel assy från läsfixtur (GS10)	0,4		
	190	Ta mixing chamber från låda (GS45)	0,7		
	200	Förmontera pressure vessel assy och mixing chamber (PP45)	1,3		
	200	Placera delmontage i vänstra elektroden (PP80+AF)	2,0		
	200	Ta bort färdigsvetsad komponent och gå ur ljusridå (GS80+1xS)	0,9		0,5
	200	Svetsning		12,1	
7,1	210	Kontrollera svetskvalitet och placera svetsad komponent i fixtur (SA2+RD+PP80)	2,3		
	210	Plocka support ur låda (GS80)	0,9		
9,5	210	Plocka pressure vessel assy ur låda (GS80)	0,9		
	210	Placera pressure vessel assy i läsfixtur (PD45)	0,7		
	210	Montera support i delmontage (PP45)	1,3		
	210	Montera pressure vessel assy i delmontage (PP10)	0,9		
	210	Ta bort slutmontage från fixtur (GS10)	0,4		
13,6	220	Placera slutmontage i vänstra elektroden (2xS+PP45+AF)	1,8		0,5
	220	Plocka ut färdig detalj i stn 220 och gå ur ljusridå (GS80+2xS)	0,9		0,5
	220	Svetsning		13,6	
17,3	230	Kontrollera svetskvalitet och placera gasgenerator i V-block i kyltorn (SA2+RD+PP45+2xS)	2,1		1,1
	230	Gå ur ljusridå och gå till stn 190 (2xS)			1,1
		Total:	19	26	4



E. Man Machine Schedule – Inertia work cell

Process:

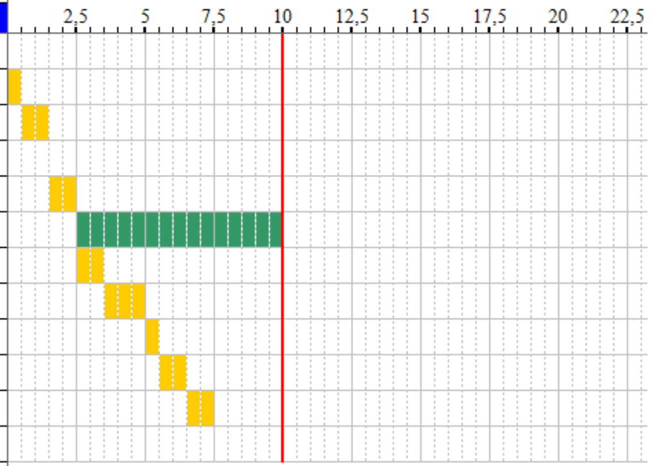
Inertia-cell G1 line (APG)

Insert Row | Delete Row

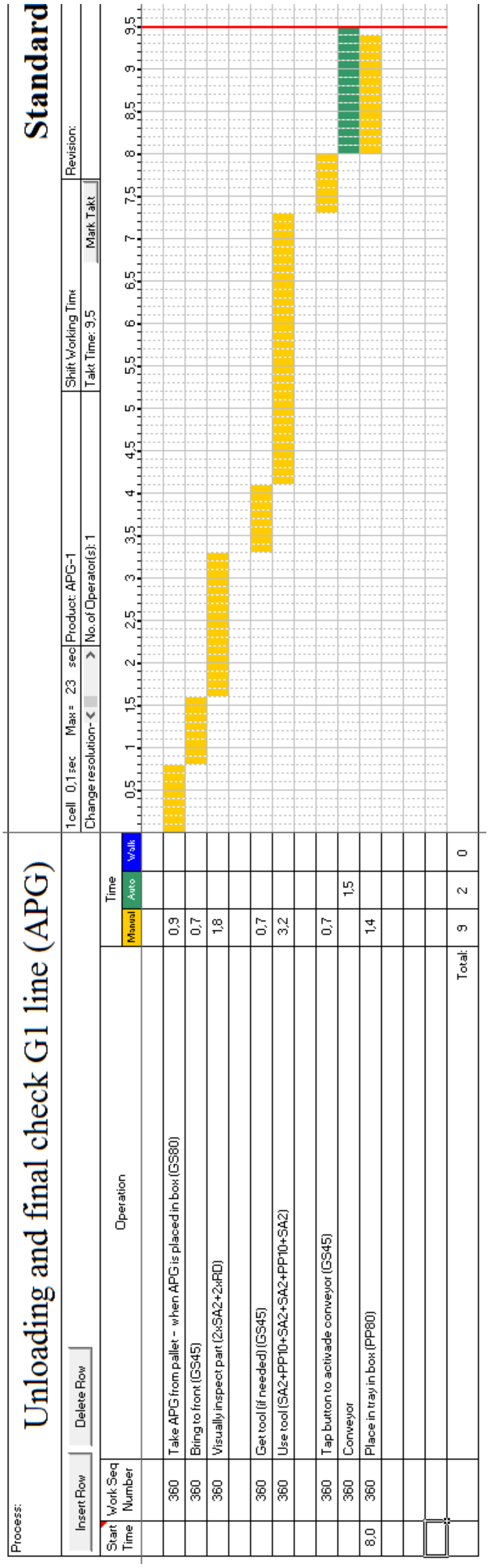
1 cell = 0,5 sec   Max = 115 sec   Product: APG-1

Change resolution->   No.of Operator(s): 1

Start Time	Work Seq Number	Operation	Time Manual	Time Auto	Time Walk
		(Assumes that machine already contains a finished pressure vessel assy)			
0,0	D1	Place pressure vessel in machine (PD80)	0,9		
	D1	Remove pressure vessel assy from machine (GS45)	0,7		
	D1	Place end cup assy in machine (PD10)	0,4		
	D1	Tap button to activade machine (GS45)	0,7		
2,7	D1	Welding		7,5	
2,7		Find indexation and rotate part (SA2+RD)	0,9		
	D1	Place welded pressure vessel assy in batch box with indexation towards label side (PP80)	1,4		
	D1	Take mixing chamber from basket (GS80)	0,9		
	D1	Take end cup assy from C3 (GS80)	0,9		
	D1	Visually inspect parts (SA2+RD)	0,9		
		Total:	8	8	0



F. Man Machine schedule – Final check station



G. Run chart

RUN CHART - FOUR OPERATORS — Production line G1, Product: APG-1

Manual work cell	Operators	Standard time	Support activities*	Allowances	Designed time	Distribution of time: Operation	Distribution of time: External activities**	Pace	Balancing loss	Hourly capacity	Levelled tact
Inertia	1	10,4 s	1 s	5%	12,0 s	100%	0%	23,9 s	0,0 s	301 pcs	150 pcs
MAG 1	1	15 s	1,6 s	5%	17,4 s	100%	0%	17,4 s	6,5 s	207 pcs	
MAG 2	1	16,5 s	1,6 s	5%	19,0 s	100%	0%	19,0 s	4,9 s	189 pcs	
Final check	1	9,5 s	1,2 s	5%	11,2 s	50%	50%	22,5 s	1,5 s	160 pcs	

RUN CHART - THREE OPERATORS — Production line G1, Product: APG-1

Manual work cell	Operators	Standard time	Support activities*	Allowances	Designed time	Distribution of time: Operation	Distribution of time: External activities**	Pace	Balancing loss	Hourly capacity	Levelled tact
Inertia	1	10,4 s	1 s	5%	12,0 s	100%	0%	23,9 s	2,0 s	301 pcs	139 pcs
MAG	1	21,5 s	3,2 s	5%	25,9 s	100%	0%	25,9 s	0,0 s	139 pcs	
Final check	1	9,5 s	1,2 s	5%	11,2 s	50%	50%	22,5 s	3,5 s	160 pcs	

RUN CHART - TWO OPERATORS*** — Production line G1, Product: APG-1

Manual work cell	Operators	Standard time	Support activities*	Allowances	Designed time	Distribution of time: Operation	Distribution of time: External activities**	Pace	Balancing loss	Hourly capacity	Levelled tact
Inertia	0,8	10,4 s	1 s	5%	12,0 s	100%	0%	29,9 s	2,5 s	241 pcs	111 pcs
MAG	0,8	21,5 s	3,2 s	5%	25,9 s	100%	0%	32,4 s	0,0 s	111 pcs	
Final check	0,4	9,5 s	1,2 s	5%	11,2 s	100%	0%	28,1 s	4,3 s	128 pcs	

* Designed (change batch, switch box, scanning, cleaning, adjustments, material filling line etc.). Cleaning in MAG-is based on the result from the frequency study and should be updated if any improvements are implemented

** Time avaliable for other activities (SQUIB-rack filling etc.)

*** One operators runs the pre-assembly line while the other are alternating between the MAG-cell and the final check station. When the buffers are filled the operator moves and helps the other at the main line until the buffers are low again.

H. Support activities – Run chart

Support activities - INERTIA

Activity	Station	Interval	Event time	Time/unit
Cleaning Bigfoot (A2/A3)	A2/A3	Every 300 pcs	60 s	0,20 s
Cleaning Lens (A2)	A2	Every 1550 pcs	60 s	0,04 s
Material handling - New box chamber assy	D1	Every 48 pcs	15 s	0,31 s
Material handling - New batch pressure vessel	D1	Every 224 pcs	30 s	0,13 s
Material handling - New batch C3	C3	Every 180 pcs	15 s	0,08 s
Material filling - Burst disc and membrane	A1/B1	Every 500 pcs	240 s	0,48 s
			Total:	**1,2 s**

Support activities - MAG

Activity	Station	Interval	Event time	Time/unit
Cleaning weld 1	200	Every 50 pcs	60 s	1,20 s
Cleaning weld 2	220	Every 50 pcs	60 s	1,20 s
Material handling - New batch chamber assy	190	Every 48 pcs	15 s	0,31 s
Material handling - New batch mixing chamber	190	Every 144 pcs	30 s	0,21 s
Material handling - New batch chamber assy	210	Every 48 pcs	15 s	0,31 s
Material handling - New batch support	210	Every 200 pcs	30 s	0,15 s
			Total:	**3,4 s**

Support activities - Final check

Activity	Station	Interval	Event time	Time/unit
Cleaning - O-rings	330/331	Every 300 pcs	60 s	0,2 s
Material handling - Trolly back and forth to leak test FIFO	360	Every 144 pcs	60 s	0,4 s
Material handling - Chamber assy	D1/190	Every 288 pcs	120 s	0,4 s
Material filling - End cup	A1	Every 180 pcs	120 s	0,7 s
Material filling - Nozzle	B1	Every 500 pcs	120 s	0,2 s
Material filling - Studs	250	Every 1000 pcs	120 s	0,1 s
			Total:	**2,1 s**

I. Cycle time measurements 1 – Main assembly line, *2014-02-03*

CYCLE TIME MEASUREMENT SHEET - *Main assembly line G1*								*Date:*
Station nr:	***Description:***	**CT 1:**	**CT 2:**	**CT 3:**	**CT 4:**	**CT 5:**	**Avg:**	***Definition of measure:***
200-220	*MAG-cell*	18,5 s	17,5 s	19,2 s	18,7 s	18,6 s	18,5 s	*Pick first part --> Picking first part for next product*
200	*MAG 1*	11,9 s	12,3 s	12,0 s	12,3 s	12,0 s	12,1 s	*Process starts closing --> Process is finished and opened fully*
210	*Support+Vessel*	5,3 s	5,0 s	6,2 s	7,3 s	6,1 s	6,0 s	*Placed in fixture --> Removed from fixture*
220	*MAG 2*	14,7 s	14,9 s	12,6 s	13,2 s	12,5 s	13,6 s	*Process starts closing --> Process is finished and opened fully*
230	*Cooling tower*	9,2 s	9,3 s	9,2 s	9,1 s	9,2 s	9,2 s	*Slide initiate movement --> Tower has finished rotating*
235	*Load pallet*	14,3 s	13,9 s	14,1 s	14,1 s	14,1 s	14,1 s	*Tower has finished rotating --> APG released and pallet continues*
237	*Support check*	9,3 s	9,3 s	9,4 s	9,4 s	9,4 s	9,4 s	*Pallet stops --> Pallet continues on conveyor*
240	*SQUIB crimp*	9,8 s	9,7 s	9,7 s	9,7 s	9,9 s	9,8 s	*Pallet stops --> Pallet continues on conveyor*
250.1	*Studs weld*	10,0 s	9,8 s	9,9 s	10,0 s	10,1 s	10,0 s	*Pallet stops --> Pallet continues on conveyor*
250.2	*Vision check*	2,2 s	2,1 s	2,1 s	2,2 s	2,2 s	2,2 s	*Pallet stops --> Pallet continues on conveyor*
260	*El-check*	12,0 s	12,1 s	11,9 s	12,2 s	12,1 s	12,1 s	*Pallet stops --> Pallet continues on conveyor*
265	*Vision check*	7,6 s	7,5 s	7,6 s	7,6 s	7,7 s	7,6 s	*Pallet stops --> Pallet continues on conveyor*
270	*Weight check*	9,6 s	9,1 s	9,6 s	9,5 s	9,5 s	9,5 s	*Pallet stops --> Pallet continues on conveyor*
280	*Pressure test*	11,7 s	11,5 s	11,4 s	11,3 s	11,4 s	11,5 s	*Pallet stops --> Pallet continues on conveyor*
290	*O2-filling*	14,2 s	14,3 s	14,2 s	14,2 s	14,1 s	14,2 s	*Pallet stops --> Weld plug placed on bottom electrode*
300	*O2-weight check*	10,9 s	10,9 s	11,0 s	10,7 s	10,6 s	10,8 s	*Pallet stops --> Pallet continues on conveyor*
310	*H2-filling*	13,4 s	13,9 s	13,8 s	13,7 s	13,8 s	13,7 s	*Pallet stops --> Weld plug placed on bottom electrode*
320	*H2-weight check*	9,9 s	9,9 s	9,9 s	10,0 s	9,8 s	9,9 s	*Pallet stops --> Pallet continues on conveyor*
330	*Leak tester 1*	19,1 s	25,4 s	18,4 s	22,9 s	24,8 s	22,1 s	*Pallet stops --> Pallet continues on conveyor*
331	*Leak tester 2*	29,5 s	26,4 s	15,7 s	24,0 s	16,2 s	22,4 s	*Pallet stops --> Pallet continues on conveyor*
340	*Labeling*	10,4 s	10,2 s	10,1 s	10,5 s	10,2 s	10,3 s	*Pallet stops --> Pallet continues on conveyor*
350	*Reject/test*	-	-	-	-	-	-	*## Seldom used ##*
360	*Unloading*	15,7 s	10,3 s	16,2 s	10,4 s	11,0 s	12,7 s	*Operator pushes button --> Next push*

J. Cycle time measurements 1 – Main assembly line, *2014-02-03*

CYCLE TIME MEASUREMENT SHEET - *Main assembly line G1*								*Date:*
Station nr:	***Description:***	**CT 1:**	**CT 2:**	**CT 3:**	**CT 4:**	**CT 5:**	**Avg:**	***Definition of measure:***
200-220	*MAG-cell*	19,0 s	18,0 s	19,5 s	18,8 s	18,9 s	18,8 s	*Pick first part --> Picking first part for next product (Tobias)*
200	*MAG 1*	12,1 s	12,0 s	11,8 s	12,1 s	12,0 s	12,0 s	*Process starts closing --> Process is finished and opened fully*
210	*Support+Vessel*	5,2 s	5,8 s	6,3 s	6,7 s	5,6 s	5,9 s	*Placed in fixture --> Removed from fixture*
220	*MAG 2*	14,4 s	13,7 s	14,5 s	12,8 s	13,8 s	13,8 s	*Process starts closing --> Process is finished and opened fully*
230	*Cooling tower*	8,9 s	9,2 s	9,0 s	9,3 s	9,1 s	9,1 s	*Slide initiate movement --> Tower has finished rotating*
235	*Load pallet*	13,9 s	13,8 s	14,0 s	13,7 s	14,1 s	13,9 s	*Tower has finished rotating --> APG released and pallet continues*
237	*Support check*	9,4 s	9,5 s	9,5 s	9,5 s	9,4 s	9,5 s	*Pallet stops --> Pallet continues on conveyor*
240	*SQUIB crimp*	9,8 s	9,9 s	9,7 s	9,8 s	9,9 s	9,8 s	*Pallet stops --> Pallet continues on conveyor*
250.1	*Studs weld*	10,1 s	9,9 s	9,9 s	10,0 s	9,8 s	9,9 s	*Pallet stops --> Pallet continues on conveyor*
250.2	*Vision check*	2,4 s	2,4 s	2,2 s	2,2 s	2,3 s	2,3 s	*Pallet stops --> Pallet continues on conveyor*
260	*El-check*	11,9 s	11,8 s	12,2 s	12,0 s	12,1 s	12,0 s	*Pallet stops --> Pallet continues on conveyor*
265	*Vision check*	7,7 s	7,5 s	7,5 s	7,5 s	7,7 s	7,6 s	*Pallet stops --> Pallet continues on conveyor*
270	*Weight check*	9,6 s	9,5 s	9,4 s	9,4 s	9,5 s	9,5 s	*Pallet stops --> Pallet continues on conveyor*
280	*Pressure test*	11,9 s	11,7 s	11,6 s	11,5 s	11,6 s	11,7 s	*Pallet stops --> Pallet continues on conveyor*
290	*O2-filling*	14,0 s	14,0 s	14,1 s	14,3 s	14,0 s	14,1 s	*Pallet stops --> Weld plug placed on bottom electrode*
300	*O2-weight check*	11,0 s	10,8 s	10,9 s	11,2 s	10,8 s	10,9 s	*Pallet stops --> Pallet continues on conveyor*
310	*H2-filling*	13,3 s	13,5 s	13,6 s	13,3 s	13,8 s	13,5 s	*Pallet stops --> Weld plug placed on bottom electrode*
320	*H2-weight check*	10,0 s	10,0 s	9,9 s	9,9 s	10,0 s	10,0 s	*Pallet stops --> Pallet continues on conveyor*
330	*Leak tester 1*	19,5 s	18,2 s	21,4 s	19,3 s	21,6 s	20,0 s	*Pallet stops --> Pallet continues on conveyor #UNSTABLE#*
331	*Leak tester 2*	24,4 s	26,5 s	18,9 s	22,3 s	19,2 s	22,3 s	*Pallet stops --> Pallet continues on conveyor #UNSTABLE#*
340	*Labeling*	10,2 s	10,4 s	10,1 s	10,3 s	10,2 s	10,2 s	*Pallet stops --> Pallet continues on conveyor*
350	*Reject/test*	-	-	-	-	-	-	*## Seldom used ##*
360	*Unloading*	11,6 s	15,4 s	9,4 s	10,9 s	13,1 s	12,1 s	*Operator pushes button --> Next push*

K. Cycle times for manual work cells, Main assembly line

MAG – Measurement	Op. 1 [s]	Op. 2 [s]	Op. 3 [s]	Op. 4 [s]	Op. 5 [s]	Op. 6 [s]	Op. 7 [s]
1	30,41	25,09	29,13	24,28	27,5	27,75	29,53
2	30,87	26,34	29,28	24,47	26,94	26,94	29,28
3	30,68	26,68	28,94	24,33	27,9	27,61	27,53
4	29,89	26,5	23,97	24,57	27,63	28	28,03
5	27,44	27,94	23,31	24,54	28,04	28,51	27,52
6	28,59	26,21	24,28	24,72	27,83	28,15	26,69
7	29,75	27,8	26,22	24,61	27,94	26,81	28
8	29,5	27,53	27,21	24,32	27,9	26,84	29,21
9	28,28	28,02	24,07	24,28	28	28,02	27,19
10	30,67	26,65	29,9	24,47	28,1	27,92	28,3

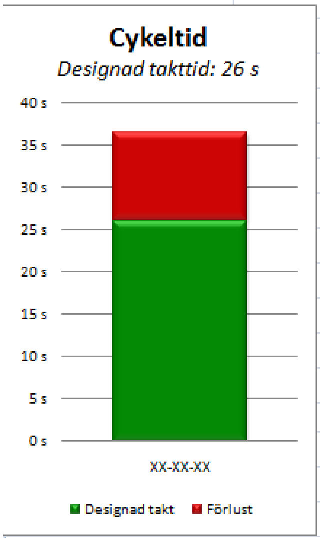
Average cycle time MAG-cell from ten cycle time measures and seven operators: 27.4 seconds

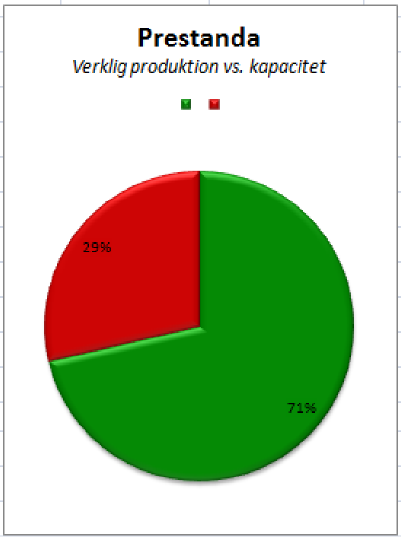
L. Interface for logging of shift results and short stops

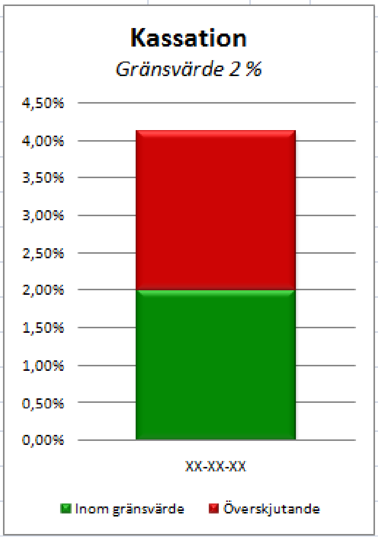
M. Shift reports

Skiftresultat - Huvudline

Datum:	XX-XX-XX	***Tillgänglig tid:***	425 min
Antal producerade:	730 st	***Cykeltid skift:***	36,4 s
Antal ok:	700 st	***Prestanda:***	71%
Antal kasserade:	30 st	***Kassation:***	4,1%

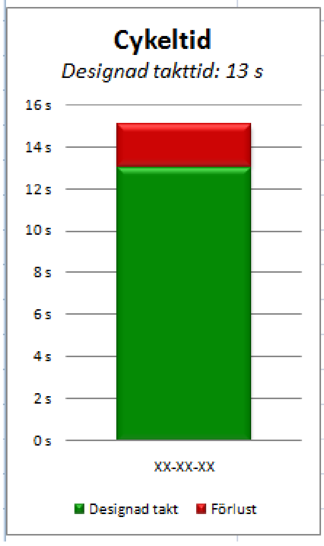


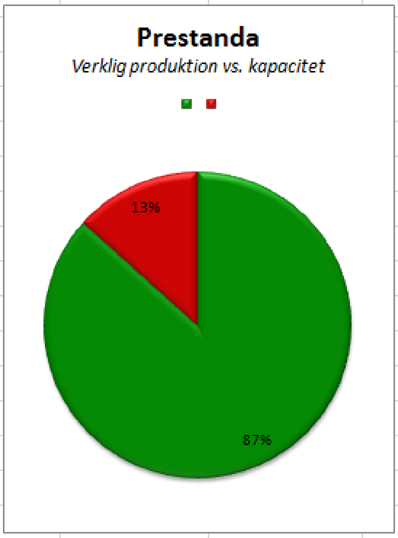


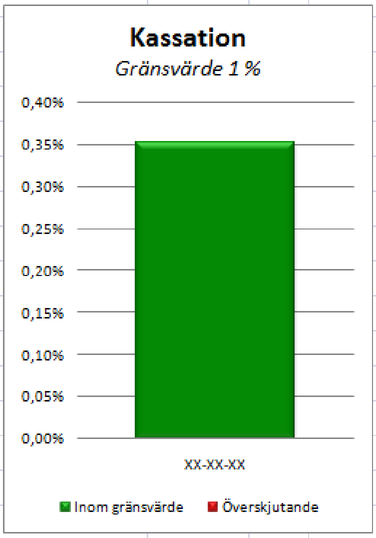


Skiftresultat - Förmonteringsline

Datum:	XX-XX-XX	***Tillgänglig tid:***	425 min
Antal producerade:	1706 st	***Cykeltid skift:***	15,0 s
Antal ok:	1700 st	***Prestanda:***	87%
Antal kasserade:	6 st	***Kassation:***	0,4%



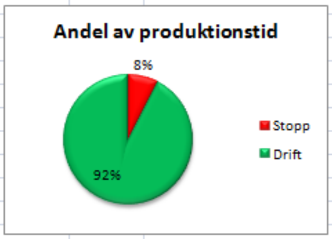


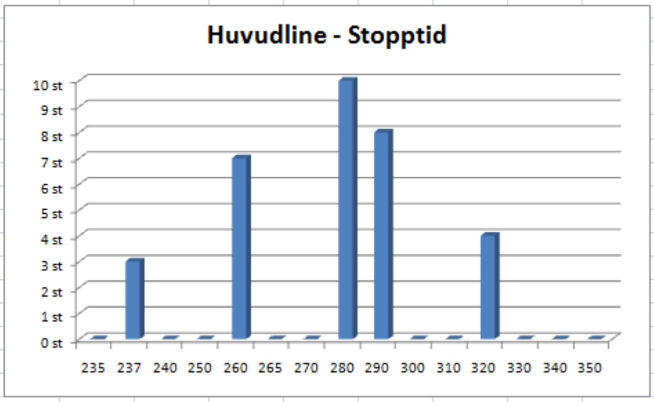


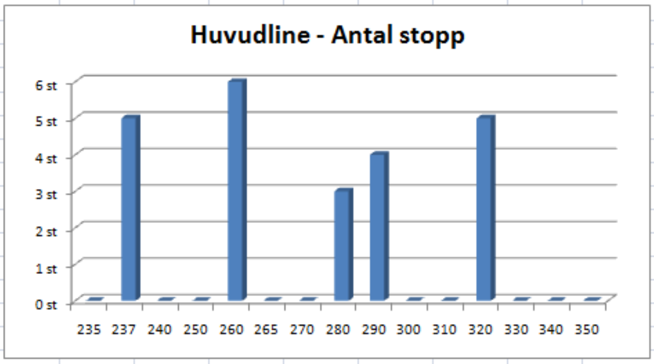
N. Short stop reports

Datum: **XX-XX-XX**

Korta stopp - Huvudline		
Station	Antal	Stopptid
235	0 st	0 st
237	5 st	3 st
240	0 st	0 st
250	0 st	0 st
260	6 st	7 st
265	0 st	0 st
270	0 st	0 st
280	3 st	10 st
290	4 st	8 st
300	0 st	0 st
310	0 st	0 st
320	5 st	4 st
330	0 st	0 st
340	0 st	0 st
350	0 st	0 st
Summa:	23 st	32 min

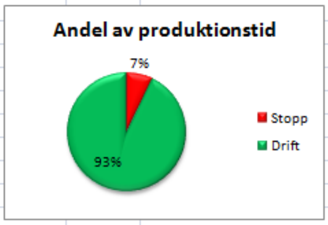


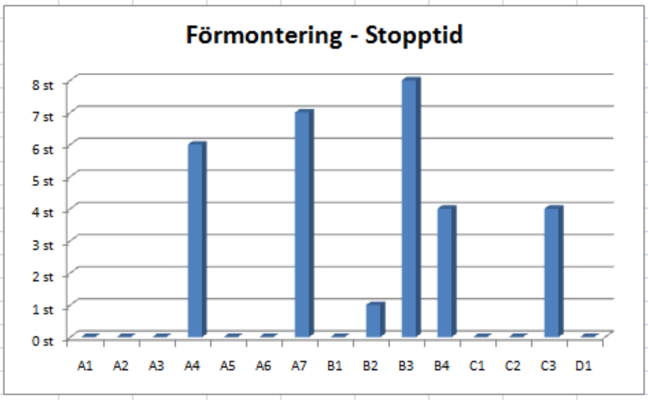


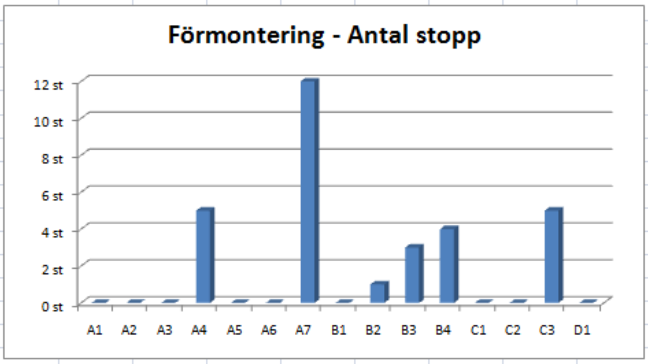


Datum: **XX-XX-XX**

Korta stopp - Förmonteringsline		
Station	Antal	Stopptid
A1	0 st	0 st
A2	0 st	0 st
A3	0 st	0 st
A4	5 st	6 st
A5	0 st	0 st
A6	0 st	0 st
A7	12 st	7 st
B1	0 st	0 st
B2	1 st	1 st
B3	3 st	8 st
B4	4 st	4 st
C1	0 st	0 st
C2	0 st	0 st
C3	5 st	4 st
D1	0 st	0 st
Summa:	30 st	30 min







O. Flow measure calculations

Flow measure	Definition from theory	Modified definitions	Formula
OEEML			
CT_{BN}	Ideal cycle time of the bottleneck		$OEEML = \frac{CT_{BN}}{CT_{LM}} * \frac{SVT_{LM}}{LT}$
CT_{LM}	Ideal cycle time of the last station		
SVT_{LM}	Station value time last station		
LT	Available time of the line	Calendar Time (CT) - Planned Stop	
TPU			
T_{ALM}	Total labor units		$TPU_{Measured} = \frac{T_{ALM}}{O_{LM}}$ $TPU_{Ideal} = \frac{T_{ALM}}{O_{IdealBN}}$ $TPU = \frac{TPU_{Measured}}{TPU_{Ideal}}$
O_{LM}	Average output of the last station		
$O_{IdealBN}$	Ideal output bottleneck		
Line efficiency			
OT_{Line}	Planned production time	Loading time (LT) - Failures and Set & Adjustment	$LE = \frac{OT_{Line}}{T_{LM}}$
T_{LM}	Total of minutes attended by all operators		
OLE			
LA	The ratio of the loading time of the line and the operating time of the last station		$OLE = LA * LPQP$ $LA = \frac{OT_{LM}}{LT}$ $LPQP = \frac{O_{LM*}CT_{BN}}{OT_1}$
OT_{LM}	Operating time of the last station	Loading time (LT) - Failures and Set & Adjustment	
LT	Available time of the line	Calendar Time (CT) - Planned Stop	
CT	Calendar time during a shift		
PD_1	Average planned downtime of the first station		
$LPQP$	Maintenance of a given speed over a period of the continuous production line		
O_{LM}	Number of good products produced by the last station		
CT_{BN}	Ideal cycle time of the bottleneck		
OT_1	Operating time of the first station		
Process OEE			
A_{BN}	Availability of the MAG-cell	Process Time + Cleaning + Material Handling	$ProcessOEE = A_{BN} * P_{BN} * Q_{tot}$ $Q_{tot} = \frac{Output_{BN} - DSD}{Output_{BN}}$
P_{BN}	Performance of the bottleneck	Ideal CTBN (26) /CTBN during time period. CTBN during time period = total time / units produced	
O_{BN}	Average output from the bottleneck		
DSD	Total number of defects and reruns downstream of the constraining operation per shift		
Productivity			
M	The ideal or intended productivity rate	Output line/ Ideal output with ideal output bottleneck	$Productivity = M * P * U$
P	Actual rate vs. standard time	SAM Cycle Time/ Real cycle Time	
U	The time spent on performing the intended work in relation to the total planned time	(Operative time - lost time during rotation between operators)/ Operative time	
MAE			
N	Number of assembled products in the MAG station		$MAE = \frac{\sum_{I=1}^{N}(t_{Iai} - \mathrm{t_{Rai}})}{N_A(t_{TOT} - t_{PS} - t_{UN})}$
t_{Iai}	Ideal assembly time for one product in the MAG station		
t_{Rai}	Rework for a product in the MAG station		
NA	Number of assemblers that are registrered for work in the bottleneck		
t_{TOT}	Calendar time		
t_{PS}	Total planned stop time per shift		
t_{UN}	Total unused assembly time per shift due to lack of order		