# Improving maintenance shutdown processes

Reducing delay and increasing work efficiency at Corus's Direct Sheet Plant



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#### Summary

This report is a description of the thesis project: *"Improving maintenance shutdown processes; reducing delay and increasing work efficiency at Corus's Direct Sheet Plant"*. This project was conducted at the site of steel manufacturer Corus in IJmuiden from October 2007 to June 2008.

The Direct Sheet Plant is an innovative plant that produces thin steel sheet in a continuous process. Its extreme operating conditions in terms of temperature and pressure are demanding on the physical installation, which therefore needs to be maintained regularly. The plants stops its production process every four weeks to allow for maintenance to take place in shutdowns that are always scheduled to take around 30 hours.

In reality the duration of the shutdowns almost always exceeds this scheduled time due to delays of maintenance activities. The delays are costly as every hour that the plant cannot produce results in a loss of income and increases labour costs. Meanwhile, the work efficiency is low; many workers can be observed idle for at least part of the day.

For these reasons, shutdown management wants to improve the shutdown processes. Firstly they wish to reduce the average delay experienced during the shutdowns. Secondly they would like to increase the work efficiency of the workers in the maintenance execution phase, thereby also increasing work pleasure in general.

These desires formed the basis for the research project, which started off by selecting a suitable theoretical framework for the problem analysis. The ideas of the business philosophy *Total Quality Management* were soon found to match the problems and their environment.

Total Quality Management (TQM) is a philosophy that advocates a focus on quality and continuous improvement for all processes throughout an organization. Along with its aim to achieve customer satisfaction and workforce commitment, this philosophy's range of thought not only fits the competitive, customer-focused global steel market but also Corus's mission to be *Best Supplier to Best Customers*. Two management approaches that were partly derived from TQM, *Lean Manufacturing* and *Six Sigma* were investigated. These approaches share TQM's main ideas but have the extra asset that they combine them with more methodological approaches that simplify implementing the philosophy's ideas. This makes these approaches more suited to provide support and guidance for improvement projects like this one.

Lean Manufacturing and Six Sigma were described and compared to each other. Lean Manufacturing was shown to be a business philosophy that focuses on efficiency; integrating TQM's ideas with a multitude of worked-out improvement tools and techniques. These improvement methods are directed at specific problem areas, yet not much support is granted for problem analysis so that, to choose the right method for the problem, the problem owner should already have good insight into the problems.

Six Sigma is an improvement approach that combines TQM's ideas with notions taken from the theory of Statistical Process Control. Six Sigma aims for quality of processes by understanding the cause-and-effect relationships within them. It advocates that full understanding of a process can help to eliminate the causes of undesired process behaviour so that the process's performance can be stabilized and improved.

To support its ideas, Six Sigma has a very good, standard improvement methodology with five phases: *Define - Measure - Analyze - Improve - Control.* This *DMAIC-methodology* is general and can be used for many types of projects. It guides project teams through its





different relevant analysis and design phases. This standard methodology is cyclic: every project ends with the identification of new improvement opportunities. Continuous improvement is thus easily institutionalized in the organization using the methodology. However, Six Sigma not offer many worked-out improvement tools for specific problems.

Six Sigma was chosen to represent the theoretical framework for this thesis, as it emphasizes the importance of being in control of a process before it can be improved. This was important as it seemed that, although everybody in the shutdown organization was trying to make the best of it, control over the shutdown processes was lacking. Increasing the insight into the complex processes was important before trying to improve anything in the first place. Six Sigma provided more support for the required analysis than did Lean Manufacturing.

Following the choice for Six Sigma, the DMAIC-cycle was used. In the *Define* phase the physical environment (the plant) and organization structure of the shutdown were described. It was investigated who the customer of the shutdown processes is. This is important as the customer decides when the process performs satisfactory. It was concluded that the shutdown organization itself was the main customer. Then the *critical-to-quality (CTQ) variables* in need of improvement were defined together with shutdown management. The value of *CTQ variables* are decisive in how satisfied the customer is with the process. For the Direct Sheet Plant's shutdown organization, the CTQ variables were defined to be 1) the *delay* of shutdown finalization, that is currently too high and 2) the *work efficiency* that is currently too low.

Finally, objectives for the improvement of these CTQs were defined. For the CTQ *delay*, the objective was based on what would be satisfactory to shutdown management. For the definition of the objective of CTQ #2 *work efficiency*, an ambitious goal was defined in cooperation with shutdown management. That goal was to do better than the industry average for shutdown work efficiency; data on which was provided by a professional work efficiency consultant for industrial firms. The industry average and the ideal figures as used by the professional consultant were used to calculate an objective for the Direct Sheet Plant.

This led to the following objectives: within two years, the delay of shutdown finalization should be decreased from the current level to 0 minutes on average (with a bandwidth between -30 and +30 minutes from the time of completion scheduled). Meanwhile the work efficiency level should go from 72% productive time, that is, 72% of the work time should be spent on activities that indirectly or directly contributed to ultimate finalization of the maintenance task.

The *Measure* phase was used for measuring the current CTQ performances. Delay figures had been recorded over the last years so that the 'measurements' consisted of gathering historical data. The work efficiency data was collected through a work sampling research during one of the shutdowns. Work sampling is a common method to study work efficiency levels. The specific sampling method for this project was designed with the help of the professional work sampling consultant mentioned before. In short, the sampling research meant following several randomly chosen workers throughout the day and categorizing their activities every two minutes. The results of the *Measure* phase showed that the objectives from the *Define* phase were quite ambitious considering the current average delay of shutdown finalization (190 minutes) and the current work efficiency (49% productive time).

The *Analyze* phase focused on finding the deeper-lying causes for the current poor performance levels through a so-called *root cause analysis*. To facilitate this analysis, the *5-Why method* and *lshikawa* (or *fishbone*) *diagramming* were employed in a combined way for both CTQ variables. This led to the identification of several root causes. The root causes that





were most influential on the CTQ performance levels were selected to be eliminated in the *Improve* phase. Some of the root causes corresponded strongly with each other, which led to a categorization of problem areas to be improved:

#### **Preparation and Planning**

• **the lack of a detailed schedule:** many activities are not scheduled with sufficient detail in terms of sub-activities, which provides no support for factual progress monitoring during the shutdown.

• **the lack of a visual planning:** jobs competing for space or scarce resources cannot be anticipated because of the lack of a visual representation of the jobs.

• scheduling for own use: experienced maintenance specialist see little need to schedule activities in detail as they often supervise the job execution themselves. Shutdown management has no insight into the factual progress and cannot timely act on delay because of that lack of insight.

#### **Communication Patterns**

• the passive approach towards progress communication: progress is supposed be communicated regularly throughout the shutdown day but rarely takes place because of an understandably passive communication attitude of coordinating supervisors on the job.

• **the number of fixed communication moments:** in practice, progress communication is restricted to twice-daily progress meetings, which is too little to timely act on delaying problems occurring in the meantime.

#### Anticipation and Resilience

• the lack of a predetermined solution set: the decision process to solve problems and mitigate their delaying effect is too slow, as hardly any thought is given to anticipation of problems and already deciding on solutions for them.

In the *Improve* phase, three improvement strategies were designed to eliminate the root causes. The strategies consist of several pillars each, combined implementation of which is expected to lead to optimal results. They are described in brief below:

#### Preparation and Planning

• with respect to detailed scheduling: obligatory incorporation of at least 1 'milestone' per 2 hours for all jobs, i.e. definition of at least 1 sub-activity per 2 hours. Avoids overlooking aspects of preparation and provides a basis for monitoring.

• with respect to a visual planning: use of a Corus best practice - the magnetic board, which displays the installation, job sites and resources such as cranes. Helps to plan scarce resources and avoid undesired job interactions.

• with respect to scheduling for own use: maintenance specialists may no longer act as coordinating supervisors on the jobs they scheduled. Other people acting as supervisors requires more conscientious scheduling.

#### **Communication Patterns**





• with respect to the passive approach towards progress communication: section coordinators should take an active approach towards progress communication. They should collect progress information from the supervisors.

• with respect to the number of fixed communication moments: progress communication should be linked to milestones instead of progress meetings to guarantee up-to-date progress information.

#### Anticipation and Resilience

• with respect to the lack of a predetermined solution set: brainstorm for problems that may occur and think of solutions. Speeds up the decision making process, mitigates delaying effects. Use cancellation standards for unexpected problems based on financial considerations.

To assess the quality of the proposed strategies and identify their trade-offs and pitfalls for the organization, an expert validation experiment was conducted. One of the main conclusions of these validation sessions was that the *quick wins* were expected of the first improvement strategy for *Preparation and Planning*. This strategy was considered the most urgent to implement, followed by the *Communication Patterns* strategy. The *Anticipation and Resilience* strategy was considered the least urgent and is expected to be more suitable for implementation at a later stage, after the main problems have been solved.

Workforce cooperation for the strategies is considered to be problematic unless shutdown management would enthusiastically support their implementation. More importantly, the current corporate culture in which individuals are not addressed when neglecting to take their professional responsibilities needs to be changed for the proposed strategies to work.

Finally, the *Control* phase concentrated on continuous improvement. Recommendations were aimed at change the way of measuring the CTQ *delay* to be more representative. Training of employees in Six Sigma improvement projects was also recommended.

A reflection on the use of Six Sigma as a theoretical framework resulted in a number of notions that may be interesting for the industry as a whole. In general, use of the DMAIC-methodology and Six Sigma is recommended for the improvement of many types of production and organizational processes in the industrial sector.

However, the measurability of some variables can make use of Six Sigma complex. Also, the reliance on data requires enough measurement opportunities; a very low frequency could be restrictive for the use of Six Sigma. Still, for many projects Six Sigma can be very useful.

More than Lean Manufacturing, which in some cases can be considered a collection of solutions looking for problems, Six Sigma approaches problems systematically and with an open mind which may be considered an asset for this approach.

On the other hand, the lack of guidance and support in the *Improve* phase may be (negatively) striking compared to the other phases. This 'gap' in the guiding structure of the DMAIC-methodology may well be filled in with the proven, structured tools of Lean Manufacturing. A combined Lean Six Sigma methodology is proposed at the end of Chapter 19.

It is recommended that more research into a combined methodology is done in the final chapter of conclusions and recommendations. That chapter also emphasizes once more that the shutdown organization will not succeed in improving its processes without a change in the organizational culture. It is recommended that it implement the proposed improvement strategies and that it institutionalize continuous improvement through the continued use of the





DMAIC-methodology. Further research should be directed at the contracting procedures; much could be gained from renegotiated maintenance contracts. Furthermore, *value stream mapping* could help solve problems caused by the late delivery of materials.









## Preface

This is the report of my final Master thesis for my studies Systems Engineering, Policy Analysis and Management at Delft University of Technology. I could not have finished my thesis project without the help of some people I would like to thank here. First of all, I owe much gratitude to my committee of thesis supervisors, formed by Dr.ir. Ms Paulien Herder, Dr.ir. Ms Zofia Lukszo, Dr. Mark de Bruijne and ir. Johan Mantz. I would like to thank them for the expertise they supported me with and for their helpful recommendations. Above all I thank them for granting me the freedom and independence to conduct the project in my own way; meanwhile I have learnt that keeping my supervisors informed is not one of my strong points. I promise to improve my progress communication patterns, much as I recommended the Direct Sheet Plant to do.

Ms Lukszo, thank you very much for your ever clear and understandable feedback that helped to improve the academic content of my otherwise quite practical report. Johan Mantz, thank you for always helping me to collect right data and information in the sometimes untransparent organization that is the Direct Sheet Plant. Mr de Bruijne, thank you for so kindly making a selection of organization theory information sources for me; the organizational perspective gave me a whole new look on things, which I needed for defining my theoretical framework. Ms Herder, thank you for taking the important place that was left vacant by Ms Weijnen on such short notice. Like my other three supervisors, the clarity of your feedback always made it helpful, never bitter.

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Enjoy reading this thesis report!

Marlies van den Heuvel Delft, 27 juni 2008









# **1. Presenting the Research Problem**

Large base industrial complexes such as power plants, steel mills and oil refineries run intensive production processes that involve high pressures, forces, temperatures and rotation speeds for the machinery. Since many of these processes are continuous, they often have to stop entirely to allow for maintenance tasks to be conducted. A production stop (also called shutdowns or turnarounds) of the plant is a costly affair: income is lost due to the lack of production of marketable product and extra maintenance machinery has to be hired (Nicholas, 2006). It is therefore most efficient to cluster maintenance activities and schedule them in predetermined shutdowns. These predetermined shutdowns can be classified as a combination of periodic and condition-based preventive maintenance (Rijnsdorp, 1991) meaning that equipment is either adjusted or replaced after a number of operational hours or after their properties have dropped below a certain norm value but in any case before failure has occurred, as opposed to corrective maintenance, which follows failure.

#### 1.1. Corus: Introducing the Direct Sheet Plant

Corus's Direct Sheet Plant in IJmuiden is an example of a continuously operating plant working with predetermined shutdowns for its preventive maintenance. This innovative steel plant built in 1998 combines the traditionally separated processes of steel casting and rolling. Traditionally, steel is cast and cooled to form thick slabs that are later reheated and rolled to thinner sheet. Compared to the traditional process, the DSP reduces energy use by eliminating the need for reheating while also cutting the number of transport motions of slabs. The production line consists of specialized, complex machinery that has to deal with high rolling pressures and temperatures of up to 1150°C. The machinery needs regular maintenance in order to prevent operational failure. The complex interactions in the production system imply that failure or deterioration in one component may lead to product that is off-spec or failure of the total system. The plant has therefore integrated regular preventive maintenance shutdowns in its planning: maintenance is conducted in 30-hour shutdowns that occur every four weeks. The plant shuts down for a full week once (or occasionally twice) a year to accommodate mayor revisions and in case of failure during operations, the plant conducts corrective maintenance in so-called 'short stops'. This report however will concentrate solely on the 4-weekly, 30-hour preventive maintenance shutdowns.

#### 1.1.1. Shutdown problems

Until now, problems have surrounded the shutdowns almost every time. Although effort has been spent on improving the processes and much experience has yet been gained over the last ten years, company data show that the shutdowns remain haunted by delays. Delays of several hours are frequent (4 hours on average in 2006) with the 30-hour regular shutdowns while on average 5% of the scheduled tasks remains unfulfilled. Meanwhile, the efficiency of work floor personnel can be observed to be low. The simultaneity of maintenance activities causes interactions, so that when one activity is delayed, others may well be conducted later too.

Maintenance progress delays (or accelerations) may result from a variety of causes. If these causes are not acted on by rescheduling and reattribution of the resources, personnel may





find itself sitting idle, waiting to start working on their jobs. This reduces the overall efficiency of maintenance activities.

Experts that have investigated the efficiency of maintenance activities say that the average productive time of maintenance personnel (both in-house and external) at industrial plants, called 'wrench time', is as low as 30% on average (Grabil, 2004). Wrench time only comprises the time maintenance workers spend working on jobs with their tools. It does not include the time needed to acquire parts or the time taken up by receiving instructions from management. (Palmer, 2007 A). The wrench time concept is not totally accepted in the research field as slow work increases wrench time, whereas this does not improve maintenance efficiency. As Tor Idhammar (2007) mentions, the low wrench time figure in itself is not a problem; the managerial planning and scheduling are, as they may cause possible inefficiencies. In his opinion, as long as equipment reliability does not suffer from the low wrench time there is no need to upset workers by telling them they do not work hard enough; which is basically the message sent by a wrench time study. Even sceptics like Idhammar see the need for increased wrench time during plant shutdowns however. These operations need to be conducted as quickly as possible in order to minimize downtime, so a higher wrench time figure is desirable at shutdowns.

Wrench time can be reduced by waiting time, caused for instance by waiting for tools or large machines that are already in use, or waiting for other groups to finish their nearby maintenance jobs for safety reasons. So as Doc Palmer (2007 B) states, the important thing to analyze when an improvement of efficiency is desired, is this 'non-wrench time' rather than the wrench time. When causes for non-wrench time are known, scheduling changes may reduce the effect of these causes: the workers could for instance be redirected to other jobs that can already be conducted safely with available tools.

Wrench time or rather non-wrench time may thus be a performance indicator for the timeliness and quality of planning and scheduling procedures. As managers at the DSP have observed that the non-wrench time is rather high, they have concluded that research should be conducted in order to find better practices for organizing maintenance shutdowns in order to increase the efficiency of the shutdowns.

#### 1.1.2. Efficiency

In this report, efficiency is defined as a measure for the amount of maintenance work that is done within a certain amount of time. The higher the amount of maintenance work fulfilled within a specific time, the higher the efficiency. Maintenance work only includes work with tools in hand, not receiving instructions or getting work permits. Although these activities are also important, they could also be done before the shutdown begins and doing them during the shutdown means wasting precious time. This definition of efficiency is thus strongly related to the wrench time concept. Like wrench time, efficiency can be decreased by waiting for safety reasons or for tools to become available or by receiving instructions. A major difference is that wrench time can be increased by slow work, whereas slow work counteracts efficiency.

When increasing the efficiency, the focus can either be to increase the amount of work done in the same time or to reduce the time spent on the same amount of work. Ideally of course, the two would be combined to reach the greatest efficiency increase. In this research project however, the focus will be to reduce the duration of the regular (4-weekly) shutdowns. The reason for this is that the amount of work per shutdown is assumed to be more or less





constant. Although the number of shutdowns could be reduced by doing more work per shutdown, the second assumption here is that the current frequency of shutdowns offers the best number of possibilities for preventive check-ups on the machinery, so that reliability levels do not suffer.

In the next section, the research questions that will guide the research project are presented.





#### 1.2. Research Questions

The research should be conducted in such a way that an answer can be found to the main research question:

How can the efficiency of the activities during regular maintenance shutdowns at Corus's Direct Sheet Plant be increased?

The main research question can be split up into several sub questions, the answers to which can finally be combined to form the answer to the main question presented above.

- How are maintenance activities currently organized at the DSP?
- Which problems are encountered during the plant's regular maintenance shutdowns?
- What are the causes for these problems?
- Which suitable tools for improvement are provided by existing theories and their methodologies?
- How can the theoretical improvement philosophies be translated into practices for the Direct Sheet Plant?
- To what extent will the designed improvements for the organization of regular maintenance shutdowns lead to increased efficiency of these shutdowns?
- What other opportunities for improvement could be investigated in the future?

These sub questions are related to each other and as answering some of these sub questions require answers to earlier ones, the research to answer each one has to be conducted successively, although iterations may be made. Answering of these questions will not necessarily be done in the sequence presented above.

The questions will guide the research in its approach of solutions to the problem to some extent. Still, even with the sub questions in mind, it is possible to analyze the problem and possible solution from very different angles. One could take on an organizational focus or look for solutions through the use of purely technical tools. The next chapter will explore possible theories to provide a framework that will be used to provide structure and theoretical validity to the research project and this report.





# 2. Exploration of suitable theory

In this chapter, several theories are presented that may provide a framework and a sound theoretical basis for this research project. The theoretical framework is supposed to provide structure to the research and this report. The perspective from which problems are perceived and analyzed dramatically impacts the solutions that will be found; for instance, a specialist in organizational psychology will see different opportunities for improvement then a mechanical engineer. Both viewpoints may be equally relevant, but constraints in time and resources for this thesis project limit the possibility to take all different perspectives into account; and a choice will have to be made.

Industry in general will first be presented as a subject of academic study. As will become clear, industrial issues have been studied from different angles over time. Several theories and business philosophies that integrate sociological and technical perspectives and that might come to mind when considering the Direct Sheet Plant's problem will be discussed. Thereafter, one theoretic approach will be chosen as a perspective for the analysis of the problem and possible solutions. The subsequent chapter will elaborate on the chosen theory. At the end of the report, we will revert to our theory of choice to see whether it has lived up to our expectations with respect to providing an adequate framework for solving the Direct Sheet Plant's particular problems. This chapter will start by considering various theoretical fields that have developed around the industrial sector.

#### 2.1. Organization theory and business philosophies

Industry can be studied in a variety of ways. The start of the Industrial Revolution in the late 18<sup>th</sup> century inspired many scientists to write articles on the newly arisen management issues associated with industrial business. Not only technical and economical issues surfaced, the new form of business also brought about changes in society. Early contributions by for instance Karl Marx, Frederick W. Taylor and Henri Fayol formed a basis for what we now call organization theory. The focus of much of these contributions was the management-worker relationship and the capitalist-communist views of the new forms of labour (Hatch, 1997). The focus was thus largely sociological as society and its layers changed along with the industrial revolution. The human factor of production was recognized as an important field of study (Jaffee, 2001).

Max Weber's theory of bureaucracy (1924) had an enormous impact on the way many organizations and businesses were shaped. Weber recognized the change of societal structures along with the rise of the Industrial Revolution. He thought a bureaucratic company structure with promotions according to achievements or seniority was rational and unbiased and therefore to be preferred over more traditional forms of authority based on for instance aristocracy or ownership of land. Weber's *ideal bureaucracy* was characterized by strict job descriptions on a horizontal and vertical level enabled an efficient division of labour, and his unity of command principle was rational to him in the sense that it ensured that an employee would only receive orders from one hierarchically superior person.

Some characteristics of Weber's *ideal bureaucracy* could be found in Ford's automobile manufacturing processes: tasks were strictly divided which led to a specialized workforce in a horizontal sense and a clear hierarchical structure in a vertical sense. This structure, along with Ford's clever assembly line, allowed for very efficient mass production of cars. The





capital investment of the assembly line and machinery could be returned by producing as much as possible on it. So the system produced as much as it could produce and was thus *production-pushed* rather than *demand-pulled*. What was not sold immediately was stocked in inventories and spare parts were also stocked to avoid having to go out of production. The production process could therefore be very efficient. Meanwhile wages were increased when production was increased, which further stimulated production growth, which again was rational according to Weber's thoughts on promotions and rewards. Over the years, modernist organization theorists therefore started linking Weber's rational bureaucracy to technical efficiency (Jaffee, 2001)

When March and Simon introduced their concept of bounded rationality in 1958, the attributed link between bureaucracy and technical efficiency was scrutinized in further detail. Simon found that the principle of unity of command conflicted with the principle of expert authority, which prescribed having strict job descriptions, with experts working on different tasks. Different experts with decision authority would lead to non-unity of command. The bounded rationality of individuals also presented an attack on the possibility of unity of command: if a person could only process a limited amount of information and could only get a limited idea of the consequences of his actions, then what was the quality of the decisions taken by a sole person with decision authority? Critics started wondering whether the theory of bureaucracy had not been oversimplified and whether or not bureaucracies were really that rational and efficient.

Also, in the 1970's and 1980's, markets for industrial goods changed. While markets grew to global proportions, customers started demanding more customized products. Suddenly, Fordist assembly lines that could efficiently produce one standard product did not fit the market anymore but rather represented a sunk capital cost that locked in its owners and did not allow them to switch along with the market. Globalization of markets, diversification of products, the demand for customization and the recognition of bounded rationality: they are all factors that led to a decreasing belief in the efficiency and rationality of bureaucratic organizational structures and Fordist manufacturing processes.

The 1980's saw the rise of a number of new theories, or rather business philosophies that followed this line of thinking. They are related to each other to some extent and were inspired on Asian production and organization processes, such as the Toyota automobile production line and Motorola's quality improvement program. These philosophies contain some fundamentally different characteristics compared to Weber's *ideal bureaucracy* and Fordism that seem to better fit the new environment in which flexibility is a key factor for the economical health of the organization. These differences will be described in the next subsection.

# 2.2. Total Quality Management, Lean Manufacturing and Six Sigma

The new generation of management philosophies as introduced above were largely modelled on individual, Asian firms that blossomed as western Fordist production lines started to struggle with their new, more dynamic environment. We will now discuss one business philosophy, Total Quality Management (TQM), and two management approaches that incorporate its ideas: Lean Manufacturing and Six Sigma. We will compare Lean Manufacturing and Six Sigma to see what differences an overlap they display amongst each





other but also compared to the traditional management approaches of western-style bureaucracy and Fordist manufacturing. The comparison will lead to an informed choice between Lean Manufacturing and Six Sigma to represent the project's theoretical framework. First, the 'ancestor' that provided the common range of thought of these two management approaches will be discussed: Total Quality Management.

#### 2.2.1. Total Quality Management

Total Quality Management, or TQM for short, is not as much a practical management approach as it is a *philosophy* that propagates a mindset for quality in all aspects and functions of an organization. Introduced in the Netherlands in the 1980's, TQM evolved from a number of less general predecessors; management approaches that focused on separate aspects of quality such Quality Engineering and Quality Assurance in the 1950's and 1960's (van der Bij et al., 2001). TQM is considered the first philosophy of the post-Fordist generation and its main viewpoints can be found in Lean Manufacturing and Six Sigma, two very different management approaches that were nevertheless both influenced by TQM . TQM itself has a somewhat vague connotation and appears to have different meanings to different people (Van der Bij et al., 2001). What is clear though is that it is a highly quality-oriented, long-term philosophy that advocates continuous improvement of quality relating to all business processes (Truscott, 2003) as opposed to just product quality. TQM has three main objectives (Groover, 2007):

- 1 (Striving for) customer satisfaction
- 2 Workforce participation
- 3 Continuous improvement

The guidelines TQM offers are relatively abstract and general (Tang et al., 2007), which can also be said from the ISO 8402:1994 definition for TQM (Truscott, 2003):

'A management approach of an organization, centred on quality, based on the participation of all its members and aiming at long-term success through customer satisfaction, and benefits to all members of the organization and society.'

Those companies that adopted TQM as their business strategy have often followed quality excellence models that have been derived from TQM in Europe and the USA (Truscott, 2003) but aside from TQM- derived Six Sigma and Lean Manufacturing that also shares TQM's range of thought to some extent, they will not be discussed in further detail.

Practice has demonstrated that TQM's objectives are hard to achieve, as it is much more of a philosophy than it is a detailed, worked-out method (Van der Bij et al, 2001) and it does not provide many guidelines for improvement. This lack of guidelines makes Total Quality Management itself less suitable to act as a theoretical framework for this project.

Its main objectives presented above however are important for this project: Corus's relatively new mission statement clearly illustrates that it wants to promote customer satisfaction and continuous improvement throughout the organization; it strives to be '*Best Supplier to Best Customers*'. To this end, the company has established a department for Continuous Improvement and also tries to get the workforce motivated to keep improving the company





processes by involving them in projects. This fit of TQM's ideas with Corus's policy as well as the need for continuous improvement with respect to the competitive global market conditions make TQM's range of ideas a suitable perspective for this project. However, its lack of tools and techniques should be filled in to be able to really let theory and practice integrate, which is why a choice between Lean Manufacturing and Six Sigma: as we will see, both approaches combine TQM's main objectives with more specific improvement guidelines for project teams.

#### 2.2.2. Lean Manufacturing

The first management approach that is considered as an option to provide a basis for this thesis is known as *Lean Manufacturing* or occasionally *Lean Production*. Since the publication of *The Machine that changed The World* by Womack, Jones and Roos in 1990 in which Lean Manufacturing was introduced, the philosophy has found itself in ever-increasing popularity of managers worldwide. *The machine that changed the world* was based upon an MIT study of Toyota's very efficient automobile manufacturing process that was outperforming western car manufacturers at the time.

Japan being a country with few natural resources, Toyota's management program was focused on eliminating waste in a wide sense (Arnheiter & Maleyeff, 2005). In other words, Lean Manufacturing's basic objective could be described as maximizing process efficiency. The management approach advocates adopting this focus on efficiency in all business processes, and seven 'deadly wastes' were distinguished that should be eliminated through adequate management: overproduction, waiting, transportation, processing, inventory, motion and defects (Smith & Hawkins, 2004). To avoid producing any of these wastes (called *muda* in Japanese), Lean proposes an organizational structure that is practically the opposite of the rigid, Fordist division of labour. It prescribes the use of functional team work in which job rotation that should lead to multi-skilled personnel that is motivated and feels responsible for the company results. Job rotation is supposed to help tacit knowledge convert into explicit knowledge and diffuse throughout the organization (Jaffee, 2001): organizational learning is a key objective within Lean Manufacturing. Like Total Quality Management, Lean Manufacturing recognizes the need for organizational changes and workforce cooperation to make improvement efforts to a success.

Regarding overproduction and inventories as deadly wastes implies that lean companies rely on *demand-pull* to steer their production, as opposed to the *production-push* mechanism that controlled Fordist companies. This makes the company more agile to respond to demand changes. Not keeping inventories could of course lead to a slow response to changing demands, but Lean covers that with its Just-In-Time (JIT) concept in which all suppliers constantly communicate so that they supply right on time, rendering buffers unnecessary. Critics of JIT mention the possibility for disturbances in the supply chain that could for instance be caused by raw material price fluctuations or logistical problems and recognize that that could lead to decreased customer service levels. Although such factors constrain its applicability (Polito and Watson, 2006), many companies report positively about the use of JIT in their supply chain.

In striving for production flexibility and agility, Lean Manufacturing aims for economies of scope rather than the economies of scale sought by traditional Fordist companies. Economies of scope can be attained through diversification of products to make them satisfy wide-ranging and/or changing customer wishes.





Lean has a strong customer orientation but the JIT principle also connects a lean company strongly to its suppliers. These facts lead to various interpretations by authors on the subject. Some consider integrated supply chains typical for lean manufacturers (Smith and Hawkins, 2004), while others seem to consider Lean a post-industrial structure that is therefore characterized by disintegrated, networked organizational structures that make ample use of outsourcing and subcontracting (Hatch, 1997). Either way, good communication and strong bonds with players up and down the supply chain are a necessity for lean companies to ensure Just-In-Time successes and customer satisfaction.

Another characteristic of Lean Manufacturing is the focus on continuous improvement of business processes. 'Kaizen', a Japanese word that roughly translates to 'change for the better' or 'improvement', has been tagged to continuous improvement approaches of lean companies and is now widely known among managers all over the world. Continuous improvement can reduce the need for radical innovations which require more resources (Santos et al., 2006). Kaizen relies on employee suggestions, which again highlights the need for widespread commitment and participation of employees as advocated by Lean Manufacturing. Kaizen is in fact a more specified version of the mindset for continuous improvement that is advocated by Total Quality Management.

Aside from Kaizen, Lean contains a number of other tools and techniques that may be applied to specific problems. Examples are the 5S methodology (*Seiri - Seiton - Seiso - Seiketsu - Shitsuke* or alternatively *Sort - Set (in place) - Shine - Standardize - Sustain*) that helps to create an orderly work environment and SMED (Single Minute Exchange of Die) that aims to systematically reduce change-over duration in between batches. These tools and techniques may be very useful when the problem owner already has some idea of what factors need to be addressed to solve a specific problem. Lean Manufacturing is very much focused on solutions; it lacks a standard improvement methodology that guides initial problem analysis however. The next section will focus on Six Sigma and reveals that while Six Sigma does provide an excellent methodology, but that it in turn does not provide improvement tools. In the section after that we will return to Total Quality Management and compare Lean Manufacturing and Six Sigma with TQM as well as with each other. This comparison may help to decide on a suitable theoretical framework with respect to the specific shutdown problems experienced at the Direct Sheet Plant.

#### 2.2.3. Six Sigma

The other management program that will be discussed here is Six Sigma. Developed by Motorola in the late 1970's to cope with increasing complexity in products and a growing customer demand for quality, Six Sigma is a data-driven approach to problem-solving with firm roots in mathematics and statistics (Tang et al., 2007). It aims for organizations to gain control on the process to be improved by introducing a fairly rigid methodological procedure (the DMAIC-cycle) that walks a project team through the necessary steps towards permanent improvement: *Define, Measure, Analyze, Improve, Control.* 

Six Sigma integrates the basic ideas on process stability and reduction of output variation from Statistical Process Control (SPC) with the main objectives of TQM: a customer satisfaction orientation, a workforce that is committed to achieving company goals and an ongoing improvement mentality. The statistics from SPC have been adapted to the current need for extra high quality, so that process variability needs to be reduced to an even lower level than was promoted by SPC advocates.





Six Sigma suggests improving all sorts of business processes by individual projects taken up by worker teams using the DMAIC methodology. The team members are selected on the basis of their expertise or skills: some of the team members come from the division normally managing the process under research, others from unrelated divisions. At least some team members must be trained in the use of Six Sigma concepts and tools. These multi-skilled improvement teams are empowered and supported by upper management (Groover, 2007). The next section will compare Six Sigma with its generation peer Lean Manufacturing to indicate overlap between the approaches, but also their fundamental differences. Both approaches will also be compared with respect to Total Quality Management. Thereafter, the research problem will be linked to a specific management approach that will serve as the theoretical framework throughout this thesis report. The current problematic situation will be mirrored with the chosen theory's standards and tools to see where improvement may be sought and how the organization could achieve better results.

#### 2.2.4. Common ground and differences

So far, two possible candidates for representing this thesis' theoretical framework have been presented: Lean Manufacturing and Six Sigma. Both combine the main objectives from Total Quality Management, that fit both Corus and its current competitive environment, with an approach that provides guidance for improvement efforts. This section serves to provide a summary of the theories and their characteristics, so that a choice among them can be made that best fits the Direct Sheet Plant's problem.

First of all, the common characteristics of the two approaches and Total Quality Management are discussed. TQM, Lean Manufacturing and Six Sigma can all be considered to be from the same 'generation' as they were all developed in the second half of the 20<sup>th</sup> century, when a changing business environment weakened the once strong Fordist machine bureaucracies in the Western world. One of their main shared characteristics is that they all proposed a possible antidote against the threats of the new, demanding customer: changing the rigid labour division and hierarchical structures of Fordism to a flatter, networked organization with a multi-skilled workforce working in teams that was highly participatory and committed to achieving the company goals.

An approach that is also shared among TQM, Lean and Six Sigma is that the organization's processes are regulated by the customer: what is produced, when it is produced, how much of it is produced, what the quality standard for production is: it is all influenced by customer demand. There is thus a strong focus on the customer and the goal is to achieve customer satisfaction. Consequently, production based on demand-pull is a key shared characteristic, although in Total Quality Management and Six Sigma it is somewhat more implicit than in Lean Manufacturing. Lean connects the customer focus to production efficiency, Just-In-Time and the reduction of inventories, whereas Six Sigma and Total Quality Management link it to meeting quality standards and thus satisfying the customer, who then may well decide to keep buying the company's products. The emphasis of Lean Manufacturing is thus more on efficiency, while the emphasis of Six Sigma and TQM is on quality.

It should be noted however that, as TQM and Six Sigma strive for quality in all business functions, quality may be seen as a wider concept, which can be applied to areas such as manufacturing and maintenance (Arnheiter & Maleyeff, 2005). This concept of quality can therefore be considered to be encompassing efficiency as one of its components.





Continuous improvement is the final shared characteristic of the management philosophies discussed here. All three are long-term approaches that have a vision of perfection, the road to which is never-ending.

The common ground of Total Quality Management, Lean Manufacturing and Six Sigma can thus be found in three shared concepts: 1) the goal of having a well-trained, multi-skilled, committed workforce to accomplish the company objectives, 2) a strong customer focus and 3) continuous improvement; long-term vision.

The differences are somewhat harder to make out. A first difference was already distinguished above, where the differences with respect to the perspective on customer focus were explained. Where Lean viewed it as a way to organize production efficiently without producing any *muda* (waste such as inventory), Six Sigma needs to know the customer's satisfaction range in order to know whether a process is sufficiently in control. That characteristic of Six Sigma is derived from TQM, which has a similar view on the need to involve customers and their desires; as the customer defines what quality (the philosophy's main objective) is.

This relates to a more fundamental difference: Lean Manufacturing's main goal is to reduce waste and thus to produce a the outcome demanded with the least possible consumption of resources, i.e. to produce *efficiently*. Defects represent one of the seven deadly wastes, so producing products outside the customer satisfaction range is inefficient. From the perspective of Lean Manufacturing, quality is thus a part of efficiency. As was discussed above, TQM and Six Sigma see it the other way around: efficiency is a necessity, an inherent characteristic of a well-performing process because of their wide concept of quality in all business functions. The customer pays for the processes that lead to the output he demands. If he has to pay for non-value adding, inefficient activities, he will most likely be less satisfied. And in Six Sigma and TQM, customer satisfaction equals quality. Quality relates to the entire customer value equation (Arnheiter & Maleyeff, 2005), so that producing efficiently is a prerequisite for achieving a high quality.

Although the concepts of efficiency and quality are covered by Lean Manufacturing and Six Sigma, the focus is shifted: Lean Manufacturing tips to the side of efficiency, Six Sigma (like TQM) emphasizes quality.

Another difference is whether or not the improvement approaches provide structured improvement methods, guidelines and ways in which their success can be evaluated. As was discussed, Total Quality management is the least detailed approach of the three. Although it provides some conceptual tools such as root-cause analysis that were copied by Six Sigma, it does not provide a further methodology for the use of these tools, nor does it specify criteria for success. Lean Manufacturing provides many tools and literature on how they can help the improvement process and how to put them to use is abundant. This makes Lean Manufacturing somewhat easier to implement in practice, though for a large part it is still left up to the organization to decide on how to start and structure an improvement project and which analysis tools are relevant to the problem and should be employed.

Implementation-wise Six Sigma scores best. Its DMAIC methodology provides a standard, step-by-step plan to follow for every improvement project. This makes it easier for the problem owner to apply the relevant tools to all sorts of business problems. Moreover, Six Sigma is the only approach to provide a standard for success; which is, keeping the process between 6-sima limits. With this standard, Six Sigma provides a world-class benchmark (Truscott, 2003) that is more absolute than the relative, internal measures of process





parameters, such as process speed or cost that have to be used by Lean or TQM adopters. With Lean Manufacturing and Total Quality Management, the absence of such a benchmark implies that the organization itself has to define when the improvement efforts are successful. On the other hand, the 6-sigma standard does not have to be taken literally for all business functions, only those problem owners who want to strive for near-perfection should use the standard as a world-class benchmark. Others could mirror new statistical figures with the old ones to see whether the projects are paying off.

These constitute the major differences among the three management approaches discussed. A summary of the main characteristics of the philosophies is given below.

**<u>Both approaches</u>**: Are long-term approaches, strive for continuous improvement, promote training of personnel in the relevant tools and techniques, strive for a participatory workforce that is committed to and feels responsible for achieving the organization's goals.

<u>Lean Manufacturing specifics</u>: Efficiency focus, increase efficiency by eliminating waste in processes, wide array of tools and techniques, several improvement methodologies for different problem types, validation through improved process parameters, success is defined by firm-specific criteria.

<u>Six Sigma specifics:</u> Quality focus, increase quality by stabilizing and gaining control of processes, tools and techniques for both conceptual and statistical analysis, standard improvement methodology DMAIC, validation of project solutions and evaluation of success may be based on firm-specific criteria and/or by the world-class 6-sigma process control benchmark.

The next paragraph will revert to the problems of the Direct Sheet Plant in IJmuiden and choose between Lean Manufacturing and Six Sigma to be the perspective from which the problems will be analysed and through which improvement will be sought.

#### 2.3. The research problem revisited

The management approaches towards improvement of business functions that have been discussed until now could each be used as a viewpoint from which to analyze the problems and come up with solutions. The perspective should however fit the objectives of the Direct Sheet Plant's shutdown management organization, as well as the plant's corporate culture and its (un)availability of resources.

The problems encountered at the regular shutdowns at Corus's Direct Sheet Plant encompass a wide range of stand-alone issues that together cause and form the undesired problems of delay, loss of income and budget overruns that are central in the problem statement.

The shutdown management organization, as a part of the division of Technical Management, wants to reduce the duration of the 4-weekly regular shutdowns whilst keeping the amount of work to be done fixed. The duration of the shutdowns is planned to be around 30 hours; there is not a fixed duration for every shutdown as the maintenance to be done to some extent decides the actual time required and thus scheduled. The objectives of the shutdown management organization imply that the same amount of work has to be done in less time





than scheduled now. This brings us to an interesting point: currently, the maintenance shutdown is almost always delayed and hardly ever finishes on schedule. Figure 2.1. shows a bar chart in which the bars represent the final delay per shutdown in 2007. As can be seen clearly, a delay of a few hours is very common. Only in week 16 did the plant return to production earlier than planned, whilst actually 94% of the maintenance jobs planned. The percentage of jobs executed compared to those planned is about 94% on average as can be seen in figure 2.2., so week 16 had a relatively good shutdown. In figure 2.1., the extremely high bar representing the delay of week 44 can be explained by the fact that that was the annual shutdown, which was scheduled for a week. The even more complex interactions of the longer annual shutdown resulted in more delay.



Figure 2.1.: Final delay on schedule (in hours) per shutdown in 2007







Figure 2.2.: Percentage of planned tasks indeed executed in the shutdowns of 2007.

Ideally, 100% of all jobs planned in a shutdown would be executed and the shutdown would finish right on the time scheduled. It may seem like it would be even better if the shutdown would finish before the time scheduled as that would reduce the loss of income. However, that would mean that the quality of the planning would be less good: there would possibly be a lack of insight into the causal factors of slower or quicker finalization of the maintenance work among the planners and maintenance specialists. But if all jobs were always finished and the shutdown as a whole would always finish right on time, than that would signify that the process was perfectly in control; that there would be insight into all factors influencing the shutdown process and that the organization would be able to mitigate the effects of disturbances to an absolute minimum. Unfortunately, reality is hardly ever perfect and comes with its own unexpected disturbances. Variability in the outcomes of the process (in this case the time of finalization of the shutdown) will therefore be present in reality. That does not mean a process cannot perform well: according to theories such as Statistical Process Control and Six Sigma variability will exist in every process and a very well-performing process does not need to perfect. As long as the process' variability can be kept within the range specified by the customer (or in this case the shutdown organization), the process is in control and can be made to behave (more than) satisfactory and, with continuous effort, ultimately reach near-perfection. This means that to improve a process, first there needs to be insight into and clear understanding of the factors that influence its performance.

Without doing any statistical calculations on the experienced delays, the bar chart already tells us that the process is not statistically stable and in control. Without even knowing the range around the scheduled time within which any delay would still be acceptable to the shutdown organization, we can again state that the organization is not satisfied and that the





process is thus not statistically in control. The current maintenance process performance of the Direct Sheet Plant would not even live up to the relatively loose standards of Statistical Process Control, let alone the stricter standards of Six Sigma. However, that is not the main point: the main point is that insight into factors influencing the maintenance process performance seem to be missing, or that the organization is not able to influence the values or effects of these factors. A degree of chaos experienced by many actors during the maintenance execution phase underlines the suspected lack of insight. What does this imply for the fitness of the two approach options discussed before (Lean Manufacturing and Six Sigma) for the specific problems experienced at the Direct Sheet Plant? What type of management program could provide the best perspective on the problems?

The original problem statement focuses heavily on efficiency: The delays experienced could be reduced if the efficiency of the maintenance execution activities could be increased by providing the right circumstances. That would mean taking away the bottlenecks that slow the flow of the activities down. Lean Manufacturing, with its strong emphasis on striving for efficiency and the need to reduce of wastes such as waiting, could provide excellent tools and techniques to resolve these bottleneck issues. Lean however would propose the use of different methodologies for every individual problem and choosing which problem to tackle first could result in a haphazard order of improvement projects. The problem owner should already have quite a good insight into factors influencing process performances to put the Lean tools to good use.

The problems could also be solved along more integrated lines. Six Sigma provides perspectives that start from a higher aggregation level than Lean Manufacturing, in which the problem owner should already have a good idea of what exactly is causing the problems he experiences. Six Sigma strives for continuous improvement of the quality in all business functions like Total Quality Management does, but as was discussed in the previous sections, TQM offers little help in terms of tools in actually resolving issues. TQM rather promotes a mindset for continuous improvement, without providing clear improvement methodologies or standards for success.

Six Sigma offers the integrated perspective that the problems seem to require. It comes with its own standard methodology that can be applied to all levels of a problem. The problem owner can start at a high aggregation level and work his way down to more detailed levels, solving parts of the integrated problem along the way. Starting with performance indicators that represent the outcome of the process as a whole, the organization can later define sub-problems with their own performance indicators, every time working along the same stepwise, cyclic methodology: *Define, Measure, Analyze, Improve, Control* (DMAIC).

This methodical way of working would allow the Direct Sheet Plant to gain insight into factors promoting the success or failure of the outcome of preparation and execution phases. This is a prerequisite for taking adequate measures to get control of the process; to get it to behave as it is currently planned. Later, in the spirit of continuous improvement, the planned shutdown durations might even be decreased to under 30 hours. Ultimately, when striving for world-class process performance, the Direct Sheet Plant could use the Six Sigma standard as a benchmark to see how well the improvement efforts paid off.

The high aggregation starting point of Six Sigma and its clear methodology make it the preferred management approach to serve as a theoretical framework for this thesis report. It will help the shutdown organization to get insight into the deeper causes and hidden aspects of the problem, before rushing off into all sorts of costly improvement projects. Once the





maintenance process is stable, improvement in terms of a reduction in planned shutdown duration may be initiated. The choice for Six Sigma does not mean that tools and techniques from other philosophies or programs such as Lean Manufacturing or Total Quality Management may not be used. The spirit of TQM is always present in Six Sigma because of their overlapping concept of quality and continuous improvement. Meanwhile; the tools and techniques of Lean Manufacturing may provide excellent help in resolving smaller issues that are part of the larger problem. There are more reasons to integrate Lean Manufacturing and Six Sigma; they will be discussed in the section *Lean Six Sigma* in the next chapter that will elaborate on the details of Six Sigma: its objectives, its statistical basis and its DMAIC methodology.





# 3. Theoretical Framework: Six Sigma

The Six Sigma program was first developed at Motorola in the late 1970's by Dr. Mikel Harry, although the term Six Sigma has been accredited to Bill Smith. At the time, while customers were demanding higher quality products, defective products were encountered more frequently than before. Motorola's products had become increasingly complex over time as they contained more and more components, each with their own risk of failure. Soon it became common for a product to have over a thousand opportunities for defects (OFD). Until then, component designers had been using 3-sigma quality limits (Arnheiter & Maleyeff, 2005). The statistical background of these quality limits will be explained shortly, but its effect was that every component was expected to have 0,3% chance of not meeting the quality standard, i.e. 0,3% of all components was expected to fail in one way or another. When calculating the expected failure of the final products (for example cell phones) which sometimes contained thousands of components, the percentage of expected defects became far too high. Motorola decided that the quality standards used by the individual component designers were to be improved to guarantee reliable end products and thereby customer satisfaction.

Six Sigma methods have been adopted by many other companies since Motorola's program, which has led Six Sigma to get the status of a management philosophy it has now. The objectives of Six Sigma programs in general (as opposed to Motorola's 'root' version) are discussed in the next section, after which Six Sigma's statistical basis is explained.

#### 3.1. Six Sigma Objectives

When the success of Motorola's Six Sigma program became apparent, other companies started implementing Six Sigma-derived programs. One of the companies that achieved major success with its own version of Six Sigma was General Electric (GE), which is therefore often mentioned in relation to Six Sigma. Most of these companies did not copy Motorola's program but designed a related version that better suited their own objectives, company characteristics and environment. Over time, some Total Quality Management principles also diffused into Six Sigma, such as TQM's customer focus and some of its problem solving methodologies (Arnheiter & Maleyeff, 2005). The resulting Six Sigma programs can still be characterized as one group by a number of common objectives. Groover (2007) summarized these objectives as follows:

- Better customer satisfaction
- High quality products and services
- Reduced defects
- Improved process capability through reduction in process variations
- Continuous improvement
- Cost reduction through more effective and efficient processes.

When we revert from these general Six Sigma objectives to the maintenance problems at the Direct Sheet Plant, it becomes clear that these goals are very similar to what the DSP shutdown management wants to achieve. The latter three goals are especially close to what is desired for the shutdowns in the coming years. Although at the starting point of this





research the emphasis was mostly on cost reduction through providing the circumstances for more efficient maintenance work and continuous improvement of the shutdowns, it will become clear in the following chapters that control on factors influencing the maintenance execution process is near non-existent. We will see that the fourth objective that advocates a reduction in process variations seems to be even more important, at least in the early stages of solving this problem. Insight into the maintenance organization and execution processes and the factors influencing its performance are a necessity before the shutdown can be improved in the first place. Six Sigma implies that process understanding is a prerequisite for improvement, which seems a suitable approach for the Direct Sheet Plant.

Six Sigma proposes one-issue projects to be solved by multi-disciplinary teams. This appears to be a good approach for the Direct Sheet Plant. The practical mentality of most people in the organization makes them relatively insensitive to long-term improvement approaches that do not demand a place in the day-to-day work processes. Working in a project team though, with a clear goal and possibly quick wins might spark their enthusiasm. Most employees have demonstrated to work well in short-term improvement efforts such as Lean Manufacturing's 5S-project for the offices, in which order was brought back to the work environment. Secondly, the multi-disciplinary character would create a system in which people from different divisions would check the other person's division's work. Currently, the difficulties around the shutdowns at the Direct Sheet Plant have led to an atmosphere in which divisions are blaming each other. This behaviour could be counteracted by having the divisions work together on such improvement projects. The appropriate use of Six Sigma's concepts and tools require team members that are trained in these subjects. The statistical basis that forms the spine of Six Sigma should be understood very well by at least a few members of an improvement project team. This statistical basis is described in the next section.

#### 3.2. Statistical basis

Six Sigma is in essence based on the statistics of the normal distribution. It focuses on reducing process output variations, thereby keeping the process output within a tolerance area specified by the customer for almost 100% of the time.

The normal distribution is also known as the Gaussian distribution and describes chances along its bell curve: high probabilities are in the middle of the curve; values that lie further from the mean value have lower probabilities, although the curve never reaches zero. The behaviour of many (natural) processes can be described by the normal curve. For example, human height can be described by the normal distribution. But to stay within a context of industrial processes, we can also consider the content of a 5 litre-bucket of paint. Normally, there is an average (mean) value of 5 litres of paint per bucket, but some buckets will contain a few drops more than others. Much fewer buckets will contain 250 ml less or more than the required 5 litres, but in very few cases this may happen. The percentage of buckets containing way too much or too little paint would be described by the extreme sides of the curve.

Staying with the paint example, suppose the paint producer has been getting complaints about there being too little paint in some buckets (assuming nobody complains about too much paint in their bucket). It wants to control the variation of the bucket content and therefore has to improve its control over the process of filling the buckets. Ideally, 100% of the buckets would be filled to a level within the range allowed by the company, indicated by an





upper and a lower specification limit of the tolerance area. As the normal curve never reaches zero, it is theoretically impossible to have a process that would be 100% between any specification limits.

Sigma ( $\sigma$ ), prominently present in the name Six Sigma, is the symbol used for the standard deviation, which is an indicator for the spread of the total population around the mean value, i.e. for the variation in process output. The standard deviation is thus not a constant, but is calculated from the population data.

Now the point of Six Sigma is to (better) control the process so that the variation in process output is reduced, leading to output that is on average closer to the mean value, assuming that the mean value is located in the centre of the tolerance area. Six Sigma proposes to take measures that allow for a process to get a smaller standard deviation.

The 6 in Six Sigma refers to the place where a process mean should be located with respect to each its boundaries of the tolerance area, the specification limits. Looking at figure ..., we see that almost 100% of a process output that follows the Gaussian curve falls is located within 3 sigma from the mean value symbolised by  $\mu$ . Still, 0,27% of the output is expected to be outside the tolerated area. That output might be unfit for sale and thus constitute a waste.



Figure 3.1.: A standardized normal distribution: There is very little process output that lies outside the ( $\mu$ +/-3 $\sigma$ ) range, but there is even less outside the ( $\mu$ +/-6 $\sigma$ ) range.(Still, M., 2008)

When the process mean is located in the middle of the tolerance area and at at least 6 times the standard deviation from the specification limits, then 99.999998% of the output falls within this range, which in the paint example would mean that only 0.2 buckets per million would contain too little or too much paint by the company's or customer's standards. This presents the company with more output that can be sold at a profitable price.

To clarify the difference between traditional 3-sigma boundaries and 6-sigma boundaries once more, the figure below shows how much of the output falls outside the specification limits when the process behaves in different ways with respect to its variance, once again assuming the process mean is centred right in the middle of the specification limits.

From the figure, it becomes clear that when the process mean needs to be at least 6 sigma away from the specification limits, control on the process needs to be improved to make sure the output is closer to the mean value, which is the desired value. The yellow bell curve thus needs a steeper slope to operate on a Six Sigma level than the other curves that operate at lower sigma levels.



*Figure 3.2.:* The specification limits are fixed, but improving process control can lead to increasing the output that conforms to these specifications. (edited from Six Sigma Tutorial, 2004)

As can be seen in the column of sigma figures on the right, the purple curve operates on a 3sigma level, which was the standard used by Motorola component designers before the Six Sigma program. The 3-sigma approach is expected to lead to a lot more defects than the 6sigma approach: 66,800 ppm for the purple curve compared to 3.4 ppm on the yellow Six Sigma curve.

The reader may have noted that before, it was stated that there would be 0.2 defects per million instead of the 3.4 defects per million as displayed in figure 3.2.. Which value is the 'right' one is explained briefly in Appendix A.

In the meantime, having explained the statistics, it is important to note that even though the statistics of Six Sigma serve as its backbone and are thus very important, the goal of acquiring a 3.4 ppm defect rate is not absolute (Arnheiter & Maleyeff, 2005). In this thesis too, the basis concept of gaining control of the process will be far more important than determining and striving for an exact defect rate that could be reached.

Now that we have an idea of the statistical basis for the Six Sigma philosophy, the next subsection will show us that the employed statistics are rooted in another methodology known as SPC (Statistical Process Control).

#### 3.2.1. Relation to Statistical Process Control

Six Sigma's statistical perspective on processes was not invented by Motorola; Statistical Process Control (SPC) as an improvement method was already designed in the 1920's by





Walter A. Shewhart. William Edwards Deming's name is also attached because he applied SPC to improve production in the United States during World War II; for instance the production of American warfare products was increased by use of SPC methods.

Users of the SPC method mostly used 3-sigma limits to control their process and used an process capability indicator  $c_p$  to measure how well a process was able to deliver output within the tolerance area. This  $c_p$  is the quotient of the tolerance area over 6 sigma and SPC users kept 1.33 as the lower limit for the process capability. Since Six Sigma stipulates that that the process mean be at least 6 sigma away from each specification limit, the Six Sigma goal is that  $c_p$  is at least 2.00, as can be seen in the left column of figure 3.2.

Another process capability indicator,  $c_{pk}$ , is equally important: this value tells us whether the process is indeed between the specification limits and if so, how well it is centred in between these limits. Without this information, the  $c_p$ -value information is worthless. Ideally, a process is perfectly centred which corresponds with a higher  $c_{pk}$ - value. Similar to what was discussed about SPC's and Six Sigma's differing  $c_p$  norm values, a difference exists between the two approaches' ideas on what is an acceptable  $c_{pk}$ -value: Six Sigma's  $c_{pk}$  norm value is 2.00, whereas SPC's norm value is 1.33.

But the difference in required sigma levels and corresponding  $c_p$  and  $c_{pk}$ -values is not the only thing that distinguishes Six Sigma from Statistical Process Control. While Statistical Process Control is a monitoring method for production processes with a technological focus, Six Sigma is an improvement philosophy of which the statistical methodology is merely one aspect. Other than SPC, Six Sigma comprises other aspects, for instance more organizational aspects relating to worker empowerment and responsibilities. In short, SPC strives to statistically control production processes, whereas Six Sigma programs strive for this level of world-class process control in order to increase efficiency, reduce wastes and keep customers satisfied.

The next sections will elaborate on other Six Sigma aspects, such as the DMAIC improvement methodology. The role of Six Sigma in this thesis project report will also be discussed.

#### 3.3. The DMAIC methodology

Whereas many improvement programs address output defects, Six Sigma has shifted its focus from the output to the process, since this is the place and stage where output defects are either avoided or produced (Tang e.a., 2007). Reducing a process' variability is to reduce the chance of producing defects (assuming the process is centred between the specification limits that indicate the desired range within which output should fall).

The DMAIC methodology is Six Sigma's roadmap towards a reduced process variability, which thus constitutes an improvement in the output defect rate. The term DMAIC is derived from its five steps: *Define*, *Measure*, *Analyze*, *Improve* and *Control*. Six Sigma advocates project-by-project improvement (Truscott, 2003) and DMAIC provides a uniform structure for all individual improvement efforts. The circular figure below visualizes the way DMAIC works and emphasizes the required repetitions of the methodological cycle to keep improving a process continuously. The repetitions suits Six Sigma's long-term and incremental character: the improvement process is never finished.







Figure 3.3.: Six Sigma's DMAIC methodology (MBF Consulting Services Inc., 2008)

Although the methodology's name and the figure below portray DMAIC as a rigid, chronological, stepwise process, iterations between steps in the same improvement process (i.e. one cycle) are common and are sometimes even necessary to come to satisfying results. The first step, the *Define* phase, is essential to the success of the rest of the improvement project. The problem needs to be defined concisely and the process' customer needs to be indicated. What are the customer's wishes with respect to the process output and where does this mismatch with the output currently produced? What characteristics in the output are critical to quality (CTQ) from the perception of the customer? When these questions are answered, the goal for the improvement project can be stated, which in generic terms is always about reducing the process variability to produce maximum output within the customer's satisfaction range.

The Measure phase serves as a specification of the concept problem definition and objective statement: process measurements help to fill in the details and may quantify the goals for the improvement effort. The data acquired in this phase may induce iterations to the *Define* step.

The Analyze phase turns the defined practical problems into statistical problems (Tang et al., 2007) from which the performance of the relevant processes can be analyzed. Root cause analysis helps to trace the underlying causes for the undesired and desired output.

The Improve phase defines possible solutions that could tackle the root causes. These solutions are designed with criteria of such as cost, effectiveness, workability and validation in mind.

The Control phase involves the setup of a monitoring system for the process after implementation of the solutions. Mostly it also involves a transfer of ownership of the project to a division that will assess the (financial) benefits of the 'new' process for an extended period of time, typically a year (Tang et al., 2007).

After the Control phase, the desire for further process tweaking can lead to the definition of new goals which would lead to re-entry into the *Define* phase and thus the rest of the cycle. That way, the DMAIC cycle fulfils Six Sigma's goal of improving continuously, while it provides a structure for data-gathering that is essential for such a data-driven approach as Six Sigma.




The DMAIC cycle has been derived from another methodological improvement cycle which has been attributed to both William Edwards Deming and Walter Andrew Shewhart: The PDCA cycle. PDCA stands for Plan-Do-Check-Act. To some extent, PDCA involves the same line of thinking, but the activities to be executed have been grouped differently. 'Plan' only involves half of the *Define* phase activities (only a rough problem definition), whereas the Do-phase contains the deeper problem definition and the Measure phase of DMAIC. The Check-phase is quite similar to the DMAIC's Analyze phase. PDCA's Act-phase incorporates both the Improve and Control phases of DMAIC.

The next section will briefly discuss another Six Sigma methodology, DFSS. After this, the possibilities for combining aspects from Lean Manufacturing with those from Six Sigma will be explored. This was already suggested at the end of the chapter '*Theoretical framework*'.

## 3.4. Lean Six Sigma

As was discussed earlier, in the chapter *Theoretical Framework*, a combination of Lean Manufacturing and Six Sigma could provide some interesting synergy effects. What was discussed earlier focused on the possibility to use Lean techniques to solve sub-problems of the delay in the Direct Sheet Plant's maintenance process. There are other reasons why integrating Lean and Six Sigma could be interesting, which has led to the development of Lean Six Sigma. This relatively new, hybrid management approach is not as common or well-developed as much the separate approaches of Lean Manufacturing and Six Sigma, but there is some relevant literature on it.

One reason for integrating the two approaches is their difference in focus on efficiency (Lean) and quality (Six Sigma). Improving a process in all its facets would require concepts and tools from both theories if relentless, on-going improvement is sought (Carreira & Trudell, 2006). Another reason are the diminishing returns of following either of the approaches singularly

(Arnheiter & Maleyeff, 2005). Figure 3.4. proposes that using the hybrid management approach of Lean Six Sigma might be a better bet from both a customer and a producer viewpoint.



Figure 3.4.: The hybrid Lean Six Sigma approach may prevent results from improvement efforts of the basic Lean and Six Sigma approaches from levelling off (Arnheiter & Maleyeff, 2005).





For Corus, combining the two approaches might prove to be valuable. Lean Manufacturing has already been recognized as a promising management approach by the higher management levels within the company. Consequently, action has been taken to train employees in the concepts and techniques of Lean and projects have been executed with good results. At this point, the internal consultancy department is deliberating upon which road to follow from here to keep improving continuously in order to prevent the diminishing returns discussed above. Six Sigma is one of the improvement pathways currently under consideration in this department.

Lean Manufacturing may prove to have paved the way for Six Sigma in the sense that it has introduced the workforce to the concepts that both approaches have in common (Tang et al., 2007), such as continuous improvement and workforce participation. Presenting Lean Manufacturing and Six Sigma as 'two peas of the same pod' or as one integrated approach by the name of Lean Six Sigma might help to overcome any resistance that might surface when Six Sigma is presented as a whole new approach. The threat of workforce resistance against 'yet another' management plan may thus be mitigated this way. But introducing Six Sigma concepts to the organizations may still prove difficult: weaknesses of and threats for the implementation of Six Sigma are discussed in the next section.

## 3.5. Six Sigma's weaknesses and threats

The reasons to choose Six Sigma to serve as a theoretical framework have been presented sufficiently in the previous sections. Possible downsides of the use of Six Sigma will be discussed here, as will be the possible misfits that may occur between the approach's advice and the reality of the plant with its own specific constraints. Parts of this analysis of weaknesses of and threats for Six Sigma were inspired by Tang & Goh's SWOT analysis of Six Sigma (Tang et al., 2007).

A first weakness of Six Sigma is directly related to one of its strengths: its objective, quantitative approach. In practice, the data-driven character of Six Sigma requires training of personnel that can later collect and analyze data. Training requires great amounts of time and money from the company. Furthermore, the data collection process can be quite time-consuming if it cannot be done through electronic data-mining tools, which would mean that resources (personnel) have to be freed from their regular tasks. Counting both the costs of Six Sigma training and the cost of data collection and analysis, Six Sigma projects may prove quite an expensive improvement method. Investment costs are thus high (Tang et al., 2007).

Another threat for Six Sigma implementation within Corus's Direct Sheet Plant is posed by the current situation on the job market. Considering the fact that the market is currently characterized by a high demand for technically educated personnel, it may be hard to fill in the new Six Sigma team positions in the first place. The Direct Sheet Plant is already running with a relatively low amount of personnel because of the labour market conditions, so freeing workers to participate in Six Sigma projects and to do measurements and analyses may be quite difficult. Also, a highly competitive job market with frequent job changing could negatively affect Six Sigma's results as the approach is designed to be long-term. Switching team members could harm the continuity of projects. Thirdly, the job market also has its impact on higher management levels. Six Sigma is an approach for which the enthusiastic support of executive management is vital (Tang et al., 2007). Within Corus, it is quite common that people switch management positions within 2-5 years. If the Six Sigma approach is not





adopted by all of Corus's departments, the support of managers new to the plant without experience with Six Sigma could be insufficient.

The top-down strategy of Six Sigma, with its need for extensive management support, poses another threat. A point of criticism that is often heard with respect to 'new generation' approaches such as Lean Manufacturing, Total Quality Management and Six Sigma, is that they are just 'the flavour of the month' (Arnheiter & Maleyeff, 2005). The approaches have sometimes been turned into a hype by the sudden global managerial attention. The fact that the philosophies were still evolving have led many managers to switch approaches when another one appeared that seemed fit the company even better. This has given the new approaches the image that they sound good but are not here to stay.

Especially in Corus's case, this threat is credible: over the last few years, Corus has invested heavily in becoming 'lean'. Lean coaches have been appointed and trained and projects in Lean spirit have taken place. Most employees seem to know at least a little about Lean Manufacturing and what it stands for. Switching to a Six Sigma approach could stimulate the idea within the company that Six Sigma is 'just another management fad', which could lead to a decreasing number of employees who would like to participate seriously in the improvement projects. On the other hand, the acquaintance of the workforce with the concepts Lean Manufacturing might prove to have paved the way for other improvement methodologies, as was discussed in the section *Lean Six Sigma*. Clever presentation of Six Sigma by management without total abandonment of Lean could overcome resistance.

This concludes the theoretical information about Six Sigma for this report. The final section of this chapter will discuss how the chosen approach will be integrated into this thesis research project and report.



## 3.6. Six Sigma and DMAIC in this report

Six Sigma will take a prominent role in this thesis report. The problems will be analyzed into more detail from a Six Sigma perspective, with the concept of process control as a central theme. Solutions will be presented that focus on taking control of the maintenance process to make it manageable. They will also include the softer themes of Six Sigma, such as workforce participation, and tailor these for the Direct Sheet Plant.



Furthermore, the DMAIC methodology will provide structure to the report: from here on, chapters will fall into a DMAIC division. The Define section will include chapters that focus on the research problem and its environment (the plant and its organizational structures) in its current state. The Measure section will contain chapters that describe the methods used to quantify the problem and of course the results of these data research projects. The Analyze section will look into the problem into more detail and will define the factors that are can be considered causes for the experienced shutdown problems. Root cause analysis, a typical Six Sigma analysis tool, will then be employed to find the deeper causes to be tackled by possible solutions. The Improve section will propose solutions that treat the root causes defined in the Analyze section. Finally the Control section will make recommendations to help the Direct Sheet Plant to improve continuously. It will provide suggestions for validation of the solutions in the Improve section of the report and it will make recommendations for improvements to be sought at a later stage.

The report will end with a discussion of the problem, its proposed solutions, the expectancy for improvement rates and recommendations for further research. This concluding part of the report also aims to critically assess Six Sigma as a management approach: Is it a useful philosophy to employ in the specific environment of Corus's Direct Sheet Plant and why (not)? The report will now continue with the first step of the DMAIC cycle, the *Define* step. This section starts of with an overview of the physical environment of the Direct Sheet Plant's maintenance problem: the plant with its casting, heating, rolling, coiling and cooling functions. The introduction to the plant and its extreme production circumstances will clarify the need for regular maintenance; maintenance (first in general, then specifically for the DSP) will thus be the subsequent theme. This will lead us into the current process of the regular maintenance shutdowns. An overview of a typical shutdown day will be followed by an explanation of the organization chart. The *Define* section will end with a renewed problem statement and a set-up for the Measurement section.





# Define

This part of the report will treat the subjects that are normally investigated in the *Define* phase of Six Sigma's DMAIC-methodology. That means the problem will need to be stated clearly: the environment of the problems and the actors affected need to be discussed. The process' customer has to be defined and it is critical to find out what is critical to the quality (CTQ) of the shutdown process.

The first chapter of this part of the report will provide an overview of the environment of the problems: the Direct Sheet Plant. The second chapter will first investigate the general theme of maintenance, after which maintenance at the Direct Sheet Plant is discussed. Here, the shutdowns enter the stage as the subject of the problems. The tasks of the people involved in the organization of the shutdowns are presented in a subsequent chapter. The last chapter defines who may be regarded as the customer of the shutdown maintenance processes: after all, the customer decides on the improvement goals. But who is the customer of these shutdowns? The *Define* part of this report ends with a renewed problem statement and a set-up for the Measure-phase.









# 4. Technology of the Direct Sheet Plant

In order to get a good view of the problems that arise during the maintenance shutdowns, it is a good idea to sketch their physical environment. This chapter will discuss the installations of the Direct Sheet Plant. The reader will see why much of the plant's maintenance needs to be executed in shutdowns. As we will see later in this report, the physical lay-out of the plant is furthermore linked to the organizational structures in the plant, which makes it important to know about the plant itself: then one can understand both the technical and organizational problems in the regular shutdowns.

The Direct Sheet Plant is an innovative plant that combines the traditionally separated functions of casting and rolling steel. Plant construction was finished in 2000 and since then, around 180 people keep the continuous process of the Direct Sheet Plant and its side business running. The next sections discuss this continuous process in more detail. Although this thesis report is not concerned with the technical installation itself, it is concerned with the maintenance of this same installation. Some basic technical knowledge is therefore essential to understand possible maintenance problems that are inherent in the technology and operational circumstances of the plant.



Figure 4.1.: A schematic representation of the production process at the Direct Sheet Plant

## 4.1. The production process

The Direct Sheet Plant consists of one long production line as can be seen above. Traditionally, the process of steel making is characterized by separated production steps. First, steel coming from a steel plant that converts liquid pig iron (*hot metal*) to steel is cast into slabs. These slabs of uniform size and weight are cooled and stored. Later, they are transported to a hot strip mill where they are reheated and rolled. The resulting sheet is coiled to form rolls. If the demanded sheet needs to be very thin, a cold strip mill can further reduce the sheet thickness. The technology of the Direct Sheet Plant is an improvement to this more common steel making process for several reasons:





- the transport of slabs and rolls between plants is eliminated
- less energy is needed for (re)heating the slabs
- the compact installation requires a smaller investment than for separated plants
- steel produced at the DSP is thinner than hot-rolled steel, which makes it suitable for more types of end product
- the operational costs can be lower than for separated plants.

The plant organization is divided into three sections that to some extent also represent a physical section in the plant. The CAD-section, which stands for Caster Department, represents the first part of the production line where pans with liquid steel are brought. The MID-section consists of a tunnel furnace and a rolling section. It also contains a coiler section where sheet is rolled to make it transportable and a quality testing section. The final section is called WISK after a Dutch abbreviation for Water, Infrastructure, Grinding Shop and Cranes. This section is supporting to the main activities in the production line. The following paragraphs will elaborate on the three sections, all of which will be researched in this thesis research.

## 4.2. CAD Section

The production line starts in the CAD section, being the Caster Department. Specially prepared and monitored liquid steel comes into the plant from the neighbouring Oxysteel Plant. The steel has been brought to a homogeneous temperature between strict boundaries and calcium wire has been injected in order to avoid clogging of the casting pipes and to give the steel the required properties for the DSP's precarious casting process. The steel pans, each with a capacity of 325 tons of liquid steel are transported into the plant one by one on wagons. They are then lifted and brought into casting position by one of two cranes. The availability of two cranes offers the possibility to cast continuously even when changing steel pans.

The steel pans are designed to cast their steel while retracting the impurities, 'slag' or 'scoria' floating on top of the liquid steel from the rest of the process. To avoid casting the impurities along with the steel, the pans are not emptied entirely. A small quantity containing a minimum of liquid steel and a maximum of impurities remains in the pan. The pan control system is equipped with a vortex detector. As soon as a vortex appears, there is a risk of slag being cast, so the casting is slowed, thereby causing the vortex to disappear. The pan is drained slowly until the slag detector detects slag being cast and the casting stops. This way, the steel contains a minimum amount of impurities. The impurities that did get cast however are removed as much as possible. Throughout the process, they rise to the surface of the slab to be removed by water, as we will see later on. The slag remaining in the pan after casting is removed before returning the pan to the oxysteel plant.

The casting process is characterized by two steps: first, the steel flows into a container that has a redistributing and buffering function. The container continuously contains around 16,000 tons of steel and has the form of a capital H, the middle of which consists of a culvert. The H-form produces a flow profile of the steel that allows non-metallic particles to rise and form a slag layer on top. The steel is cast into one leg of the H through a pipe surrounded by





argon to avoid contact with oxygen from the surrounding air and passes through the culvert, leaving the majority of its contaminants behind as a slag layer. The steel reaches the other leg of the H from where the casting process continues. From this leg, the steel enters an immersion nozzle that again shields the flowing steel from air, thereby preventing the oxidation of the steel which would result in the formation of more slag. This time argon gas is not usable because it might lead to the formation of bubbles in the steel.

The immersion nozzle that is equipped with a delta-shaped end casts the liquid steel into a water-cooled adjustable mould that forms a thick slab of steel. Casting powder prevents the steel from sticking to the mould and a thin skin forms on the edge of the steel slab. The slab flows downwards into a series of rolls that slowly bend the slab to a horizontal position while it is being cooled directly by water.

## 4.3. MID Section

At the end of the rolls, the (theoretically infinite) slab is cut by a pendulum shear to form shorter slabs of variable length. These slabs then enter the organizational section of the Mill Department (MID). The slabs are moved into a 315 m long tunnel furnace that is used to decrease the temperature difference between skin and core of the slabs and homogenize their temperature to 1150°C. The final 20 m of the tunnel furnace are mobile. In case of a problem in the rolling section, a torch cutter cuts 18 m slabs that fit into this shuttle and the shuttle can be removed from the production line until the rolling problems are solved.

Through the shuttle part of the furnace, the slabs reach the first rolling stands that reduce the thickness of the slabs from 70 mm to 12-25 mm. The weights used to roll the steel at this point are as high as 45,000 kN; the power of the equipment is 12,000 kW.

In between rolls, high-pressure spraying pistols remove oxides off the slab at pressures of up to 400 bar; the remaining impact pressure being 12.5 bar.

These first rolling stands are followed by a cooling section called UFC (Ultra Fast Cooling) that can be employed if necessary. This depends on the desired properties of the resulting roll of steel sheet. The crystalline structure and therefore the ductile and magnetic properties of steel differ along with the temperature at which it is rolled. The DSP can produce steel of two types of crystalline structure: ferrite and austenite. Ferrite is harder, but less ductile than austenite and unlike austenite, it is magnetic (Callister, 2005). If the desired structure is ferrite as displayed in figure 4.2., the slabs need to be cooled rapidly to around 800°C.



Figure 4.2.: Steel structures: α- ferrite (left, x90) and austenite (right, x 325) (United States Steel Corporation, 1971; taken from Callister 2005)

Five four-high stands as displayed below determine the final thickness of the produced sheet to a theoretical minimum of 0.7 mm. The slabs pass through the five stands with speeds up to 72 km/hr for austenite; for ferrite the rolling speeds are lower.







Figure 4.3.: Schematic representation of a four-high stand. The middle rolls are called work rolls, the outer (larger and heavier) rolls are called back-up rolls and support the work rolls.

The last roll is immediately followed by the Ultra Fast Cooling Section where austenitic sheet is cooled. This cooling section cannot be long as ferrite sheet has to be coiled as quickly after rolling as possible without cooling it. The sheet is then coiled at the coiler section. It consists of a carrousel with two spinning reels that serve as coilers. The reels coil the sheet to steel rolls of 10 to 35 tons. When the sheet reaches the section, it is wrapped around an empty reel at high speed. While one reel is coiling the sheet, the carrousel turns to bring the empty reel towards the start of the coiler section. The almost full reel in turn is brought over the walking beam, which is a transportation system for coiled sheet. When the coiled sheet has reached its desired length, a high speed shear cuts the sheet. This cut leads to a new sheet, the start of which is immediately caught by the empty reel which starts coiling. The finished coil is put onto the walking beam, which takes the rolls outside, where the rolls cool in fresh air. The walking beam leads to the cooling basin, where an automated crane puts them at a designated spot to cool further. The crane takes the rolls out again after several hours, after which they can be sent to the client that ordered them. The steel is finished now, but the process would not be possible without the third and final section, the WISK-section.

## 4.4. WISK Section

The third and final organizational unit, the WISK section, is a process-supporting section that is less attached to the physical production line than the CAD and MID sections but rather consists of several geographical areas. WISK is an acronym for the different supporting tasks the unit has. First, the W stands for Water. There is an extensive water treatment plant with three circuits. The indirect cooling system for the caster and furnace section with water running through the mould and furnace rolls is a closed system with a large heat exchanger so that the water remains clean. There are two direct cooling circuits that are open systems. The first one serves the rolling section and is equipped with cooling towers, sand filters and a sedimentation basin. The other direct system is used for the Ultra Fast Cooling System and the basin where the finished coiled sheet is cooled.

Infrastructure, the I in WISK, is present all over the plant, ranging from roads to stairs and from fork-lift trucks to walking beams.

The Grinding Mill representing the S after the Dutch word Slipperij is a large hall where rolls from the rolling stands in the MID section are ground. The production process with its enormous forces on the rolls leads to cracks and deformations that will ultimately lead to sheet that is off-spec. Therefore the rolls have to be brought to the Grinding Mill to be ground





on a regular to get them back into their required shape. Special equipment measures the deformations of the rolls, localizes the cracks and defines where repair is needed and then grinds the rolls accordingly. This job is largely automated and due to the heavy mobile equipment that operates autonomously, most of the hall is inaccessible for people during operation.

The K in WISK represents the cranes. These are present throughout the plant: the main hall where the caster, tunnel furnace, rolling stands and coiler are is equipped with two overhead cranes, the grinding mill has another two. The cooling basin and the storage and transportation section are also equipped with cranes.

Clearly, the adequate functioning of this section is a prerequisite for the operation of the other two.

## 4.5. Capacity

The three sections work together closely in order to produce quality steel rolls from liquid steel. The current yearly capacity of the DSP should be around 1.3Mton of sheet, although the plant currently runs under this capacity. Over the next 10 years, the goal is to go from 1.3Mton through 1.6Mton to 1.8Mton. This goal can only be attained if the plant's operation is improved significantly. Current operation is suboptimal due to process failures that occur in all three sections. Serious failure in any of the sections may lead to a production stop of the entire line. Common failures are 'breakthroughs' in the CAD section, when ruptures in the new-formed skin of the slab result in liquid steel pouring out; and in the MID section rolling failures occur when the sheet starts to flutter in the stands. The resulting sheet is then rumpled and unfit for sale. Part of these failures occur because of the relatively unexplored process interactions and their implications. Another part is caused by mechanical faults. These mechanical faults have to be corrected, or better yet, prevented through maintenance. The next chapter will first discuss maintenance in general, after which the DSP-specific implications of the technical background described above will be linked to the general theme of maintenance. Maintenance at the DSP is considered for all three sections CAD, MID and WISK.







# 5. Maintenance

This chapter will discuss the theme of maintenance, which is central in this thesis project. First some general theoretical notions will be given, after which the specific maintenance arrangements for the Direct Sheet Plant will be explained. The shutdowns that represent the main subject of this report will be discussed at the end of this chapter.

Over the last decades, industrial managers have increasingly recognized the importance of maintenance as a source of sound operations. Maintenance has therefore grown from being perceived as a necessary evil to a business function with its own strategy and planning (Pinjala, 2002).

In literature, maintenance is generally categorized in two groups: *corrective* and *preventive* maintenance (Rijnsdorp, 1991). *Corrective maintenance* has a problem-solving character and is conducted only after failure of machines or components has occurred. *Preventive maintenance* is conducted prior to failure so that failure of the process as a whole is prevented.

Preventive maintenance itself is split up into three subgroups: *periodic preventive maintenance, condition-based preventive maintenance* and *opportunity-based maintenance*. *Periodic preventive maintenance* is planned after a number of time units (days, hours or even minutes) since the installation of the component. When operation is strictly continuous, the maintenance activities can be planned according to the calendar, but many companies with semi-continuous operation have automated planning of this type of maintenance according to the number of operational hours, sometimes with extra weight attributed to start-up or stop hours.

*Condition-based preventive maintenance* activities are conducted when component properties fall below a given norm. This preventive norm is still above the limit at which the component does not perform appropriately anymore, but sends a signal to the operator that ongoing degeneration of the component will ultimately result in a large risk of it failing. The rolls in the rolling stands are measured to check whether they are not too deformed to produce on-spec sheet.

Automated control systems thus play a fairly large role in the contemporary planning procedures of maintenance jobs, whether they keep track of the periodic jobs to be done, or they assess the properties of components according to their norm values.

*Opportunity-based preventive maintenance* is conducted when operations are temporarily stopped for other reasons. This type of maintenance is found mainly in plants where it is rare to stop operations for maintenance. As an example at the Direct Sheet Plant, one could for instance imagine a production stop suddenly organized for corrective maintenance to the coiler in the MID section, which could provide an opportunity to maintenance workers at the caster to adjust the settings for the pendulum shear as casting cannot occur when the rest of the production line is not ready to handle the slabs. The job at the pendulum shear would then classify as opportunity-based maintenance. Opportunities could also arise from production problems at the ox steel plant that supplies the Direct Sheet Plant. That way, the problems can at least partly be turned to a Direct Sheet Plant advantage.

As will become clear later in this chapter, these categories of maintenance activities do not exclude each other. The next paragraphs will continue by connecting these general notions of





maintenance to the practices at the Direct Sheet Plant. First, the schedule of maintenance activities used at the Direct Sheet Plant will be explained. After that, the organizational structure of the Direct Sheet Plant's maintenance will be clarified.

## 5.1. Maintenance at the Direct Sheet Plant

Maintenance at the Direct Sheet Plant is organized in a way that combines all categories of maintenance mentioned above, albeit each in their own proportion. Although only about 20% of the 2007 maintenance budget was designated to corrective maintenance, almost 43% of the actual maintenance costs proved to be related to corrective activities. The budget for corrective maintenance was hugely overrun: 2.8 times the amount budgeted for the year was spent in practice. Corrective maintenance is conducted whenever a failure occurs that threatens operations and the produced material's guality. If possible, the required maintenance is done without stopping the whole production line but it may also be necessary to temporarily stop all operations in so-called short stops. These are organized as soon as possible, but sometimes convenience may play a role and the plant may for instance decide to stop casting after finishing the current pan instead of sending the half full pan back to the steel mill. Short stops for corrective maintenance can also be used for other, opportunitybased preventive activities. The Direct Sheet Plant would like to decrease the number of corrective actions taken, as these usually involve costly last-minute arrangements. Unexpected failure may lead to extended downtime if spare parts are not in stock, so these surprises should be avoided through preventive maintenance.

This preventive maintenance, and some opportunity-based maintenance, is done in longer *shutdowns*. In this report, the word *shutdown* indicates a pre-planned simultaneous operational stop of all production processes at the Direct Sheet Plant to allow for mostly preventive maintenance activities. Although a short stop is to some extent also a shutdown, this report excludes short stops from the term shutdown due to the difference in maintenance type and the difference in preparation of the activities: where short stops contain mostly corrective work and are planned ad-hoc, the shutdowns have a preventive focus and are planned months in advance.

The emphasis of this thesis report is on preventive maintenance of the periodic and the condition-based types, with the special condition that the maintenance is done in *regular shutdowns*. The next sections will explain what maintenance shutdowns are and what types occur at the Direct Sheet Plant.

#### 5.1.1. Maintenance shutdowns

As was described in the chapter Technology of the Direct Sheet Plant, the operations of the Direct Sheet Plant are characterized by high temperatures, rolling speeds, and pressures. Beside the fact that large maintenance jobs like the replacement of rolling torques would interrupt and obstruct the production process, the normal operational conditions would pose a threat to the health and safety of the maintenance workers. Though the Direct Sheet Plant was designed to operate with a minimum of human interference, human labour is still very much needed for large maintenance activities. Besides the obvious need to interrupt the continuous process to replace or repair components within the installation, large maintenance tasks also take place during a shutdown to secure occupational health and safety.



The Direct Sheet Plant works with two types of maintenance shutdowns. *Regular shutdowns* are held every 4 weeks (for some weeks in 2008 the interval has been increased to 5 weeks due to holiday interferences) and once a year, the *annual shutdown* is held in autumn.

The annual shutdown provides time for major maintenance and revision tasks. It takes a full week and often contains long-duration tasks such as for instance the replacement of the refractory lining of the tunnel furnace or gas purges. Another example of a task too time-consuming to do in a regular shutdown concerns the cleaning of the cooling basin in which oxides and dirt from the environment settle on the bottom. Cleaning requires emptying the basin and is done manually, which takes quite some time.

This research project however focuses on the regular, 5-weekly shutdowns. These are scheduled to take around 30 hours each in total from shut-down to start-up, that is to say from cast to cast. The most time-consuming activities in the regular shutdowns do not take more than around 12-14 hours in the middle of the shutdown interval. About 16-18 hours are needed for shutting down and starting up together, needed among other things to cool and reheat the tunnel furnace. Some maintenance jobs can be done during the 8-9 hours of shutdown or the 8-9 hours of testing and start-up, but the majority of the jobs is done in between these shut-down and start-up hours in the maintenance execution phase. There is little variety in this pattern, though there may be some variation in the duration planned. This duration variation mostly ranges from 1 to 2 hours more or less than 30 hours, but occasionally (roughly once a year) an extended shutdown of around 60 hours occurs.

Since the annual shutdown only takes place once a year and has an increased complexity due to the large number of interrelated activities, this was eliminated as a suitable subject for a six-month thesis project. The annual shutdown's problems are too wide-ranged to be treated in such a short time and the lack of frequency resulted in too few opportunities to analyze the problems and their causes while the yearly maintenance is being done. The scope of this thesis has therefore been restricted to the regular shutdowns, because of their higher frequency and the assumption that their complexity is somewhat lower, which makes it suitable for the limited time and resources for a thesis project. As the main topic of this thesis, the next section will elaborate on the regular shutdowns in terms of their organization, planning, scheduling and the type of maintenance activities conducted.

## 5.2. Regular shutdowns

As was discussed earlier in this chapter, regular shutdowns account for a large part of the preventive maintenance. As much as 62% of the maintenance budget was supposed to be spent on shutdowns in 2007. This budget was overrun, but because the total maintenance budget was overrun by an even larger percentage (mostly because of the unexpectedly large amount of corrective maintenance), the actual part of the maintenance money spent taken up by the shutdowns was 48%.

It takes around 8 hours before the conditions in the installation are suitable for maintenance: the total installation and the tunnel furnace in specific need time to cool to a temperature that is safe for manual work. Meanwhile, the installation needs to be physically prepared to enable the replacement of components and other maintenance. This requires a process that has been termed 'setting aside' the equipment by the Direct Sheet Plant-employees, which will be described later, in the chapter *Overview of a Regular Shutdown's Course*.





The start-up phase comprises preparing the installation for operation with respect to electrical controls, hydraulics and again physical positions of the stands. During start-up, a number of tests are executed, one of which is the ghost cast in which a non-existent slab is cast, rolled and coiled so that the operators can see whether all functions in the production sequence work. Meanwhile the tunnel furnace is reheated. If any installation problems remain after the maintenance jobs have finished, they are likely to surface in this test phase and they may be treated before going into production.

The phases overlap to some extent as specific maintenance jobs and job preparations can already be done during shutdown or while start-up has already has already begun, but at least 12-14 hours is left exclusively for maintenance activities. An example of an activity that is already executed during the shutdown is cleaning the tunnel furnace by removing the slag on the furnace floor by 'scale blazing' with burners from the basement below it. Another is removing the rolls from their stands to increase the rolling stands' accessibility for the internal maintenance work.

As all three phases (shutdown, maintenance execution and start-up) are different from operations-as-usual, the managerial responsibility is shifted from one division to another within the Direct Sheet Plant as soon as the last slab leaves the mould; the next chapter focuses on this special management structure for the Direct Sheet Plant shutdowns.





# 6. Shutdown Organization and Management

Shutdowns are far from business as usual. To accommodate the shutdown 'anomalies', a special management structure has been devised for the duration of the maintenance execution phase. Prior to the shutdown, in the planning and scheduling phases, the normal organization structure holds. During shutdowns, management of the plant is transferred from the Production division to the division of Technical Management. As of the 'last cut', which refers to the cut made by the pendulum shear at the end of the mould to form the final slab before shutdown, the production line is under the responsibility of the Shutdown Management team that is part of Technical Management. The organization chart of all shutdowns (during the execution phase) looks as follows:



Figure 6.1.: Shutdown Organization Chart

The different posts come with specific tasks and responsibilities before, during and after the shutdown. The next section provides an overview of the different roles that are played during regular shutdowns.

## 6.1. Roles in shutdown management

Below, the organizational roles displayed in the above presented organization chart are described one at a time. The lower levels display a lot of overlap, so that only one of the three sections (CAD, MID and WISK) will serve as a background to explain the tasks of section planners, supervisors and scaffolding and crane coordinators. The descriptions will be given from the top down.

#### Shutdown Leader

The Shutdown Leader is in fact the same person as the head of the division of Technical Management. Although he carries responsibility for the overall results of the shutdowns and for the rough allocation and possible exceeding of the budget, he is not concerned with the





practical organization of the shutdown. His role during the shutdown is largely advisory but from time to time he needs to employ his decision power or mediating skills in crisis situations. When opinions about how to mitigate effects of shutdown failure differ among those involved; his day-to-day role as head of the division gives him a little more authority compared to the Shutdown Manager, who carries the actual executive power throughout the shutdown. In case of proposed schedule changes the Shutdown Leader's consent is a prerequisite for definite rescheduling of jobs.

#### Shutdown Manager

As the operational chief of the shutdown, the Shutdown Manager holds the responsibility for the organization and the successful execution of the shutdown. The role demands the Shutdown Manager's survey over the project and requires integrated knowledge on all its aspects in all sections. In order for this integration of up-to-date knowledge to successfully take place, the Shutdown Manager is informed by the Shutdown Coordinators of the three sections. During the actual shutdown, the emphasis of the Shutdown Manager's tasks is placed on the maintenance execution phase: as the position of Shutdown Manager is filled by one person only, the physical presence is limited compared to the 30-hour duration of the whole shutdown procedure. The execution phase is most hectic and requires the most planning and managerial attention. Since problems may also occur during the start-up phase with its testing activities and cumulative problems from the execution may still await solving, the Shutdown Manager is more likely to stay around for this phase than to already be present during the relatively calm shutdown procedure. The Shutdown Manager is the chairman of the progress meetings that are held at regular intervals during the shutdown. During these progress meetings, the Shutdown Coordinators from all sections submit and discuss their updated schedules with the Shutdown Manager and with each other. They may also report possible problems that have surfaced in their section with respect to delays or capacity.

In the planning and scheduling phase, the Shutdown Manager is concerned with issues that affect all three sections, for instance the decision how many hours to shut down for. He also has to formally approve of planning and scheduling changes in writing.

#### Production Supervisor

The Production Supervisor's task is self-explanatory during production: he is in charge of the shift that is running the production process. But during shutdowns there clearly is no production let alone shifts to be supervised. Nevertheless the Production Supervisor also fulfils a role during the shutdowns. He serves an advisory role to the Shutdown Manager and progress meetings take place in his office which is located nearest the production line and thus the maintenance activities. He takes the minutes during progress meetings and in crisis situations he often knows the right people to contact to help resolve the matter: he works with relevant people from the Production Division on a daily basis. It is also highly important to keep him posted on the progress as he has to know when he can start up production again. He has to make sure that a pan of steel from the oxysteel plant is delivered at the right time, so he has to know when to order it. Since his office is so close to the maintenance work, he also sometimes collects and receives information about the progress of the activities which he can later report to the Shutdown Manager, who is a little harder to track down physically as he moves through the plant. Still, the Production Supervisor has no hierarchical or decision power in shutdowns; he has an indirect role as he has to be involved for start-up purposes.





#### <u>Planner</u>

The Shutdown Manager is supported by a planner who integrates the three separate section schedules into one master document. The software used for the final scheduling activities is MS Project, but SAP plays an important role in the planning phase. Although the organization chart clearly presents the main planner, there has not been such a person in reality until halfway into this report.

The three sections have their own shutdown organization and planning. Since each section's modular structure with respect to the shutdowns is the same, only one section, the randomly chosen MID, will serve as a background for the explanation of section-specific positions.

#### Shutdown Coordinator

The post of Shutdown Coordinator is the highest section-specific one. The post is generally taken by at least two people to accommodate the duration of the shutdown. Their shifts overlap shortly (one hour) to ensure the possibility for them to brief each other on general progress and special issues. The Shutdown Coordinators have great experience in the section's installation whether it is in production or in maintenance. The Shutdown Coordinators are responsible for the timely and successful execution of maintenance activities in their section. As they have an insight into the technical implications of all maintenance jobs, they can supervise choices of other section employees with regard to material and personnel to hire and they can assist in planning.

#### Section Planner

The section planner integrates all proposed maintenance activities for his section into one schedule. The MID section planner for instance integrates all activities concerning the tunnel furnace, the rolling area and the coiler. Maintenance orders originate from different sources: part of the orders come straight from the ERP system (Enterprise Resource Planning) that uses SAP software. The SAP-derived activities are typically periodic preventive maintenance jobs that surface when the system checks the expiration dates of the machinery's components. Other sources of maintenance orders are perceived failure that is not serious enough to result in a short stop, inspection rounds that result in mostly condition-based orders or recommendations from production coordinators. The preparation staff consisting of maintenance specialists and work preparation employees supply the section planner with the information he needs to make a planning: an estimate of how much time the need and estimates of when certain parts of their specific maintenance job should be finished. The orders are entered into MS Project, which facilitates the scheduling process with milestones and time lines. The section schedules are discussed on a weekly basis among the section's shutdown coordinator, the preparation staff and the different coordinators for scaffolding, cranes and cleaning. The planner updates the schedule after these meetings prior to the actual shutdown. These weekly updates are needed as in the weeks prior to the shutdown, the planning can still change quite a lot. These changes originate from the arrangements that have to be made to get the materials and skilled workers required for the shutdown. When starting the initial planning, there is still a lot of uncertainty: the jobs still have to be defined, often contractors have to be found and hired to do the job and the materials and components have to be ordered and delivered in time. As the shutdown is approaching, the arrangements become more definitive and the planning has to be adjusted to incorporate changes resulting





from the decreased uncertainty. During the shutdown, the planner receives information on the progress status of maintenance jobs and adjusts the schedule accordingly. Schedule changes that could come to form a threat to the total shutdown duration need to be communicated to the Shutdown Manager either directly or in the progress meetings so that the measures required to mitigate the risk of delay can be taken as soon as possible.

#### Production Coordinator

People from the Production department are involved sideways in the shutdowns: their presence in the plant, close to the production line often allows them to signal where problems occur and what these problems are. Together with maintenance specialists of the Technical Management division, they can discuss where repair or maintenance is needed. These people from the Production division could possibly be considered the customer of the maintenance processes, but this will be discussed in the chapter *Process Customers and CTQ's*. During the actual shutdown, they are involved mainly in the beginning and towards the end of the shutdown, when the Production division and the shutdown organization have to coordinate their shutdown and start-up activities and have to transfer responsibility over the plant.

#### Scaffolding Coordinator

During the shutdown, large parts of the installation are taken apart to allow for maintenance workers to enter the equipment and repair or replace components that are hidden or inaccessible during production. The large size of the equipment requires placing scaffolds for the workers to stand on and reach every possible part of it. These scaffolds need to be custom-made for every maintenance site. As many as possible are made before the plant shuts down, but it is not hard to imagine that scaffolds within a four-high stand can only be placed after the rolls have been taken out, the equipment as a whole has been set aside properly and the installation has been released for maintenance. The scaffolding teams then have to build the scaffolds so that the maintenance jobs can be started as soon as possible. In between different maintenance jobs in the same equipment, the scaffolds may need to be adjusted. This causes interactions with the maintenance activities, which results in a need to carefully plan the scaffolding in accordance with the maintenance schedule. The scaffolding coordinator plans or schedules the scaffolding jobs in the preparation phase and coordinates the scaffold builders during the shutdown day, sending the workers to the jobs where scaffolding is needed, integrating the schedule he made with real-time progress statuses of the relevant jobs. He arranges that the presence of a scaffold inspector, who checks the construction with respect to safety and adequacy for the relevant maintenance job.

#### **Supervisors**

The section supervisors supervise the maintenance jobs and check whether their actual progress is according to schedule. The supervisor is experienced around the equipment and can instruct less experienced maintenance workers or assist them in problem-solving issues. The supervisor is not supposed to get his hands dirty, i.e. he is not supposed to manually assist the workers on the jobs, his role is solely one of checking and coordinating. If the progress rate is not in line with the schedule, the supervisor should contact the Shutdown Manager and the relevant section planner to enable appropriate handling of possibly emerging problems.





#### Crane coordinator

The machinery contains many removable, but heavy and large components that can only be taken out mechanically. As was described in the chapter Technology of the Direct Sheet Plant, the plant is equipped with several permanent cranes that move on linear tracks. During the maintenance execution phase, a number of mobile cranes (with operators) is hired. The permanent cranes have the widest range as they travel overhead the equipment and can carry the heaviest loads. Even the largest mobile cranes are limited in their range as they cannot heave anything across the equipment (for instance from one side of the production line to the other). So there are a number of loads that need to be handled by the permanent crane. These permanent cranes are constrained to one area and cannot access each other's tracks. This means the availability of permanent cranes is limited to one per area. In an area like the rolling section, where a regular shutdown contains a large number of movements of heavy components, this limited capacity has to be allocated carefully. A crane schedule has been made, but the crane coordinator coordinates the allocation of all crane availability per section according to both the schedule and reality with its possible schedule changes and delays. He is also the person who the crane operators can contact in case of any questions and is therefore equipped with a phone which number is available in the work instructions.

#### Cleaning coordinator

In a production line like the Direct Sheet Plant's, with lots of cooling water, dust, large amounts of lubricants and removed oxides, there is a lot of cleaning to be done. In some cases, this cleaning has to be done before the maintenance job starts for reasons of worker safety or accessibility or workability of the job site. The cleaning coordinator helps coordinate the cleaning groups to do their jobs in an optimal way, i.e. causing the least delays for maintenance jobs while cleaning as much as possible.

So far, the descriptions provided were all tasks fulfilled by Direct Sheet Plant employees and all descriptions concern coordinating jobs. So where do the maintenance workers fit in? The large range and number of maintenance jobs require many maintenance workers, many more than are available at the Direct Sheet Plant alone. This has led the Direct Sheet Plant to outsourcing the majority of the jobs to other Corus-departments or other firms. The next paragraph treats this subject that, as will be shown later, somewhat complicates the organization of the shutdowns.

## 6.1.1. Contracted personnel

To do all maintenance required within the limited time frame of a regular shutdown, the Direct Sheet Plant hires extra personnel. The plant that was designed to operate with a minimum of human interference had originally outsourced all of its maintenance, but in recent years the level of outsourcing has been decreased and more jobs (or the preparation/organization of them) are handled with full-time in-house personnel. The annual shutdown attracts some extra external part-time people who are hired for their expertise to help out in preparing specific jobs, but the preparation of regular shutdowns is handled with in-house personnel only.





Still, around 350-400 extra workers from a wide range of companies enter the plant on a regular shutdown plant. A significant part of these workers come from Corus's central maintenance department HTD that carries out jobs all over the IJmuiden site, but there is also a large number of other contractors, most of which work for the Direct Sheet Plant on a regular basis. During the execution phase, the coordination of these maintenance workers is organized as follows.

The Direct Sheet Plant-employed section supervisors (in shutdown jargon coordinating supervisors) have to keep a close contact to the foremen who act as hierarchical supervisors by directly coordinating the executing maintenance workers. This structure is represented in the figure below. The section supervisors that were displayed in the bottom organizational layer of the previous chart are now represented as the top layer in the chart below, which can thus be considered to be 'hanging' from the previous figure. The one-headed arrows can be drawn two-headed to represent communication lines between maintenance workers and the Direct Sheet Plant shutdown management as opposed to the more or less hierarchical representation below. The coordinating supervisor organizes the work to be done by the hierarchical supervisor's men and provides the right circumstances for the work to be done. He coordinates any interactions with other nearby jobs. He keeps track of the job's progress and reports it to the shutdown coordinator. He coaches the maintenance executers but has no direct hierarchical power over them as the workers report to their foreman. Maintenance executers may need extra tools, advice or assistance of a crane which they may request at the coordinating supervisor, but they will mostly do so through their foreman, who carries the responsibility for their well-being.



#### Figure 6.2: Coordination of contracted personnel

In practice, sometimes the coordinating supervisor communicates directly with the maintenance workers but mostly the structure above holds. The foreman generally has the most experience, although not necessarily at the Direct Sheet Plant, and he has been informed on the jobs to be carried out and their safety issues and procedures in a kick-off meeting. He in turn has to communicate this information his own workers on their respective tasks, so they can start their work well-prepared. To accommodate the identification of the





different types of coordinators and supervisors, these people wear coloured smocks, each colour indicating a different role.

We have now seen the different actors on a regular shutdown day. But before the actual day can take place, lots of preparations have to be made. The people responsible for these tasks have not been described yet. The next section will focus on these people, as of now called the preparation staff.

## 6.1.2. Preparation Staff

The preparation staff plays an important role in the organization of the shutdowns. To some extent, the quality of their work is reflected in the final course of the execution. The success of the shutdown is largely dependent on the preparation of the activities: when the shutdown is well-prepared , the maintenance workers know when to come, where to go, what to do, where to get the materials they need, et cetera.

Every section has its own preparation staff, which is formed by three sorts of employees: planners, maintenance specialists and work preparation employees. The planner was already discussed in the previous section as he is also active during the actual shutdown; for that reason he is also displayed in the shutdown organization chart at the beginning of this chapter. The maintenance specialists and work preparation employees are only active in the preparatory phase of the shutdown, which is why they are not considered to be part of the shutdown organization.

The maintenance specialists are experts on maintaining a specific part of the installation, for instance the tunnel furnace or the coiler. Their expertise is either electro-technical or a mechanical. They do installation inspections and discuss where and when maintenance is required with people from Production. They state what needs to be done technologically and investigate what is required to enable the execution of the job. The maintenance specialists then turn to the work preparation employees to arrange the job in terms of manpower and materials. After that, they approach the section planner who should integrate their jobs in the planning and final schedule.

Meanwhile, the work preparation employees hire workers to do the job from within Corus or from outside contractors. They arrange the appropriate contracts, the work permits and the work instructions. They order the replacing components, materials and tools, which are then supposed to be in at least five days before the shutdown starts if a job is to remain in the schedule.

Later in this report, we will see that preparation issues are an important factor in the success and failure of shutdowns. In case of any preparation neglects, the preparation staff is often the victim of their own faults, as during the shutdown they often fill the position of coordinating supervisor or other type of coordinator on the floor (scaffolding, cranes, cleaning).

This concludes the description of the organizational structure of the regular shutdowns. But how do the people who fill these positions interact during an average regular shutdown? The next chapter will provide an overview of the course taken by the shutdown activities.









## 7. Overview of a regular shutdown's course

So far, it has been only been described what the positions in shutdown comprise, but they have not been illustrated by a description of an average shutdown day. This chapter will describe the course of a regular shutdown by giving a chronological representation of what happens from beginning to end.

The *last cut* ushers in the shutdown procedure: the Production division hands over control of the plant to the shutdown management under the authority of Technical Management when the final slab is cut in the Caster Department. This is usually planned at around 23:00hrs to allow for a convenient start time of the maintenance activities. The last slabs are heated, rolled, coiled, transported and cooled. The tunnel furnace is switched off and starts to cool down. After several hours, scale blazing starts. Scale blazing refers to the process of cleaning the tunnel furnace. Hatches in the bottom of the tunnel furnace can be opened from the basement below it and oxides and steel that has dripped from the slabs is removed with burners. The remainder of scaffolds that can be built prior to the start of the activities are built or finished and when the appropriate conditions are reached within the installation 'the signs are set to green' which signifies that workers can enter and work safely and securely.

## 7.1. 'Setting aside' the equipment

The equipment is positioned as has been specified in the work preparation phase; the rolls are taken out. This positioning process dubbed 'setting aside' the equipment is illustrated in the figure below. All moving parts such as handles, grips and clamps have to be put in the right position to allow for components to be taken out, for scaffolds to be built in or around it and for people to reach the components needing maintenance. Faultless execution of this process is therefore crucial for the course of the shutdown. It takes place as soon as the last slabs have left the installation and is finished before most maintenance jobs start, at 7:00am. As maintenance workers generally work from 7:00am to 3:00pm , they are reluctant to work other hours which is why the schedule of a regular shutdown is relatively fixed in a standard time frame where the workers start at 7:00am and all preparations take place in the nightly hours before. Although the process of setting aside the equipment can technically be considered a bottleneck action, the process is undoubtedly necessary to allow for the all maintenance activities to take place. The figure shows a rolling stand in normal operation position and the other positions that can be taken for the different handles and clamps.







Figure 7.1.: The positioning of moving parts in a rolling stand allows for specific maintenance activities. The left part shows the normal position during operation, right displays the other positions the moving parts can take.

## 7.2. Signing in

Between 6 and 7am the majority of the maintenance workers come in, as most workers start at 7am. They sign in at the *pull pit*, which is the operator's room that overlooks the production line, which is now ready for maintenance and surrounded by mobile cranes and scaffolds. The maintenance workers receive their work permits and work instructions, which include technical directions, scale drawings of the equipment and safety instructions. The workers then turn to the signs that indicate the access status of the equipment. These signs are attached to a board known as the lock board. Previously, it was already mentioned that signs were set to green to indicate that the equipment is safe for human access. These signs each represent a specific unit in the installation, for instance a rolling stand or the coiler, and have two sides, one red and one green. The signs can be flipped over like a page in a book and they can be fixed to either colour by hanging a padlock from a ring sticking through the sign. All foremen, both contracted and in-house, carry a personal lock. This personal padlock is locked to a specific green sign before the foreman and his workers enter the corresponding maintenance site and removed after finishing the job. The padlock is carried by the foremen and not the Direct Sheet Plant coordinating supervisor as the foremen carry the responsibility for the security of their workers. Before the plant goes back into production, all signs have to be reset to red. This cannot happen when one of the green signs is still locked, meaning that someone is still working in and on the installation. The signs are thus a safeguarding mechanism to ensure the safety of the workers by disabling a production start before everyone is out of the equipment.

## 7.3. Maintenance execution

As mentioned, the maintenance execution phase starts at 7am for most parts of the installation. The workers work on the jobs they were assigned or hired for and they do so according to their work instructions and permits. These work instructions and permits have been made or arranged by the preparation staff described in the chapter before. In case of any problems the workers consult the hierarchical supervisor (their own foreman) who in turn may consult the relevant coordinating supervisor if necessary. The coordinating supervisor checks the work on progress according to the schedule and he and the foreman check the quality of the delivered work according to the work instructions and their tacit knowledge gained through experience in maintenance.

A work day generally runs from 7am to 3pm for most workers, but as was mentioned in the research proposal at the start of this report, problems often emerge during the maintenance execution phase. Causes for this will be present later in this report, but consequences are that many workers experience waiting time and delays, so that they may not always go home on time. When the workers have finished their job, the work is checked once again by both the coordinating supervisor and the foreman. If the work is approved, the foremen report the finalization of the job at the pull pit and sign out. They remove their personal padlocks from the lock board and leave the plant.



## 7.4. Testing and starting up

At around 2pm, the reheating process of the tunnel furnace is started. Meanwhile, maintenance at the CAD, the rest of the MID and the WISK can continue. The maintenance jobs are scheduled to finish at around 6pm. After finishing the maintenance, the testing phase begins. At first, individual components are tested, but the phase ends with a *ghost cast* in which a non-existent slab runs through the production line in order to test all functions and see whether the appropriate interactions of the process take place. At 4am, the first slab is supposed to be cast into the mould so that production is up and running again.

This representation of a shutdown day only includes the activities that are supposed to occur on a regular shutdown day, but the problems that may also occur have not been given attention yet. The following chapters will focus on the problems that are frequently experienced and observed during the regular shutdowns. The first subsequent chapter will start by presenting the studies that were conducted at the Direct Sheet Plant to identify possible problems and their effects on the performance of the regular shutdowns. The results will provide a first insight into some of the problems. Later chapters will elaborate on the problem symptoms and analyse the causes behind these effects.







# 8. Process customer and CTQs

A central theme within Six Sigma is the customer focus: who gets to decide what process outcome is satisfactory? This chapter will define who the customer for the regular shutdowns is, or rather who decides what the desired performance for the shutdown is. Defining factors that are critical-to-quality (CTQ) will help set the goals for the improvement efforts the Direct Sheet Plant will have to undertake.

## 8.1. The process customer

Although it will always require due consideration, for many processes it may be easier to define the customer than for the maintenance problems that are the centre of attention in this report. In fact, stated differently, it is not so difficult to define who are the actual customers, but it is questionable whether these customers can play a meaningful role in the improvement process.

Indirectly, there is of course a final customer for every part of steel that leaves the Direct Sheet Plant. However, these end customers' satisfaction range would be hard to define and aggregate for the maintenance process, so it would not be very useful to involve them.

The most direct customer of the maintenance processes conducted by the division of Technical Management is the Production division. The Production employees signal the need for maintenance and have to operate the process with the equipment as taken care of by Technical Management. In case of lagging production, they might be held at least partly responsible for the incurred losses. They are thus dependent on the quality of the maintenance work done. They are also helped by timely finalization of the shutdown, because that means that they can produce as much as planned and they do not need to rearrange their production plans. The quality of execution of the jobs is much more important than the relatively small inconvenience of a delayed shutdown finalization. But the quality of the maintenance work is not the thing that is to be improved within this thesis project, it is the duration that is under consideration here. Because of the relatively low impact of this criteria on the division, the Production division cannot be considered a customer that could really, usefully define what would be a satisfactory performance for the shutdown process in terms of timeliness.

In the end, it is the shutdown organization itself that is dissatisfied with its process' performance and wants to improve it, especially the shutdown management consisting of the shutdown leader and shutdown manager. In their dissatisfaction, those involved in the shutdown are of course also driven by financial considerations of the plant as a whole and by their reputation within the plant, but most of it comes from the opportunities for improvement perceived by the shutdown organization. The idea that a lot can be improved is shared throughout the organization. The shutdown management will therefore be the customer of its own process and will decide on its own objectives for the improvement efforts. What is critical to quality, i.e. what has to be improved and to what level will be defined in the next section.

## 8.1.1. Critical to Quality

The critical to quality characteristics (CTQs) of a product or process are those features or elements that directly impact the customer's satisfaction (Groover, 2007) and could or should be changed to improve process performance up to or beyond a satisfactory level. To enable





use within a Six Sigma project, the CTQs should be redefined into measurable indicators. The CTQs for the Direct Sheet Plant's shutdown management will be defined below in a way that directly takes their measurability into account.

To the shutdown management, the duration of the shutdown should be decreased. A decreased duration for shutdowns would however be no improvement in shutdown performance if no change in efficiency would be brought about however. It may sound rather ridiculous and pointless to say, but in fact the shutdown duration could be reduced by just planning less maintenance activities. But that would mean that less maintenance would be conducted and it is supposed that that would lead to a serious deterioration of the installation. Doing less maintenance per month is therefore not accepted as an option; the amount of work do be done per shutdown is assumed fixed. So, considering it is also undesired to increase the duration as planned, that means that roughly the same amount of work (of course, the number and type of activities differ with every shutdown) should be executed in less time than currently is the case. Stated differently, the efficiency of the maintenance activities as a whole should be increased.

In order to do so, it was already established in the chapters *Theoretical Framework* and *Six Sigma*, first there needs to be full understanding of the factors influencing the course of the shutdown and after that, these factors need to be controlled so that the performance of the shutdown process as a whole is also stable and in control. So before reducing the planned and actual shutdown duration, how can the shutdown organization control its process?

A controlled shutdown process implies that the activities can be planned and made to finish on time. Right now, to the regret of shutdown management, finalization of the shutdown as a whole is almost always delayed. As shutdown management is dissatisfied with this situation, delay on schedule of the shutdown activities, or rather the absence of delay, is critical to quality. So (a minimal) delay is our first CTQ. Delay is an indicator for the shutdown process' performance that can be measured very simply and effectively by comparing the actual time of finalization with the time that was planned beforehand. Figures on delay have been collected by shutdown management for a long time and this collection of data can be continued without the need for taking measures such as hiring extra personnel to do the measurements.

The second CTQ that will be investigated is assumed to be related to the first one: a good efficiency level for the maintenance jobs could decrease delay on current schedules; and could eventually even help in shortening the total duration of the shutdown. Besides this assumption, the current inefficiency of the maintenance jobs is unwelcome for other reasons: firstly, it harms the moral of the maintenance workers. The joy they experience in their work is often decreased in case of long waiting times which leave them bored and negatively impacts the effort they put into their work when they can start working again. From a Six Sigma standpoint, a committed and participatory workforce is essential for high quality in business processes, so the boredom deriving from waiting time is to be reduced to a minimum. Secondly, the maintenance workers are paid for on an hourly basis, so every extra man hour counts.

There are some assumptions for this second CTQ, that are highly important to state explicitly: it is assumed that the efficiency of maintenance workers can be increased through adequate and accurate planning and preparation. For instance, the deployment of resources that need to be shared, such as the fixed crane, should be planned very carefully in order to avoid one maintenance job having to wait for another job in need of the crane to finish.





The second assumption is that the individual maintenance workers' work ethic is good and that workers do want put in a good effort as long as the right circumstances are provided for them to do their work normally. This means that in case of a very low work efficiency, it should be investigated why the workers *cannot* work more: what is obstructing their work? Questions like this one can lead to the root causes for the efficiency problems.

It will be somewhat harder to measure the work efficiency of maintenance workers during the shutdown, but a relatively common method for data collection is available in the form of *work sampling*. This sample test and its pros and cons will be discussed in the next part of this report where the Measure step of the DMAIC methodology will be conducted.

Concluding, we have now chosen two CTQs: 1) delay on schedule and 2) work efficiency. These indicators differ in type, and the second one influences the first. The first one is therefore called an *output measure*, whereas the second one is an internal *process measure* (Groover, 2007) when we consider process control and stability the main objective for this thesis. Once again, this process control is not the final goal. The final goal of the improvement efforts of the Direct Sheet Plant's shutdown organization is to decrease the duration of the shutdown whilst doing the same amount of maintenance at the same levels of quality and safety as are currently attained.

A third category of CTQs, *input measures*, are not represented in this thesis report, but when root causes have been defined further along in the report, input measures could be defined that deserve recommendation for later research within the Direct Sheet Plant. Most probably, there are interesting, measurable input variables influencing the work efficiency which in turn influences the delay, or better said: the factor influencing the satisfaction level of the process customer, the shutdown management team.

Because of the Six Sigma viewpoint of this thesis, the search for control of the influential factors will start at their effects: the values taken by measurable process performance indicators. The search will then work its way back to the causes of these effects from there, trying to finding root causes that can be eliminated or the effects of which can be mitigated.

The next section will summarize the findings of the *Define* phase and link these findings to the approach to be followed from this point. This will result in explicit objectives for improvement in the two CTQs. These objectives will serve as reference points for validation at a later stage in this project.

## 8.2. Objectives statement

The process to be improved is the regular shutdown process that occur at the Direct Sheet Plant every four weeks. Two process characteristics that may be considered critical-to-quality (CTQ) that are currently not on a satisfactory level for the customer, the shutdown management team. The non-conformance of these CTQ variables to the specification range of the customer is the problem that will be investigated in this thesis project. The CTQs under investigation are the delay of the finalization of the shutdown (an output measure that is currently too high) and the work efficiency during the shutdowns (a process measure that is currently too low).

The current values of these CTQs will be measured in the next part of the report which represents the Measure step of the DMAIC-cycle. The root causes that influence the values taken by these CTQs will be investigated to see how there impact may be eliminated or





changed to come to more satisfactory CTQ values, in other words, to reach an *improvement* in the CTQ values and thus in the satisfaction level about the shutdowns. After the work efficiency has been increased and the shutdowns are running on schedule, steps towards further improvement in terms of the shutdown can be taken.

Objectives for the improvement in the CTQ values should be defined here. First, let us note that any improvement is expected to be a *process*, which implies that achievement of the objectives cannot and may not be expected overnight. Nevertheless, it is a good idea to at least state a period within which the objectives that will be defined below should be achieved. As it is expected that the organization might need to take some far-reaching measures to improve its shutdown procedure, for the acceptance and implementation of which time is needed, the period in which the objectives should be achieved is set to two years.

The ideal delay on schedule is 0. It may seem that a negative figure would be even better as that would mean the shutdown duration would be shorter; however that would mean that the preparation staff would still not have a proper insight into the causes of the differing speed of shutdown finalization. That would mean that there still would not be process control. So the ideal value is 0 minutes of delay, but reality often has surprises in store, so that it may be a better and more realistic idea to use a bandwidth objective for delay: from -30 minutes to +30 minutes compared to the time scheduled. That would be quite an improvement, considering that the average delay on schedule for the regular shutdowns was 190 Minutes in 2007.

For the work efficiency, the objective is a little harder to decide on, as little reference is publicly available for this matter. Luckily, a Dutch company that specializes in work efficiency research, Buro Walravens, was willing to supply some data. The average value for the work efficiency is 60% productive time, of which 33% contributes directly to finalization of the task and 27% contributes indirectly. The definition of productive time and its two categories *direct* and *indirect* will be given in the Measure phase. For now, it is important to know that Buro Walravens uses 84% productive time (55% directly productive and 29% indirectly productive) as an objective value that would represent nearly ideal circumstances. This thesis project will not copy this objective value: although it represents a good goal for long-term improvement, a more reasonably attainable goal may prove more stimulating for the organization in the short run. The objective value can always be raised, whilst lowering an objective value may be rather disappointing and discouraging to those involved in the improvement effort.

The objective will therefore be in the middle of Buro Walravens' empirical average and their 'ideal' value: 72% productive time; at least 43% of which should be directly productive and less than 29% indirectly productive. Further explanation as to why this split between directly and indirectly productive time was chosen is given in the section *Interpretation of the Results* in the subsequent *Measure* part of this report.

Although Buro Walravens has done research at many types of plants ranging from refineries to chemical plants, the figures provided by the company are assumed to be representative for maintenance work in general, whether at the Direct Sheet Plant or elsewhere. This is assumed because at the most detailed level the work activities are quite similar and revolve around wrenching and welding et cetera. What is wrenched or welded is assumed unimportant for the work efficiency that can be reached.

The Measure phase will now be initiated, in which the values currently taken by the CTQs will be measured. The next chapters will explain the methods used to measure the variables and the assumptions that were made to enable the measurements. In the subsequent steps of the DMAIC-methodology in this report, the results will be analyzed to track down causes for





undesired process behaviour in terms of the CTQ, after which approaches for improvement will be defined.

Summarizing, within two years starting from the beginning of the improvement effort taken by the Direct Sheet Plant on the basis of this thesis' recommendations:

Shutdowns should always end within a range of -30 minutes to +30 minutes around the time scheduled originally

The work efficiency level should be characterized by a share dedicated to productive activities (both directly and indirectly productive) of at least 72% of the total shutdown time.

These objectives will also serve as reference points for ex-ante validation by an expert panel at the end of the *Improve* phase.











The *Measure* phase represents the second step on the DMAIC improvement pathway. In this part of the report, the current values of two critical-to-quality (CTQ) variables will be measured. These CTQs are the delay with which shutdowns are finished compared to the schedule, and the work efficiency of maintenance workers during the shutdown. The following chapters will explain the methods followed to measure the variables and will discuss the assumptions that were made. These assumptions are important to keep in mind in later chapters, when the measurement results are interpreted and plans for improvement are made on the basis of these results.








# 9. Measuring current performance levels

The regular shutdowns at the Direct Sheet Plant do not run smoothly but are subject to recurring problems which were already described in the Define step of this report. But so far the problems described were based more on initial presumptions than on measurements or thorough analysis, and root causes representing ways to tackle the problems remained unknown. The *Define* phase resulted in two variables that were not performing satisfactory, but which were critical to the process quality as a whole to the shutdown management team. In order to gain more insight into these variables and their problematic behaviour and to improve the efficiency of the maintenance work, reduce the delays and eventually the performance of the shutdown as a whole, these problems had to be assessed and analysed. Several techniques were put to use to analyse the problem situations. The methods that were put to use in this project will be discussed below. Results of analyses will also be presented. These can then be used for deeper cause-and-effect analysis in the following chapters. This chapter will start by presenting an overview of the Direct Sheet Plant work study by describing and justifying the methods used. Results of the work study will be given and discussed. The remaining ways through which information was collected, such as interviews, will be described at the end of this chapter.

It is important to note that this report will not go as far as to do elaborate statistical analyses with respect to sigma levels, as this would not be very meaningful: as will be shown, the values are almost always outside the satisfaction range of the shutdown management team and are thus not in control. Most importantly, the main reason for using Six Sigma as a theoretical framework for this report is not to know the exact statistics of the process, but to help view the maintenance shutdowns as a process that could and should be controlled to perform in a stable way before any attempts for drastic improvement can be made. Therefore, the deeper statistics matter less in this report.

# 9.1. CTQ #1: Delay

The first and most important critical-to-quality characteristic under investigation in this chapter is the time with which finalization of the shutdown is delayed compared to the schedule made before the start of the shutdown. Some measurement results of this output variable were already shown in the section The Research Problem Revisited in the chapter Theoretical Framework. That figure concerned delays that occurred in 2007. In this section, the delay for 2006 is also taken into account. Figures from before 2006 will not be used, as that period is unrepresentative for and incomparable with the current situation: since 2006, the organization of the shutdowns has been changed quite drastically. Firstly, tasks were rearranged and then assigned differently to the employees, which caused the organization chart to change to its current form as seen before in the chapter Shutdown Organization and Management. Secondly, a shutdown manager was appointed who is still currently in charge. Before his appointment, there was no shutdown manager and the shutdowns had a low managerial focus. These two reasons make figures from before this new organizational structure less useful for analysis in this chapter. Below, we see a bar chart, representing the delays that occurred in 2007. The bars from week 44 are excluded from analysis as this concerns annual shutdowns.





Figure 9.1.: Shutdown finalization delays experienced in and 2007.

The figures on the delay have already been collected by the shutdown manager as a key performance indicator since his start in this position. Simple comparison of the planned time of the start of the casting process versus the actual time of casting start has led to these data. It is important to note this for the following reason.

Using the start of the casting process as a reference point implies that the time to get a pan of liquid steel from the oxysteel plant ready for casting is included. In other words, when the steel plant cannot deliver any steel because of disturbances in their own process, the waiting time caused by the steel plant is added up to delay that was caused internally, within the Direct Sheet Plant's shutdown. For this reason, when confronted with these figures, employees in the shutdown organization and the preparation staff were a little reluctant to accept full responsibility for the delays. It is a fact that part of the delay may be caused by other actors and that these figures may therefore be less representative for the organization and execution of the shutdown than desired. The data will still be used for the analysis however. This due to three reasons.

The first reason for using the data after all is that, if there is any delay at the oxysteel plant, it is often caused by the need to reschedule the order for liquid steel placed by the Direct Sheet Plant's Production division. When the maintenance execution phase is extended beyond its planned finishing time, the Production division has to delay ordering a pan. Then later, when the Direct Sheet Plant is ready to receive the pan, the order for such an especially prepared pan has to fit with the other orders at the steel plant, for instance from the hot-rolling plant. If the Direct Sheet Plant would finish the shutdown on time, the steel plant might be more able to deliver on time as well.

Secondly, it is not often the case that a delay is worsened by delivery issues at the steel plant. The fraction of those occurrences compared to the total delay is small and therefore assumed insignificant. The third reason is one of practicality. These are the only figures that are available right now, and it is impossible to track back how much of the delay was caused within the Direct Sheet Plant and how much was caused outside it. For future measurements it is worth recommending to collect data that only comprises delay caused within the Direct Sheet Plant.

Continuing with the figures, it can be calculated from the data that the average delay over the shutdowns in the year 2007 was 3.2 hours (190 minutes). Unfortunately the figures from the year 2006 have gone missing which is why only the 2007 average delay will serve as a reference point. This is quite a lot more than the newly defined satisfaction range of -30 to +30 minutes compared to the scheduled time. Not once in 2007 did the shutdown achieve to contain its delay within the satisfaction range, so as an objective range it will prove quite a challenge.





The delays experienced now are thus seriously degrading the quality of the shutdown process as perceived by the people shutdown management. Improvement is necessary. With that in mind, attention should now be shifted to the factors that cause the current delays and see whether those causes can be eliminated. That will be done in the *Analyze* part of this report.

# 9.2. CTQ #2: Work Efficiency

The second variable that is critical to the quality of the shutdown process from the perspective of the shutdown management is the efficiency of the maintenance workers. When the efficiency of the maintenance workers could be increased, more work could be done in the valuable shutdown time or shutdowns could finish earlier. Workers might also be sent home earlier, or the shutdown organization could decide to hire fewer people. As the extra personnel is hired on an hourly basis, both options could save the shutdown organization a considerable amount of money. The possibilities for decreasing the shutdown duration and saving on the costs are the main reasons why this process variable will be investigated in further detail here.

Until the start of this thesis project, no collection of work efficiency data had taken place at the Direct Sheet Plant, so the required data had to measured during the shutdown. Defining the work efficiency was not a straightforward process. The efficiency of all individual workers could never be assessed because of their large number and the long duration of the shutdown. Moreover, what does it mean for a maintenance worker to be efficient? Which activities 'count' during the shutdowns and conversely, which activities could be done without with finalization of the shutdown in mind? Because of the extensive explanation needed for the work efficiency measurements, a separate chapter will be dedicated to it. The next chapter will discuss the methods used to collect the efficiency data and will show that efficiency is not a black-and-white concept. It will then proceed with the measurement results and prepare the data results and knowledge collected for use in the *Analyze* phase.









# 10. Work study

This chapter will discuss the details of the measurement phase with respect to the collection of data on the second critical-to-quality characteristic: work efficiency. The maintenance work at the Direct Sheet Plant is supposed to run very efficiently to enable the plant to go back into production as soon as possible and so that it can make the most revenues. In order to measure the current efficiency levels of the work done on the maintenance jobs during shutdowns and to identify the major causes for inefficiencies, a work measurement research is conducted. The general purpose of work measurement studies is to analyze the time spent on work tasks. More specifically they are designed either to set a time standard for known tasks in order to assess the productivity level of workers or to study the proportions of time that workers dedicate to different activities.

For the Direct Sheet Plant, two things are important and form the basic reasons for doing a work study. Firstly, the goal of the Direct Sheet Plant is to know what percentage of time is really spent on the maintenance task during regular shutdowns to have an idea of the urgency to maybe revise parts of the way the shutdowns are currently organized. Secondly, it wants to collect these numbers to serve as a reference point for assessing future efficiency levels. Only then can revised organization practices for shutdowns be tested objectively and quantitatively in the future, to see whether the efforts have really led to improvements.

The most important goal however is to find out what factors in the Direct Sheet Plant's shutdown cause the workers to spend their work time more or less efficient and productive. This more qualitative information could be gathered while doing the quantitative work study.

To measure the desired type of data for the first two goals, a work measurement technique had to be chosen. Below, we will continue with a description of the main available techniques for work studies and choose a methodology that provides the right tools to get the information needed. As was already stated in the final section of the previous chapter, efficiency is not a black-and-white concept, which means that measuring it could be rather difficult and requires a well-conceived approach. The custom-made form of the chosen measurement method for the Direct Sheet Plant will be presented as a result of those considerations. The measurement results will be discussed after the summary of the course of the research. The interpretation of the results forms the final section of this chapter. But first, the thesis will turn to what literature has to say about work study.

# 10.1. Work efficiency and Taylor

One of the first scientist to be involved with the theme work efficiency was Frederick Winslow Taylor (1856-1915). Coincidentally, his interest in the theme was sparked when working as a foreman in a steel plant in the beginning of his career (Jaffee, 2001). He saw human labourers as a factor in the production process that added uncertainty. The cause of this uncertainty was mainly found in the fact that management had less insight into the work processes than the workers had themselves. Because the workers' specialization made them fairly independent in the execution of their work, they could regulate their own work pace. This posed the managers at a disadvantage, because how were they going to know whether the production rate was optimal or whether they could demand more effort form their work at a suboptimal pace. Especially when working in teams, he considered them prone to display a





behaviour he referred to as 'soldiering': pretending to work while in reality loafing (Jaffee, 2001). He proposed to counteract this process of soldiering by increasing the knowledge and insight of management with respect to the work activities. Science, he claimed, could help in reducing labourers to almost mechanical parts of the production line. To make the organization of human labour more scientific, he introduced time and motion studies. These studies were supposed to set standards for the work activities so that managers could assess a worker's work pace and also pick the right person for the job. The chosen workers would be then trained in their job according to rules laid down by management that should ensure use of the optimal method to complete the task.

The results from these time and motion studies were that tasks were standardized and individualized and that extra effort could never lead to promotion, because excellent work would only strengthen the idea that the right person had been chosen for the job and that he or she should not be replaced.

Although this thesis project has also led to a work study, the purpose of this study is explicitly <u>not</u> to be used to standardize maintenance execution tasks or to assess the effort of maintenance workers. The perspective taken in this project is that maintenance workers will work at an appropriate work pace as long as the right circumstances are provided by the shutdown management. Not only does observation during the shutdowns strengthen this outlook on work efficiency, there are also some practical reasons for it.

One practical reason for the believed good moral among workers is that during the shutdowns there is only limited time to do the work the people were hired for. The workers normally know for how many hours they were hired and base their plans for the rest of the day on that schedule, so they do not like to work longer hours than necessary since that requires them to rearrange their social appointments or other work activities. Moreover, if the right circumstances are provided, then the coordinating supervisors are usually too close to the work and too experienced in the maintenance activities to work in a very slow pace intentionally. So at the Direct Sheet Plant, the typical Taylor situation in which the workers can easily mislead the managers does not hold.

Of course, at a later stage in the improvement process, when the right circumstances for the work were always taken care of by the Direct Sheet Plant, strategic behaviour for instance in the form of soldiering could start occurring because of the hourly pay of contracted personnel. The contracts should then be revised or monitoring should be increased. But at this stage, interviews with maintenance workers showed that many of them experience waiting time during the shutdown to an extent that they feel bored at least part of the day. For this reason, intentional suboptimal work is assumed not to occur.

Beside the reasons mentioned for not expecting a low work effort from the workers, there is another reason for not wanting to approach the measurement the Taylorist way: Taylor's vision of people as nearly mechanical parts used in standardized processes conflicts with Six Sigma's vision of a committed, participatory, multi-skilled workforce.

Philosophies such as Total Quality Management have been criticized for their almost Taylorist practices (Hatch, 1997) such as standardizing work tasks. The same criticism could be turned to Lean Manufacturing and more importantly, to Six Sigma, which also promoted standardization of work. The big difference between Taylor and each of these new generation philosophies is that the latter do not aim to constrain the worker. Although they strive for the highest possible work efficiency, they also see the need for a committed and flexible workforce. When treating the workforce as mechanical parts working on one task only, it may





hardly be expected that any enthusiasm for achieving the company goals will be sparked among the workers. Secondly, Taylor ignored the flexibility that Six Sigma and Lean Manufacturing promote by training the employees to develop multiple skills (preferably all skills required in the process) through job rotation.

These fundamental differences between Taylor's view and the view advocated by Six Sigma make it clear that a Taylorist work study does not fit within this thesis. The goal is not to standardize the work activities, set time standards and train the workers accordingly - which would not even be possible given the fact that most workforce during the shutdown is contracted - but rather to study what the current level of the aggregated work efficiency is and, even more important, what factors cause the work to be slowed down or accelerated.

The next section will elaborate a little more on the different work study methodologies that have evolved since Taylor and choose an appropriate method for this specific type of research.

### 10.2. Work measurement techniques

There are several work measurement techniques (Groover, 2007) that will be discussed here. Three of these techniques have the specific goal of setting engineered time standards, much as Taylor proposed. Direct Time Study, Predetermined Motion Time Systems and Standard Data Systems are all techniques that focus on a relatively detailed level of work activities.

Tasks consist of work elements that are in turn made up of basic motion elements, which are physical movements of the worker (Groover, 2007). A Predetermined Motion Time Systems (PMTS) research focuses on the latter category of physical movements and is very useful for the analysis of highly standardized tasks that involve repetitive movements of the workers body. One could for instance think of an assembly line: a PMTS study would then set a standard time for all movements so that standard times for work elements and tasks (in essence nothing more than a set of movements) could be calculated.

The Direct Time Study (DTS) method consists of measuring the amount of time needed to finish a specific task by stopwatch. The analysis level is thus one step up from the basic physical motions as it focuses on tasks instead of single body movements. The analyst also classifies the measured worker's pace, so that the individual worker's performance can be recalculated to a *normal time*, which can then be set as an allowed time for the task.

A Standard Data System (SDS) is not as much a measurement tool as are the former two techniques; instead the system applies measurement data to set normal times for new tasks or to evaluate newly measured worker performance. Using an SDS in fact means using the sampling dataset gathered in a PMTS or DTS study, or figures from other sources such as work sampling studies or historical records. The SDS contains data on work elements in the form of normal times. Calculating the normal time for a task as a whole simply requires summing up the normal times for the tasks' work elements as they are stated in the SDS.

The above techniques are all focused on setting time standards for relatively detailed tasks. The fourth and final work measurement technique, work sampling, has another goal: to identify how work time is spent on different activities. This fits the goals of the Direct Sheet Plant which were stated above in the introduction of this chapter. As this final technique will be put to use in this thesis project, it will be presented in some more detail below.





# 10.3. Work sampling

Work sampling in general is a method to analyze the way that time is proportioned over work productive and less productive activities by classifying the types of activities that are conducted at certain moments during the research time span (The Improvement Encyclopedia, 2007). These activities differ in the way they contribute to the finalization of the maintenance activities, that is to say they are very productive or less productive with the work goal in mind. For instance, the activity of a mechanic turning bolts with a wrench contributes more to finalization of the work task than the activity of that same mechanic chatting with his colleagues about personal matters. By grouping the activities into rough categories, the analyst can measure the percentage of work time that is spent productive.

It is clear from the descriptions of work measurement techniques above that work sampling is the methodology that is most fit to get the results desired: data on how much shutdown time is spent usefully with respect to the maintenance jobs. This is due to two main reasons (Groover, 2007):

- Work sampling is fit to be used when studying more subjects rather than one subject
- The work that is studied is non-repetitive and consists of various tasks rather than one repetitive action.

The maintenance jobs at the Direct Sheet Plant are generally worked on by several people which means that there are also more people to be studied. Most of the work is non-repetitive, save some standard actions such as turning bolts. Work sampling was therefore chosen as the adequate methodology for the Direct Sheet Plant work study.

There is no standard work sampling method however; trade-offs have to be made with respect to the desired accuracy and the time and resources available, so a custom research design needed to be made. Below the design for the work sampling method used during the shutdown of week 51 in 2007 is presented. The resulting design was partly based on the recommendations and tips of Jan Walravens of Buro Walravens, a Dutch consulting agency that specializes in work and time studies.

# 10.4. Custom-made work sampling method

Although work sampling has been chosen as the preferred technique to measure the work efficiency during regular shutdowns at the Direct Sheet Plant, this does not present us with a ready-to-use method. Work sampling can be done in a variety of ways dependent on the subjects at hand, the work they are performing and the available resources to do the measurements. A first example of a design choice for the work sampling routine is to measure at random moments or at fixed intervals. Groover (2007) recommends doing random measurements over time to ensure statistical soundness. The argumentation for this is missing, but probably it has to do with avoiding strategic behaviour of the subjects. This strategic behaviour could for instance manifest itself when workers think their personal work ethic and effort is assessed. These workers could then be overly active in their work compared to their normal work pace, which could influence the results of the sampling study. The Hawthorne-experiments conducted by assistants of management scientist Elton Mayo are a textbook example of how the act of observation itself may influence the behaviour of a subject group (Kelly, 2006; Hatch, 1997). This has led to much discussion on the use of work





studies, for instance between industrial management gurus on the internet. Some claim doing time studies sends the upsetting message to the subject workers that they are not working hard enough (Idhammar, 2007). As Mayo concluded from his partly-failed Hawthorne-experiments, people have emotional needs (for instance for managerial appreciation) that need to be fulfilled in order for them to deliver good work and for organizations to reduce labour turnover, absenteeism and employee discontent (Jaffee, 2001). So if that is indeed the case, sending such an unappreciative message would be counter-effective to the main goal of this thesis: increasing the efficiency of maintenance work during the regular shutdowns. The work sampling instruction book (Van 't Hof, 1965) provided by Buro Walravens mentions no details about a need for random measurements. So, for reasons of practicality and to rule out any bias of the observers, the Corus work measurement project is based on fixed intervals.

The strategic behaviour of the subject workers as described above that could influence the results in case of fixed intervals was taken into account but was assumed to be mitigated by two design choices. It is assumed that the strategic behaviour of workers would be overcome by taking relatively short intervals of roughly 2 minutes. If the workers who are the subject of the work sampling study misunderstand the objective of the study they might display strategic behaviour to make it seem they The subjects were expected not to be able to show strategic behaviour every two minutes, as they would not be able to focus on their tasks anymore. The subjects were not informed about the length of the intervals. Their ignorance of the interval length combined with the frequency of the measurement was expected to greatly reduce the strategic behaviour of the subjects. The assumptions proved to hold in reality, but that will be discussed later when the results are presented.

A second design choice was the definition of activity categories. Activity categories have to defined that are consistent with the research objectives. They have to be mutually exclusive (an activity should only be able to be classified in one category) and clear and recognizable for the observer (Groover, 2007). But satisfying these criteria still leaves a lot of design space with respect to the categories.

How could the categories be defined to be consistent with the research objectives? In some cases, sampling research is done to estimate the percentage of time dedicated to a specific activity, for instance the time a secretary spends answering the phone or how much of is time a mechanic spends on welding. In the case of the Direct Sheet Plant however, there were not any specific maintenance activities that needed to be measured, but rather how much time was spent on activities that were 'useful' with the finalization of the maintenance job in mind. The categories were thus designed to represent four rough grades of usefulness with respect to the maintenance job finalization. An aspect of cause for unproductive activities was incorporated in the final two categories. The next sections will elaborate on the definition of each of the four categories.

### 10.4.1. Activity Categories

The categorization used in the Direct Sheet Plant work sampling project discerned 4 types of activities:

Directly productive





# Unavoidably unproductive

The colour coding of the categories as displayed above was used to indicate the categories on the form to be filled in by the 7 observers. The definition of the categories is presented below.

### **Directly productive**

In the industry, this category goes by many other names, such as 'hands on tools', 'tool time' and 'wrench time'. The category contains all activities that directly contribute to finalization of the maintenance task. As is indicated by the other names for the category, these activities consist mainly of individual tool work.

### Indirectly productive

Another type of activities do not contribute to finalization of the maintenance job themselves, but they are meant to help accomplish the task in an indirect way by providing the right circumstances for the workers to be directly productive. One could think of transportation movements of manpower and materials towards the job site, instructions and discussions on emerging problems, clearing and cleaning of the job site, etcetera.

### Unavoidably unproductive

The third category does not contribute to finalization of the maintenance job in any way and is thus unproductive. But every person in every business sector needs time to go to the toilet, have lunch or a cup of coffee every once in a while. So although this type of activities does not contribute to the accomplishment of the maintenance task in any way, one cannot expect workers to work all day without short sanitary breaks at the minimum. This means that unproductivity for this type of reasons can be considered unavoidable when working with human forces. This category of unproductive actions often goes by the name 'personal time'.

### Avoidably unproductive

The final of the four categories comprises activities of workers that do not add to the progress of the maintenance work in any way, but that cannot to be classified as personal time either. The lack of productivity that comes with these activities should thus be avoidable in theory without harming the worker's personal well-being. Examples of 'activities' that fall into this category are waiting for all kinds of reasons and the time spent on correcting mistakes that were made on the maintenance task (this activity could have been avoided by doing it right the first time!). Taking excessive breaks can also be classified as avoidably unproductive, as can be chatting outside break time or starting late.

Although the categories presented above seem quite clear-cut, in practice it is difficult to decide where to classify some activities. For instance: what to do when two workers take turns in physically demanding work. Strictly following the categorization, one would be waiting for the other to finish and thus be avoidably unproductive, while in reality, there is no other way but for two people to perform the job and rest in turns. Another point of discussion is when personal time is excessive. Is smoking a cigarette personal time or an avoidably





unproductive activity? If not decided on beforehand, the answer to this will vary considerably with whether the analyst that is classifying this behaviour is a smoker himself or not. To make sure the categorization would be done uniformly and as independently as possible of the particular observer's mindset, the categorization of activities was thoroughly discussed among all 7 observers, who all had sufficient knowledge of the Direct Sheet Plant's shutdown but were not in any way responsible for the shutdown's performance and were not involved in its organization.

### 10.4.2. Work sampling procedure week 51

The work sampling research was held in the final shutdown of 2007, week 51. The shutdown was representative for the regular shutdowns at the Direct Sheet Plant, with no anomalies in work load, planned duration or difficulty of the jobs. Three jobs were chosen in consultation with the shutdown manager, one in each of the three sections. The jobs were chosen on the basis of their planned duration because the 7 observers had to be divided over the three jobs and most could only dedicate limited time of their work day to the observations. Jobs representing the critical path for the shutdown duration were deliberately excluded from the observations. These jobs, timely execution of which is essential for finishing the shutdown on time, go by the name *'red thread jobs'* among the Direct Sheet Plant's personnel. Every section has one red thread job per shutdown and priority is attributed to these jobs to ensure their flow. As their special prioritised status frequently gets them extra attention and resources, which could influence the measurements, these jobs were excluded from the measurements.

A few days prior to the shutdown, the shutdown coordinators of all three sections were informed about the planned observations and asked for their consent. They were asked to brief the relevant coordinating and hierarchical coordinators, who in turn had to brief their workers.

On the shutdown day, the observers went to the jobs they were assigned and introduced themselves and their project once more to the maintenance execution group. They were free to pick two workers who they followed throughout their observation shift. The workers were chosen randomly but generally the observer chose two people working in close proximity of each other (possibly on the same part of the job) to facilitate the observations. When a new observer took over the observations, he was informed on which workers to observe so that the same workers were followed and possible efficiency fluctuations and their causes in the course of the day were registered.

The observers took an unobtrusive position at some distance from the two workers and categorized both their actions into the four groups every two minutes. In the few cases where the observer could not visually identify the activity or in some cases the causes for a lack of productivity, he asked for clarification, but other than that social interactions were kept to a minimum. There were two reasons for this: firstly, the observations were not to hinder the course of the work and secondly, mutual influences between observers and subjects could bias the observation results.

The scores on each of the activity categories of all observers were combined into one measurement report. The data results and the observers' qualitative observations will be discussed in the subsequent sections.



# 10.5. Data results and observations work sampling

The work sampling project resulted in 1539 observations combined over all three sections and a number of qualitative observations on the causes of unproductive activities. The circle diagram below displays the observed percentages taken by the categories without the statistical treatment. As can be seen quite clearly from the circle diagram, less than half of the maintenance downtime is used efficiently and productively in achieving the workers' main goal: finishing the maintenance work.



### Figure 10.1.: Work sampling project week 51: (in)efficient use of maintenance downtime

The binomial distribution serves as the statistical basis for work sampling but in the case of sufficient observations, it may be recalculated to a normal distribution. This simplifies the calculation of 95%-confidence intervals. Below, the 95%-confidence intervals of all four categories are presented. Calculations and the actual observation data can be found in Appendix B. The 95%-confidence intervals represent the percentages of time that are on average spent on activities in the four categories presented earlier.

95%-confidence intervals	Lower bound	Upper bound	
Directly productive	21,84%	26,11%	
Indirectly productive	23,29%	27,65%	
Unavoidably unproductive	17,45%	21,40%	
Avoidably unproductive	28,81%	33,44%	

The confidence intervals are used to rule out statistical error of the observations. The intervals give a 95% reliability that the actual value of the time spent in the four categories is somewhere between the upper and lower values. The next section will discuss these results from a more qualitative angle.



# 10.6. Interpretation of the results

In the previous section, the results of the work efficiency measurement were presented. It is not as easy as it seems to interpret these results correctly, when no reference is provided. The necessary reference is therefore provided by the data supplied by Buro Walravens. Below, their empirically found average values for the four categories are now compared to what was found at the Direct Sheet Plant. As the definition of the categories and the way of measuring were based on Buro Walravens' methods, it is assumed that the comparison is fair.

Work sampling categories	Direct Sheet Plant	Average (Buro Walravens)	Goal
Directly productive	24%	33%	43%
Indirectly productive	25%	27%	29%
Unavoidably unproductive	19%	10%	10%
Avoidably unproductive	31%	30%	18%

When we compare the results from the work sampling project in the left column with the averages in the right column, two categories attract attention. First of all, the green category *directly productive* takes up significantly less time than it does in an average maintenance shutdown. Since the time that was spent *directly productive* contributes most to achievement of the goal, that is finishing the planned maintenance work, a higher percentage is highly desirable. The directly productive category takes up much less time than it does on average, so the shutdown organization seems to have a reasonable ground for its discontent regarding the work efficiency. When comparing the current score with the objective values that were defined earlier in the section *Objectives statement* at the end of the *Define* phase, it shows that an improvement of almost 20% is needed for the category of work that directly contributes to finalization of the maintenance.

The second category in which the measurement results show quite a difference compared to the average and objective value for the unavoidably unproductive time, also known as personal time. The high value measured at the Direct Sheet Plant is also a reason for discontent, because this percentage, being unproductive, should be lowered to a reasonable percentage from the perception of workers. And as can be seen when looking at the average from Buro Walravens (which the company also uses as the norm percentage for personal time), people apparently do not need more than 10% of their time for personal use in terms of going to the bathroom or taking a short break.

The percentage of personal time taken up at the Direct Sheet Plant's shutdown is thus very high; and it is assumed that at least a part of this personal time could also be classified as waiting time. This issue was also mentioned by some the observers. When people have to wait anyway, it is tempting to smoke a cigarette or have a coffee while waiting. Although the observers tried their best to separate this 'waiting time in disguise' from personal time, some of the excess personal time compared to the norm may be explained this way. For instance, one observer mentioned that the cause for the waiting time was removed right after the workers had left for an extra cup of coffee to make their expected waiting time a little more





pleasant. From that point on, he (correctly) counted their absence as personal time. So in short, when adding up such dubious cases, some of the unavoidably unproductive time taken up could have been avoided after all. It is also assumed that some of the indirect work done, especially cleaning up during the execution of a job was actually veiled waiting time. If these assumptions are valid, the percentage of avoidably unproductive time should be reduced by more than the 1% currently indicated in the table.

A last remark should be made concerning the objective values in the utmost right column. An explanation for the split among the categories chosen in the *Define* phase was still owed to the reader. The most interesting question is: why is the percentage for indirectly productive work increased, but by a much lesser degree than the directly productive time?

To answer that question, it is necessary to remember what type of activities were categorized as *indirectly productive*. Examples in the yellow category are transportation of goods or workers *towards* the job site, getting the tools ready for use, getting or receiving instructions, discussion on problems to be solved, and cleaning up. Usually, a high percentage of *indirectly productive* time indicates a poor to mediocre preparation of the work (Walravens, 2006). This sounds fairly logical, because as shutdown time is expensive due to the loss of income incurred by the lack of production, all work that could reasonably be done before the start of the shutdown, i.e. during the preparation phase, should not be done during the shutdown. In many cases, the time spent on instructions are a particularly good example of such an activity that is classified as an *indirectly productive* activity but could also be characterized as avoidable, at least during the shutdown. This implies a lower share for the *indirectly productive* category of activities is desirable.

On the other hand, *directly productive* activities always entail some indirectly contributing work, for instance cleaning needed during the job. So if the share of *directly productive* time is increased, the share taken up for *indirectly productive* activities is expected to rise as well.

When the two notions on *indirectly productive* activities are combined, it appears that this category contains both reasonably avoidable as well as unavoidable components when the costliness of shutdown time plays a role as a background.

Consequently, because of the increase desired in the category of *directly productive* activities, the *indirectly productive* category is allowed to take a larger share in the objectives stated due to its unavoidable components, but as the avoidable components should be minimized, the indirect category should grow by a much lesser degree than the direct category.

As for the other categories, the objective for the personal time is based on Buro Walravens norm value; the *avoidably unproductive* category is simply what is left of the 100%.

The next section closes this chapter and mirrors the current performance with the objectives to see what this means in terms of the magnitude of the improvement required.

### 10.6.1. Relative objectives

Although the objectives were already stated at the end of the *Define* part of this report, at that point there were not any clues as to what that would mean in terms of the relative improvement needed: the current performance was still unknown. Now, with the current performance levels specified, it is wise to reflect on the objectives to be achieved within two years.

For CTQ #1 it means that the average delay has to be brought back from 190 minutes to 0 minutes. For CTQ #2 it means that the work efficiency has to be improved from 49% to 72%, which means an increase of 23% is required.





This concludes the *Measure* phase. So far, the current scores on the critical-to-quality (CTQ) variables have been measured and interpreted. Also, the necessary improvement was indicated, but the question as to how the current values are caused remains unanswered. The next part of this report will describe the *Analyze* phase, which picks up from here and continues by searching for root causes for the CTQ variable behaviour.









# Analyze

The previous part of this report left us with a number of questions. In the *Measure* phase, the current scores on the critical-to-quality variables defined by the members of the shutdown management were measured. Subsequent interpretations indicated that the performance of both variables should be improved significantly to achieve the objective values. But how should any improvement be realized when the causes for the undesired process outcome are unclear?

This part of the report picks up where the *Measure* phase left off and employs several analysis methods to find root causes that impact the current disappointing performances of the two critical-to-quality variables chosen for improvement in the *Define* phase. In doing so, the *Analyze* phase aims to provide a basis for the improvement approaches designed in the subsequent *Improve* phase.









# 11. Starting points for improvement

In the previous chapters, it was described what regular shutdowns are, what they are for, how they are organized and how they are supposed to run. But as the words 'supposed to' already indicate, reality may well be different. Two variables which performances have a large impact on the level of satisfaction of the members of shutdown management were investigated. Figures on their current performance indeed indicated that improvement was needed. But numbers and figures alone do not provide a good starting point for improvement. The data needs to be complemented with information on what is causing the process to perform the way it does.

This chapter starts the *Analyze* phase off with a description of how information was gathered to provide insight into the data previously measured. It ends with a generic causal analysis that provides a basis for the next chapter, which continues with the main activity in the *Analyze* phase: the root cause analysis.

# 11.1. Semi- structured Interviews and DILO's

The information that provides a basis for the root cause analyses was gathered in a number of ways. Firstly, observation during the preparation phase and the shutdown as well as during the evaluation sessions can give even an outsider to the process a good idea of what is not going as it should in the shutdown procedure. Insights gained from these unobtrusive observations were combined with information from semi-structured interviews with all sorts of people involved in the shutdown, ranging from contracted foremen and maintenance workers to in-house workers, maintenance specialists and shutdown management members. The information from these interviews mostly confirmed the things concluded from the observations, but in some cases they brought new insights into what was observed.

For the semi-structured interviews, a list of questions was made that could help to investigate certain areas in which there was a lack of insight. Also some of the questions were supposed to be used to harvest the ideas of the people that work in and with the processes under investigation every day (or rather, once every four weeks). Appendix C displays a list of questions that were asked to more or less random people during the shutdown. It should be emphasized that not all questions were asked to everyone and that sometimes questions were asked that were not on the list. The experience and cooperation of the respondent but also the focus of the respondent (which may change during the day as more information is gained) is decisive in where the conversation leads.

Other valuable insights were gained in so-called *DILOs*. *DILO* is an acronym for Day In the Life Of, and constitutes a day in which the researcher tags along with a person involved in the process under investigation, to see what that person comes across in a day's work. A *DILO* thus combines the opportunity to interview the employee all day long with the chance to do observations that may not be easy to do otherwise. It can also make the employee's behaviour with respect to proposed changes (for instance due to improvement projects) more insightful, so that their ideas and desires can be incorporated in the design for solutions.

Three DILOs were conducted for this research project: twice, the subject was the shutdown manager and once a maintenance specialist was followed. They were followed right from the beginning to the end of their work day, so that every aspect of their work could be considered for the project.





The problem with DILOs and semi-structured interviews is that the reproducibility of their exact results is low: a lot of the results depend on the specific circumstances of that day. Subjectivity of the observer also plays a role, for instance in choosing who to interview and what questions to ask the person. Despite the downside pertaining to the low reproducibility of there results, DILOs and semi-structured interviews can be valuable to help the researcher or project team to gain insights into the process using inside information. The following chapters and paragraphs in this *Analyze* part of the report will use the information from the observations, interviews and *DILOs*.

The next section contains an initial cause-and-effect diagram that includes a number of causes for some problematic effects, such rising costs and delay on schedule and the low work efficiency.

### 11.2. Initial cause-and-effect diagram

The information that was gathered either parallel to the measurement data or in stand-alone interviews or observations has been combined into a large diagram which links factors in the shutdown to each other in cause and effect relationships. The CTQ variables are printed in bold letters. As the diagram shows, increased delay on schedule and decreased work efficiency both lead to increasing costs for the Direct Sheet Plant, which is of course a most undesirable effect from a commercial standpoint.

The cause-and-effect diagram displays arrows pointing from the cause to the effect. The + and – symbols that are shown in the middle of the arrows indicate the positive or negative effect one factor has on the other. As an example, the effect of breaks on the work efficiency should be read as follows: *an increasing number of breaks will lead to a decreasing level of the work efficiency*.

The factors have been clarified by the use of units that are placed between square brackets. In some cases, the brackets are empty; in these cases the factors are ordinal variables, the value of which can be assessed within the shutdown organization. An example of this is the quality of the work instructions, the organization can easily assess on experience whether these are good, mediocre or poor, whereas a quantifiable unit can not be found that is representative of the concept of quality of a work instruction.







Figure 11.1.: Initial cause-and-effect diagram of the shutdown problems

Explanations for the most interesting (in other words, less obvious) cause-and-effect relationships are given in Appendix D.

This type of diagram can be helpful, but in complicated situations like the shutdown problems at the Direct Sheet Plant, their appearance can become unclear. Especially when a greater level of detail is required, these types of diagrams are not suitable. They are also not especially fit for finding root causes, which is the main objective of this part of the report. The next chapter will introduce more suitable methods for finding root causes and put them to use.

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# 12. Root cause analysis

Root cause analysis is a central tool within Six Sigma as it identifies the factors that (negatively) impact relevant process indicators, so that they can be treated to improve the process output. Root cause analysis (often shortened to RCA) makes sure that the *roots* of problems are eliminated, instead of treating the symptoms which will lead to the problems recurring. Taking the problem's roots away guarantees a long-term improvement. RCA is therefore not only important in Six Sigma but also in many other philosophies; some authors even go as far as to call it the Holy Grail for problem solving (Borris, 2006). This thesis combines two root cause analysis methods, which will be described in the next section.

# 12.1. The 5-Why method and Ishikawa diagramming

One of the easiest and most applied RCA techniques is the 5-Why method developed by the Toyota company. It is popular in use because it requires no technical skill and is easy to use for all sorts of people (Borris, 2006) involved in the improvement process. This does not mean that RCA users do not need to know much about the problem; as RCA uses a well-defined problem statement as its input, they need to be quite well-informed on the stated problem. For this reason, the technique is usually not applied for exploratory objectives such as the problem definition, but generally enters the problem solving arena at a later stage (Tang et al., 2007).

The method is so simple that it might make one wonder if it deserves the name 'method', but at the same time this simplicity may be its strongest feature, leading to high acceptance rate (Borris, 2006; Tang et al., 2007). The method's name says it all: root causes to any problem should in theory always be found when asking the question 'why?' five times in a row, much like a toddler would do. Although it is called the 5-why method, there is no fixed rule as to how many times the question should be repeated: sometimes five times will do, at other times the root cause is much deeper and 8 whys may be required.

The method takes a problem statement as its starting point and works its way back to the root cause. An (entirely fictitious) example:

'The maintenance to the rolling section is experiencing delay'. Why? 'A roll that needs to be replaced cannot be taken out of the stand'. Why? 'The new bolts that we tried out last time that attach the roll to the stand will not come loose'. Why? 'They are bent too much'. Why? 'Apparently the bolts are too weak for forces as high as in the rolling stand'. Why? 'The material they are made of is too ductile'.

The example demonstrates how the 5-Why method can very simply lead us from a problem to its root cause: the material of experimental new bolts is too ductile for use in the stands. Elimination of this root cause is now easy: this type of bolts will never be used again, so that they can never cause a maintenance delay again.

In many cases elimination of root causes may be less easy, but in general the method always leads to a root cause that can be acted on by the problem owner. There is a downside of the 5-Why method however, which is that answering the question 'Why?' five times will generally





lead to one root cause at a time, while in fact a problem may well stem from several causes. To ensure that all root causes to a problem are found, this thesis combines the 5-Why method with another well known analysis technique: *Ishikawa diagrams*.

These diagrams, which plotted form has earned them the nickname fishbone diagrams, acknowledge the fact that a problem might stem for more than one cause. This characteristic makes it an excellent supplement for the 5 why-method, use of which can lead for some causes to be overlooked. Fishbone diagrams force the analyst to work systematically, which gives less chance for overlooking important causal factors.

A sample fishbone diagram is displayed below. Arrows connect the main causes or root causes to a central arrow that combines all causes and leads to one effect displayed on the right of the diagram. Standard diagram types exist, for instance the M<sup>5</sup>E type in which the arrow ends have been filled in with the 'cause categories' *Man, Machine, Method, Measurement, Material* and *Environment*; these standard types can be a good guideline to make sure that these directions are considered (Tang et al., 2007). On the other hand, it seems likely that such standard types could also constrain the analyst.



Figure 12.1.: A sample Ishikawa (fishbone) diagram (University of Hong Kong, 2008)

Therefore, the mentioned standard cause categories are kept in mind, but the standard diagram is not used. The combined use of the 5-Why method and the fishbone diagrams is expected to lead to the best of both worlds: not only will the 5-Why method make sure that the right root causes are found, the fishbone diagram will mitigate the risks that other root causes are overlooked and display the cause-and-effect relationship in a clarifying way.

The next section will discuss the results from this combined root cause analysis conducted for the two problems that were chosen in the *Define* phase: the critical-to-quality delay that is scoring too high and the critical-to-quality work efficiency that is scoring too low.

# 12.2. Root cause analysis for CTQ # 1: delay

Delay on schedule is the biggest shutdown problem from the perspective of the shutdown management members. The absence of delay is critical-to-quality. In this section, delay is regarded as an effect for which several causes may apply. However, delay itself can also be a cause for other effects; for instance, the costs of the shutdown rise with the lack of income



that is incurred in the extra shutdown hours and personnel has to be paid for the extra time as well. Still in this case, the focus will be on delay as an effect rather than a cause. The next figure represents the Ishikawa diagram for the problematic effect that the finalization of shutdown activities is sometimes delayed.



Figure 12.2.: Ishikawa diagram representing the possible causes for delay of shutdown activities.

The graph shows us that there is indeed a large variety of causes for the delay that is experienced during the regular shutdowns at the Direct Sheet Plant. Still, four cause categories can be defined that largely comprise the complex structures of deeper causes and effects: *Unforeseen technical problems*; *Progress communication*; *Planning and Preparation* and *Resources*.

The categories each include a number of causes that in turn may be caused by something else. The deepest causes are represented by the smallest oblique arrows; these will be considered the root causes. Only in one case will a horizontal arrow be considered the root cause because its deeper causes are very disaggregated and work in a complex combined manner. Later, the deepest oblique causes can help in how to tackle the root causes in the *Improve* phase.

As can be seen, some factors are mentioned several times, in different categories or on different levels of the cause-and-effect structure. This has been allowed as the fishbone diagram does not include rules on repetition of factors; moreover, it is the most realistic representation of the actual causes and effects. The next sections will take you through the four categories one by one to explain how the indicated factors influence each other and how they work together to cause a delay of the finalization of the shutdown maintenance activities.

# 12.2.1. Unforeseen technical problems

As was explained in the chapter *Technology of the Direct Sheet* Plant, the Direct Sheet Plant is a complex combination of interrelated machinery operating under extremely heavy





circumstances in terms of temperature, pressure and speed. The production process puts a strain on the equipment and components may bend or break. Although many inspection rounds are held, it may still happen that technical problems remain unforeseen as they are for instance not visible from the outside. An example of such an unforeseen problem is when the hook of a crane in the Caster department had to be replaced, but could not be taken out due to a badly bent axis.

In case of such unforeseen problems, the section shutdown organization has to decide for itself whether or not execution of the job is still possible within that shutdown, for example with the use of other tools, or that the job has to be cancelled. This decision process takes quite a long time as the problem may be so complicated that people do not have sufficient installation-specific technical knowledge or experience yet: the plant is only ten years old and things may occur that have not occurred before. That usually means that drawings of the equipment have to be analyzed which can be a time-consuming activity.

The lack of a predetermined solution set for technical problems means that every problem has to be considered separately; no guidelines exist that could speed up the decision process. A guideline could for instance be to determine a time standard that helps in deciding when to cancel a job: if the expected extra time needed is more than ... hours then the job is cancelled.

If the section decides to continue the job, arrangements will have to be made for other tools, materials or experienced specialists to come into the plant. The Improve part of this report will elaborate on a solution set in more detail.

### 12.2.2. Progress communication

Another rough category of delay-causing factors can be characterized as *Progress Communication*. The shutdown manager, who is in charge of the shutdown process and its timely finalization, is supposed to receive progress updates from the section shutdown coordinators who in turn are updated by their coordinating supervisors. The idea is that the shutdown manager is notified as soon as possible in case of any delay so that he can organize all activities optimally to mitigate the delay's effects and keep the total delay at a minimum. But in reality, the supervisors rarely communicate with their section coordinators other than at the progress meetings they have twice a day, at 10:00am and at 3:00pm.

When problems arise, the supervisors often try to sort them out themselves and they keep their communication restricted to people working on the job, such as foremen. Only if they run into problems for which they need extra resources do they communicate to their superiors. So they communicate to superiors for help, but forget that their jobs are part of a bigger whole and that shutdown management wants to know how things are going. Their sense of independence of the total shutdown causes a lack of the feeling of urgency to communicate to shutdown management.

Another reason that they do not feel pressure to communicate is that the schedule for most jobs has a very low level of detail. Jobs are often planned for 8 hours, without any *milestones* that serve as a reference point for progress. A *milestone* indicates the completion of a work task within a project. Many tasks in the Direct Sheet Plant's shutdown planning do not have a schedule in which the work is split up into separate phases or tasks and only the time of completion of the total job can be compared to the scheduled time. Assessing how well the job is going according to schedule is mostly a matter of experience and subjective opinion.





The lack of factual reference points causes that the supervisors seldom feel urged to communicate possible delays.

The current communication patterns do not help the timely and objective reporting of progress either. As supervisors are generally involved in several jobs asking for their attention, they are often too busy to even think about reporting delay to their section coordinator. They only do so at the two progress meetings. The section coordinators in turn have a rather passive approach to progress information: the rule is that the supervisors inform them, not that they go to the job sites to collect the information firsthand. In several cases, observations showed that when the section coordinator made visits to the job sites, they got the information they needed more readily. Changing the passive pattern may therefore help solve the delay problem, as we will see in the *Improve* phase.

### 12.2.3. Planning and preparation

One of the most influential categories for the factors that cause delay is the category *Planning and Preparation*. Even the some of the other categories contain factors that can ultimately be traced back to factors in this category. The lack of a detailed schedule is a problematic issue that is also a cause for the lack of urgency for communication explained above. Aside from that, the lack of detail in the schedule means that the preparation staff can easily overlook any interactions that jobs may have in terms of the use of scarce resources, such as cranes or scaffolding workers. The absence of a need to specify clearly what needs to be done (where, how, by whom and with what tools and resources) makes job interactions more likely. When jobs simultaneously need to make use of scarce resources, this often leads to at least one group of workers having to wait, which causes delays.

There is also a lack of a visual planning in which all the jobs within a section are represented. This means that people may plan maintenance jobs above another job prepared by someone else. On the day itself, supervisors may discover dangerous interactions, which lead to unsafe work; imagine for instance a welding job where hot metal parts may fall down on workers below.

The lack of a detailed schedule thus has an enormous impact on the maintenance delay experienced at the plant. The unspecified nature of the schedule has a large variety of causes. First of all, the competitive job market has left the Direct Sheet Plant with a workforce that can only just manage. The people on the preparation staff do not have a lot of time to detail their jobs. On the other hand, there is also a lack of effort to specify the jobs more carefully, as the preparation staff does not really see the need for more detail in the planning: they trust that the current level of detail is enough for the supervisors to manage the job. And they are hardly likely to get any complaints, because in most cases, on the shutdown day the maintenance specialist and work preparation employees take the role of coordinating supervisors for the work they prepared. They are thus scheduling for their own use, and they do not see that other people in the shutdown organization need factual and objective progress reports that come from comparison with a detailed schedule.

The work preparation staff members also rely on their experience for planning the work for a subsequent time; they do not use an evaluation or feedback system that helps them to tweak the planning for next time. So for that they do not need a detailed schedule either.

There is no regulation that stipulates that the planning contain a standard number of *milestones* per time unit and although shutdown managers have indicated that they would



prefer a much more detailed planning and preparation of the work, nobody really checks the schedule for its detail level in advance.

So much of it depends on the effort the preparation staff wants to put in for something they do not see the need for, since they are the users of their own schedule on the shutdown day. Another factor that influences the level of detail of the schedule is the experience the preparation staff has with the installation. The relatively young age of the plant means that the shutdowns may still contain a few maintenance jobs that have never been done before, which makes scheduling more of an estimation than a matter of informed planning. But also routine jobs may be difficult to plan for someone new on the preparation staff, as little detailed information is kept on the course of the same job in earlier shutdowns. The preparation work thus depends heavily on experience, but when experience is lacking, this becomes a problem.

Another cause for delay in the *Planning and Preparation* category is more related to preparation than it is to planning and scheduling. The preparation of the shutdown day in terms of materials could do with some more attention as was confirmed by maintenance workers in several shutdowns. The material they needed (either tools or replacement components of the equipment) was not ready for use. In some cases, this was due to a poor organization and labelling within the storage room. In other cases, it appeared that the materials had not been delivered on time. For materials that have been ordered but have not been delivered yet, there is a rule that it has to be in at least 5 days prior to the shutdown day or else the job has to be cancelled to avoid idle workers at the plant. But in practice it is often too tempting to wait and see whether the parts will still come in just before the shutdown and the preparation staff do not cancel the job. In both cases, there are people waiting and searching for solutions. This also causes delay also for other jobs that interact.

The causal factors in *Planning and Preparation* category are assumed to be the most influential for the timely execution of the shutdown. That will also become clear in the next section.

### 12.2.4. Resources

To a large extent, this final category of causes for delay is caused by factors that fall into the *Planning and Preparation* category. The shutdowns always contain resources that have to be shared among the jobs. These resources include scaffolding and cleaning workers that provide the right circumstances for the maintenance workers to do their job in, but also cranes and fork-lifts. The sharing of these resources causes jobs to interact, which may lead to delay. Often, the management of the scaffolding and cleaning activities is rather ad-hoc: if their activities are scheduled for all jobs, then the schedule is hardly obeyed. The workers are sent to wherever they are required, but other jobs may then be left waiting. The scaffolds also need to be checked for safety reasons, but there are not many people who are certified to do that. Until the scaffolds have been checked, it is not allowed to use them, so when the certified inspector takes a long time to come and check the scaffolds, this may cause delay.

The fixed hall crane is also a resource that often leads to delay. There is only one such crane per section which can lift the most heavy components and carry them over the top of the installation. This scarcity and the fact that different jobs may need to make use of it at the same time leads to delay.



This concludes the root cause analysis for the shutdown delays. The next section will define which root cause are suitable for improvement, so that the *Improve* phase can build on these findings.

## 12.2.5. Root causes for delay

To sum the above information up, there are many causes for delayed shutdown activities. In fact, there are so many causes that it would be somewhat of a utopia to eliminate them all at once. This section will define the most promising factors in terms of opportunity for improvement and effect on the delay. In general this means that the most frequently occurring and most influential causes will be promoted for improvement in the *Improve* part of the report. They are indicated in red print in the figure below.



Figure 12.3.: The same Ishikawa diagram for delay, this time with red labels indicating the best possibilities for improvement.

Many other causes in the figure remain printed in black and will thus not be eliminated in this thesis. Reasons for their non-selection differ. In some cases, improvement possibilities are already investigated. For instance, at the moment Corus is investigating the possibilities for a second fixed crane in the rolling section which would reduce the number of *scarce resources*. Meanwhile, the Corus Training Centre is doing research on skills and craftsmanship in order to reduce the *lack of installation experience*. Other causes just cannot be treated, such as the *Invisibility to inspection* of some faults in components. The workload of supervisors is also expected to be too difficult to influence sufficiently within two years due to the extremely competitive job market for technical personnel.

The root causes that remain in red are assumed to be fit to be treated with success. The most influential causes for the critical-to-quality variable delay are related to a category that could be described as *Planning and Preparation*. The lack of a detailed schedule is the major root cause for delay as it manifests in many factors that cause delay such as job interactions over scarce resources and the lack of a feeling of urgency to report delay. The deeper causes for the lack of a detailed schedule provide a foothold for improvement efforts.





Also in the category *Planning and Preparation*, a the lack of a visual planning makes it easy to overlook possible undesired job interactions beforehand. Ideas for a visual planing will be worked out in the *Improve* part of the report.

The current lack of progress communication is also a cause for root cause for delay, or rather a cause for the inability to reduce the delay to a minimum. The communication should be improved by tackling the root causes that take the form of a passive approach to progress communication and a low frequency of predetermined communication moments.

Last but not least, it is expected that much could be gained from an effective strategy to mitigate the effects of unavoidable technical problems. A predetermined solution set to avoid or decrease delays will therefore be investigated in the *Improve* phase.

This concludes the discussion of the root causes for delay. The *Improve* phase will try to influence the red causes in a way that will ultimately promote reduction of the delay of finalization of the shutdown activities. But first, the next paragraph will conduct another root cause analysis, this time for the low work efficiency experienced during the shutdowns.

# 12.3. Root cause analysis for CTQ #2: low work efficiency

The fishbone diagram displayed below represent the causes for the second critical-to-quality variable that performs poorly: the work efficiency. The low work efficiency is a problem as it negatively influences the moral of the workers. Also, a low work efficiency compared to the industry average may indicate that too much money is spent on labour: the workers should be able to do the work in less time or with less people. Workers hanging around idle on the work site are an eyesore for shutdown management, who want to preserve an atmosphere of productivity and keep the plant organized. Idle workers sometimes obstruct the work of other work efficiency. As will be seen in the next section, many causes for a low work efficiency are heavily interrelated with the causes for delay investigated earlier.

The next figure displays the cause-and-effect structure for the low work efficiency experienced during the maintenance execution phase at the Direct Sheet Plant. Since less factors apply to this critical-to-quality variable, the diagram could be made at a higher level of detail while still being clear. This time, the root causes are represented by the horizontal factors that influence the smaller oblique ones. This means that the level of detail is generally one step higher than in the *delay* fishbone diagram.







Figure 12.4.: Ishikawa diagram for the low work efficiency during the maintenance execution phase

# 12.3.1. Breaks

*Breaks, the first category of factors causing a low work efficiency is the only category that is related to the work ethic of the maintenance workers and their foremen. When people take excessively long breaks, they will not be able to spend as high a percentage of their time on the maintenance work. Although most of the workers take regular breaks, some contracted personnel takes longer than average breaks which they spend on other locations. Although shutdown management has explicitly indicated that personnel is to take breaks on the work site, some contractors hold on to their habit of relocating to a place outside the plant. This is not necessary as during the shutdown, part of the plant is rearranged into a seating area and coffee and tea is provided.* 

The root cause for the undesired behaviour of taking breaks outside the plant is probably due to the company culture of the contractors and the fact that the contracts do not include strict regulations on where to take breaks.

# 12.3.2. Job interactions

As was explained in the earlier root cause analysis for the first critical-to-quality variable, delay, job interactions often lead to delay. For similar reasons, job interactions may lead to a low work efficiency. First of all, the scaffolding and cleaning activities are planned relatively ad-hoc. When cleaning or scaffolding is required, the workers responsible for this need to be called in. If they cannot execute the required task immediately, waiting time may result for the maintenance workers. This ad-hoc organization is not always optimal and is caused by the lack of a detailed schedule for these work activities.

Another undesired effect of job interactions is that there is too little space to work. The spaces within the installation are too small to allow for many people to execute maintenance in the small spaces simultaneously. Because of the relatively low detail of the work preparation, the preparation staff is more likely to incorporate extra slack, also in terms of workforce. When too many people are hired, they will be in each other's way, which reduces their work pace and thus lowers the work efficiency that can be attained.



As was also explained in the root cause analysis for *delay*, the job interactions may lead to waiting time related to the use of scarce resources such as the fixed crane. Similarly to what was described earlier, the lack of a detailed schedule increase chances that such undesired waiting time results from the interactions of jobs that need to share resources.

The last factor in the category of *Job interactions* that may cause a lower work efficiency is related to the issue of work safety. The Direct Sheet Plant is very strict where it comes to safety and takes pride in its low level of work accidents. Remembering the welding example of the previous root cause analysis, it is easy to see how the proximity of one job to another may lead to unsafe situations, for which the work of at least one of the jobs has to be stopped temporarily. The waiting time resulting from this reduces the work efficiency. The lack of a visual planning makes it harder to identify possibly unsafe situations in the preparation phase.

### 12.3.3.Materials

Finally, the workers experience waiting time and therefore a reduced work efficiency due to the absence of materials. Either the materials are not in yet, or the materials are in but are lost. The loss of materials is caused by a poor organization of the material storage. The example below of two contracted maintenance workers illustrates this type of waiting time, as well as the waiting time caused by job interactions. Although this is an example from the annual shutdown, such experiences are frequent in the regular shutdowns as well.

10:30am: 'A few days ago I dropped our materials off here at the plant, but now they [people from the Direct Sheet Plant] seem to have lost it. They've been searching our stuff for over an hour now! We have nothing else to do... By the way, we've been waiting since 7:00am, because for the first job we were supposed to do in the cooling basin, the cleaners were not ready. They are in the basin with brooms right now, but it seems they still have a lot of work to do. I wonder if we can execute our job today.'

The next section will define which root causes are chosen to be improved within the scope of this report.

### 12.3.4.Root causes for the low work efficiency

Similarly to what was explained in the root cause analysis for the first critical-to-quality variable, not all root causes are equally suitable for the organization to direct its improvement efforts on. This time too, a selection is made of causes for the low work efficiency that are to be eliminated or at least mitigated. The selection of causes that will be treated by solutions in the following *Improve* part of this report are indicated in red print in the fishbone diagram below.





Figure 12.5.: The Ishikawa diagram for the problematic low work efficiency; selection of causes to improved within this project indicated in red.

The 5 red labels are actually 3 root causes, 2 of which were already selected in the first root cause analysis: *lack of detailed schedule* and *lack of visual planning*. The final root cause selected here was also selected in the previous analysis, albeit implicitly and with a different focus than here: *planning for own use; slack incorporation* is one of the deeper causes for the lack of a detailed schedule in the previous root cause analysis. There, it regards slack incorporation in terms of the planned duration for activities. Here slack incorporation in terms of manpower is meant.

The organization of the storage room is outside the scope of the storage rooms; a investigation has already been done by another student. The contracts for external workforce are also outside the scope of this thesis: it is recommended that the contracts are revised in total, also with respect to incentives such as bonuses. The *Control* phase will come back to this. Finally, the company culture of contracted firms is assumed to be too hard to change within the next two years, this root cause is therefore also discarded in terms of fitness for improvement efforts.

The root causes that should be treated with the objective of improvement in the two critical-toquality variables have now been defined. The next section provides a short overview of the chosen root causes once more, before the report continues with the *Improve* part in which improvement strategies are proposed that aim specifically to eliminate the root causes of the unsatisfactory performance of the shutdown variables.

# 12.4. Summary of the root cause analysis

This chapter defined root causes for two variables critical to the quality of the shutdown processes in the perspective of members of shutdown management but that perform unsatisfactory: the *delay* that is currently too high and the *work efficiency* that is currently too





low. Ishikawa diagrams and the 5-Why method helped define the root causes to the problems with these two variables' performances. A selection of root causes was made that are most suitable for improvement efforts from the Direct Sheet Plant.

Improvement efforts should target the following root causes:

- the lack of a detailed schedule
- the lack of a visual planning
- the planning for own use and corresponding slack incorporation, both with respect to planned duration of the maintenance activities and to manpower
- the passive approach towards progress communication
- the number of fixed communication moments
- the lack of a predetermined solution set

The next part of the report will describe the *Improve* phase of this thesis project: approaches for treatment of the above root causes will be proposed in the following chapters.





# Improve

This part of the report represents the I in DMAIC: *Improve*. This fourth phase of the report is about finding answers to the problems that the Direct Sheet Plant's shutdown management wants to solve. In the previous parts of this report, first the problems to be solved were defined and then the deeper causes for these problems were investigated. The solutions that this thesis report will come up with in this part of the report targets these root causes to eliminate the problems from the base, instead of just treating the symptoms.

The next chapters will divide the root causes in three rough categories, for each of which one improvement strategy will be designed that aims to eliminate all root causes in the category at once. The results of an expert validation will be presented at the end of this part of the report; possible downsides and pitfalls of the proposed strategies will be sketched that should be kept in mind when implementing and using the strategies.








# 13. Improvement strategy design process

After gaining much insight into the maintenance shutdown processes using the structured and stepwise approach of Six Sigma's DMAIC methodology, it is now time to put these insights to use. Remembering the objectives from the *Define* phase and the current performances of the critical-to-quality variables found in the *Measure* phase, it is easy to see that the shutdown organization has quite a challenge in front of it. The following chapters propose strategies that should be able to help the Direct Sheet Plant to win that challenge.

So far, the two critical-to-quality variables (CTQs) were always considered apart from each other. The *Analyze* phase showed however that the two variables are interrelated to such an extent that much of their root causes overlap or are in essence the same. As the improvement should target the root causes and not the symptoms (the CTQ performances), the improvement strategies designed here will not focus on one CTQ at a time, but will try to tackle all problems at once. Until now, the structure of the chapters was determined by the discussion of the CTQs. That structure will now be abandoned in favour of a structure determined by rough categories of root causes. These categories will be described in the next section, after which each subsequent chapter will present the improvement strategy for one of those categories.

Since it is important to validate the proposed strategies before implementing them, an ex-ante validation investigation will conclude this part of the report : does an expert panel expect the proposed strategies to be able to achieve the defined objectives within two years? Do they think the strategies are workable? And what are possible downsides and pitfalls of the strategies that could hinder success? The final chapter will discuss the possibilities for ex-post validation. But first, the categories that can be made for the root causes are presented below.

# 13.1. Improvement categories

The six root causes that were the main result of the *Analyze* phase show a considerable amount of overlap in character. In fact, this overlap was so significant that the six root causes could be grouped in three categories to enable more efficient discussion of improvement strategies. The three categories are *Preparation and Planning, Communication* and *Anticipation & Resilience*. Which root causes these categories comprise is discussed very briefly below, before going on to the next chapter focusing on the improvement strategy for the first category starts off with the essence of this report: the road to improvement.

# 13.1.1. Category 1: Preparation and Planning

The first category contains three root causes that are all related to the preparation phase of the shutdown:

- the lack of a detailed schedule
- the lack of a visual planning
- the planning for own use and corresponding incorporation of slack in terms of planned duration of activities and manpower

The first subsequent chapter will focus on eliminating all three root cause with a single improvement strategy.





# 13.1.2. Category 2: Communication Patterns

The second category pertains especially to the maintenance execution phase and contains root causes for delay and low work efficiency that have to do with the current communication patterns that seem to misfit the nature of the shutdown and the desires for timely information of the shutdown manager. The category contains two root causes defined earlier, being:

- the passive approach towards progress communication
- the number of fixed communication moments

A separate improvement strategy will aim for elimination of these two root causes.

# 13.1.3. Category 3: Anticipation & Resilience

The third and final category in which improvement is recommended is also restricted to the maintenance execution phase and only contains one root cause:

• the lack of a predetermined solution set

It is expected that improvement in this category will better enable the shutdown organization to cope with disturbances. The final improvement chapter will address the theme of resilience.

This sequence for the categories has been chosen on the basis of the frequency of root causes actually causing delay and low work efficiency as well as on the effect that improvement in the category is expected to have on the process' total performance. For this reason, it is important to note that one should consider improvement in the first category much more urgent than in the second or third.

The next chapter will present the improvement strategy for the category of root causes that is considered most influential on the performance of the shutdown process: the preparation and planning category.



# 14. Improving shutdown preparation and planning

The first category is related to the pre-phase of the shutdown in which the basics for a successful shutdown are laid - or not. Maintenance management literature abounds in quotes on the enormous importance of a careful preparation of maintenance activities which is reflected in a schedule that provides support for the management of the activities on the shutdown day itself. Two such quotes nicely illustrate the importance attributed to preparation and planning, the first one does so in catching general terms, whereas the second quote clearly illustrates the importance of an improvement of this phase for one of the specific Direct Sheet Plant CTQ variables, *delay*:

'Failure to plan is planning to fail' (Smith & Hawkins, 2004)

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' Delay avoidance is the basic goal of planning and scheduling' (Kister & Hawkins, 2006)

As can be concluded from the root cause analyses in the *Analyze* phase, the preparation and planning activities often cause delay and low work efficiency during the shutdowns, which is why the first improvement strategy is aimed at improving the work done in the weeks prior to the shutdown in terms of planning and preparation.

# 14.1. Improvement strategy for preparation and planning

The root causes in this category were the following three factors:

- the lack of a detailed schedule
- the lack of a visual planning
- the planning for own use and corresponding incorporation of slack in terms of planned duration of activities and manpower

All three causes are addressed by the following strategy. The strategy contains some separate techniques, but the effect of these separate parts in terms of improvement in the CTQ variable performances is assumed to be greatest when they are combined. It is important to note that the strategies designed are subject to threats and that they do have downsides, for instance in terms of an increasing work load for the shutdown organization. Such trade-offs are not discussed here but in chapter 17 on validation.

The improvement strategies presented here are designed to help the shutdown organization gain control over the shutdown processes. Control over the process requires the ability to monitor the process and its progress on the shutdown day, but also to be able to see threatening factors such as job interactions in advance. Such anticipation and progress monitoring is hardly possible when a detailed schedule is lacking. The first and foremost recommendation is therefore that the preparation staff puts more effort into making a schedule that contains more information on the jobs to be executed and the estimated time of completion of sub-activities. The next section explains what is exactly proposed with respect to scheduling and why this is expected to significantly improve the shutdown's performance.



# 14.1.1. Need for detail

For scheduling of the maintenance activities at the Direct Sheet Plant, the shutdown organization uses Microsoft's MS Project, a project management software tool. The tool enables clear visual representation of the project schedule in the form of Gantt charts, as displayed in the figure below. This specific figure demonstrates how two maintenance jobs with the same duration can be scheduled with a very different level of detail. The black bars demonstrate the total duration of the jobs; both jobs are said to take from 7:00am to 5:00pm. The blue bars indicate sub-activities; the black stripe from beginning to end in the middle of them represent the percentage completed, which in this case is 100% for all sub-activities since the chart comes from a completed shutdown. As soon becomes clear from the figure, it appears that the second job has no sub-activities at all and consists of one single activity for 8 hours on end.



Figure 14.1.: Two maintenance jobs in a Gantt chart from MS Project: the first one contains a detailed schedule whereas the second one contains hardly any information on sub-activities and their durations, which makes progress monitoring much more difficult.

In reality of course, this job may contain various sub-activities such as preparing and setting up the tools, checking the work after the maintenance has been executed and cleaning up afterwards. But this one bar provides no information whatsoever on the content of those activities, how much time they may take up or what scarce resources are needed for them at what time.

With an unspecified schedule like the second one, progress estimation has become a matter of experience of the coordinating supervisor responsible for the job. Often the coordinating supervisor is the same person as the maintenance specialist that made the schedule, so the experience of the supervisor is generally not a problem. What is a problem however, is that insight for shutdown management or people less expert in the area in general is completely lost.

This makes it impossible for other people to judge how the job's progress is coming along. Progress reports then turn into subjective statements from the responsible supervisor, who may want to use his knowledge to his strategic advantage, for instance to disguise mistakes made or just to be independent and keep management at a distance. But also, the coordinating supervisor may simply forget to watch the time (and the schedule) as his maintenance specialization and interest may cause his attention to be drawn to technical rather than organizational issues. With an unspecified schedule, no one else can do the progress checking for him.



Aside from these possible negative effects of a lack of detail in the schedule, it increases the shutdown organization's dependence on individuals. A maintenance specialist who cannot perform his role as a coordinating supervisor in the shutdown due to illness constitutes a short-term problem. But long-term problems may also be expected: the maintenance specialists / coordinating supervisors that do not turn their tacit shutdown knowledge into documented knowledge leave a void when they change jobs, which is common within Corus in general but which is also promoted by the current competitive job market. When shutdown documentation is lacking, important company knowledge may seep away along with resigning employees.

Another problem of unspecified jobs is that interactions with other jobs cannot be anticipated. A single bar in the Gantt chart provides no support for finding out when jobs are expected to share spaces or scarce resources. If these interactions then occur on the shutdown day, they are unexpected and delay can easily result from them.

The final issue that detailed scheduling could eliminate is the overlooking of requirement details for the shutdown. When the maintenance specialist is obliged to incorporate and describe a number of sub-activities, he is forced to think his job through chronologically and consider al the preparation details. This may help him remember to make certain arrangements: for instance, he may find that the installation has to be 'set aside' (see the chapter *Overview of a regular shutdown's course* in the *Define* section) in a certain way, or that he needs to arrange for special safety measures. All these considerations may help to increase the level of preparation of the shutdown, which may lead to a lower job cancellation rate and less delay. The work efficiency could go up as a good preparation can remove obstructions for efficient work such as last-minute material arrangements or safety stops.

It is clear now that there is a need for more detailed scheduling. The next section discusses how more insightful schedules could be made by incorporating so-called milestones.

### 14.1.2. Milestone standard

The MS Project software that was discussed before, enables the digital use of a typical project management concept known as *milestones*. A *milestone* marks the completion of a specific sub-activity or work task within a larger project such as a maintenance job. Milestones can be incorporated in the Gantt chart, in which they take a diamond shape. In the schedule, milestones are planned to be achieved at a certain time. Ms Project can provide project managers with an overview of all milestones within a specific period of time. This makes it easy to see all the sub-activities that should be completed within a specific timeframe, for instance, the time frame of the maintenance execution phase.

Milestones are very useful for progress monitoring and make monitoring to a simple task for which in principle little technical experience is required. A good schedule with sufficient milestones would enable anyone at the Direct Sheet Plant to do a progress check around the plant. For example, he or she could tell from the schedule that between 10 and 11 am, three milestones should be reached: the scaffolding in the rolling section should be finished at 10:20am; the old hook of one of the cranes at the grindery should be removed at 10:35am and the replacement of a component of the pendulum shear should be finished at 11:00am. A simple check-up round could result in information as to the achievement of the milestone objectives. Even without a technical background this information can be collected through simple yes-or-no questions with respect to the completion of the sub-activities at the respective job sites.



The improvement strategy for the *Preparation and Planning* category proposes a standard for the incorporation of milestones into the schedule of *every* maintenance job. That standard is to take the form of an obligation; a strict requirement for the preparation staff.

The standard for milestones that is proposed here stipulates the use of <u>at least 1 milestone</u> <u>per 2 hours</u>. In practice, this means that no job with a scheduled duration of over 2 hours can be scheduled without definition of sub-activities with their own planned finishing times in the form of milestones.

This standard was chosen because of its reasonable expectance of being achieved without posing impossible or impractical requirements on the preparation staff in terms of work load. Also, two-hour timeframes seem to fit the medium-length duration of most of the maintenance work tasks.

An important aspect with respect to improvement in the *Preparation and Planning* category is related to the issues of evaluation, documentation and organizational learning. All three issues are currently underdeveloped within the shutdown organization. The milestone standard can help to promote these issues in the following way.

As the milestone standard will enable better and easier progress monitoring it is also easier to compare actual durations of activities with the durations planned. Documentation of the differences between the two and possible explanations could help to evaluate the maintenance execution as well the schedule: was the schedule unrealistic or did something go wrong (or extremely well) during the execution phase?

These insights could then be used for next time the same job or the same sub-activities are planned. This should incrementally lead to optimization or 'tweaking' of the schedule. At later stages, the shutdown organization could incrementally increase the number of milestones required per unit of time for routine maintenance jobs to plan these ahead as much as possible and to make them optimally manageable in case of disturbances.

Summarizing, this section proposes to institutionalize the strict rule that no job scheduled to take over 2 hours may be planned without the definition of sub-activities. At least one *milestone* per two hours of work should be defined to enable objective progress monitoring. The advantages of making a more detailed schedule for the maintenance execution phase including milestones are expected to be the following:

- detailed schedules with milestones enable factual and objective progress monitoring
- detailed schedules are insightful to practically anyone and thus reduce dependence on specific supervisors during the shutdown
- this clarity of detailed schedules makes knowledge on maintenance jobs transferable to for instance new employees, which prevents company knowledge disappearing with resigning employees in the long-term
- detailed schedules enable identification of interaction threats at an early stage
- detailed schedules and post-shutdown documentation on the compliance of the execution to the schedule can help to tweak



the planning for next time; thus constituting a technique for continuous improvement

 when making a detailed schedule, the maintenance specialist is forced to consider every step of the job and what is required for its execution, reducing the chance that things are overlooked and increasing the quality of the preparation.

The next section will introduce an idea that has a good chance of seriously reducing undesired job interactions with jobs competing for space or the use of scarce resources.

### 14.1.3. Visual planning

Sometimes an idea for improvement can be right around the corner. The following suggestion for implementation at the Direct Sheet Plant is certainly a good example of this. A shutdown best practice within Corus's IJmuiden site can be found right at the neighbouring oxysteel plant: since four years, this steel factory uses visual planning boards for the shutdowns.

This very simple idea has since proved to be very effective in avoiding job interactions that lead to delay. The oxysteel plant claims that delay due to undesired job interactions has been decreased to a minimum since the magnetic boards are in use.

The boards displays the technical drawings of the installation, over which all sorts of magnets in the form of for instance cranes and forklifts can be attached. By running through the planning of the shutdown day in the preparation phase, different people from the work preparation staff may find out that the crane they were intending to use for their job is already in use elsewhere or that someone else has planned a welding job right above the place where they planned people to check the hydraulics at the same time. The early discovery of such interactions may enable rearrangement of the conflicting jobs, or else the shutdown organization can at least anticipate problems and for instance assign the jobs extra management attention.



Figure 14.2.: Corus's own best practice: the successful visual shutdown planning at the oxysteel plant



During the shutdown the board may also provide assistance in case of any disturbances. If for instance technical problems occur, delay may result for specific jobs. Shutdown management may want to look into ways to mitigate the effect of the technical problems; a visual board would enable them to test their ad-hoc solutions for undesired interactions to prevent opting for a solution that only makes things worse in the end.

The advantage of the board is that it is very insightful and easy to use, even for people new to the plant such as contracted personnel. It is an *off-the-shelf* improvement technique that requires no more than simple copying of the oxysteel plant's idea. This makes it a very eligible opportunity for improvement.

It needs to be noted however, that without careful and realistic planning with the incorporation of sufficient milestones per activity as recommended above, the board is much less valuable. The probability of the board showing the 'right' job interactions is much lower when the different phases of jobs and the durations of these jobs are not specified sufficiently. It is there important to strengthen the use of the visual board with a more detailed maintenance execution schedule.

Conversely, the visual board may work in favour of more careful scheduling. If sections would make running through the shutdown planning on the visual board a group occasion, the preparation staff might better see the interdependence of their activities and might feel obliged to prepare their work on a more detailed level.

### 14.1.4. Checks and Balances

So far, the improvements suggested have targeted the root causes of the lack of a detailed schedule and the lack of insight into job interactions due to the absence of a visual planning. One root cause within the *Preparation and Planning* category remains however, and this section will add a component of organizational nature that will eliminate that final root cause: the scheduling for own use. As discussed before, also at the start of this chapter, the effort of maintenance specialists to make a detailed schedule is low as they themselves are often the coordinating supervisors who use the schedule for progress monitoring during the shutdown. Since they are experienced, they feel they need not spend so much effort on detailing the activities they are coordinating: they implicitly know what tot needs to be done.

This organizational structure corrupts the detail of the schedule for the shutdown as a whole and the consequential lack of insight of the members of shutdown management reduces their ability to steer the performance of the shutdown processes, leaving the shutdown hardly protected against the effects of disturbances.

The organizational structure should therefore be changed: maintenance specialist may no longer fulfil the role of coordinating supervisor. This division of powers (and even more importantly responsibilities) may remind one of the system of *'checks and balances'* determining the governmental structure of the USA, hence the title of this section.

The coordinating supervisor is someone who is supposed to offer the maintenance workers a safe and clean work environment and who is supposed to conscientiously monitor and communicate progress of the activities to shutdown management. He is not supposed to become involved in technical issues and he is not supposed to get his hands dirty. Those are tasks of the hierarchical supervisor, in other words the foreman. It is therefore far from necessary that the coordinating supervisor be a maintenance specialist. In fact, the responsibilities of the coordinating supervisor may even be in better hands with someone with a more objective view than a maintenance specialist.



It is therefore recommended that in the future, the role of coordinating supervisor is only fulfilled by people who are not on the preparation staff and if possible, who are not otherwise involved in the shutdown at all. The lack of technical experience of these people is assumed to make them more objective in their assessment of delay.

Appointing technically inexperienced people to be coordinating supervisors guarantees that maintenance specialists will get complaints if they do not specify their schedule in sufficient detail for the supervisors. They will thus need to put more effort into their preparation work.

Although it is expected that the maintenance specialists will certainly not be happy about strict scheduling regulations, their opinion on this new organizational structure may change for the better when they find out that their role during the shutdown is also changed. Their role will change from being someone who has to take care of a lot of administrative tasks during the shutdown and is actually not supposed to be involved in their area of expertise, to being an area expert who has no other responsibility than to assist on issues that lie in their field of interest and expertise. They are still supposed to be present at the shutdown, but only to inform the technically inexperienced coordinating supervisor in case of questions or to help out if a problem occurs. They may even have some time left to educate new maintenance workers, because they do not have to attend the progress meetings anymore. It is expected that this organizational structure will not only make better use of the knowledge of maintenance specialist, but will also lead to a greater level of work satisfaction for these specialist. In the meantime, progress reports become more factual and objective and schedules need to be prepared in more detail.

# 14.2. Summary of improvement strategy components

The category of *Preparation and Planning* is one that contains many root causes for unsatisfactory performance of shutdown processes. Three of these root causes are mitigated or eliminated by an improvement strategy which consists of three pillars, the combined implementation of which is of greater strength than their sum:

- A strict obligation to incorporate at least one milestone per two hours of work in every job schedule forces maintenance specialists to define subactivities. While doing this, it becomes less easy to overlook preparation issues that still need to be arranged. This approach eliminates the lack of a detailed schedule which is a root cause for delay and low work efficiency.
- The time indicated for detailed schedule's milestones have to be compared to the time when the milestones were achieved in reality. Also considering information on disturbances, this information should be documented to enable better scheduling for the same job next time. This suits Six Sigma's objective of continuous improvement.
- The use of visual planning boards using resource-shaped magnets should be introduced in combination with the detailed schedule. This off-the-shelf best-practice from the oxysteel plant can help to identify undesired job interactions at an early stage.
- Maintenance specialists may no longer fulfil the role of coordinating supervisor. Technically inexperienced and non-shutdown involved people





will take on this role. This will force the maintenance specialist to make more detailed schedules since they are no longer for own (or other experienced) users.

 Meanwhile, maintenance specialist gain the liberty of doing what they like best during the shutdown: getting involved in the technical issues of the shutdown. They are freed of their administrative tasks and take up an advisory role in their own area of expertise. The inexperienced coordinating supervisors will do the administrative tasks more conscientiously and with more objectivity.

It is expected that these combined methods will enable a better anticipation of disturbances, more objective progress monitoring and consequently a higher level of manageability of the shutdown. It may even lead to a happier workforce.

In the final chapter of this *Improve* part of the report, experts will give their opinions on whether the strategies will indeed tackle the root causes and improve the performances of the critical-to-quality variable. They will also help to define downsides of and pitfalls for this strategy as well as for the other two strategies. These downsides can then be acted on and pitfalls can be anticipated and avoided to make the strategies more successful.

This concludes the improvement strategy for the *Preparation and Planning* category. The next chapter will propose a strategy to deal with negative effects of the current communication patterns.



# 15. Improving shutdown communication patterns

Communication problems during the shutdown are an enduring issue at the Direct Sheet Plant. The communication patterns are characterized by a certain passiveness. Two root causes for shutdown performance problems have been categorized as belonging to the problem category *Communication Patterns*. This chapter will present an improvement strategy that aims to eliminate these two root causes: the passive approach towards progress communication at the Direct Sheet Plant and the low number of fixed communication moments.

# 15.1. Improvement strategy for communication patterns

This chapter's structure is very similar to the previous one and will also present a collection of improvement methods, an improvement strategy, to eliminate the two root causes grouped in the category *Communication patterns*. Once again, the improvement strategy consists of pillars that can also be implemented in the shutdown organization separately, but synergy effects between the pillars are expected to enhance each others functioning.

The first pillar of the strategy is aimed at counteracting the passive approach towards progress communication.

# 15.1.1. Active approach top-down

As was observed on many occasions in shutdowns and in *DILOs* in specific, the communication of progress compared to the schedule is considered a more or less necessary evil by many coordinating supervisors. Information sharing with respect to maintenance progress seems to be nearly restricted to the two progress meetings per shutdown day.

Part of this was probably due to the fact discussed before, that many of the coordinating supervisors are maintenance specialists whose attention is much more easily caught by technical issues of the maintenance job than by the rather obligatory administrative tasks that come with the job. However, until now the coordinating supervisors have always been attributed the responsibility of keeping shutdown management updated on progress and delay issues.

As the *DILO* with a coordinating supervisor (and maintenance specialist) demonstrated, this organizational structure is quite unnatural. The supervisor has a number of jobs to coordinate that keep him busy with all kinds of questions. At times, there is not even the time to make a phone call for a quick progress update, especially when the good cause of it is not at all urgent to you. All of this makes it very easy to forget that the maintenance jobs under the coordination of this supervisor are actually part of a bigger whole. It therefore seems natural that most supervisors seem to have taken on an attitude that says *'I'll call you when I need anything'*. The supervisors are simply too busy to keep in touch more.

On the other hand, when the section coordinator or shutdown manager takes on the active role of collecting the required progress information top-down, most coordinating supervisors are happy to explain how they are getting along. Although maybe in some cases supervisors might withhold information about delays in order to retain their independence in resolving the issue, the majority will tell shutdown management everything they want to know.

It is therefore recommended to transfer the responsibility for progress reporting from the supervisors to the section coordinators.





The section coordinator could pass by all supervisors at least once an hour to get the latest progress updates to report right to the shutdown manager. This way it is easier to guarantee that progress and delay issues are indeed reported in a timely fashion. Meanwhile, the supervisors can direct all their attention on the jobs they are coordinating.

### 15.1.2. Milestone-dependent communication

The second pillar of the improvement strategy for *Communication Patterns* coincides with a suggestion from the improvement strategy for the category *Preparation and Planning*: the regulation to incorporate more milestones in the schedule.

As was described, milestones make it easy to check the compliance of the maintenance execution in reality to the schedule. That compliance level could then be documented and used for improved planning next time. A prerequisite is then of course that the achievement of the milestones is reported. The accuracy of the milestone achievement time is expected to be higher when the achievement is directly noted down than when people wait until a progress meeting to report achievements. The information is then also out-dated if delay has occurred. Therefore, the second pillar of the improvement strategy is that the communication moments

are no longer fixed to the twice-daily progress meetings but to the milestones. In practice, the section coordinator should keep a schedule indicating the milestones and their scheduled time of achievement. He should then check at that scheduled time whether achievement has occurred or is about to occur. If yes, then he should note the actual time of achievement. If not, he should ask the supervisor (possibly assisted by the foreman or maintenance specialist) when achievement is expected and come back then. Meanwhile he should communicate the delay to the shutdown manager, also when it does not concern a job on the critical path. When achievement of the milestone then occurs before the 'new' time indicated by the supervisor, it is the supervisors responsibility to note the time of achievement down and communicate it to the section coordinator next time he comes by.

# 15.2. Summary and remarks improvement strategy

In this chapter, a simple but effective improvement strategy for the problem category *Communication Patterns* has been presented. The two pillars of this improvement strategy eliminate both root causes of the category and should be implemented together for the best effect:

- The responsibility for the communication of information on progress and delay is to be shifted from the coordinating supervisors to the section coordinators. That way, the flow of progress information is better guaranteed and the supervisors can direct their full attention on the coordination of the jobs. Responsibility is then concentrated on one person per section, who will really feel responsible; instead of with several people who do not feel really responsible for progress communication.
- The communication of progress and delay should be linked to the milestones (see previous chapter) instead of to the twice-daily progress meeting. This makes timely progress communication more likely.



It is expected that technically inexperienced coordinating supervisors will take a more active stance towards bottom-up progress communication as this is one of their main responsibilities. As they also have less tools for solution of delaying problems at their disposal, they are likely to call in help from shutdown managers earlier than an experienced maintenance specialist would do. This is an extra reason to implement both improvement strategies so far together.

There are a number of trade-offs concerning this improvement strategy; chapter 17 describes them and discussed ways to mitigate the undesired effects. The next chapter will discuss the final category for improvement: *Anticipation & Resilience*.







# 16. Improving problem anticipation and resilience

Delay during the regular shutdowns is often caused by some sort of technical problem. As was described in the root cause analysis for delay, these technical problems may still occur as surprises due to inexperience with the installation or due to the invisibility of the faults leading to these problem to the inspection. But there are also problems that have a greater predictability or chance of occurring so that the organization can anticipate them through its experience. This third and final improvement strategy is aimed to make the shutdowns less vulnerable to problems that (may) occur through an increase in anticipation and resilience in the shutdown organization.

Although the use of both the words *anticipation* and *resilience* in the category name may seem a little double and superfluous, these words actually indicate two concepts that are (though related) quite different. The concepts can be considered two sides of the same coin.

At least, that is when one agrees with the viewpoint taken by Wildavsky, whose definitions of the two concepts (de Bruijne et al., 2008) are presented in the text box below to clarify the difference:

**Anticipation** – 'a mode of control by a central mind; efforts are made to predict and prevent potential dangers before damage is done'

**Resilience –** 'the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back'

Both concepts could help the Direct Sheet Plant to deal with problems surfacing during the shutdown, as they complement each other in terms of the different types of problems they address. The occurrence of disturbances is often unavoidable, but the delay that results from them certainly is avoidable to some extent. In order to mitigate the delaying effect of completely unforeseen disturbances, the shutdown organization has to become more *resilient*.

It was already defined in the root cause analysis that a lack of a predetermined solution set was the cause of slow solution and decision making process in case of problems, which led to an inability to quickly react in order to reduce the delay incurred. Such a predetermined solution set is a an example of *anticipation*. This chapter will introduce ways to increase the Direct Sheet Plant's resilience and reactivity with respect to shutdown problems occurring.

# 16.1. Improvement strategy for anticipation and resilience

In order for the shutdown organization to be more resilient in case of disturbances to the shutdown processes such as unforeseen technical problems, the shutdown organization needs to develop quick ways to cope with all sorts of disturbances to mitigate their effects as soon as possible. A disturbance with respect to scheduling in an industrial manufacturing environment is defined as follows (Schumacher, 2003):

'A disturbance is a deviation from the assumptions upon which the schedule was based'





The result of a disturbance is therefore that it upsets the (other) contents of the schedule, which should than be adapted to the new conditions in what is often called a *reactive schedule* or an *adaptive schedule* (Schumacher, 2003). It can be hard to make a good reactive schedule under the time pressure of a shutdown, but this chapter suggest some methods that together form an improvement strategy for the resilience of the shutdown organization.

# 16.1.1. Risk category scheduling

Although for many routine activities the amount of slack time incorporated could and should be decreased in order to incrementally reduce the duration of the shutdowns, some maintenance jobs contain a higher risk for problems than others. One could think of activities that have never been executed before in the history of the plant, jobs that need to make a lot of use of scarce resources for which they have to compete with other jobs, or jobs for which a new contractor is whose work speed and quality level is unknown. In these cases, it would be good to take a very anticipatory approach and incorporate some more slack into the schedule, in order to reduce chances of delay for the shutdown as a whole and the corresponding need for reactive scheduling. This type of anticipation could protect the shutdown from the delaying effects disturbances that could reasonably be expected to occur (though not in what form) due to the nature of the job.

It is therefore proposed here to start working with risk categories that take notice of the risk involved in specific maintenance jobs. In cooperation with a maintenance specialist form within the shutdown organization, the following slack were defined to be incorporated in the schedule for the specific risk categories:

- 10% slack time for small routine jobs with inexperienced individuals in the execution personnel
- 25% slack time for routine jobs using scarce resources, and/or involving new contracted personnel (that is, a new company, not individual workers)
- 50% slack time for big jobs that have never been executed before in the history of the plant and use scarce resources such as the fixed hall crane.

In the former two cases these percentages should be added to the historic average duration of the maintenance jobs; they therefore rely heavily on documentation. It is therefore wise to implement this improvement strategy together with the *Preparation and Planning* improvement strategy.

In the latter case the percentage should be added to a slackless estimation of the maintenance execution duration of sub-activities. By breaking the new job down into very detailed jobs, such as wrenching a number of bolts or welding over a specific length, it becomes easier to make a slackless estimation as these very detailed sub-activities are found in many jobs. There is therefore experience with how long these detailed activities take, so that the sum of the activities can form an estimation for the new job.

The slack percentages allowed here were defined in cooperation with a maintenance specialist from within the shutdown organization. They rely on his experience and estimation, but are not based on any accurate (historical) data. It is therefore advised to regard the slack percentages proposed here as preliminary standards to be adjusted in an iterative process to





become more representative for the reality of the shutdowns. This iterative process would consist in comparing documented milestone achievement data with originally scheduled milestones and equally important, with information on why milestones were achieved earlier or later than scheduled. This means that again, for the iterative refining process of the slack categories the implementation of the improvement strategy for *Preparation and Planning* is a prerequisite.

Perfecting the use of slack incorporation categories in the schedule is a process that may take years, which means that implementing this pillar of the improvement strategy will not suddenly form a lot of extra workload. This may make its implementation feel less urgent, however, management should try to guard that the workforce slowly but surely gets used to this way of scheduling with consideration of the risks involved in jobs. Management may even want look into *probabilistic scheduling* practices which integrate risk consideration into scheduling to a greater and more scientific extent, but for the coming years it is advised to just create the organizational mindset for risk consideration and anticipation.

Then it is expected that this method will decrease the need for reactive scheduling because it will reduce the chance that disturbances in one job lead to many disruptions of other jobs and thus in the total schedule.

But if disturbances are of a magnitude that they are still going to disrupt the total shutdown, how can reactive scheduling be done optimally? How can the shutdown organization be resilient, how can it 'bounce back'?

### 16.1.2. Reactive scheduling and the use of scenarios

The time-pressured process of reactive scheduling can be improved through being prepared for anything to happen, and to anticipate it. This can be done by constructing a predetermined solution set for to help make quick decisions. Making such a predetermined solution set can be done by using scenarios: maintenance specialists and work preparation could brainstorm about all sorts of possible disturbances and come up with mitigation strategies for their effects. In the beginning, there should not have to be a lot of work involved, for some problems less likely to occur, just noting down the phone number of an expert in the field and making sure this person is available in case of shutdown emergencies may do. This anticipatory tool box full of solutions for disturbances that are reasonably likely to occur could be complemented with a resilience-enhancing tool: a cancellation standard.

Setting such a standard could help to decide quickly on cancellation or continuation of jobs in case of problems, for instance: if this specific job is delayed with more than one hour, it has to be cancelled because it is not urgent enough to risk the delay transferring to other activities in the shutdown or to the shutdown as a whole. This sort of agreements is a form of resilience instead of anticipation because it is totally independent of the type of problem that surfaces. It merely increases the speed of decision making processes during the shutdown a lot, which could avoid delay spiralling out of control.

A cancellation standard should to some extent take into account the costs sunk in resources executing the maintenance job at hand compared to the economic loss that a delay would cause in terms of a lack of production. This may sound contradictory to microeconomic theory that has deemed precisely this - making decisions based on sunk costs - the *sunk cost fallacy*. This microeconomic concept states that rational actors should never base their project continuation decisions on sunk costs, because, to put it in over-simplified layman's terms, bygones are bygones (Squire and Van der Tak, 1975). Sunk costs are costs that have



already been incurred and cannot be returned no matter what decision is taken, so it is logical that a rational actor should ignore whatever sunk costs have been made and concentrate on which strategy will maximize value.

So let us rephrase on what costs the cancellation decision should be based. To begin with, all maintenance jobs that are scheduled have to be executed sooner or later to avoid threatening the production process, or at least it is assumed that this is the case. This means that sunk costs paid for resources have to be paid again if a job is cancelled, which could leave the annual budget worse off. So, in fact the sunk costs *now* are not the main issue, it is rather the *future need to make the same costs again*. In other words, the shutdown organization should consider the future costs of repeating the operation, but since these are essentially the same costs as the ones sunk in the current shutdown, it is easier to say that the sunk costs have to be taken into account. The sunk cost fallacy is not committed in doing so as in essence future costs are considered.

A good parallel but simplified example of how this works is the example of heading towards the post office and deciding on whether to stay or leave when there is a long line (Henderson and Hooper, 2006). Already having incurred the 'cost' of travelling to the post office you could leave them out of the decision to stay or return later. However, the costs of travelling there and back again in the future should be considered, as they would likely cause the process as a whole to take longer.

Cancellation standards should thus be calculated on the basis of future costs when repeating the operation. As costs on resources should be (and are) accurately recorded within the shutdown organization, this should not be a difficult job.

Documentation of the anticipatory scenarios and the corresponding mitigation strategies could lead to a valuable predetermined solution set and cancellation standards, thereby leading to a more ready and more resilient shutdown organization.

# 16.2. Summary of improvement strategy anticipation and resilience

The improvement strategy for the category Anticipation & Resilience contains two pillars:

- Anticipatory slack incorporation in the schedule dependent on job-specific risk categories: close to none for routine jobs, but much slack for risk-prone jobs. This should reduce chances of disturbances in one risky job influencing other activities or even the whole of shutdown duration.
- Improvement of the reactive scheduling process by increasing the amount of anticipation through scenario use. Brainstorming on possible disturbances occurring and corresponding mitigation strategies of their effects in the preparation phase is expected to lead to an increase in the speed and quality of decision making processes during the shutdown in case of problems. Cancellation standards independent of the type of problem surfacing should increase the organization's resilience.





This chapter concludes introduction of the improvement strategies for characteristics of the shutdown processes that are related to the most influential root causes for delay and low work efficiency. The next chapter will discuss the opportunities for ex-ante and ex-post validation and will describe the ex-ante validation experiment conducted with the help of an expert panel. The experts helped to define downsides and pitfalls to the strategies that will be discussed along with possible tactics to avoid them.







# 17. Validation and Implementation

In any 'normal' improvement project, the end product of the *Improve* phase would be the implementation of the new improvement strategy. After all, why design improvement strategies if no one is intending to use them in the end? This being a thesis project which is constrained by time and resources, unfortunately prohibits implementation. What can be done however is to prepare the solutions for implementation within the shutdown organization as much as possible, so that the organization can implement the improvement strategies for itself.

Before implementing any strategy, it is important to asses whether and to what extent the strategy will deliver on its promises in reality. To avoid the investment of time, effort and money into ill-designed solutions, it is common to conduct a *validation experiment*. The idea of *Validation* is to test a model's match with reality or in this case a solution's match to the real environment in which it is to be implemented. So for this project it is important to find out whether the proposed improvement strategy will lead to an enhanced performance of the two critical-to-quality variables *delay* and *work efficiency*. Before going on to the next phase of the DMAIC-methodology, the *Control* phase, the three improvement strategies proposed for the areas of *Preparation and Planning*, *Communication Patterns* and *Anticipation and Resilience* will thus be validated. An expert panel will assess the proposed improvement strategies and will help to define the downsides, trade-offs and pitfalls that could influence their success in the reality of the shutdowns and their organization.

This chapter will discuss this type of validation, which is possible before implementation of the improvement strategy. Six Sigma improvement projects are extraordinarily suitable for ex-post validation, but since that is in essence a type of monitoring and control, the ex-post validation possibilities will be discussed in the *Control* phase. Furthermore, this chapter will discuss that, even in case of ex-ante validation of the improvement strategies, some difficulties may still lay ahead in the implementation process. After that, the last phase of the DMAIC-road can begin.

# 17.1. Ex-ante validation

It was explained above that an assessment should be made of the fitness of the improvement strategy for the environment in which they are going to be implemented. It should be determined beforehand whether these solutions really tackle the right root causes to lead to a significant improvement in the critical-to-quality variables. An improvement in fact, that leads to achievement of the rather ambitious objectives from the *Define* phase within two years: a work efficiency level of 74% productive time during the shutdown, and delay practically never exceeding the scheduled time of finalization by more than -30 or +30 minutes.

One of the difficulties of ex-ante validation of course is that nobody can really know about the results of the strategies until they have been tried out: the future holds many uncertainties that may influence the level of success, and also the effort that is put into the implementation and usage phases can determine to what extent the improvement strategies deliver on their promises.

However, a good forecast can be made by experts whose experience in the field has given them the insight and intuition to judge the quality of the designed improvement strategy. This thesis project will therefore also include an expert validation research. The research will take the form of a series of interviews with different people who are all experienced in the



environment in which the improvement strategies will have to work: the Direct Sheet Plant and its shutdown organization. The next section will elaborate on the composition of the expert panel.

# 17.1.1. The expert panel

The panel for the ex-ante expert validation consists of a number of people who all have experience with the Direct Sheet Plant and with the organization of maintenance shutdowns, but who all have a different perspective. These different perspectives will provide different insights on how the environment and the strategies will influence each other.

The panel is formed by 5 people, 3 of which are representatives for each of the different layers of the shutdown organization;

- The shutdown manager
- The chief of the WISK section's technical department
- A maintenance specialist from the MID section who frequently acts as a coordinating supervisor during the shutdown

and 2 of which are outsiders to the shutdown process:

- The manager of the Technical Bureau, who is the direct superior of the shutdown manager
- A former Lean coach of the Direct Sheet Plant

The experience these people have in the relevant area and their specific role during the shutdown or at the Direct Sheet Plant in general will be briefly explained below. These explanations will also clarify the choice of involving these people in the validation investigation.

#### The shutdown manager

It would be unthinkable not to involve the shutdown manager in the validation sessions: he is in charge of all shutdown processes, so his consent is needed before implementing any strategy that will impact their performances. He may be considered the most experienced person in the expert panel in terms of shutdown experience as he is always present on shutdown days and has to deal with people from all sections. He knows all about how the current organizations are organized and can judge whether the proposed improvement strategies have a chance of succeeding.

#### The chief of the WISK section's technical department

The chief of the MID section is in charge of all maintenance specialists and work preparation employees. He is therefore an insider to all of the planning and preparation work tasks. However, during shutdown days his presence and responsibility is very limited.

#### The maintenance specialist/ coordinating supervisor

This person is a textbook example of the maintenance specialist who is also a coordinating supervisor during the shutdown as discussed in the chapter on the improvement strategy for





*Preparation and Planning.* His experience is great in preparation tasks, supervising maintenance jobs and shutdowns in general alike. Some of the improvement strategies will influence his job to a great extent. It is therefore very important to involve him in the validation process.

#### The manager of the Technical Bureau

Although he is the direct superior of the shutdown manager, he has no role within the organization of the shutdowns. His presence on shutdown days is limited, but his inquisitive nature and work experience from earlier consulting jobs have led him to take a special interest in the performance of the shutdowns. He has signalled many things going wrong in the shutdown organization and as the shutdown manager reports to him, he is informed on the issues that the shutdown manager keeps running into. He therefore commissioned this improvement project. His limited responsibility during the shutdown has led him to be a person who knows a lot about the shutdown without being responsible for it, all of which has led to preservation of his critical attitude towards the organization.

#### The Lean coach

This former lean coach of the Direct Sheet Plant has just started on a new job. However, during this thesis project he was involved a couple of times, for instance in the work sampling study. Also at other occasions has he collected information on maintenance and shutdowns. Still, his experience with the regular shutdowns and their organization remains limited. The main reason to involve him in the validation research, besides his knowledge on Lean Manufacturing and other improvement methods, is his experience in organizational transformations and improvement projects. He knows the people and the company culture at Corus and more importantly at the Direct Sheet Plant and he can forecast the attitude the employees will take towards the proposed improvement strategies.

The panel's thoughts on the strategies will be extracted through the use of interviews, which will focus on issues such as workability, expected commitment and cooperation from the workforce and expectance for achievement of the objectives. The next section will present the structure of these interviews.

#### 17.1.2. Structure of the validation interviews

The expert validation was conducted using semi-structured interviews. This type of interviewing guaranteed that the experts would answer a number of questions that were the same for everyone, while also allowing the experts to express their feelings in terms of for instance concerns or surprise. There was also plenty of room for them to give their experienced suggestions on improving the improvement strategies in terms of practical implementation.

The common questions addressed issues of workability (both in terms of expected workforce cooperation and in terms of resource capacity) and of effect: does the expert actually think that the proposed improvement strategy can cause a positive change in the performances of the critical-to-quality variables *delay* and *work efficiency*? Grades from 1 to 10 (10 being the best score) were attributed for these aspects of the improvement strategies to clarify their aggregate opinion on the strategies. The respondents were also asked to give an estimate of the expected change in these performances; the estimates were then compared to the





objectives from the *Define* phase, the exact values of which most respondents were unaware. The differences between the objectives and the expected effect were discussed subsequently.

The interviews lasted about 45 minutes each and were conducted independently of one another, i.e. the experts were not aware of the reactions of other respondents. This approach was chosen to stimulate the respondents' free expression and to avoid *groupthink*.

The next section will discuss the results of the validation and the conclusions for the project as a whole.

# 17.1.3. Validation results and main conclusions

The results of the separate validation interviews can be found in Appendix E. They have not been transcribed; instead they are brief but accurate representations of what was discussed and suggested. Although they are not transcriptions, the reader may take the answers as personal statements of the respondent; the opinion of the author was not included. The results as displayed in the Appendix Eo not withhold any other information. Since the results can be found in Appendix E, this section will discuss the overall conclusions of the aggregated validation interviews.

The main conclusion that can be drawn from the validation interviews is the level of expected cooperation of the workforce is the soft spot of the proposed collection of improvement strategies. Although most respondents acknowledge that the shutdown organization's employees are increasingly motivated to put effort into improving their work, the cooperation for the improvement strategies for the *Anticipation and Resilience* category can be expected to be very low: people do not like to spend time on brainstorming for solutions for threats that may never materialize. Although some more cooperation could be gained by enthusiastic 'marketing' of the proposed measures, one may want to put implementation of this improvement strategy on hold.

The first priority should be to get *Preparation and Planning* on a higher level, especially by introducing the milestone standard. Although resistance to obligatory milestones per unit of time was expected, expert validation showed that consensus is slowly formed throughout the organization about the need for detailed scheduling and that cooperation levels will be quite high for that specific measure. The checks-and-balances system would then not be necessary to coerce the scheduling effort.

As long as the organizational transformation with respect to the proposed change that maintenance specialists may no longer supervise their own jobs is not necessary it should not be implemented as it is subject to a few concerns: the experience of the maintenance specialists may not be fostered if they are not employed as supervisors and there is already a shortage of supervisors as it is. Moreover, much time would be spent on the transactions of the required job knowledge and the responsibility over the job.

This leads to the following central validation conclusions:

• More detailed scheduling is highly important and urgent. Implementation of the milestone standard should be done right away. The preparation will need to be checked on their scheduling (effort) by shutdown management as well as their peers.





- If the detailed scheduling works well, improvements in the other two categories (Communication Patterns and Anticipation and Resilience) are much less urgent and can be done at a later stage.
- If the monitoring of the scheduling processes is not enough to guarantee good quality scheduling, the proposed organizational transformations could be tried out. Because it requires more work and might lead to a decreasing installation experience of the maintenance specialists, this is not recommended unless necessary for the success of the measure of the milestone standards.

These main conclusions only hint towards the trade-offs and pitfalls that the experts expect to come with the proposed improvement strategies. These trade-offs and threats are much too important to the success of the organization's improvement efforts not to mention them in detail. The shutdown organization will have to anticipate the trade-offs and avoid the pitfalls. The next section concentrates on this issue and gives advice on how to make the improvement efforts to a success.

# 17.2. Trade-offs and pitfalls

Expert validation is essential before implementation of the improvement strategies, but it does not guarantee a problem free implementation process, let alone success in terms of the strategies' results after their use has started. The experts each had their own view on the obstacles inherent to the strategies that might be in the way of success. This section will discuss the trade-offs and pitfalls that come with each of the three proposed improvement strategies. The strategies will be discussed one by one and recommendations will be made on how to overcome their downsides.

# 17.2.1. Improvement strategy Preparation and Planning

This improvement strategy consists of 3 pillars: the *milestone standard* that requires the preparation staff to make a more detailed schedule; the *visual planning board* that helps to identify job interactions early on and the *checks and balances* requirement that does not allow people on the preparation staff to supervise the maintenance jobs they have prepared and scheduled themselves. Each of the pillars will now be discussed one by one to see which downsides, trade-offs and pitfalls exist according to the expert panel.

The *milestone standard* has one big downside: the preparation staff will need to spend more time on scheduling when greater detailing of all activities is required. The experts, even the respondent representing the preparation staff, all agreed that the current workforce could easily take the extra workload if people would work more efficiently. This may be easier said than done. A hint to why people on the preparation staff might currently be working sub-optimally was given in the validation interview with the maintenance specialist: a little over a year ago, the roles and responsibilities within the shutdown organization were rearranged. People have not yet fully adjusted to the new organizational structures and are unsure of what is their responsibility and what is another's. This causes people to do double work.

The cause of the staff's unease with the new organizational structure may have resulted from the implementation phase; perhaps guidance during the implementation phase was insufficient. The respondent recommended that shutdown management or the Technical Management department's management reinforce the organizational transformations by





clarifying once again the way responsibilities are divided in the new situation. When better aware of what is their task, people on the preparation staff could concentrate on their own work and increase their work efficiency.

If the workforce's capacity would be insufficient after all, the shutdown organization could get hold of extra money for more personnel. A trade-off then emerges: do the advantages resulting from a more detailed schedule (a reduction in shutdown durations) outweigh the costs for extra personnel? It is expected that this is the case, but only ex-post validation can prove extra personnel worthwhile.

A pitfall to avoid is that the new milestones standard is not obeyed due to a lack of motivation of the workforce. Actually, the third pillar of this category's improvement strategy was designed to counteract disobedience to the milestone standard. But since the validation interviews showed that the organization is not very keen on immediately implementing that *checks and balances* measure that prohibits maintenance specialists to schedule their own supervision jobs, another way around the pitfall has to be found.

The experts believed that the *checks and balances* measure would not be necessary if the general attitude within the shutdown organization with respect to detailing the planning would be improved. Since the motivation for improvement is already increasing throughout the organization, it is expected that many people on the preparation staff will grant their cooperation. However, for those that do not wish to cooperate immediately, the company culture should undergo a transformation: currently, people who do not obey company rules or guidelines are rarely addressed. Introducing the milestone standard as an obligatory scheduling practice means that people who do not detail their schedules accordingly should be addressed with respect to their responsibilities. Not only management, but also co-workers such as the section planners who integrate all the job schedules into the main schedule should take a more active approach in addressing people on the preparation staff whose schedules do not fit the requirements.

A pitfall for the *visual planning board* is that it is not used in combination with a detailed planning. Making and updating the board takes extra work, but it is expected to pay off if the board is used to its full potential, that is, when it can display possible job interactions with some level of accuracy. If the schedule is not accurately detailed, the visual board can never forecast which job interactions will occur with sufficient accuracy. The trade-off that exists between the extra work and the advantage of being able to avoid or anticipate delay-causing interactions will then render the visual planning board infeasible. The shutdown organization should thus first get the detail of the schedules right before introducing the visual board.

Finally, the *checks and balances* measure within this improvement strategy was actually designed to be a reinforcement to the milestone standard and the *Communication Patterns* improvement strategy for a more active stance towards communication. The downside is that the expert validation showed that maintenance specialists gain most of their experience from supervising shutdown jobs. Some of the experts in the validation sessions doubted whether the proposed arrangement in which the maintenance specialist would be freed from his administrative tasks and would be assisting as an expert will sufficiently foster the experience that maintenance specialists should gain during shutdowns.

If the shutdown organization should decide not to implement the *checks and balances* measure to protect the maintenance specialists' learning processes, then it should carefully monitor whether the preparation staff is following the new scheduling requirement in terms of



milestones. It should also promote a culture in which people are not reluctant to address each other's behaviour where company processes are involved.

This concludes the section on pitfalls and trade-offs for the improvement strategy for the category *Preparation and Planning*. The next section will continue with the *Communication Patterns* category.

### 17.2.2. Improvement strategy Communication Patterns

The improvement strategy for the category Communication Patterns also has some issues to keep in mind when implementing its two pillars. One of these issues is the time that section coordinators will have to spend on actively gathering progress information on the jobs. Since there is only one section coordinator per section who also has other tasks during the shutdown, his availability for checking milestone achievement is limited. Although most experts believe the active role in progress communication can be achieved with the current number of section coordinators, one respondent (not the section coordinator but the maintenance specialist) believed that the capacity would be insufficient. The same respondent feared that the frequent check-ups by the section coordinators might constrain their (feeling of) freedom to coordinate their own jobs. In case they arise, both problems can be mitigated with a single measure. The measure consists of a simple addition to the improvement strategy that slightly shifts the balance of the activity in terms of progress communication behaviour. The traditional arrangement was that communication on maintenance progress was regulated bottom-up, with the responsibility for timely communication lying with the coordinating supervisors. The improvement strategy proposed placing that responsibility with the section coordinators, thus steering communication topdown. The measure to take in case of problems with insufficient capacity or resistance to the frequent check-ups with the supervisors moves the balance towards the middle: a schedule that can be updated is hung inside the plant, very near to the job sites. The supervisors can then easily and accurately update the schedule according to the achieved milestones, whilst not having to reach the section coordinators who may be in meetings or otherwise occupied. In return for their small effort, they will feel less supervised and checked up on.

Meanwhile, the section coordinator will still need to come to the plant frequently, but he does not have to make a full round every time which will save him time. He could for instance decide to only check up on the jobs of which the progress is lagging.

Although this measure is simple to implement and may be better under the circumstances described (low availability of section coordinators, resistance among the supervisors), it is still recommended that the improvement strategy for the category *Communication Patterns* as proposed in chapter 15 be implemented. That would allocate the responsibility with one person, who would most probably feel this responsibility and would put in more effort. If not, it is much easier to hold one person accountable than it is to hold a large number of people responsible.

The possible surfacing of resistance among the supervisors is very dependent on the way they are approached by the section coordinator: the atmosphere for the proposed form of progress communication should remain very easy-going, cooperative and collegial as it normally is among people in the shutdown organization. It should be made clear to the supervisors that progress information is important for the shutdown's total performance and that the section coordinator is also there to help when problems arise. It is very much expected that resistance will then hardly come to exist.





As will be discussed in the next section, the final improvement strategy is subject to a considerable trade-off, which has consequences for its implementation process.

### 17.2.3. Improvement strategy Anticipation and Resilience

As was discussed before, in section 17.1.3., the experts signalled the probability of a low cooperation for the improvement strategy for the category *Anticipation and Resilience* where the anticipatory brainstorming measure is concerned. That is because a very clear trade-off exists that is observable to everyone and may not be advantageous at an early stage: a lot of time may be involved in brainstorming problem scenarios and making arrangements for when they occur, whilst certainly not all problems may materialize. This measure is not expected to lead to quick wins in the short term.

Motivation among the workforce in the preparation may therefore be low: they may feel they already have enough to do (especially with the new milestone standard) and may not see the need. This perspective may be very just; as it is expected that in the short run much bigger results may be expected from other improvements, especially in the *Preparation and Planning* category. Implementation of the *Preparation and Planning* strategy is also important because the pillars of the *Anticipation and Resilience* strategy rely on progress documentation as proposed in the *Preparation and Planning* strategy.

It should therefore be stressed once again that this improvement strategy is one to follow at later stages, to tweak already improved shutdown processes. It is expected that the improvement strategy in the category *Anticipation and Resilience* could certainly help to reduce effects that come from problems occurring but that the other categories deserve to be prioritized: when the point is reached that these areas are subject to much less problems, this improvement strategy may start to pay off. Meanwhile, shutdown management should already start on creating the right mindset for for instance risk consideration in scheduling practices throughout the organization.

Implementation at a later stage would give the shutdown organization time to investigate probabilistic scheduling methods to incorporate slack into the schedule with respect to riskier maintenance jobs; and make the most of probabilistic scheduling if so desired.

The next section takes the information given on trade-offs and pitfalls to a more generic level in order to make recommendations for the implementation process.

### 17.3. Implementation recommendations

The previous sections discussed a number of concerns that were expressed during the expert validation sessions. Many of these concerns were rooted in issues of workforce cooperation, which is fair as none of the improvement strategies proposed in this thesis will work when the people in the shutdown organization are not up for it. This issue therefore deserves some recommendations to help make the implementation of the proposed strategies and later improvement projects to a success.

Firstly, it should be noted that workforce resistance is not something specific to the Direct Sheet Plant or the shutdown organization, rather it is one of the more obvious, general obstacles towards implementation; resistance to change characterizes the human being and consequently also organizations in which people work. It is very common that new projects,





strategies or solutions that need to be implemented in existing organizations and cultures experience resistance to change.

This will probably be no different for the Direct Sheet Plant and shutdown organization either. During the shutdowns and in the preparation phase, regular conversations, semi-structured interviews and DILOs all indicated that fear of things changing for the (personal) worse sometimes overrule the feeling that the current processes are not ideal either. This may partly be a cultural inherency to Corus's corporate culture.

The company, which started under the name *Koninklijke Hoogovens*, has existed for over 90 years at the time of this project. Many employees have worked there for decades, often they started their career in Koninklijke Hoogovens-era and never left. They are used to the company culture and the organizational and social patterns. Their longstanding employment may be considered an indicator that they are happy with their occupational environment and improvement projects proposing changes pose a risk towards their satisfaction. Resistance from the workforce may result from this as a consequence, especially when changes are proposed by people from outside the regular workforce, such as in the case of this project. Other improvement projects running at Corus have indeed confirmed the expectance for resistance: new consultants at Corus's internal consultancy department are even trained to

recognize resistance to change through the use of 20 frequently used quotes, such as:

'But this is how we've always done it'

'I think they've tried that before and it just didn't work'

Even though the internal consultancy department of course consists of Corus employees, they are still considered outsiders in most plants and departments as they do not belong to the regular workforce and are not equally experienced with the respective department's practices. It is therefore legitimate that the people affected by the proposed changes approach these propositions with reasonable criticism. Since this report was also based on an outsider's idea, it may be expected that implementation of the improvement strategies from this thesis project will also be met with some scepticism or resistance. This however does not mean that the implementation of the proposed improvement strategies will necessarily be problematic, for resistance may be overcome.

The fact that overcoming workforce resistance may be overcome and that cooperation may be fostered was already demonstrated by a number of Lean projects at the Direct Sheet Plant, which have run with considerable cooperation and enthusiasm from the workforce affected by the projects. It is assumed that these projects were so successful because they involved the employees to a great extent and made participation attractive.

One of the more recent examples was a 5s-project (*Sort - Set (in place) - Shine - Standardize - Sustain*) to create an orderly work environment at the preparation staff offices. Desks were cleaned, documentation was sorted out and files and tools were rearranged in a logical and easily maintainable way. An immense load of paperwork and objects was discarded. An aspect of fun was introduced by an auction at which discarded, but working objects got a new owner, or were thrown away when nobody was interested. The event took two full afternoons, but resulted in cleaner, more organized offices in which information was easier to find. The working environment was made much more pleasant for everyone.



Four aspects are assumed to have made the project to a success:

- 1) the project was guided by someone from within the preparation staff
- 2) the project was a team effort; everyone was involved
- 3) the project had been made more appealing by introducing fun aspects
- 4) consensus on the need for achievement of the project objective (i.e. better work environment)

Ideally, the implementation phase for the improvement strategies proposed would also incorporate these aspects to maximize workforce cooperation and through that, success for the improvement efforts.

With this in mind, some recommendations will be made in parallel with the successful Lean projects and the four aspects that are assumed to have been critical to their success. In some cases, these recommendations may no longer apply to this project but can only be used for later improvement undertakings, the reasons for which will be mentioned.

First of all, it is recommended to keep the possibility of resistance to change in mind and avoid it as much as possible by involving those affected from an early stage. This worker involvement should go beyond the advisory-type role through DILOs and interviews towards workers actually forming the improvement team. This deeper type of involvement is an example of a recommendation that can not be followed for this project: the master thesis project being an individual project subject to time and money constraints left no room to start up such a shared undertaking involving all workers in the shutdown organization to a level beyond DILOs, interviews and validation sessions. Still it is recommended to involve workers as much as possible and make improvement undertakings into team projects from an early stage.

Because not only may the employees' ideas improve the quality and workability of the strategies, their involvement is expected to spark their effort in cooperating to make the implementation of the strategies to a success. Consensus can be built from an early stage which reduces the risk of resistance to a minimum. When success or failure is shared among all involved, a culture of responsibility, reciprocity and accountability is easily formed, which is expected to keep the efforts up.

The guiding role should also be attributed to an experienced and sociable person from the team, for whom it is expected that nobody would like to compromise the relationship with this co-worker. Appointing suitable people from the disciplinary teams, for instance the preparation staff, to promote and guide improvement projects is therefore highly recommended.

Purely top-down implementation of the strategies, for instance by a team exclusively made up of external consultants, should be avoided. Not only is cooperation of the workforce an absolute necessity for implementation, it could also constitute an added value through the use of their insights and ideas. External people (whether Corus employees or contracted people) could however facilitate the projects by helping with the use of the DMAIC methodology and explaining the necessary statistics whilst supporting the guiding team member.

Although it is discouraged that management should introduce improvement strategies purely top-down, shutdown management should on the other hand definitely carry the improvement project and keep it under everyone's attention. Six Sigma projects are very much in need of strong top-down support because of their project organization with a *Champion* (problem





owner) who commissions the improvement effort (Tang et al., 2007). Although this thesis does not necessarily promote implementation of the Six Sigma organization structure with Champions, Master Black Belts and Black Belts, top-down commitment remains important.

Returning to the four aspects, aspects 1, 2 and 4 are covered by this type of project team formation. Aspect 3, the aspect of introducing some fun to the project may require some creativity, and may best be thought up by a project management expert from the outside. An example of making a strategy more appealing and user-friendly is the First Aid kit idea for the category *Anticipation and Resilience*. The idea came from the Direct Sheet Plant's former Lean coach who is experienced in 'marketing' lean projects among the workforce. He proposed that the anticipatory brainstorming measure, which is supposed to help the shutdown organization to cope quickly with anticipated problems, be formed into a First Aid kit for shutdown problems to make its underlying concept more appealing.

A file with a red cross on it could be used by every section to document mitigation procedures for specific problems. The file should be filled and kept organized by a *Doctor*, who would be someone from the preparation staff who would carry responsibility for the file.

This may all sound a little overly creative, but most experts agreed that such an approach would make using the measure more appealing because the concept is more recognizable. Selling the improvement strategy with a catchy name, logo or appearance can help to overcome resistance, as the current production improvement project I-prod (logo and name derived from Apple's Ipod) demonstrates.

Let us now return to the three improvement strategies that were introduced in this report; how can the above general findings on workforce cooperation (and conversely resistance) be used to make the implementation phase for these strategies to a success?

First of all, it should be noted once more that most validation experts expect the cooperation on the improvement strategies to be very good, as most people are motivated to improve the shutdown processes. Nonetheless, recommendations to avoid or overcome workforce resistance to the strategies are:

- Before implementing, shutdown management should present the improvement strategies to the workforce in a convinced way, but with room for dialogue. The ideas should be 'marketed' with a considerable amount of managerial enthusiasm, but they are not meant to be fixed, one-right-way measures: the shutdown organization could make adjustments if necessary.
- 2. Resistance that is expected with respect to the Anticipation and Resilience category, and to a lesser extent for the Communication Patterns category is legitimate: the downsides of the trade-offs for these strategies may weigh too heavy in the short run, when there is much more urgent work to do that may lead to much quicker wins. The improvement strategy for Preparation and Planning contains the most urgent measures to implement, then Communication Patterns and then Anticipation and Resilience.
- 3. As there is a clear difference in urgency and expected results between the different improvement strategies, do not (necessarily) implement them all at once. If it works better, try to introduce and implement one new strategy or even one new measure at a time to avoid flooding the workforce with new procedures to get used to.
- 4. Shutdown management should promote the improvement projects in a positive way and also keep the strategies under everyone's attention. It should try to make it into a





team effort, in which all employees have a share. It should also be appreciative when the employees show effort (and not necessarily result yet).

5. Shutdown management should help institutionalize the idea of continuous improvement by starting off on new improvement projects fulfilled by (a selection of) organization's employees right away.

With these recommendations in mind, it is now time to head towards the final phase of the improvement trajectory: the *Control* phase, in which the basis for ongoing improvement is laid.







Finally, the improvement project has arrived at the final stage of the DMAIC methodology: the *Control* phase. This is the phase from where the shutdown organization itself has to pick up the improvement process. As none of the improvement strategies proposed could be implemented within the limited time span of a thesis project, this section will discuss continuous improvement in general along with conclusions and recommendations for the Direct Sheet Plant based upon the experiences gained while conducting and writing this thesis project. The final phase ends with recommendations for further improvement research.







# **18. Continuous Improvement**

A shared characteristic of the new generation business philosophies presented in chapter 2 is the focus on continuous improvement. Six Sigma has institutionalized continuity of improvement efforts through its circular DMAIC-methodology: the *Control* phase identifies new opportunities for improvement, for which a new *Define* phase is initiated and the whole process starts all over again.

As can be deducted from the demise of the Ford production system described in chapter 2, no management approach is perfect under all circumstances. As the world and thus the Direct Sheet Plant's environment keeps changing, it is wise to keep improving processes, adjusting them to changed customer desires and technical opportunities.

Continuous improvement of the shutdown organization could be institutionalized by finishing every *Control* phase with conclusions and recommendations that identify new areas for research to be conducted right away. This way, every completion of an improvement project is followed by a new project and continuity is guaranteed.

Meanwhile, the performance of the variables that have already been under investigation as a subject in earlier improvement projects should be monitored: are the performances of critical-to-quality variables really improving? Answering this question to guarantee continuous improvement is the main reason to perform ex-post validation.

Like its ex-ante sibling discussed in chapter 17, ex-post validation research is done to test the success of the improvement strategies in reality; but this time, implementation has occurred. This means that the validation results are no longer based on experienced assessment, intuition and informed forecasting, but on measurements of the changes in performance of the critical-to-quality variables. The next section will discuss ex-post validation in more detail.

# 18.1. Ex-post validation: Meaningful metrics

Nothing can validate improvement strategies to the extent of certainty that permanent improvement in the performance of critical-to-quality variables can. Monitoring of the CTQ performance levels is therefore a good form of ex-post validation. Recommendations with respect to future measurements will be described in the next section.

# 18.2.1. Future measurements

For the future, measurements of CTQ variables can help monitor the performance of the shutdown organization and consequently of the shutdown maintenance processes. Not only delay and work efficiency levels could and should be monitored; new CTQ variables from ongoing improvement efforts may help monitor other processes within the shutdown.

With respect to the critical-to-quality variable *delay*, it would be good to measure only the delay explicitly caused by the Direct Sheet Plant itself. Currently the figures on delay are based on cast-to-cast measurements, which means that any possible delay caused by the oxysteel plant is included. Although this may not occur frequently, it may still distort the figures.

A second recommendation regards the use of more variables. New critical-to-quality variables have to be identified in later *Define* phases. So far, the root causes targeted by the improvement strategies relate to one *process measure* and one *output measure* (Groover, 2007). An *input measure* (for instance, the number of schedule changes in the week before





the shutdown) could provide interesting new insights. The next section will briefly discuss the fact that measurements and interpretation of the results require training of employees to be Six Sigma *green belts* or *black belts* or *Master black belts*.

# 17.2.2. Interpretation training

Although it is not especially recommended that the Direct Sheet Plant implement the martial arts rank terminology that is regularly used in Six Sigma organizations, training of at least some employees to achieve the measurement and analysis skills corresponding to the different ranks is a necessity.

Corus has successfully trained Lean coaches and although it would take extra time and money, a similar training method for Six Sigma 'belts' is recommended. Six Sigma seems to be an excellent complement to Lean Manufacturing principles and methods as was explained in chapter 2. It is expected that process improvements from Six Sigma would more than return the training investments.

This concludes this chapter on continuous improvement. The next chapter presents a reflection on Six Sigma as a theoretical framework for this thesis project. Pros and cons for its use will be discussed, which will be used to make recommendations for use in the industry in the final, concluding chapter.




## **19. Reflection on the theoretical framework**

This chapter will reflect on the theoretical framework that was used to provide a perspective on the shutdown problems experienced at the Direct Sheet Plant. This theoretical framework was based on Six Sigma theory and methods and in general, this approach was very helpful. Reflecting however, a clear distinction between pros and cons for use of this method can be made for the Direct Sheet Plant's problems. These insights can be translated to more general implications for the use of Six Sigma in industrial processes. The downsides of Six Sigma for this project will be discussed first. The advantages will be presented subsequently, which will be followed by some concluding, generic remarks on industrial use of Six Sigma.

One of the main downsides of a Six Sigma approach for this improvement project is actually related to an aspect of Six Sigma that is often considered its strong point in relevant literature (for example Tang et al., 2007): its data-driven character. The fact that Six Sigma has a strong focus on data makes processes easy to monitor, makes solutions easy to validate expost and makes soft suspicions on problems factual and recognizable, even to outsiders and sceptics. Consider for instance the figures gathered on the work efficiency. The productive percentage of the work hours was much lower than many people expected, which strengthened the motivation to improve the organization of the shutdowns throughout the Direct Sheet Plant. But the data focus may also work against an improvement project team as it makes any organization using Six Sigma very reliant on good data, which is not always easy to gather for every sort of process to be improved.

An example of a difficulty with data collection for this specific project was related to the frequency of the shutdowns. Only once in every four (and for a few months in the beginning of 2008 only once in every five) weeks could shutdown measurements be conducted, which slowed the project down to some extent.

Another difficulty with gathering data was the complexity of one of the performance indicators, work efficiency. Work efficiency is already a concept that can be defined differently by different people, so quite some time went into defining what work efficiency was for this specific project and how it should be measured.

Before the measurements could take place, more time went into instructing the measurement analysts that were helping out, so that they would categorize the workers' activities along the same lines as much as may be reasonably expected from different individuals with their own background and perspective on maintenance work.

Then, the accuracy of the measurements from a more practical view was problematic: even when assuming that all measurement analysts would make similar judgements in their categorizations of activities, how detailed could they measure? Sampling intervals of 2 minutes were assumed to give sufficiently representative results, but in fact of course, a second-to-second approach to measuring would be more accurate. On the other hand, that would not be workable. A trade-off between accuracy and workability for the measurements thus definitely existed.

As workability took the lead in the trade-off for this project, accuracy is considered less than perfect, which means that the Six Sigma statistics with the corresponding percentages of satisfactory process output are less valuable for use of setting objectives or assessing current behaviour with accuracy.



Finally with respect to the measurements, though the same for the main part, every shutdown is at least a little different from every other. For instance, more or less jobs may be cancelled and more or less problems may occur. Six Sigma relying on data for process performance monitoring on the long term means that the processes measured should display at least some similarity to make comparison just.

Concluding the remarks on problematic aspects Six Sigma's *Measure* phase, accuracy is a problem for many performance indicators that are less tangible than product characteristics such as thickness or temperature of a roll of steel sheet. Low frequencies for measurement opportunities may slow improvement projects down and different measurement opportunities may be less comparable than desired for fair comparison and monitoring.

The *Improve* phase brings about another type of conspicuous aspect of Six Sigma's DMAIC methodology. After the relatively guided earlier phases, the *Improve* phase leaves all the improvement work to be done up to the creativity of the project team (or individual in this case). This is not necessarily a problem as the previous phases have already sharpened the analysis of the problem and its causes to the point where it is almost clear and even nearly needless to say what should be done. The fact that the *Improve* phase is so open to creative solutions from other methodologies and theories may therefore be seen as an advantage; an opportunity for out-of-the-box, tailor-made solutions.

Still, it may feel like the guiding and structuring help in the form of the DMAIC methodology that was there before has suddenly left the project in the lurch. A little more guidance on the options for the *Improve* phase would be welcome.

This why this thesis proposes to integrate Lean Manufacturing tools and techniques into the *Improve* phase. The Lean toolbox is full of practical, standardized tools to improve a multitude of process characteristics. More on this will follow at the end of this chapter.

Before that generic recommendation, we will return to Six Sigma to discuss its advantages. Because so far, the difficulties discussed may have given the reader the impression that Six Sigma was quite an unsuitable theoretical framework for this project, which is certainly not the case.

On the contrary, Six Sigma's advantages more than outweighed the difficulties. The main strength of Six Sigma for this project was in the use of its DMAIC methodology. Especially in the *Define*, *Measure* and *Analyze* phases, the methodology is of great value: it helps to structure the problem analysis process to such an extent that reporting the analysis with clarity becomes a breeze.

The guidance of these phases makes sure that no important aspects are overlooked and forces project teams to define who the process customer is, and what variables are critical in the process of achieving this customer's satisfaction. This thought process guarantees that the improvement effort is immediately directed at the process variables that matter and that no time is spent on less important output characteristics. It thus promotes the efficacy of the improvement efforts and provides a sound basis for the solution design process.

The fact that the DMAIC methodology is cyclic and ends with the *Control* phase defining new values to be improved is also considered a big plus; not as much for this project in itself but mostly for the Direct Sheet Plant's shutdown organization, which can easily institutionalize a mindset for continuous improvement through this methodology.

Strangely enough, the final advantage that should be mentioned for Six Sigma was already mentioned when discussing its disadvantages: its data-driven character. Even though the difficulties related to measurements and their accuracy levels may sometimes be hard to





overcome, the advantages are also clear: results from improvement methods can be traced back with considerable ease which makes it relatively simple for an organization to see whether they are on the right track towards improved process performance.

The disadvantageous side of the data reliance may be mitigated when the organization recognizes the difficulties related to data accuracy and does not aim to do very accurate calculations on the basis of this data, but rather uses the data for conceptualization of the problems. This is one of the more generic conclusions and recommendations that can be made about use of Six Sigma for use in industrial processes. The next section discusses these generic conclusions and recommendations.

### 19.1. Use of Six Sigma in the industrial sector

Generically, it can be concluded from this thesis project that Six Sigma provides an good theoretical framework for the analysis and improvement of many types of processes. These processes should be characterized by:

- 1) A reasonable frequency of measurement opportunities to keep the project from slowing down
- 2) A considerable level of similarity between measurement opportunities to allow for fair comparison on the basis of data, i.e. the process circumstances should be relatively constant

The DMAIC methodology provides an excellent, standardized road map that can be used for improvement of almost any process that contains measurable variables. Although virtually any process characteristic can be measured in some way (whether more or less directly), 'soft' and ill-defined process characteristics may be very hard to measure with sufficient accuracy. This is not necessarily problematic, but the organization should then refrain from doing elaborate statistic calculations on the basis of these relatively unreliable data. It should then use the data merely as an indicator to be compared to desired values so that more qualitative statements can be made.

Only in cases where data is highly reliable and accurate (and representing often more tangible aspects such as product specifications) are organizations recommended to use the full set of statistical techniques that Six Sigma comprises. In other cases, the amount of training involved in educating project team members in these complex statistics may prove to be money that is not returned on in the form of improvements.

The DMAIC methodology's cyclic form is one of its great advantages for any organization that wishes to institutionalize continuous improvement: every project is terminated with the identification of new opportunities for improvement.

A great opportunity to improve Six Sigma's DMAIC methodology itself is considered to be in the possibility of incorporating Lean Manufacturing's practical tools and techniques in the *Improve* phase to increase the guidance this phase provides for project teams. The next section elaborates on this.



### 19.2. Integration of Lean Manufacturing and Six Sigma

As was mentioned at the start of this chapter, one of Six Sigma's strongest features is its DMAIC-methodology and the support that this methodology provides to structure improvement projects. Using the DMAIC-methodology practically guarantees a sound analysis of the problem at hand because of its rigidly guiding *Define*, *Measure*, *Analyze* and *Control* phases. The *Improve* phase is remarkably less guiding however, solving the problems is totally left up to skills of the project team.

On one hand, the openness of the *Improve* phase may be considered an advantage for project teams: it opens the project up for creativity to be employed in designing an improvement strategy that is custom-made for the specific situation and is thus likely to fit the problem and the organization.

On the other hand however, project teams may feel left in the lurch when reaching the *Improve* phase. All of a sudden, the previously rigid structure that provided support on what to do next falls away. Especially inexperienced improvement project teams may feel this sense of abandonment. The *Improve* phase more or less representing the climax of the project would justify some more guidance for such inexperienced teams.

It is suggested in this thesis that that is where Lean Manufacturing is integrated with Six Sigma's DMAIC-methodology. Chapter 3.4 on Lean Six Sigma already proposed some advantages for integrating Lean Manufacturing and Six Sigma from theory, but the recommendations made in this chapter have been derived from using the DMAIC-methodology in this specific project.

As was already discussed in chapter 2, Lean Manufacturing is in essence a collection of improvement techniques, each relating to a specific problem. To put it in other words, Lean Manufacturing is a toolbox full of high-quality, proven tools. As a management approach however, Lean Manufacturing fails in guiding a project team towards selecting the right improvement tool for a given problem, which was why Six Sigma was chosen to guide and structure this improvement project.

But as will be clear, Six Sigma ceases to guide the project team right where Lean Manufacturing starts to provide structure: in the *Improve* phase. Its improvement tools are very standardized and have been used successfully by countless organizations. The quality of its tools and techniques is basically what has given Lean Manufacturing its good reputation.

Using Lean Manufacturing improvement tools would often be a very good option for project teams. Although the tools tackle specific problems, they are *common* problems as well, many of which may occur in a given, industrial environment.

Among other things, these problems comprise excessive set-up and switch-over times for batch processes (tackled by the Single Minute Exchange of Die or SMED method), workflow problems between different actors (tackled by value stream mapping) and problems with the management of materials and files (improved by the 5S-method). Using Lean Manufacturing tools for such problems would be utterly logical: consider someone designing and producing a new tool to do exactly what a traditional wrench could do. He would be wasting his time and money (the wrench would have worked just fine) but also, he would be risking to put that time and money in designing and producing a tool that is *less suitable* for the job at hand.



This simple, everyday-life parallel may sound ridiculous but is actually quite similar to what a project team would do if they would not (at least) consider to use proven Lean Manufacturing tools in the *Improve* phase.

This thesis proposes to integrate Lean Manufacturing tools into Six Sigma's DMAICmethodology by use of a combined Lean Six Sigma methodology introduced below. It is expected that using this combined methodology may reduce the time and money spent on designing custom-made improvement methods, of which there is a greater risk that they may not work as well as the proven Lean methods.

**Define:** Commission an improvement project for a specific problem. Appoint a multiskilled, mixed-experience project team in which at least some members are trained in the use of Lean Manufacturing and Six Sigma. Sharpen the problem definition; answer the following questions: 1) Who is the customer of the unsatisfactory process? 2) What variable values are considered critical to the quality of the process outcome by the customer? Define objective values for these critical-to-quality (CTQ) variables.

<u>Measure:</u> Find ways to accurately measure the current (unsatisfactory) performance of the CTQ variables. Conduct the measurements and process them into usable and communicable data (e.g. tables, charts, percentages et cetera).

<u>Analyze:</u> Use analytical tools associated with Six Sigma, for instance Ishikawa diagramming, to identify the deeper causes (so-called root causes) for the unsatisfactory CTQ performance levels.

**Improve:** Scan the Lean Manufacturing 'toolbox' for standard improvement methods. Consider for instance Poka-yoke's fail-proofing method which aims to eliminate human error in work activities, Kanban signalling methods to guard Just-In-Time inventory levels, or 5S to create an orderly work environment in which materials or files can no longer get lost easily. Put these well-guided methods to use where possible, in other cases, make a creative yet careful design to eliminate the root causes from the Analyze phase. Do an ex-ante validation experiment, e.g. an expert validation session. If necessary, revise the improvement method; then implement it.

**Control:** Monitor the CTQ performance levels; are the improvement efforts paying off? Evaluate the improvement project and its results and identify (possibly with customer cooperation) new areas for improvement. Return to the Define phase and start a new project for the newly identified problem areas.

This combined methodology may prevent improving organizations to put effort and resources into re-inventing the wheel. Of course, as is emphasized in the boxed text, Lean tools may not always apply. In that case the project team could look at other theories for help, or design a custom-made solution. It is expected however that the Lean tools will be useful in many projects.





A less pleasant aspect of this methodology is that it requires project teams to be trained both in the use of the DMAIC-methodology and Six Sigma's statistical legacy and in the use of Lean Manufacturing tools. The upside is that this combined methodology was designed especially for rather inexperienced improvement project teams: the guidance throughout the project is excellent. Practical literature on Lean tools is abundant and many helpful books can be found that introduce the methods in an uncomplicated do-it-yourself style. The methodology is also not meant to integrate the most complex statistics of Six Sigma into the project. Six Sigma's influence can mainly be traced back to the DMAIC-structure of the project and the fact that there is still a focus on data. This data should not necessarily be used for sigma level calculations, but could and should enable simple comparison of current performance levels and objective levels. One or two people with a basic understanding of one of the management approaches or both could already be enough to guide a project team for a range of relatively simple projects. More complex projects would require more knowledge on Six Sigma and Lean Manufacturing.

Specifically speaking for Corus, the recommendation of this combined Lean Six Sigma methodology implies that this thesis's recommendation to start using Six Sigma for improvement projects is certainly not rendering the investments made in Lean training infeasible. The Lean skills will still be very valuable for the organization, but they should be complemented with the structured analytical approach of DMAIC to avoid haphazard use of the Lean methods.

The next and final chapter of this thesis report will present the final conclusions and recommendations for the shutdown organization.





## 20.Conclusions & Recommendations

This final chapter forms the conclusion of this thesis report. Conclusions and recommendations for the shutdown organization will be presented. An attempt to generalize findings of this thesis for the industry will be made in the second paragraph. This chapter, and the report of this thesis project as a whole, ends with recommendations for further research.

### 20.1. General conclusions and recommendations

This section will present the conclusions and recommendations that are the results of this long-term project, in which many more opportunities for improvement were perceived that could not be treated within the limited scope of this thesis research project. First, the conclusions and recommendations on the shutdown organization as a whole and issues regarding shutdown management will be discussed. The focus will then shift towards Six Sigma: was this theoretical framework useful and is it worth recommendation for future projects?

### 20.1.1. On the shutdown organization and management

The shutdown organization consists of motivated people who all try to make the best of the shutdowns. The problem is that the organization is currently not in control of the processes that jointly constitute a 'shutdown'. The shutdown organization's employees, motivated for improvement as they are, all have different perception of what is going wrong. This is not strange at all as 1) <u>many</u> things are going wrong and 2) nobody likes to blame themselves, so it is always easier to emphasize the urgency of problems that could not have been prevented by you or your department. This results in the fact that many people in the shutdown organization do not feel overly responsible for the shutdown as a whole, let alone for keeping promises or agreements that were made on the initiative of shutdown management. Finger-pointing will not get the organization as a whole anywhere though: elimination of root causes requires a team approach that surpasses the organization's department boundaries. A change in corporate culture with respect to (the sense of) responsibility and accountability is thus required.

The area categories for improvement surpass the section and department boundaries: *Preparation and Planning, Communication Patterns* and *Anticipation and Resilience* are issues in all sections of the plant during the shutdown. All sections should improve their practices. With respect to the shutdown organization and its road to improvement, the following recommendations are made:

• The missing link in the organization of the shutdowns can be characterized as *Evaluation and Documentation*. Although evaluation sessions are held, the conclusions and action points are not documented centrally, nor are they followed up or institutionalized. They do not become part of the mind set of the people who are at the execution level of the shutdown processes: the preparation staff members, the coordinating supervisors etcetera. This constitutes a waste of valuable knowledge and leads to unnecessarily recurring problems.



Although the improvement strategy for *Preparation and Planning* emphasizes the need for documentation of the actual versus the scheduled progress, and the strategy for *Anticipation and Resilience* also relies on documentation of mitigation of materialized problems, the strategies do not address the need for documentation of evaluation conclusions and derived action points.

It is recommended that the shutdown manager and the chiefs of the sections' technical departments take their responsibility in keeping the *lessons learnt* under everyone's attention to avoid unnecessary repetition of mistakes.

• Secondly, the fact that the members of the shutdown organization do not feel responsible enough to keep their end of the deal is a cause of not only recurring problems but also a lot of frustration. Much of the lack of responsibility comes from the fact that people do not see the need for what they have been asked to do, such as in the example of a maintenance specialist detailing his own supervision schedule in chapter 14. The improvement strategies for *Preparation and Planning* have already redefined tasks, for instance for maintenance specialist, section coordinators and coordinating supervisors, to make responsibilities more visible and to increase self-regulation through co-workers addressing each other. However, shutdown management should also address the workers' responsibilities more, as long as it is backed with compliments and appreciation in case of good work. This latter recommendation is one to remember: not only at the Direct Sheet Plant but throughout Corus, complaints are heard on the lack of managerial appreciation for good and hard work. Often, a simple verbal compliment or 'thank you' is all that is needed to keep the work moral up and the workforce motivated.

• The chief of the Technical Department should offer more support to the shutdown manager, whose position does not automatically grant him the required superiority over other people in the shutdown organization. Too often, his desires are not sufficiently heard and honoured with cooperation.

The next section contains more remarks and recommendations that are focused especially on improvement projects for the shutdown organization of the Direct Sheet Plant.

### 20.1.2. On shutdown improvement

If shutdown management indeed decides to carry out the implementation of the improvement strategies proposed in the *Improve* part of this report, it is important to note the following.

• The measurements in the *Measure* phase should be made more accurate and representative for reality through repeated measurements by trained analysts. This is especially the case for the work efficiency metric. It is highly recommended that the shutdown organization regularly hire professional analysts to do the work sampling study and/ or to train employees in work sampling. The current basis of only one work sampling study is too thin to be used for ex-post validation of the improvement strategies. When considering that resistance to the proposed improvement strategies may be expected, the single work sampling study conducted by inexperienced analysts (and co-workers) may become an easy target for criticism. Careful definition of metrics is therefore also important. With regard to definitions of metrics, in the future, the figures collected on delay should only contain extra time caused explicitly by the shutdown. Delay caused by the steel plant should be excluded.

• New projects should lead to new metrics to improve. The more metrics, the more the performance of the shutdown as a whole can be monitored and predicted. Cause-and-effect



relationships could be validated by incorporating metrics of different types (*input, process* and *output*) into the projects and investigating their interactions.

• On any account, repetition of the measurements is needed for all critical-to-quality metrics that have been or will be part of an improvement project: monitoring of their performances forms the basis for ex-post validation of improvement strategies and can lead to the identification of other areas for improvement.

### 20.1.3. On Six Sigma

Chapter 2 was focused on finding a suitable and helpful theoretical framework for this thesis. After a comparative study of three management approaches, Six Sigma was chosen to provide not only its specific 'process perspective' on the problems but also its very workable standard DMAIC-methodology. The latter has proved itself to be the most useful component of Six Sigma within this project: the methodology provides a rigid guideline that institutionalizes continuous improvement through its cyclic, repetitive motion through the phases *Define, Measure, Analyze, Improve* and *Control*.

It is highly recommended that the Direct Sheet Plant (or better yet Corus) invests in training employees in Six Sigma improvement. More than the current framework used by Corus, Lean Manufacturing, it approaches problems with an open mind. Six Sigma's view that all business functions can be seen as processes with their own performance metrics, helps to lead the project team from the problem in the form of an unsatisfactory performance to its root cause. Elimination of this root cause is then left up to the creativity of the project team: help to tackle the root cause can be sought in any other theory or business philosophy.

As discussed in chapter 19 and in the scientific paper that comes with this thesis report, Lean Manufacturing is a toolbox full of solution techniques that may very well be applied at this point. Lean Manufacturing is therefore still very useful, but does not provide a standard pathway to systematically explore the problem and its causes; it presupposes the cause to be eliminated is known.

It therefore deserves recommendation that Corus start a Six Sigma training program. Project improvement teams could then contain both Six Sigma and Lean Manufacturing specialists, who bring together the best of both theoretical worlds.

Furthermore it is recommended that the Direct Sheet Plant start on implementation of the improvement strategies proposed in this thesis right away; and also that they start up new improvement projects following the DMAIC- or combined Lean Six Sigma methodology from chapter 19 right away. This way, the methodological improvement cycle is not broken and the mind set for improvement is institutionalized within the shutdown organization.

The next section will generalize this recommendation for use of Six Sigma in maintenance and other business functions to possibilities for use in the industry as a whole.

### 20.2. Generalization of findings for the industry

The most important finding of this thesis that is relevant to the industrial sector as a whole is the suitability of Six Sigma as an improvement approach for all sorts of business functions. Six Sigma suffers the image of being an overly complex statistical method for control of manufacturing processes (Arnheiter and Maleyeff, 2005). However, in reality the statistical control of process variables adopted from the theory of Statistical Process Control is only one pillar of Six Sigma.





Six Sigma's other side is equally important, if not more important than the statistics: its focus on quality for all sorts of business processes. Its idea that all aspects of a process can be measured, improved and monitored is valuable and can be inspiring. The DMAIC methodology it supplies as a standard roadmap for any kind of improvement project provides an excellent guideline in the analysis of problems and the search for their root causes.

Six Sigma's focus on root causes stimulates that causes are eliminated permanently, instead of just mitigating the problems symptoms. It leaves freedom and creativity to the project team in how to tackle the root causes: it does not restrict the team to the use of predetermined tools, but rather leaves the road open for the project team to use tools and techniques from other theories and approaches. This openness increases the chance of the optimal technique for root cause elimination is chosen.

However, the use of Six Sigma could be improved by complementing it with the use of the proven improvement methods of Lean Manufacturing in DMAIC's *Improve* phase. The scientific paper written in combination with this thesis report and chapter 19 discuss the advantages that companies could achieve in their improvement efforts when combining Six Sigma's systematic approach towards increasing quality in a wide sense with the practical tools and techniques boasted by Lean Manufacturing. Lean's wide array of improvement techniques for specific problem areas can excellently fill in the blanks that Six Sigma leaves in the Improve phase. A step-wise Lean Six Sigma methodology can be found in the scientific paper and in chapter 19.

The next section will conclude this thesis report with recommendations for further research.

### 20.3. Recommendations for further research

In this section, recommendations for further research are made. During the thesis project, some areas that were subject to recurring problems could not be included into the scope of this project due to their magnitude and complexity. Two issues especially deserve management attention:

• One of the most urgent recommendations for further research concerns the Direct Sheet Plant's arrangements with maintenance contractors. The hourly pay used now is an approach to contracting that would be far more logical in a situation of infrequent contracting. Here however, the frequency of contracting is high: the firms that are contracted are always the same. Much more feasible contracts could be established that could also tie the contractor to other agreements, such as the shutdown management's order for workers to stay on the plant during break time. Another possibility to negotiate would be the start time of the activities: currently all contractors want to work from starting from 7:00am. This puts a strain on the sign-in procedure; in the early morning there is often a queue to sign in and get the work permits.

Moreover, there are many jobs that could be done sooner after the installation has been shut down. If contractors were prepared to start earlier, some activities could be attributed an earlier start time and eventually even the total shutdown duration might be decreased.

Improved contracts could also include incentives such as financial bonuses for efficient or high-quality work. Huntsman Holland reported good results after revising their maintenance contracts (Peter Spiegelenberg of Huntsman Holland in a telephone interview, November





2007). It is recommended that the Direct Sheet Plant investigate the possibilities for new contracting procedures.

• Another issue relates to the purchase and delivery of materials needed for the shutdown. It happens much too often that materials are delivered late. This means that maintenance jobs have to be cancelled, which involves rearrangements of the schedule and the cancellation of contracted personnel, all of which costs time, effort and money.

It is unclear at this point where the recurring problems are caused exactly. The fact that orders should run through Corus's central purchasing department do not exactly increase the transparency of the procedures, so root causes are hard to define. It is suspected that the main reason for late delivery is slow processing of the orders. It is therefore recommended to do a Lean-style *value stream mapping* analysis in which the orders are tracked as they move through the organization: which stages in the process cause orders to be delayed, but also, do all stages in the process add value? This creates an image of the system of waste and the opportunities for improvement (Carreira and Trudell, 2006).

Doing a good value stream mapping analysis is quite difficult and requires thorough training. If the shutdown organization wishes to look into the material delivery issues as soon as possible it is recommended to hire a professional consultant who uses specialized software such as for instance Engage!.

• The final recommendation for further research pertains to the use of the combined Lean Six Sigma methodology proposed in chapter 19 and could benefit not only the shutdown organization but also Corus as a whole and other organizations. It would be interesting to test the combined methodology in practice: are the expectations on user-friendliness for inexperienced project teams true in reality? Does the combined methodology really provide a more structured analytical basis that guarantees that the right Lean tools are put to use? Is the combined methodology applicable for many improvement projects or do other constraints on its use apply than the ones that were brought forward here?

Such empirical information could help to improve the combined methodology to serve Corus and organizations that want to improve both the quality and the efficiency of their processes in an ongoing way.









## Personal reflection on the thesis process

This is a section in which I will briefly reflect on the process of writing a thesis project in a personal sense. The thesis project being an individual endeavour teaches you a thing or two about yourself and your work patterns: to my surprise I found that like the shutdowns at the Direct Sheet Plant, I too displayed a low work efficiency and delay on schedule. Knowing that my work pace picks up when under pressure, I allow myself to work very slowly for a very long time until the pressure builds up enough to create a feeling of urgency that helps me to increase my work speed.

Unfortunately, sometimes the pressure built up a little too late in this thesis project. My thesis committee suffered the consequences of my delay on scheduled submission deadlines on one occasion: submitting some of my chapters only half a day before the green-light meeting meant that they had to adjust their own schedules to read them.

Luckily, delay on schedule did not turn out to be a critical-to-quality variable for the thesis report and I was allowed to present my thesis project's findings on June 27, 2008.

Aside from my low initial work efficiency and delay, my personal performance throughout the project coincidentally appeared to share more overlap with the Direct Sheet Plant's shutdown processes. I have even found that two of the improvement categories used in this report (*Preparation and Planning*, *Communication Patterns* and *Anticipation and Resilience*) could do with some improvement with respect to my personal performance on projects.

In the category *Preparation and Planning*, I reluctantly accept that I should revise my strategy of not planning and waiting for pressure to build up. Although the strategy has worked for me on numerous occasions ranging from exams to small projects and reports, the size of this project was just a little too big for this type of approach. The importance of getting a good grade was also more important this time. Still, as I am planning and scheduling for my own use, I still have trouble seeing the need for detailing my schedule. Now where did I hear that before?

With respect to preparation, my presentation for the Energy and Industry section colloquium at my faculty was an experience that taught me once and for all to never face an informed audience with a less than perfectly prepared speech...

In the category *Communication Patterns*, I have learnt that I should involve my supervisors much more than I have done: like many coordinating supervisors, I do not communicate much about my project's progress. This is probably due to the fact that I do not like to submit work that is only half-done; and a lot of my work remains half-done for a long time due to my low initial work efficiency. I also do not like to ask for a lot of guidance, I rather figure everything out by myself. I realize now that I may have kept my supervisors a little too much at bay and therefore may have missed opportunities to exploit their expertise.

Finally we have arrived at the category *Anticipation and Resilience*, and well, I am happy to say that I have not been able to learn any valuable lessons in this category, as fortunately no problems worth mentioning have materialized during this thesis project.

Doing this thesis project I learnt another thing about myself: I do not like to work on projects individually. I have used this insight during my job hunt and am happy to say that I have found myself a team-work job, at Corus. Now 'all that is left for me to do' is improve my *Preparation and Planning* and *Communication Patterns* during the next few years!



All in all, I think this was a valuable experience, and a fun one at that. Once more, I would like to thank my supervisors very much for their support.

Marlies van den Heuvel June 11, 2008



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## Appendix A: Long-term process shift

### A.1. Process shifts: 4.5 sigma

The expectancy for defects that is associated with Six Sigma programs is 3.4 parts per million (ppm). But as we saw in the paint example, theoretically 6-sigma processes should produce no more than 0.2 ppm defects. Although both values are extremely small, compared to one another they differ quite a lot.

The 3.4 ppm defect rate, which corresponds to a 4.5 sigma level, is used in Six Sigma programs in order to take process shifts into account. Process means tend to shift in the long run or even from lot to lot by a maximum of 1.5 sigma (Groover, 2007; Arnheiter & Maleyeff, 2005). This process shifting is visualized in figure A.1.

As long as a process is centred right in the middle of the tolerance area, 6-sigma expectancies hold. But when a process mean shifts over time and does indeed do so by the 1.5 sigma maximum, it will approach one of the specification limits up to 4.5 sigma.

As Six Sigma is a program that focuses on the long term, the possibility of process shifts needed to be incorporated in it and so 4.5 sigma levels are still considered an acceptable defect rate.



STANDARDIZED PROCESS VARIATION (SIGMA UNITS)

		Number of OFDs per product				
Sigma laval	OFD quality (NCPPM)	100	500	1,000	5,000	20,000
oigina ievei	OFD quanty (Ner Fill)	(70)	(70)	(70)	(70)	(70)
2.5	158,655	0.0	0.0	0.0	0.0	0.0
3.0	66,807	0.1	0.0	0.0	0.0	0.0
3.5	22,750	10.0	0.0	0.0	0.0	0.0
4.0	6,210	53.6	4.4	0.2	0.0	0.0
4.5	1,350	87.4	50.9	25.9	0.1	0.0
5.0	233	97.7	89.0	79.2	31.2	1.0
5.5	32	99.7	98.4	96.9	85.3	53.1
6.0	3.4	100.0	99.8	99.7	98.3	93.4
6.5	0.29	100.0	100.0	100.0	99.9	99.4
7.0	0.019	100.0	100.0	100.0	100.0	100.0
7.5	0.0010	100.0	100.0	100.0	100.0	100.0

Figure A.1.: Process shift and (non-)conformity levels (from: Arnheiter and Maleyeff, 2005)









## Appendix B: Work sampling

### B.1. 95% confidence intervals

The 95% confidence intervals in chapter 10 were calculated in Excel using the following formulas:

For the lower bound:

$$p - \sqrt{\frac{p(1-p)}{n}}$$

For the upper bound:

$$p + \sqrt{\frac{p(1-p)}{n}}$$

Where p is the measured percentage for the activity category and n is the sample size (1539). The different values of p for each activity category are:

Work sampling categories	p-value	
Directly productive	23,98%	
Indirectly productive	25,47%	
Unavoidably unproductive	19,43%	
Avoidably unproductive	31,12%	









## Appendix C: Semi-structured interviews

These are examples of questions asked in semi-structured interviews in shutdowns. The experience, cooperation and enthusiasm of the respondent regulated which questions were asked to whom. Other questions were asked too, so these are merely examples.

- On a scale from 1 to 10, how would you rate the organization of this shutdown and why?
- How was the preparation for this shutdown for you personally? Did you receive information in a kick-off meeting with a coordinating supervisor from the Direct Sheet Plant?
- What do you think could be improved in these shutdowns? How would you improve these things?
- Do you know another plant within Corus or another company where you thought the shutdowns were better organized? If so, what is it that goes better over there compared to here?
- Did you encounter any problems today? Could you have avoided these problems yourself?
- Did you experience a lot of waiting time during this shutdown?
- How long did it take you to sign in at the pull pit this morning?
- How experienced are you in your profession in general? And how experienced are you working in this plant? Could you easily take on another job at another part of the installation with the right supervision?

Many of these questions address problems that were not included in the final scope of this project in detail, such as the line formation at the pull pit when signing in the workers in the morning. Other questions that do address problems within the scope may not have been on the list but were asked spontaneously.







## Appendix D: Initial cause-and-effect diagram

This appendix explains the cause-and-effect relations displayed in the diagram below, which is presented in chapter 11. The cause-and-effect diagram displays arrows pointing from the cause to the effect. The + and – symbols that are shown in the middle of the arrows indicate the positive or negative effect one factor has on the other. As an example, the effect of breaks on the work efficiency should be read as follows: *an increasing number of breaks will lead to a decreasing level of the work efficiency*.

The factors have been clarified by the use of units that are placed between square brackets. In some cases, the brackets are empty; in these cases the factors are ordinal variables, the value of which can be assessed within the shutdown organization. An example of this is the quality of the work instructions, the organization can easily assess on experience whether these are good, mediocre or poor, whereas a quantifiable unit can not be found that is representative of the concept of quality of a work instruction.







When starting the analysis of the diagram in the lower right corner, we see the three basic categories of work activities during the shutdown: cleaning, scaffolding and maintenance jobs. The more there are of each of these activities, the more work activities there are that have to share the limited amount of space in the installation or scarce resources and the likelier it will be that at least one of the work groups will experience waiting time.

The more work activities there are and the more they start at the same time (6:00 or 7:00am) the likelier it is that line formation for the sign in at the pull pit will lead to waiting time for the maintenance workers.

Waiting time is also caused by materials for the work that are not ready or lost and by problems that need attention before the maintenance work can be continued. The lower the experience with the installation is, the more unexpected the occurrence of some problems may come, and the longer the shutdown organization needs to resolve the issue.

The low experience with the plant of some maintenance workers reduce their work pace as they are still learning; and it can also negatively influence the work they deliver in terms of quality. Part of the effect of the lack of experience can be mitigated by supplying good work instructions.

The work efficiency is defined by a combination of factors: waiting time of course negatively impacts the work efficiency, as does a low work pace. The influence of work quality on the efficiency may be somewhat less clear, but the work measurement conditions stated that rework after mistakes made should be considered avoidable, so low quality and rework negatively affect the work efficiency, as does break time.

A good work efficiency promotes progress, which decreases the delay experienced. When there is less delay, there is less loss of income as the production can be started up earlier. That means that the cost for the shutdown are decreased. A good work efficiency also influence the shutdown costs in a more direct way: the sooner the work is finished, the sooner the workers can be sent home. Since the worker's are paid an hourly wage, every hour counts with respect to the costs spent on human resources.

A detailed schedule is highly important for the shutdown, but it is harder to make such a schedule when there is little experience on the job to be planned. Still, a detailed schedule is a necessity to enable monitoring which leads to up-to-date knowledge on the progress of the activities. That knowledge can be collected through progress supervision which consists of comparing the actual grade of maintenance completion with the scheduled one. The results of these comparisons have to be communicated in time to keep the progress knowledge up-to-date.

If the knowledge on the progress is of a good quality and the organization can make use of enough resources in terms of (experienced) personnel and materials, the problem-solving ability and thus the resilience of it is increased in terms of problems materializing. This problem-solving ability can strengthen the progress of the maintenance work, thereby reducing the delay caused by the occurred problems.





## **Appendix E: Validation results**

### E.1. Results of the expert validation interviews

The next sections contain the results of the validation interviews. Although the respondents' reactions have not been transcribed so that they may not be paraphrased, the reader may take the cursive text below as personal statements made by the respondents.

### E.1.1. Validation interview #1

#### Respondent: Shutdown Manager

#### Assessment workability in terms of workforce cooperation:

Grade: 9

A high acceptance rate is expected due to the large amount of time the organization has already spent on discussing the problems and emphasizing the need and possibilities for improvement. The workforce is increasingly motivated to improve their work processes. On the other hand, the Direct Sheet Plant is a professional organization: if employees do not want to cooperate, shutdown management will address their responsibility to accept and obey the organization's plans.

Assessment workability in terms of resources (both financial and workforce capacity): Grade: 9

Much more efficient use could be made of the capacity that is already present in terms of human resources. If however there proves to be a capacity problem, money can be made available to deal with these capacity constraints.

Expectance of effect of the improvement strategies on the two critical-to-quality variables: *Grade:* 9

Expected reduction of the average delay of shutdown finalization: 100%

Expected increase in work efficiency: 100% increase of the directly productive category [this leads to a work efficiency level of approximately 75% productive time]

The expected effect of the improvement strategies on the critical-to-quality variables' performances is almost exactly the same as the rather ambitious objectives from the Define phase. The shutdown manager's motivation for this expectance was that as long as the organization is motivated enough to make this to a success, it is possible to achieve these results within the defined period of two years. The shutdown organization should then let go of the desire to improve other, less relevant problems and concentrate on implementing the proposed measures.

On second thought, the shutdown manager revised his statement of the expected increase in work efficiency: 74% seems to be somewhat of a utopia; a level of 60% work efficiency would already be more than satisfactory.

#### Other remarks:

• The suggestions for improvement are clear and recognizable.





- The shutdown organization should involve contractors from a much earlier stage in the preparation and planning process. The preparation and planning phase could lead to much better work instructions when the contractors are used early on.
- The magnetic visual planning board will not be implemented if the shutdown manager is concerned. Even if it is an off-the-shelf improvement from the oxysteel plant, it seems very complex and laborious. MS Project offers quick-and-dirty visual tools that he considers much more urgent to use. Only at later stages does he see an opportunity for use of the magnetic board.
- The organization will also need a milestone planning for the implementation process of the strategies itself.
- The shutdown manager would have liked to see recommendations for differentiated start times of the maintenance jobs. Recommendations with respect to this currently pertain to recommendations for further research into renewed procedures for contracting out maintenance jobs. The shutdown manager emphasizes that new contracts are not needed per se for getting contractors to start on other-than-regular times.

### E.1.2. Validation interview #2

Respondent: former Lean coach of the Direct Sheet Plant

Assessment workability in terms of workforce cooperation:

Grade: 7

On the whole, the level of cooperation will probably be okay. The workforce at the Direct Sheet Plant's Technical Department seems motivated to improve. The cooperation of the maintenance specialists will probably be a lot less since they have to change their work processes in a way that causes their jobs to be more labour-intensive.

Assessment workability in terms of resources (both financial and workforce capacity): *Grade:* 7

The workforce could spend their time much more efficient, so in general the improvement strategies could be implemented and used using only the current capacity. It will however be difficult to stimulate the workforce to use their time more efficiently, as the general perception among the employees is that they are already very busy.

Expectance of effect of the improvement strategies on the two critical-to-quality variables: Grade: 9 [ a 10 for importance, but also a 10 for resistance to expect from maintenance specialists]

Expected reduction of the average delay of shutdown finalization: 80% Expected increase in work efficiency: 65%

There is no doubt that the proposed strategies really target the performances of the critical-toquality variables, however in the end the effect will be determined by the motivation and cooperation of the relevant workforce. The objective for the work efficiency from the Define phase is considered rather unrealistic.





Other remarks:

- A lot of the success of the strategies depends on the workforce cooperation. To get workforce cooperation, it is important to market changes as well as possible, so that the people who need to cooperate see the need to do so. Good marketing often means appointing someone to be in charge of making the project work and making the proposed work task more appealing. Such as in the case of the brainstorm sessions to define problem scenarios and determine solutions for them, you introduce the project under the name of 'the Installation First-Aid Kit'. To accompany the name, you hand out files with a big red cross on them. You appoint someone to be responsible for the quantity and quality of the content of the files. This is likely to spark much more enthusiasm among the workforce than introducing a obligatory brainstorm sessions.
- If you would want to employ other people than the usual employees to take the role of coordinating supervisor during the shutdown, you will need to check their skills with respect to their ability to approach people and address their behaviour [e.g. in terms of abiding to safety rules] if necessary. You may even want to train them in such skills.
- It is a good idea to have the maintenance schedule for another person acting as a coordinating supervisor to stimulate feedback on scheduling. A point in time prior to every shutdown should be defined in which the maintenance specialist and the coordinating supervisor go through the schedule together. It should be a meeting in which responsibility over the job and its progress is also transferred clearly. People generally appreciate clarity about who is responsible when and for what.
- The active approach towards progress communication as proposed for the section coordinator could be made even more workable if a planning was located near the jobs, so that supervising coordinators could supply their information there. This would save the section coordinator time collecting the progress information from all the job sites.
- A 4D-visual planning could be made when integrating images of job sites or resources such as mobile cranes into 3D-CAD visuals with special software. It would cost a considerable amount of time to make the visuals but they could then be used over and over again. Maybe it would be good to implement this at a later stage.
- The need for workforce cooperation is the soft spot of the proposed improvements.

### E.1.3. Validation interview #3

Respondent: chief of the Technical Department of the WISK section

Assessment workability in terms of workforce cooperation: Grade: 7 The motivation for improvement efforts is currently high throughout the plant.

Assessment workability in terms of resources (both financial and workforce capacity): *Grade:* 7





Although a lot more could be achieved if the workforce would arrange its work tasks differently and more efficiently, the plant is nearly always short of coordinating supervisors during the shutdown. If you decide to no longer employ maintenance specialists as coordinating supervisors, where will you take these people from? You could hire people from the Project Services department, but you could also decide to let maintenance specialist still be coordinating supervisors, just not on the jobs they scheduled themselves, for instance in another section. Employing them in other sections would of course mean that your maintenance specialists are located away from their area of expertise and experience, so maybe that is not such a good idea after all.

Maybe it would be the least heavy on the capacity of the personnel if we would implement this in a phased manner.

#### Expectance of effect of the improvement strategies on the two critical-to-quality variables: *Grade:* 8

Expected reduction of the average delay of shutdown finalization: 30% Expected increase in work efficiency: 50% directly productive (i.e. 57% productive time) The objective for the reduction is quite steep, a 30% reduction of delay would great already. The work efficiency increase expected is lower than the objective of 74%, which is considered very high and a little unrealistic.

#### Other remarks:

- The strongest points of the proposed strategies are the milestone standard for the scheduling process and the active top-down approach that requires section coordinators to go and collect the information they need. A lot of result may be expected from those suggestions. The urgency of the other measures (for instance the scenario brainstorming and documentation) is considered less high and as they require a lot of work they could be implemented later on, when everything is already on a roll.
- Considering risks during the scheduling process is indeed expected to provide clarity and to improve validity of the schedule.

### E.1.4. Validation interview #4

Respondent: chief of the Technical Bureau

#### Assessment workability in terms of workforce cooperation:

Grade: 8

The organization will probably want to cooperate on most suggestions, but the organizational transformation in terms who may and may not fulfil the role of coordinating supervisor may count on less support. If people would just do their jobs like they are supposed to, such a 'checks-and-balances' structure for the coordinating supervisors and the maintenance specialists would not even be necessary.

Assessment workability in terms of resources (both financial and workforce capacity): Grade: 8





The current workforce would have sufficient capacity to implement the improvement strategies, especially if the organizational transformations are postponed. If however the transformations would be supported throughout the shutdown organization and capacity would be insufficient, extra capacity could be hired.

Expectance of effect of the improvement strategies on the two critical-to-quality variables: *Grade:* 7

Expected reduction of the average delay of shutdown finalization: 50% Expected increase in work efficiency: 60% (25% indirectly and 35 indirectly productive) The objectives in the Define section are a little overambitious. The success of the strategies is highly dependent on the moral within the organization. A culture has to be developed in which management (or co-workers) address people's responsibility.

#### Other remarks:

- The Anticipation and Resilience strategies nicely target the fact that people within the organization often think in terms of problems instead of solutions. A mind set for seeing solutions and opportunities is something that should definitely be developed here. The cancellation standards are also a good idea, a definition of a sort of 'point of no return' can speed up decision making processes.
- Documentation of evaluation conclusion should indeed be improved and can increase the learning capacity of the organization as a whole.
- The success of any improvement effort depends on the behaviour and culture within the organization: are people approached if they do not follow the rules or are they approached about them?

#### E.1.5. Validation interview #5

Respondent: maintenance specialist in the MID section (rolling section)

Assessment workability in terms of workforce cooperation:

Grade: 5

For some things it will not be so difficult to get cooperation; it is for instance slowly agreed on that a better, more detailed planning is necessary. The things proposed in the category Anticipation and Resilience scores a -2 on expected cooperation: the preparation will not want to spend their valuable time on things that might not pay off, such as the brainstorming sessions. A lot of the things you spend time on may never happen.

Assessment workability in terms of resources (both financial and workforce capacity):

Grade: 10

If everyone would just do what they are responsible for, but not more, then there would certainly be enough capacity. Here however, a lot of people feel responsible for stuff that they are not officially responsible for. That leads to a lot of extra work.

Expectance of effect of the improvement strategies on the two critical-to-quality variables:





Grade: -

Expected reduction of the average delay of shutdown finalization: -Expected increase in work efficiency: -

Too hard to judge the expected effect. If everyone would do his job like he is supposed to the effect should be good.

#### Other remarks:

- A lot of what is suggested has already been improved a lot over the last 3 or 4 shutdowns: progress communication has definitely improved and people are also making their schedules more and more accurate.
- The visual planning is already used within the section, although the team recently discussed that it should be used more.
- Some people already calculate risk in their schedules and use more slack.
- The plan for maintenance specialist no longer supervising their self-scheduled jobs is not considered a good plan: 1) the shutdowns is where the maintenance specialists feed their experience, a lack of which already exists. 2) Having other people supervise the job would waste too much time on the 'transaction' of the responsibility.
- The maintenance specialists would not like to be present during the shutdown without having to coordinate jobs, because they suspect they would be sitting idly in their office.
- If people do not schedule accurately enough, they should be addressed about that by the planner who has to put it into the main schedule. A checks-and-balances system as proposed is not necessary as long as long as people would just be checked on their work responsibilities.
- The section coordinators taking an active approach could feel like they are monitoring you, which is not necessary as the progress communication is improving already.
- The maintenance specialist talks from his own perspective but recognizes the fact that many other people are not scheduling and communicating sufficiently yet and that that indeed causes problems. He also sees that some people cannot be moved or motivated to improve their work in a rather anarchistic way.
- 'Scope changes', changes made in the schedule at the last moment are causing a lot of problems and commotion. Sometimes it is just necessary to do these last-minute jobs, but people should then consider removing less urgent jobs from the list. Now the extra job is often crammed in the already tight schedule.





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