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Increase in efficiency through process optimization in tunneling

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In co-operation with:

Marti IAV Solbakk DA – Norway

AFFIDAVIT

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Abstract

This master thesis was developed at the tunnel construction site Solbakk in Norway in co-operation between the Technical University of Graz and Marti IAV Solbakk DA. Initial situation in Norway was that three different processes at this construction site had to be analyzed and urgent improved. Therefore it was necessary to visualize all relevant processes at this site because the existing weak points within these specific processes had to be detected. Every fundamental process which is performed by Marti IAV at this tunnel site was illustrated with a process map. For the creation of this map many explorative interviews, monitoring of processes as well as co-operation had to be done directly on-site. With the established process map an overview about the current situation of each single process is given. It was necessary to achieve a higher level of detail between these processes in order to show the weakness within the existing processes in this process map. For the illustration of more detailed processes within the process map the notation language BPMN (Business Process Model and Notation) was chosen. After identification and illustration of the current states of the different processes at this tunnel site it was necessary to perform some expert interviews in order to improve these current process states. Altogether nine expert interviews with intern and extern experts were made. With the obtained information and solution statements out of these expert interviews it was possible to improve the existing processes at the tunnel site in Solbakk. Main statements were successful implemented at this site and significant process improvements could be achieved. Afterwards all target states were illustrated with the notation of BPMN as a kind recommendation for handling of future tunneling projects. High cost savings at this tunnel construction site can be achieved with the results and recommendations out of this thesis. This thesis showed that it is possible to increase the efficiency of processes at a tunnel site through the introduction of expert interviews.

Preface

First of all I want to thank my parents for supporting me whenever I needed help. Also my older sister and my older brother should be mentioned here. But I am especially thankful to have a twin brother. My twin brother Stefan studied together with me at the Technical University of Graz. From Stefan I learned a lot in the past years and he always helped me if I was in trouble, no matter which kind of trouble I had. He has a great personality and his attitude about life is very motivating and inspiring also for other people. Stefan and I have worked on different tunneling projects in the last few years and so we have learned a lot from each other.

I am also very thankful to diverse people who enabled me to work on different tunnel sites in order to finance my field of study on my own and to gain important experience in this sector. In particular I say thank you to Mr. Schreitmüller which enabled me to work on the tunnel site Solbakk in Norway. Also Mr. Pas and Mr. Jakobitsch must be mentioned here because they initiated this unique opportunity for me. Special thanks also to my supervisors Mr. Kerschenbauer and Mr. Koch from the Technical University of Graz for supporting me during my thesis. Thanks to all my friends for the great time which we had together and for supporting me. These moments will be unforgotten.

Since nearly four years I am learning Mandarin besides my studies at the University of Graz because I will start to work in China at the beginning of 2015. In this time I had many language partners from China or even Taiwan. So I was able to improve my skills quite fast. Thank you to all my friends from Asia for helping me. With the help of my Asian friends I was able to pass three international Chinese certificates. I just can say thank you all in your native language:

你好我的亚洲朋友们!我很高兴认识了你们.我说话谢谢为你们因为你们很多帮助我.
我希望你们很好和我祝你们最好我们的朋友们.谢谢我们的中国朋友你们的.

At the end I want to cite my own favorite slogan which keeps me motivated and hungry for my life:

你会获得全部如果你想在你和你工作很硬.

This means that you can achieve everything if you really believe in yourself and if you are willing to work hard in order to achieve your goals.

Table of content

1 Introduction

Tunneling is necessary for the production of below ground cavities for utility service and underground traffic facilities. Tunnel construction belongs to the most difficult tasks in civil engineering and the importance of performing all kind of different processes in an efficient way increases due to global competition. On the tunnel site Solbakk in Norway three important processes have been scientifically analyzed and improved. Therefore it was essential to cooperate practically and theoretically with experts, workers and miners directly on this tunnel-site to understand these processes. The resulting cost savings and improvements for the company Marti IAV Solbakk DA can be seen at the end of chapter 3.

1.1 General facts about the tunneling project Solbakk in Norway

The Marti IAV Solbakk DA (consisting of Marti Contractors Ltd., Marti Norge AS, IAV and TuCon a.s.) is one of the executing construction firms from the 14.3km long Solbakk subsea highway tunnel in Norway. The Swiss-based Marti will construct about 8km of two-lane bidirectional tunnel sections with the drill and blast excavation method. The diameter of the tunnel profiles is about 11m. With the length of 14.3km the Solbakk-Tunnel will be the longest subsea tunnel in the world.

The construction site is located in the south of Norway. The subsea highway tunnel will be finished in 2018 and will connect the village Tau with the city Stavanger. Until today the only possibility to travel from Stavanger to Tau is to take the ferry. This transport takes about 40 minutes. Due to weather turbulences the transport is sometimes stocking or even cancelled. The deepest point of the tunnel under the sea is nearly 300m below sea level. In figure 1 the portal of the Solbakk tunnel can be seen. Stavanger has about 130.000 inhabitants and is the fourth biggest city in Norway. The village Tau has 3000 inhabitants.

Figure 1: Solbakk tunnel in Tau - Norway

1.2 Personal motivation

After I finished the private higher technical academy in Lienz I was working nearly a year as a miner in a tunneling project in Austria until I went to study mechanical engineering and economics at the University of Technology in Graz. Already at this point of time the tunnel-fever packed me.

Tunneling was always fascinating me with all the huge machines and tunneling vehicles. Since I am studying in Graz I was working every summer 3 months on a tunnel site also in other countries of Europe for different companies. Because I had to finance my field of study on my own I am today very happy that I got every summer the opportunity to work hard on tunnel sites. Due to the fact that I have worked in a lot of different areas at tunnel construction sites I gained a lot of experience in the drill and blast excavation and also on tunnel boring machines. The most important what I have learned was to connect theory and practice.

Due to all my commitments on diverse sites I got a very good overview about all kind of processes on a tunnel site. I have recognized a lot of potential for improving these processes on tunnel sites. With my knowledge in this sector I wanted to improve tunneling processes at the construction site Solbakk in Norway. It was a great chance for me to prove myself in a foreign country. From February until August I was on-site in Tau - Norway. On the tunnel site Solbakk I was working in a lot of varied sectors like the workshop, the tunnel or even in the office. Working in different departments within the processes was fundamental for me to get the necessary overview about these processes.

1.3 Initial situation in Solbakk

A lot of diverse nations are working together on the tunnel site Solbakk and English is the main communication language. A big challenge of this thesis is to get a good overview about three different processes at the construction site. Everybody within the processes must understand his function in the process chain. Due to the thesis an appropriate method for visualization of these special processes must be found. Sometimes there are no process guidelines and the process documentation leaves a lot to be desired and so the workers are performing given tasks on their own way because of missing instructions giving to them. The results are occasionally bad or wrong executed working tasks.

Three different processes on the tunnel site Solbakk have to be analyzed, illustrated and improved. Therefore appropriate tools have to be found. Resulting improvements and cost savings for the company Marti IAV have to be shown.

1.3.1 Process 1 - Workshop administration process

The first process at the site is located at the workshop area of Solbakk. In figure 2 the plan view of the initial situation of the workshop hall is shown. In the workshop hall the spare parts for the tunneling vehicles and tools for the mechanics and the blacksmiths are located. Tool kits and spare parts of the different vehicle suppliers are in separate storage containers. There is also a huge portal crane for lifting the heavy parts of the vehicles or big steel assemblies. This picture is also attached in the appendix.

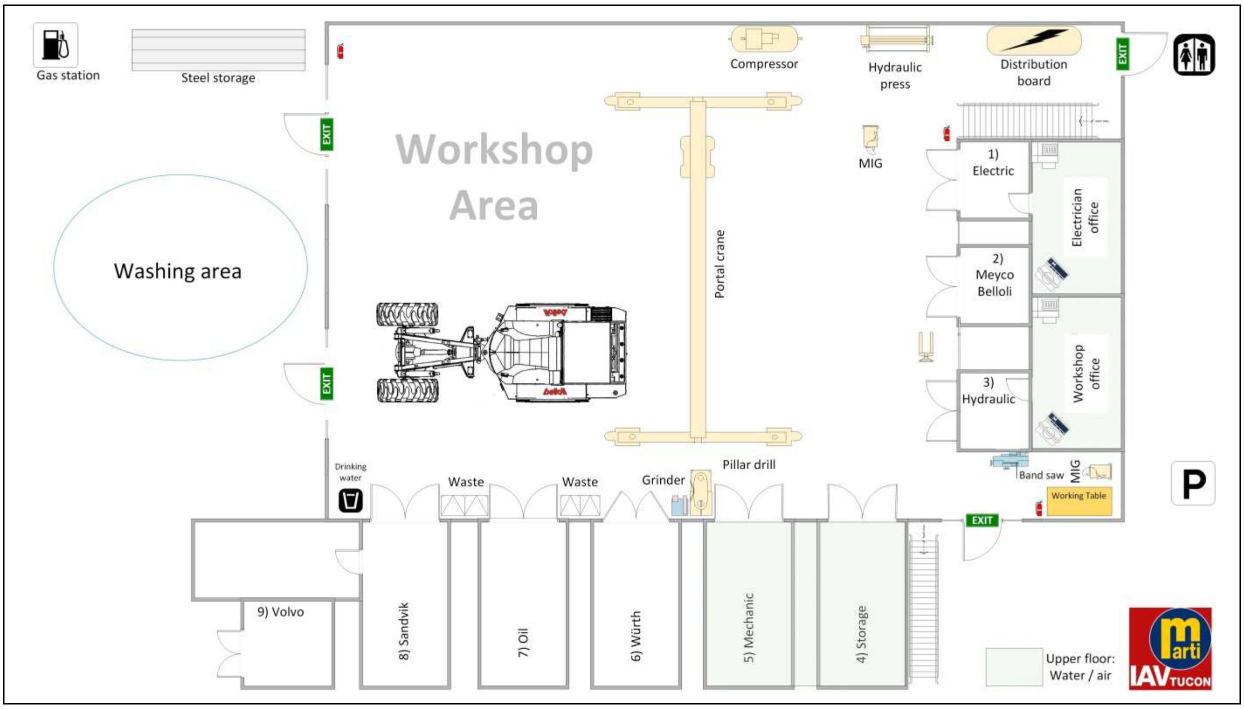

Figure 2: Plan view of the workshop hall in Norway in May 2014 (Own illustration)

The most important working tools are two MIG welding devices, a hydraulic press, a pillar drill, a band saw and two gas cutting devices. The electricians have own containers for the electrical stuff. The workshop hall is mainly used for the maintenance and repair processes of the tunneling machines. Also a lot of different steel assemblies or steel parts are produced for the tunnel area at the workshop. Outside of the workshop hall there is the washing area and the steel storage.

1.3.1.1 Process 1 - Problem 1

Blacksmiths and mechanics are complaining about high searching times for searching tools and spare parts in the workshop of Solbakk. The average searching time of the workers and the resulting costs due to wasting of time for searching these needed things every day is unknown. Sometimes the workers even don’t find the needed tools and parts. This causes additional costs for ordering new tools and special parts which should be avoided. Also the general overview about the content in the storage containers in the workshop is bad.

A total disorder on a tool shuttle can be seen in figure 3. Workers are using these tool shuttles as deposition possibilities for all kind of stuff. The overview about tools gets lost. Also the loss of tools is a big problem in the tunnel workshop of Solbakk. Mechanics and blacksmiths are also complaining about less convenient tools for making their job. It isn't clear why many of the tools are missing. The current situation with loss of tools and the annoying long searching times must be urgent improved.

Figure 3: Disorder on a tool shuttle in the workshop hall

1.3.1.2 Process 1 - Problem 2

The workshop hall is quite big and the way of the material flow is quite long. The blacksmiths have to carry heavy steel profiles from the steel storage outside of the workshop hall into the hall to the band saw which can be seen in figure 2. It is also a long way from the only working table to the pillar drill and the grinder. This causes long ways and times for transportation of steel material for the blacksmiths. It isn't obvious if the arrangement of the machines and the ways of the steel material flow in the workshop hall can be improved.

1.3.1.3 Process 1 - Problem 3

Another problem at the construction site is that all the delivered goods are unloaded directly in the workshop hall. Often the suppliers block the rail of the portal crane - figure 4. The workers have to remove the incoming goods from the rail. External suppliers are also blocking the main gates of the entrance from the workshop hall with their trucks.

Figure 4: Incoming goods blocking the rail of the portal crane

The workshop personal and the miners have to wait until the unloading is finished that they can drive in or out with the vehicles. This causes unnecessary waiting times. Often workers unpack the palettes and cardboards and put the things somewhere in a container. The problem is that needed goods often will not be found because the workers change from day to nightshift and the other workers don’t know where the parts are stored. This often causes additional costs because things will be ordered twice. It isn’t obvious which costs and times this procedure take.

1.3.2 Process 2 - Operating instruction process

The second process is located at the tunnel area and in the workshop. On the workshop level of the tunnel site Solbakk the most common instruction method is the verbal instruction and the main communication language between the workers is English. There are many steel parts or assemblies, which are frequently used on every tunnel site. For a lot of those parts or assemblies the appropriate drawings with the bill of material are totally missing. Every time some constructions have to be made new. The leading personal in the workshop Solbakk always has to take measurements and if they give the order in the workshop they give at most a sketch to the workers made by hand. Such hand drawings are not accurate and the length ratio is often not good chosen. This causes scrap due to inaccurate hand drawings. As a result from continuous measuring on every construction site it generates a notable expenditure of time for the measurements, hand drawings and also for the production. This unnecessary repetitive procedure should be avoided and improved. For documentation, reusability or as a kind of recommendation such handmade sketches are not appropriate.

Due to verbal instructions at the workshop level in Solbakk occasionally problems through misunderstandings occur. This often causes loss of time and scrap even for not very complicated tasks. Also under design or oversizing of steel assemblies can happen which should be also avoided. As example figure 5 shows a simple weld joint between two steel profiles.

Figure 5: Poor execution of a weld joint

Instead of cutting the square tube with the appropriate inclination the worker put an iron rod between to achieve the necessary angle. The result of the inclination is the same as it was explained to the blacksmith but the execution and even the performance of the connection is very bad. The life time of this weld joint will be short and reoperation will be required. Also the motivation for performing all tasks well is unfortunately sometimes missing. The Slovakian blacksmiths sometimes cannot imagine how the finished steel constructions should look like and the foremen are not able to give them appropriate drawings for these constructions. If the introduction of 3D-CAD drawings would be accepted by the blacksmiths isn't known yet. It is also unidentified whether the efficiency of the steel production in the workshop Solbakk could be raised with CAD drawings.

1.3.3 Process 3 - Drill steel administration process

The third process is located between the tunnel and the workshop area. In figure 6 a drilling jumbo from Sandvik can be seen. With this drilling jumbo the miners drill boreholes in the tunnel for the blasting explosive and the armature bore holes for the rock consolidation. There are four jumbos in usage at this tunnel site in Norway.

Figure 6: Sandvik drilling jumbo

For drilling the different boreholes in the tunnel the miners need drill bits. On the tunnel site Solbakk are three different types of drill bits in usage. The needed diameter of the drill bits for drilling holes for the blasting explosive are 48mm and 102mm. The boreholes for the rock consolidation are drilled with the diameter 54mm. In figure 7 the three types of new and re-grinded drill bits are shown. While drilling in the hard rock a significant wear of the drill bits occur. Because of the high prices for the drill bits there is the financial consideration of grinding the drill bits by the company itself. The problem is that no experienced data for the grinding process is available.

Figure 7: Three different types of new and re-grinded drill bits

On the construction site is a storage container for the drill steel. New, used and re-grinded drill bits are located there. The foremen have to write down if they take drill bits into the tunnel or if they bring them back into the container. The problem is that there is a significant loss of drill bits recognizable. It isn't clear why there are many drill bits missing.

1.4 Area of analysis on the tunnel site

Due to the thesis three different processes on the construction site Solbakk should be scientifically analyzed. An appropriate method for visualization of these processes has to be found that everybody within the process chain understands his area of responsibility to improve the existing process.

1.5 Scope of Work

For all processes a suitable method for visualization of each single process on the tunnel site Solbakk must be found. Through internal analysis a systematic approach should be introduced to uncover the weak points of the existing processes. With this system an upgraded target state of each single process must be made. The main focus of the thesis should be on process improvements, sustainability and cost savings. Standard processes should be implemented for future tunneling projects as a kind of recommendation for handling new tunnel projects. Resulting time and cost savings must be calculated.

1.6 Goals of the thesis

The aim of this thesis is to determine the current states of each single process. An adequate illustration of every process must be done to show the weak points within the existing processes. Afterwards an improved target state of each process must be made to achieve smooth process cycles without interruptions. These target states must be also illustrated. For the affected people within the process chain clear instructions must be elaborated that they can decode their task without any problems. A documentation of the current and the final target state is desirable. The standardization of the improved processes will be considered and implemented by the company Marti IAV in the future.

By reason that there are three different processes on the tunnel site in Solbakk there are some unequal sub-goals:

1.6.1 Process 1 - Workshop administration process - Sub-goals

For the workshop administration process the current states of this process must be determined and illustrated. Afterwards improved target states must be generated. A recommendation for this tunnel site in Norway and even for handling new tunnel projects in the future should be given.

1.6.1.1 Process 1 - Sub-goal 1

The inexplicable loss of tools must be urgent uncovered. Also the average searching time for tools and spare parts per person per month should be evaluated and shortened. A better overall overview of the storage containers in the workshop hall would be desirable.

1.6.1.2 Process 1 - Sub-goal 2

Due to the fact that the ways of the steel material flow are quite long in the workshop of the site it must be analyzed if it is possible to change the arrangement of the existing machines in order to shorten the ways of this material flow to achieve a higher efficiency of the blacksmiths.

1.6.1.3 Process 1 - Sub-goal 3

If the situation with the incoming goods directly at the main gate of the workshop is disturbing the mechanics and the blacksmiths must be found out to initiate counteractive measures. The average time for removing palettes and boxes should be figured out.

1.6.2 Process 2 - Operating instruction process - Sub-goals

Mistakes made by communication error due to verbal instructions have to be avoided in future. If the introduction of CAD drawing sets could improve the current situation and will be accepted by the blacksmiths in the workshop must be found out. It must be shown if the efficiency of the blacksmiths could be raised by giving them finished CAD drawing sets. Arising expenses for the CAD program and the design engineer have not to be considered.

1.6.3 Process 3 - Drill steel administration process - Sub-goals

The unaccountable loss of drill bits must be urgent clarified because of the high costs for these drill bits. Because of the heavy wear of the drill bits during the drilling process an investigation concerning grinding these drill bits by the company Marti IAV itself must be done in order to get an overview about the grinding process. The needed time for grinding each type of these bits must be evaluated.

1.7 Course of action

First the necessary knowledge about each single process has to be established. Therefore it is important to work directly on-site theoretically and also practically within these processes. With an appropriate method or tool the current situations of the processes have to be visualized. Specialized literature research is essential for the scientific examination. Through internal analysis a suitable method for determination of the improved target states must be found. The resulting cost savings and benefits for the company Marti IAV have to be figured out in chapter 3.

1.7.1 Process 1 - Workshop administration process

The identification of the current state is essential for the visualization of each single process. Through literature research an appropriate method for the visualization must be found. A suitable approach for advancing the current status is mandatory. Afterwards the resultant reduction of costs has to be calculated.

1.7.1.1 Course of action for problem 1

To receive the needed searching time for tools and spare parts in the workshop Solbakk it is required to obtain the attended time through interviews with the blacksmiths and the mechanics in the workshop. Through the visualization of the current state of this process the unaccountable loss of tools must be visible. With a suitable method an improved target state and target visualization of process 1 should be made. The visualization of the target state must be shown to the workers in the workshop and they should give a new estimation about the target searching times with these improved conditions in the workshop. For a better overview about the storage containers in the workshop hall the containers should be labelled.

1.7.1.2 Course of action for problem 2

In the workshop hall the arrangement of the entire equipment should be analyzed. Via time measurements the required time for the material transport through the hall must be recorded. It must be obvious if an improved arrangement of the machines could improve the efficiency of the blacksmiths. Required information will be obtained with appropriate interviews.

1.7.1.3 Course of action for problem 3

Concerning all incoming goods which are unloaded in the workshop hall the time for removing these goods by own workers and disturbing their work flow by the suppliers must be evaluated through interviews. A better solution for this problem would be preferable.

1.7.2 Process 2 - Operating instruction process

An introduction of some urgent needed set of drawings with the suitable bill of material for the standardization of frequently used steel parts and steel assemblies with a 3D-CAD program has to be done. With these drawing sets the blacksmiths in the workshop Solbakk must be confronted. They will get some drawings of steel assemblies with the appropriate bill of material. Afterwards they will be interviewed regarding the needed time for the production of this steel assembly with the finished drawing sets compared to a verbal instruction. Thereafter exactly this steel assembly has to be produced by the blacksmiths without any verbal instruction. Increase in efficiency has to be evaluated afterwards. If the Slovakian blacksmiths are able to work autonomous with the printed CAD drawings then tremendous increase in efficiency and reduction of scrap and required time for the production will arrive.

1.7.3 Process 3 - Drill steel administration process

To get an overview about the grinding process and the grinding parameter itself it is necessary that the company Marti IAV will grind the different types of drill bits internal. The average time per each type of drill bit must be figured out with a scientific statistic of this manufacturing process because the required time for re-grinding each type of drill bit isn't known yet. To get the meaningful grind data it is essential to grind over a longer a period split. In figure 8 the grinding machine, the grinding operator and the box for storing the used bits can be seen. The grinding machine is located in the drill steel container where all three types of new, used and re-grinded drill bits are stored. With this grinding machine on the tunnel site Solbakk all three types of drill bits can be re-grinded.

Figure 8: Sandvik grinding machine

The remarkable and unexplained loss of drill bits must be urgent clarified. With an appropriate scientific illustration of the drill steel flow on the tunnel site Solbakk it must be visible where the source of error is located. After determination of the current state an improved target state of the drill steel flow has to be established and pictured. With this new visualization it must be possible to minimize the loss of these drill bits. These results will be important guidelines and recommendations for the company Marti IAV for future drill and blast excavation projects in Scandinavia.

2 Theoretical basics

For a better appreciation of the measures which have been applied in the practical part to solve the given tasks, some basic information and definitions about processes, visualization of processes, the value chain of a company and for the improvement of the existing processes some fundamentals of the company-internal analysis will be given in the following chapter.

2.1 Definitions and term explanations

At first, essential required general definitions and relevant process fundamentals will be explained:

2.1.1 Process fundamentals

In every company a lot of different processes exist. On the tunnel site Solbakk many repetitive processes are performed parallel. First of all it is important to clarify the some fundamentals about processes in general.

2.1.1.1 Elementary process

Following statement is quite fitting and food for thought: *"There is no product and/or service without a process. Likewise, there is no process without a product or service[1]."* According to this statement it is obvious that we are surrounded by processes every day. Also on the tunnel site in Norway there would be no tunnel without any process and converse. A lot of definitions about basic processes exist in the literature and for this thesis the following definitions are convenient:

Usually an elementary process transforms an input into an output and therefore a special amount of steps can be necessary[2]. This is a basic statement of a simple elementary process out of the literature. On tunnel sites some input factors are for example the explosive agent, different kind of machines, miners, other workers, raw material, and also data. Output factors are for instance the mucking material, when it is needed for landfill engineering, or even the finished tunnel itself.

Harrington defines a process as following: *"Any activity or group of activities that takes an input, adds value to it, and provides an output to an internal or external customer. Processes use an organization´s resources to provide definitive results[1]."* On the tunnel construction site Solbakk many different value-adding processes are performed and executed. These processes consume resources of the company Marti IAV. An economic relation between input and output of the processes must be considered to be competitive on the Scandinavian

[1] (Harrington 1991) p.9
[2] (Schmidt 2012) p.1

market. The focus of all processes on the tunnel site in Norway is especially on the internal customers.

The input of a process can be a physical or immaterial input factor like resources or raw materials. Also information can be an input factor. These input factors will be transformed into physical or immaterial output products which have a customer value for internal or external customers. External customer can be for instance an end user. An internal customer can get the output of the process as input for the following internal process[3]. On tunnel sites even construction drawings or instruction materials for the workers and miners in the tunnel are for instance some input factors.

Companies are considered occasionally in their functions as productions systems in the producing industries. In the literature these transformation processes within the value performance of the company are sometimes described as input-output-processes or input-throughput-output-processes[4]. An illustration of a simple process can be seen in figure 9. The input will be transformed into an output due to the transformation process.

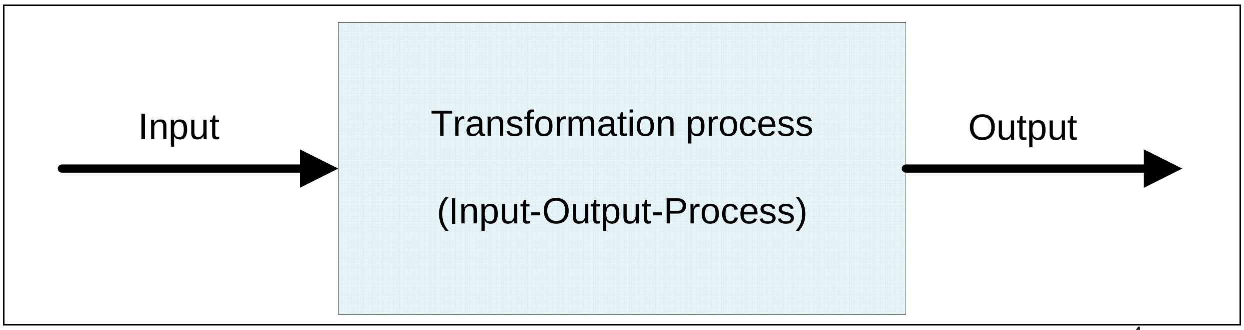

Figure 9: Production system respectively -process as input-throughput-output-process[4]

Figure 10 shows by way of example a simple process from the tunnel site in Norway according to Atzert. It is a welding task for a blacksmith in the workshop. Assuming that the worker gets a construction drawing he will prepare the needed tools and materials. Afterwards he will cut the steel profiles and so on. Input factors are for example the needed construction drawings with the appropriate bill of material for preparation of the steel profiles, the welding device, maybe a grinder, and a band-saw for cutting the material and finally the blacksmith itself. The output, a finished welded steel assembly, is produced through transformation of the input goods into the finished output steel assembly of this process. Therefore some activities are necessary. The input is transformed into an output and value will be created through each single step or activity. So this process creates a customer value for the internal and external customers. Every step of the blacksmith raises the value creation percentage of the output. The output, the finished welded steel construction, can be for an internal or external customer as well. Not all steps of this welding process are mentioned in this simple example of a basic process.

[3] (Atzert 2011) p.16 f.
[4] (Dyckhoff & Spengler 2010) p.13

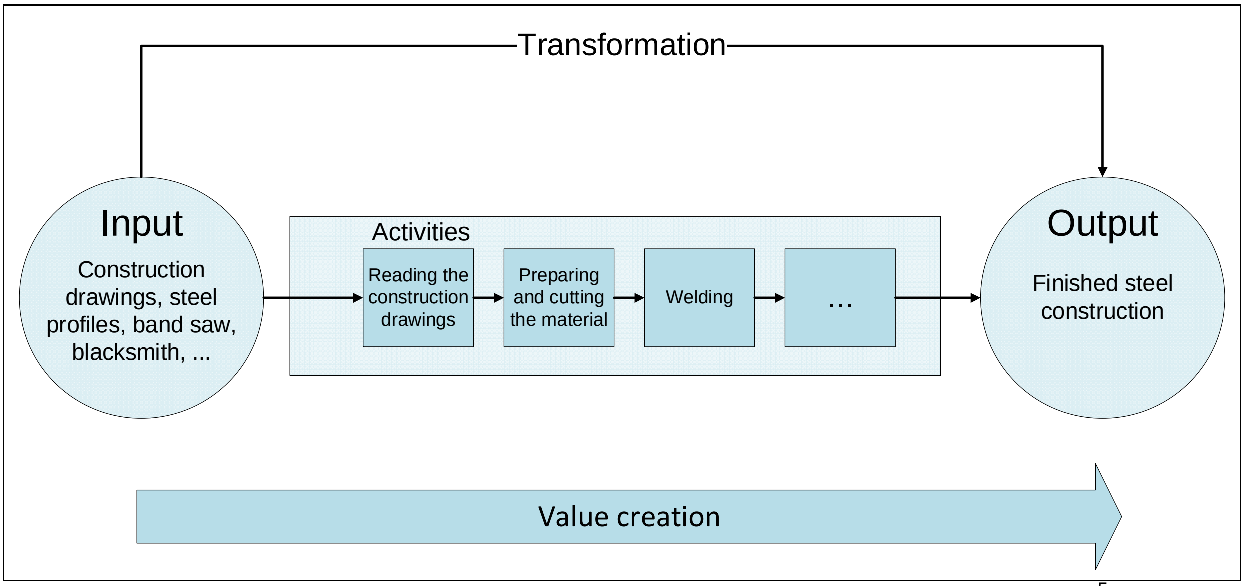

Figure 10: Simple welding process on the tunnel site in Norway according to Atzert[5]

Processes can be classified between departments, companies and persons. The orientation is always on the customer. So the focus is on the fulfilment of the customer´s needs because without customer there is no process. Before an analysis it must be clear who the customer of the specific process is. Customers can be internal or external. External customers are in general obvious purchasers of the products or services of the company. Internal customers are customers of partial results. The internal customers need also the best possible quality to deliver the best for the external customers. They will continue processing the received deliverables. A process can have more customers and their interests can be different. Internal customer relationships aren't so intense cultivated in the praxis. Often the awareness to be a supplier for goods and services or to see the co-worker as customer is missing[6].

In the case of Marti IAV it is also very important that the company focuses on both types of customers. The importance for focusing on the external customers is quite good identified and developed by the company on this tunnel site in Norway. Problems occasionally can occur because the awareness that the own people, the so called internal customers, aren't really seen as customers.

On the site in Norway some external customers could be e.g. all kind of suppliers or the even the building owner. Internal customers could be some own employees like blacksmiths, mechanic or even miners which are involved with a special process.

So a process is a repetitive sequential arrangement of operations with clear defined inputs and outputs. Examples therefore can also be writing a letter or to make an appointment[7]. On the tunnel site Solbakk in Norway there are a lot of repetitive processes. The drill and blasting process is also repetitive. It starts every time with drilling, charging, blasting,

[5] (Atzert 2011) p.16
[6] (Brecht-Hadraschek & Feldbrügge 2013) p.14 ff.
[7] (Seidlmeier 2010) p.3

mucking out the material of the tunnel, hand scaling, machine scaling, washing, shotcreting, cleaning and preparation. When all these steps are done the miners in the tunnel can start again in the same order.

2.1.1.2 Business process

At first an interesting thought-provoking impulse: *"[…], you can see that almost everything we do is a process and that business processes play an important role in the economic survival of our organizations[8]."* That means that nearly everything we do, for example preparing presentations, is a process. There are many definitions of a business process in the literature and for this thesis the following statements are appropriate:

The business process has the aim to produce output goods through commitment of input goods. Business processes are representing the organization of the production for the value creation of the company[9].

A business process is a cross-functional sequential arrangement of value-adding operations within a company with the justification to customer´s benefit and for the attainment of the company targets. Therefore a contribution to the securing of the competitiveness of the company is given. This distinguishes business processes from other processes in a company[10]. In this statement it can be seen that the awareness also for the competitiveness of the company is essential for these kinds of processes. In the previous description of an elementary process the focus on competitiveness wasn't mentioned.

Business processes have a special main target and external interfaces. These interfaces could be e.g. suppliers or patients. Every business process consists of several sub-processes. And these sub-processes include many activities[11].

A process object (PO) is represented through the input and the output of activities in business processes. Process input objects are applied to an activity from outside. Process output objects are representing the result of an activity and these output results can also be input process objects for the following activity. Figure 11 shows a business process model with some refinements. In this figure also the different levels of refinement can be seen. A larger image of this business process is added in appendix 2 at the end of this thesis. Business processes can be sub-divided into sub-processes due to their objective and chronological relationships. In this case the business process is sub-divided into the sub-process 1 and the sub-process 2. Sub-process 2 is split into the sub-process 2-1 and the sub-process 2-2. Sub-process 2-2 is also sub-divided into the activities 2-2-1 and 2-2-2. In this example the output process object of activity 2-2-2 is at the same time the process object output of the entire business process[12].

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[8] (Harrington 1991) p.9
[9] (Schmidt 2012) p.1
[10] (Koch 2011) p.1 f.
[11] (Kruse 2009) p.54
[12] (Bartsch 2010) p.11 f.

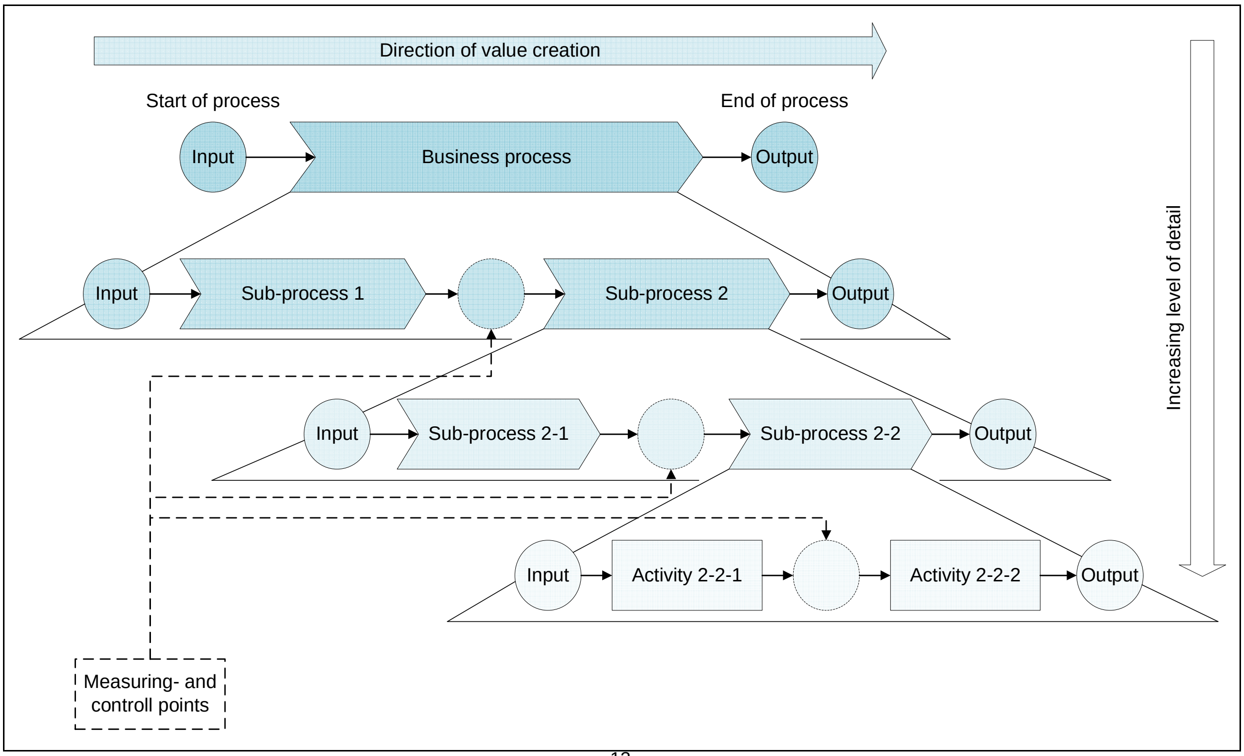


Figure 11: Business process with refinements[13]

A business process model is able to represent real business processes. With such a model planning and steering of business processes can be also done. Depending on the business process a refinement with increasing level of detail can be made. This refinement can be done until it isn't possible to make more sub-divisions. The measuring- and control points between the sub-processes and the activities are for the acquisition of information and data[13].

If such control- and measuring points are necessary for the relevant processes on the tunnel-site in Norway must be analyzed and considered. Also the level of detail must be appropriate for the involved persons in order that they are able to understand their function within the relevant process. Different process levels will be explained in chapter 2.1.4.

2.1.2 Process chain

A process chain is generated when some processes are connected one after another. This is the simplest connection method for processes. A process chain is a sequential arrangement of single processes, process steps or sub-processes within a process level. Every process or sub-process needs at least one input and produces minimum one output. The output of the previous process or sub-process is the input for the following process or sub-process. In nearly every company there is a typical illustration of a process chain with the sequence of the primary processes of the company which can be seen in figure 12. This illustrated overall process is mentioned corporate policy[14].

[13] (Bartsch 2010) p.12
[14] (Weidner 2014) p.42 f.

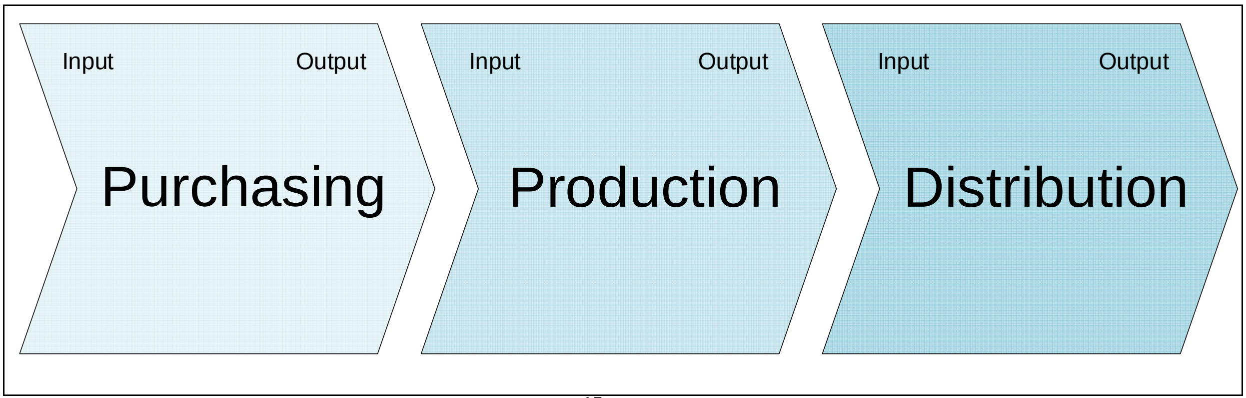


Figure 12: Process chain – corporate policy[15]

The process chain corporate policy consists in general of purchasing, production and distribution. Also tunneling companies could be divided into this category of a process chain. This example of the process chain shows that every primary process has at least one input and one output. E.g. the output of purchasing is the input of the following primary process production and so on.

In the area of technical workflows a process chain describes the sequence of sub-processes[16].

2.1.3 Process types

In tunneling but also in other industries there are different types of processes which are performed parallel or consecutively. For this thesis relevant process types will be explained:

Quality management distinguishes between three different process types. There are management processes, core processes and support processes. In figure 13 you can see these three process types[17].

The interaction of these three processes can be visible with the short example of tunneling in accordance to Weidner[15]:

- **Management process:**
  Leadership and communication through the site management
- **Core process:**
  Tunnel construction and performance of the miners in the tunnel
- **Support process:**
  Work of mechanics and blacksmiths for repair, maintenance and so on

In figure 13 these three different process types can be seen. Afterwards each single process type is explained in detail.

15 (Weidner 2014) p.43
16 (Maßberg 1999) p.106
17 (Weidner 2014) p.43 f.

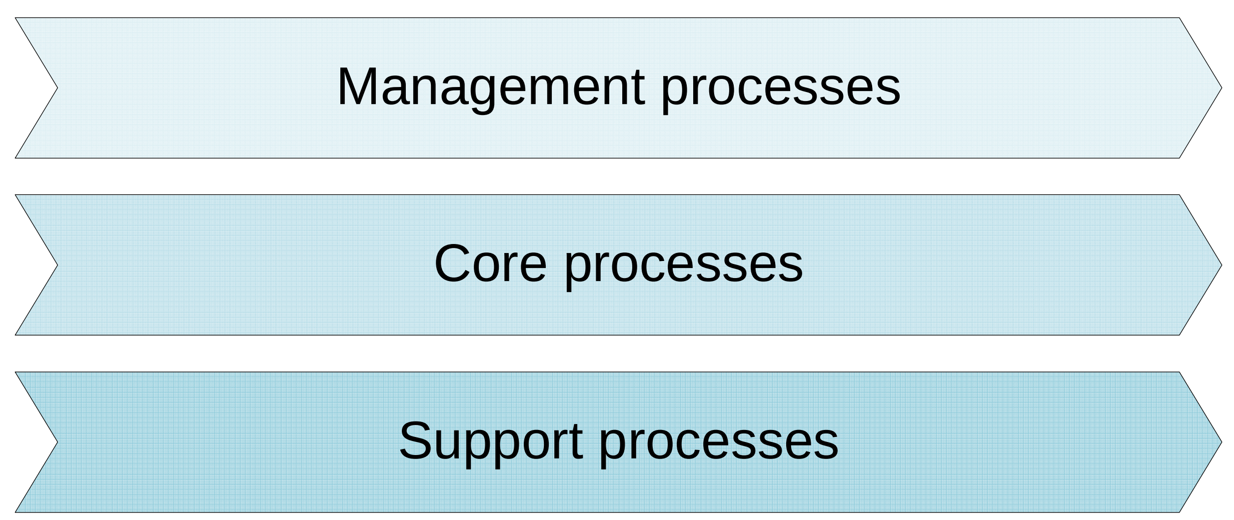


Figure 13: The three process types[18]

For a better understanding of these three process types the definition of each process is the following:

2.1.3.1 Management process

Management processes are responsible for the leadership of a company and they have a trend-setting nature. Due to the fact that they give the orientation to the enterprise they affect the core processes and the support processes indirect but in a crucial way[18].

Management processes influence the sustainable success of a company. The correct definition and execution of these processes is an essential basis for the enterprise. Some examples for management processes are leadership and organization, quality management, controlling, and strategic planning[18].

In tunneling some management processes could be the site management, the site supervision, the production management, the construction planning or the workshop management. Characteristically are the communication and leadership style of these processes.

2.1.3.2 Core process

These processes are value-adding processes of a company. We can say that within core processes the money of will be earned. Core processes are direct involved in the production of products and services of a corporation[18].

Production, purchasing, logistics and distribution are examples for core processes. They contribute to the value creation of the company[18].

Core processes are located at the operational level of the company[19].

[18] (Weidner 2014) p.44
[19] (Brandt 2004) p.75

On the tunnel site Solbakk such a core process is for instance the drill and blast excavation itself. This process creates a value for the company through the generation of the tunnel. The company Marti IAV is specialized in tunneling since many years. Marti puts on very modern machine inventory and with the long lasting experience and know-how in this industrial sector the company dominates its core process.

2.1.3.3 Support processes

Support processes have no direct influence to the value creation but without them it would be almost impossible to produce products or services[20].

Examples for support processes are personal management, service, judiciary, finance and the information technology[20].

Support processes are supporting other processes. For instance the maintenance and repair process of the tunneling vehicles in the workshop is a support process. Maintenance has nothing to do with value creation for the company itself but it is necessary for the drilling and blasting process in the tunnel. Without necessary service, maintenance and repair tasks on these tunneling vehicles it would be nearly impossible to generate a tunnel. Other support processes on tunnel sites are for instance the tunnel logistics process, the steel production process in the workshop and so on. These different support processes are depending on the excavation method, if there is a tunnel boring machine (TBM) in usage or drill and blast excavation.

2.1.4 Process levels

For a better illustration and transparency of comprehensive primary processes the processes can divided into sub-processes. This can be done through splitting the primary process into different levels. In figure 14 an example for such a process chart in accordance to Weidner is shown[21]. The core process driving a truck on a tunnel site can be sub-divided into the sub-processes run-up, acceleration and braking. This main process on process level 1 is broken down into his elements on process level 2.

The first sub-process run-up on the second process level can be subdivided into the sub-processes monitoring the on-site traffic, releasing the parking brake and activate the gas pedal. On the following sublevels every sub-process can be divided in any order. Attention should be paid to the conscious breakdown of the processes because the general survey of the process landscape must be given. Appropriate scales for a proper breakdown of processes are the process co-operators which are executing this special process. The operators should be able recognize the function and the cycle without any doubt to perform their task within this process error free and efficient. This description of figure 14 is also in accordance to Weidner[21].

[20] (Weidner 2014) p.44
[21] (Weidner 2014) p.45

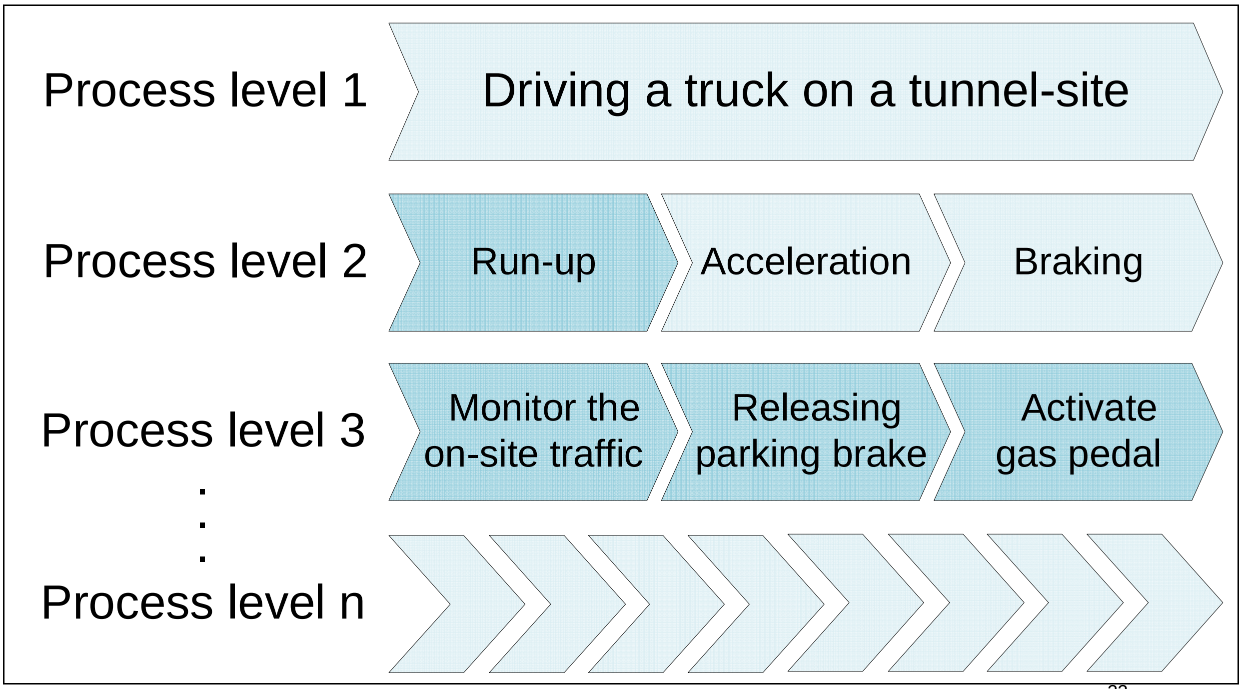


Figure 14: Process chain “Driving a truck on a tunnel-site” in accordance to Weidner[22]

For this thesis in Norway three supervised processes have to be analyzed, recorded and illustrated. The reason for the unexplainable loss of tools and drill steel has to be figured out and pictured. Therefore an appropriate method for the exposure must be found and applied on this tunnel site in Solbakk. Also the weak points in every process cycle should be uncovered and eliminated. With the received information these three processes will illustrated and improved. The main focus of attention must be on the correct illustration of each process and the process cycles should be clear to the workers within this process. For instance miners in the tunnel, blacksmiths and mechanics in the workshop or other workers on the site in Norway must know their area of responsibility in order to work in an efficient way. It should be easy for them to see their tasks and function within this process chain of Marti IAV.

2.1.5 Efficiency versus effectiveness

It is essential to understand the difference between efficiency and effectiveness. Rough we can say that effectiveness is a measure for the achievement for objectives and efficiency is the relation between input and output[23].

2.1.5.1 Definition of efficiency

Efficiency or performance means **doing the things right**. Crucial are the optimum sequence of the processes and the optimum commitment of the resources. An organization is efficient when the business objective will be achieved with low as possible input. It will be distinguished between resources efficiency and process efficiency. Low process efficiency is negative for the productivity. It also stresses the quality of the products, the processing time,

[22] (Weidner 2014) p.45
[23] (Bär & Purtschert 2014) p.255

the adherence to delivery dates and the customer satisfaction. As a result the sales will decrease[24]. To be competitive in the tunneling sector it is important to perform all kind of different tasks and processes in an efficient way.

Efficiency problems are especially widespread in processes and their effects can be seen in figure 15[25]. This statement is also true for tunneling in accordance to Schmelzer & Sesselmann. If there is no or low control about the processes the resulting side effects can be many mistakes and as a result a lot of modifications within these processes have to be done. The product and process costs will increase dramatically. Many complaints due to delivery time and supplier´s reliability could occur. Another side-effect due to lack of control of processes could be that the inventory will be unnecessary high. The conclusion will be higher costs for the company which has to be avoided.

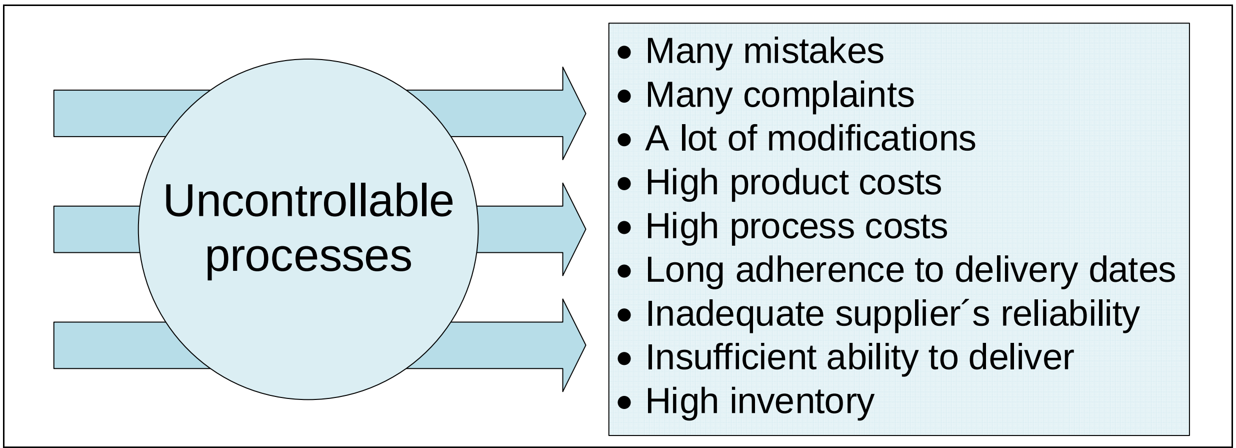


Figure 15: Efficiency problems within processes with effects in accordance to Schmelzer & Sesselmann[25]

2.1.5.2 Definition of effectiveness

Effectiveness means **doing the right things.** An organization is effective when the right goals are persecuted. This could be for example to build on the right core competences. Many companies have low effectiveness in doing their business because of unclear strategic goals. Even the process goals can be confused to the company. Unfortunately sometimes also the knowledge about the customers' needs, their problems or even their expectations is missing[24]. On the tunnel site Solbakk it shouldn't be the goal to work just effective. Sure, to track the right goals is important for giving the direction but without considering the efficiency would be a waste of resources and money.

Peter F. Drucker´s statement is quite interesting: *"To be effective is the job of the executive. "To effect" and "to execute" are, after all, near-synonyms. Whether he works in a business or in a hospital, in a government agency or in a labor union, in a university or in the army, the executive is, first of all, expected to get the right things done. And this is simply that he is*

[24] (Schmelzer & Sesselmann 2013) p.2 f.
[25] (Schmelzer & Sesselmann 2013) p.3

expected to be effective.[26]" This would signify that in Norway the executive personal would be expected to give the appropriate goals and related directions to their workers. It is essential that the executives are aware of their area of responsibility at the tunnel site Solbakk.

Drucker also adds: *"For manual work, we need only efficiency; that is, the ability to do things right rather than the ability to get the right things done. The manual worker can always be judged in terms of the quantity and quality of a definable and discrete output, such as a pair of shoes. We have learned how to measure efficiency and how to define quality in manual work during the last hundred years – to the point where we have been able to multiply the output of the individual worker tremendously.[27]"*

This means that on the tunnel site Solbakk in Norway the management or executives would be responsible for giving the right requirements to their workers. The achievement for objectives is also predetermined by the management or the executives. For the manual work of the workers and miners at the tunnel site it is essential that they work in an efficient way, because this can be measured and so they must perform their given tasks right in order to be efficient. Therefore it should be expected that the executives and the management choose the right goals to follow. The combination of effectiveness and efficiency is urgent needed to be competitive in tunneling nowadays.

A practical example from tunneling should point the difference between efficiency and effectiveness according to the author of this thesis: If a blacksmith in the tunnel workshop is cutting big steel profiles with a handsaw he will be effective and also goal-oriented. But cutting steel profiles with a handsaw is very exhausting and energy-sapping. For instance it could be that the worker got an instruction from a foreman or the workshop manager. Maybe this person said him what do but not how to do. If the blacksmith doesn't consider the high input which he has to put into his work when he uses a handsaw the blacksmith will not be efficient because he has to put so much time and effort into the cutting process. When the blacksmith should work efficient he could use a band-saw for cutting the steel profiles. Then he could perform his task, to cut the steel profiles, in a very efficient way.

2.1.5.3 Process efficiency versus process effectiveness

Process effectiveness is available when the process generates the required result. Process efficiency means if the process result will be achieved with minimum input. Process effectiveness and process efficiency are two independent parameters. Effective processes reach the right result. Efficient processes achieve the result with the minimum input. Ideal processes are efficient and effective. Figure 16 shows an illustration example of efficiency and effectiveness[28].

[26] (Drucker 2002) p.1
[27] (Drucker 2002) p.2
[28] (Becker 2005) p.11

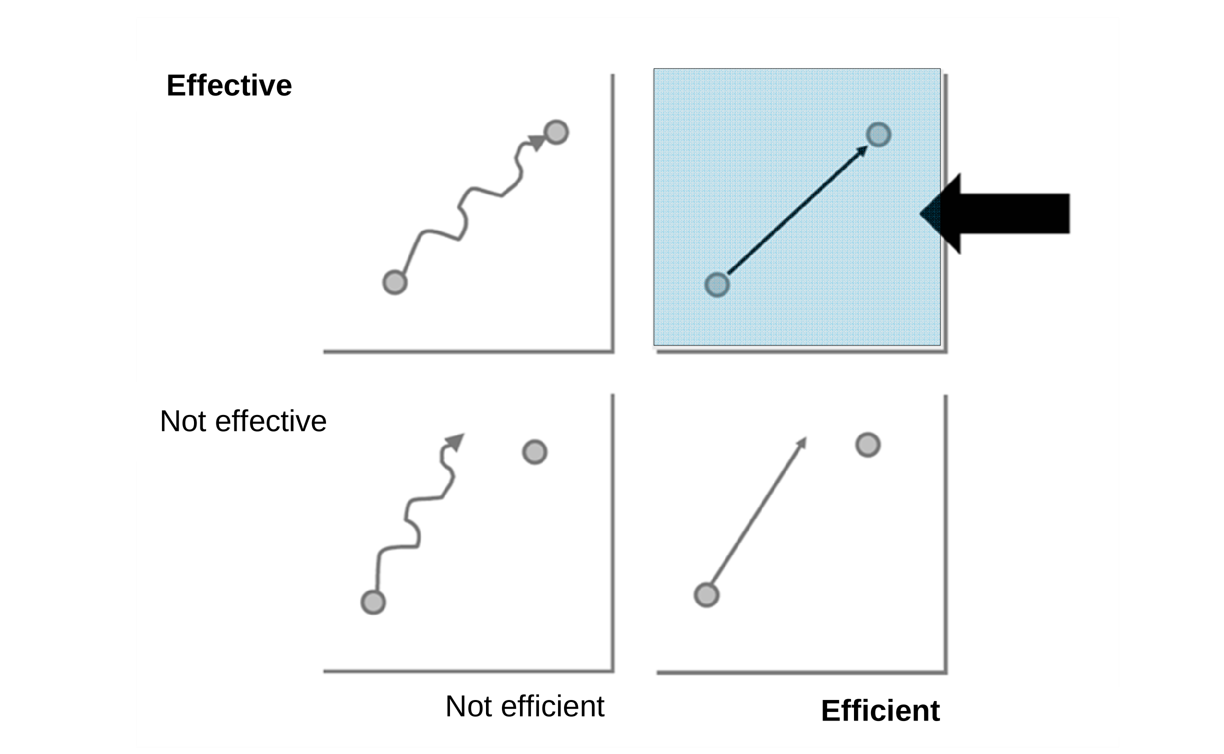


Figure 16: Efficiency and effectiveness[29]

All requirements of the process result must be known in order to create an effective process. Just the accurate knowledge of the result parameters ensures a process layout with the best possible output. In comparison efficiency describes how to achieve the result with the given input parameters. In order to be efficient it is essential to minimize time and effort for the result[29].

In figure 16 it can be seen that being just efficient or just effective concerning to the entire process isn't constructive. The focus of a company regarding to its processes should be on the combination of efficient and effective process sequences.

Therefore a short example in accordance to Becker: The customer requirement is to deliver a special product within 2 days. This process would be only effective if the product could be delivered within these 2 days. A process is efficient when the required product can be delivered with the smallest possible input but independent from the delivery time. This process is efficient and effective at the same time if the product can be delivered within these 2 days with the smallest possible time and effort[30].

2.1.6 Process optimization

In process optimizations usual the efficiency is in the foreground. Effectiveness is unusual at the first place[30]. This statement confirms that increasing the efficiency of processes at the tunnel site Solbakk in Norway is the right direction to go.

[29] (Becker 2005) p.11
[30] (Becker 2005) p.12

For a process optimization some essential points have to be considered. In the following for this thesis relevant activities can be defined as a process in accordance to Schneider[31]:

- Activities which are running structured
- Activities which can be repeated
- Activities which are essential for the observation of standards

If the activities are repeatable or run structured for instance means that these activities can be defined as processes[31].

2.1.6.1 Definition optimization

In general the term optimization means change of a condition to the best possible respectively the improvement of a situation. It is important that the change of the condition will not lead to a change into the worse. The transformation of the conditions should always be in a positive direction. We must be aware that an absolute optimum can never be achieved under realistic operating conditions. A relative optimum can be achieved by a company. An optimization can be seen as steps of improvement regarding to a goal of the corporation[32].

2.1.6.2 Process analysis

A process analysis establishes transparency over the considered processes and the involved organizational units. This analysis also measures the command variables costs, time and quality parameter. Theoretically it’s possible to optimize a process without an analysis of the current state before. But without process analysis it could be that some important detail information gets lost. This could endanger the suitability for daily use of the new processes. The reasons for the existing problems will be inspected during the systematic process analysis. A process analysis is also a fundament for the formulation of the re-design goals and for all further steps which have to be taken. If the analysis of the processes isn’t accurate done it could happen that the entire optimization is made on a bad fundament[33].

2.1.6.2.1 Generating a process map

After the introduction of the process analysis it makes sense to create a process map of the company. The advantage is that the process map shows the location of the considered process according to the whole process landscape. Also the relevant interfaces between the processes can be seen in this illustration. This is an important step because the boundaries of the processes will be defined. If the boundary of the processes is diffuse it can happen that the focus on the important processes gets lost or that some less important processes obtain too much attention[34].

[31] (Schneider et al. 2008) p.39
[32] (Ristau 2011) p.14
[33] (Best & Weth 2009) p.62
[34] (Best & Weth 2009) p.63

Also for this thesis it was essential to generate a process map of the tunnel site Solbakk to get an overview about the different relevant processes in Norway. The process map of Solbakk can be seen later in the practical part.

2.1.6.2.2 Excluding the processes

With the process map it was possible to establish an overview about all processes. Now the process or more processes which should be improved must be excluded. Starting points and end points must be determined. In the practical experience some problems can occur because the determination of the starting and end points has wiggle room. This must be clarified in the run-up to the process analysis. Occasionally it can be that starting point and input are identical. On the other side it can also happen that the output and the end points are the same. An example is a signed purchase order. This purchase order is for the process of order fulfillment a starting point as well as an important input because it contains relevant information about the price, the product and the delivery date. When the purchase order is available the process starts. To avoid misunderstandings it can be necessary to separate starting points with inputs and end points with outputs[35].

Also in the process map of the tunnel site Solbakk it was important to exclude the relevant processes in order to get a better overview on a higher level of detail. Required theory concerning the level of detail of processes can be seen later in the theoretical part of this thesis.

2.1.6.3 Improvement opportunities

The term “Optimization” must not be necessarily linked with the absolute optimum. Normally it is about the improvement of a process. In figure 17 some typical opportunities for the improvement within processes are shown[36]. In appendix 3 a bigger illustration can be seen.

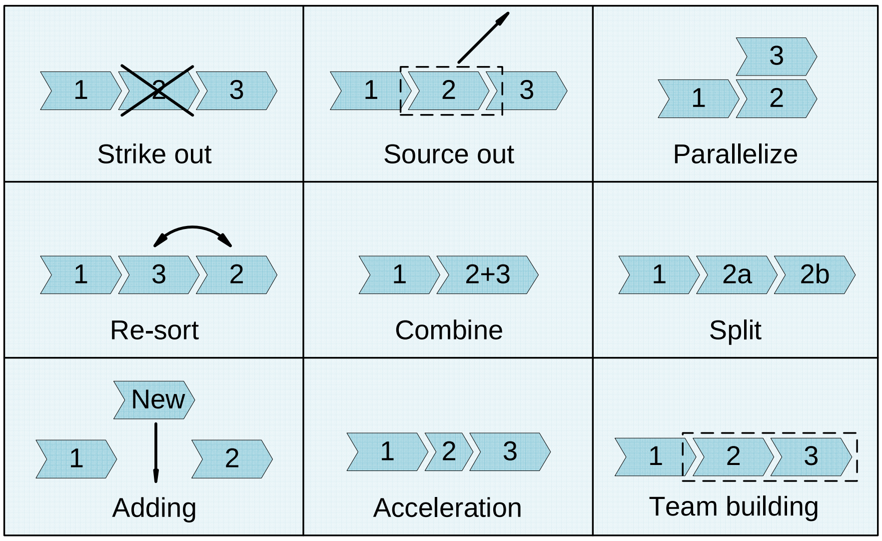


Figure 17: Improvement opportunities within processes[37]

[35] (Best & Weth 2009) p.64 ff.
[36] (Hedtstück 2013) p.8
[37] (Hedtstück 2013) p.9

Pre-condition for the optimization of a process is that its performance for the attainment of the goal can be measured and evaluated[38].

For the relevant processes at the tunnel site Solbakk in Norway these opportunities for improvement within the specific processes have to be analyzed, weighted and implemented into the appropriate processes.

2.1.6.4 Goals of process optimization

In general optimization aims for process improvements are costs, time and quality. These three main criteria were extended with flexibility and capital expenditure in the last years. All five criteria can be seen in figure 18[39].

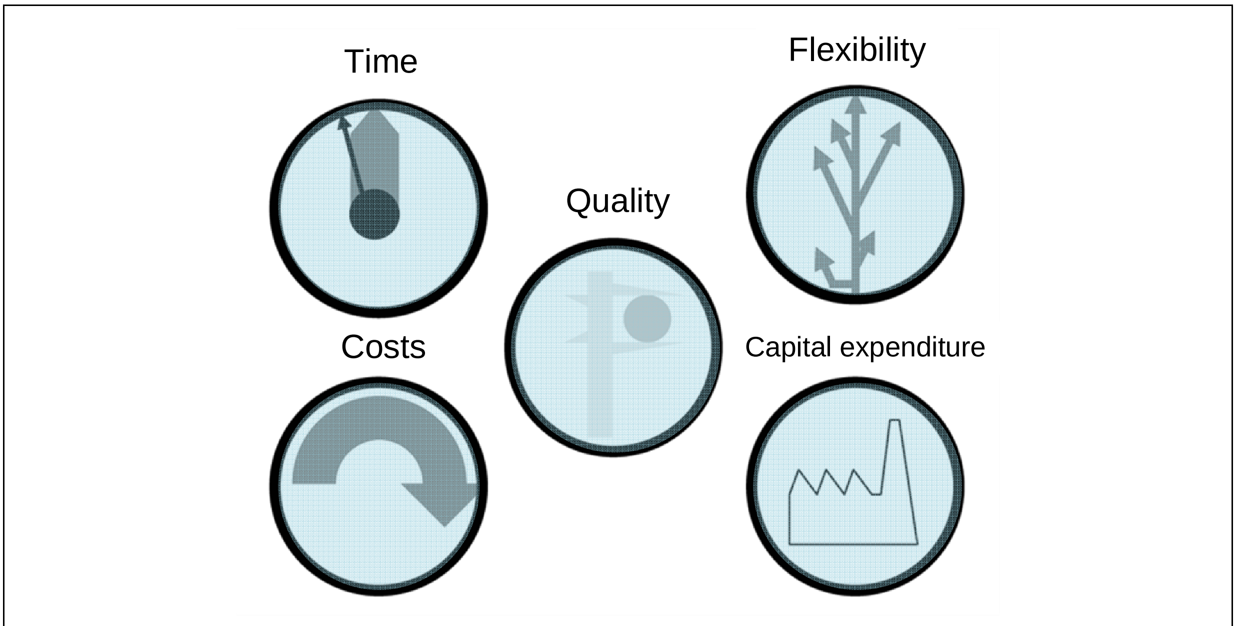


Figure 18: Optimization goals of processes[39]

Some process improvements are tending to increase the output quantity to produce more sales volume. This would mean quality improvement or reduced time of process steps without significant change of costs. The goal of many process optimizations is the reduction of costs. The most important impulse for a process improvement of an economic oriented company is of course the reduction of costs[40].

2.1.6.5 Steps of process optimization

In this sub-chapter the steps of the process optimization, which were necessary for the practical part, are explained. First it is important to choose an improvement strategy for the process optimization. Therefore three different strategies will be illustrated and the chosen one will be explained more in detail.

[38] (Hedtstück 2013) p.9
[39] (Becker 2005) p.12
[40] (Becker 2005) p.13

2.1.6.5.1 Improvement strategies

It is essential to clarify which processes of the company have to be improved and how much improvement should be implemented at the same time. There are three different strategies for a process improvement[41]:

- Continuous improvement
- Process modification
- Radical modification

In figure 19 the different strategies of improvement strategies are shown. The process modification or process optimization will be explained more in detail. The other two strategy types are just mentioned shortly.

	Process Re-engineering	Process Optimization	Continuous Improvement Process
Changes within the process	Very high	Medium to high	Rather small
Employee involvement in the whole company	Strong integration of the management	Integration from the managemant & production	High engagement of the workers in the production
Risk (Acceptance, job security)	Relatively high	Small to medium	Small

Figure 19: Various opportunities for the improvement of processes[42]

This figure gives an overview about the different opportunities for process improvements. For instance process reengineering has very high changes within the improvement of the process. Also a strong integration of the management with less cooperation with workers of the production could be negative for the process improvement. Very negative is that the there is a quite high risk that workers maybe will not accept the new process conditions. For this thesis on the tunnel site Solbakk in Norway this approach seemed to be unappropriated

[41] (Becker 2005) p.63 f.
[42] (Ristau 2011) p.17

for the process improvements. Also the continuous improvement process wasn't convincing with its characteristics. The achieved improvements here are very small but frequently. For the tunnel site in Norway the grade of improvement is too small. Process optimization is in the middle of the strategies. This method was chosen for the improvement of the processes in Norway and will be explained more in detail:

2.1.6.5.2 Process optimization as strategy

The process optimization is the most commonly used method to achieve better results within the optimization of processes. Main focus of the method process optimization is on the existing processes which will be changed. Weak spots in sub-processes or even in process steps will be analyzed and improved with the appropriate measures. Process optimization is located between a continuous improvement process and process re-engineering. Solutions which are found with the strategy of process optimization are a very good compromise between the terms and conditions, because these terms can´t be changed occasionally, and the best possible optimum. Risks and influences on the sociological and technical level are quite low compared to other strategies[43].

2.1.6.5.3 Course of action of the process optimization

To achieve process improvements it is very important that the company has the necessary technical know-how. But the methodology at problem statements with whose approaches is also essential to achieve an optimization of the processes. For this thesis the term methodology can be seen as a structured approach with a defined sequence to reach a process optimization. In general a process optimization can be divided into the following steps[44]:

- Acquisition of the current situation
- Analysis of the gained data
- Technical preparation of the measures
- Implementation of the measures

These steps were done directly on the tunnel site Solbakk in Norway. At the beginning of the thesis it was essential to get an overview about the current situations of the different processes at this tunnel site. To obtain the necessary data many explorative interviews with different internal and also external experts had to be done. Also co-operating in different areas of the company Marti IAV was important to get the best possible overview about the specific processes. The main measurements were found through the further execution of expert interviews with many different experts at this tunnel site in Norway. All steps regarding to these interviews as well as the output and the measures out of the interviews can be seen in the practical part of the thesis.

[43] (Ristau 2011) p.16
[44] (Ristau 2011) p.17

2.2 Value chain of Porter

The value chain was established in the eighties by Michael Porter. Porter's model of the value chain is largely accepted in economy and science[45].

The value chain of Porter is for the identification, creation and sustainment of competitive advantages. This basic approach of the value chain was widely spread through Michael Porter. For searching of competitive advantages Porter´s value chain is an analytical tool which separates a corporation into strategically relevant activities. In this way the cost behavior can be identified and understood. Porter´s value chain consists of value activities. Every single value activity represents a potential competitive advantage[46].

For the company Marti IAV it is essential to figure out and to understand the own value activities. The corporation must be separated into the strategically relevant areas. Therefore it must be analyzed where the relevant processes of the thesis are located in order to create an advantage out of these processes against the competition. To analyze the company with the value chain of Porter in combination with other tools for the process visualization will lead to significant improvements of the specific processes.

2.2.1 Competitive advantage

If a company is seen as a whole the advantages in competition cannot be understand. These competitive advantages grow through single activities of the company. The areas are design, production, marketing, delivery and support of a company's product. To analyze the reason of a competitive advantage some systematical methods are needed. Analyzed will be all activities of a company and whose interaction. The analytical tool therefore is the value chain. When a company can do these strategically activities better or cheaper than their competitors, then the company has an advantage in competition[47].

Also tunneling companies can be broken down into single activities for analyzing the competitiveness of the company compared to competitors. The elaborated value chain of the company Mart IAV can be seen in the practical part.

2.2.2 Definition of the value chain

Every company can be seen as an accumulation of activities. The product of the company will be designed, produced, distributed, supported and delivered through these activities. All these activities can be illustrated in the value chain. The value chain consists of the value activities and the profit margin. Value activities can be distinguished into technological and physical activities of a company. With these elements the company creates a product for its customers. Profit margin is the difference between total value and the sum of the costs which

45 (Kowsky 2013) p.25
46 (Reckenfelderbäumer 1998) p.104
47 (Porter 2000) p.63

have been developed through the execution of the value activities. It will be distinguished between primary and support activities[48]. Figure 20 shows the value chain of Porter. Primary and support activities will be explained in detail on the following pages.

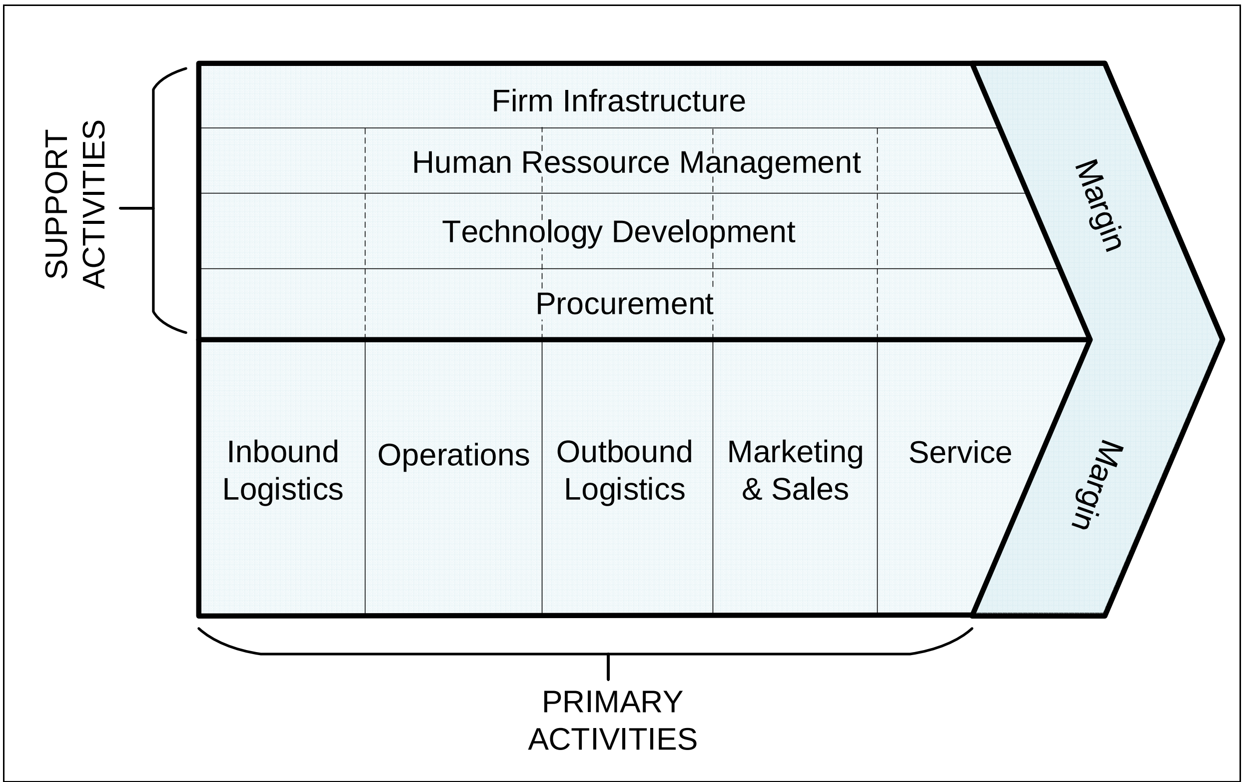


Figure 20: Model of a value chain[49]

According to Porter value activities are the only components which bring competitive advantages to the company. Therefore an analysis of the value chain is the right way to explore these advantages[48].

2.2.2.1 Primary activities

Primary activities can be classified into the categories inbound logistics, operations, outbound logistics, marketing and sales and service. These activities give attention to the physical creation of the product, its sale and delivery to the customers as well as the customer service[48].

2.2.2.2 Support activities

Supporting activities support the primary activities. These supporting activities are responsible for purchasing of inputs, human resources, technology and functions for the entire company. The dotted lines in the value chain (Figure 20) mean that procurement, technology and human resource management are linked with certain primary activities. But they can also support the whole chain. Attention must be paid to the firm infrastructure

[48] (Porter 2000) p.67 ff.
[49] (Porter 2000) p.66

because the firm infrastructure supports the whole value chain. There is no connection between some certain primary activities and the firm infrastructure[50].

2.2.3 Definition of the value activities

For the determination of the value activities it must be distinguished between strategic and technologically activities. They have to be treated separately[50].

2.2.3.1 Primary activities

Every industry has five categories of primary activities. These primary activities can be seen in figure 20. According to the business strategy and the industry sector of the company these five categories can be sub-divided into following different activities[50]:

2.2.3.1.1 Inbound logistics

These activities are for instance stock holding, the internal material transport or inventory control. Inbound logistic activities have to do with reception, warehousing and distribution of capital equipment for the product of the company[50].

2.2.3.1.2 Operations

Package, mounting, machine processing, maintenance of the equipment or test procedures are operation activities. Operation activities have to do with the transformation of the inputs into the finished product[50].

2.2.3.1.3 Outbound logistics

Material transport, warehousing of the finished products, time scheduling and order fulfillment are for instance outbound logistic activities. These activities deal with collection, warehousing and the physical distribution of the product to the customers[50].

2.2.3.1.4 Marketing and sales

For example advertisement, outside sales, selection and maintenance of the distribution channels or pricing are activities of marketing and sales. Marketing and sales activities are provision of funds which should entrap the customers to buy the product[50].

2.2.3.1.5 Service

Service activities are for instance installations, repairs, education, product adaption or delivery of spare parts. These activities are services for the conservation of value or the advancement of the product[50].

Depending on the industry every primary category can be crucial for the competitive advantage. Some short examples: The most important areas for a trading concern are the inbound and the outbound logistics. In contrast a service company which operates on its own ground will have nearly no outbound logistics. But the area operation is the main category of

[50] (Porter 2000) p.67 ff.

such a company. An example could be also a restaurant. In every company are all these categories of primary activities available to a certain degree[51].

2.2.3.2 Support activities

The supporting activities can be sub-divided into four categories which can be seen in figure 20. Every category is industry-sector-specific demountable[52].

2.2.3.2.1 Procurement

Procurement is the function of the purchase of the used inputs in the value chain. The bought inputs itself aren't meant here. Bought inputs are for instance raw materials and utilities or other consumables. Investment goods like machines, office equipment or buildings are also bought inputs. As a rule procurement is available in every area of the company. For instance raw materials are bought in the purchase department and machines are bought by the factory manager. Improved purchasing methods can have a positive effect on the quality and the costs of the bought inputs[52].

2.2.3.2.2 Technology development

Every value activity is linked to a technology. The technology development can support the whole value chain or just some single primary activities. In every industry the technology development is important for the competitive advantage[52].

2.2.3.2.3 Human resource management

Human resource activities are for example education and further education of employees. Also the recruitment, employment or even the compensation are such activities. The human resource management can support single primary activities or even the whole value chain. The HR management has a significant influence on the costs for education, motivation and the knowledge of the co-workers in every company. This influences the competitive advantage of the corporation[52].

2.2.3.2.4 Firm infrastructure

Firm infrastructures are for instance planning, finance, accounting, the business management, contacts to public authorities and quality control. The infrastructure of the company is supporting the whole value chain as an exception. Firm infrastructure can be also important for competition advantages. For some companies bargaining and maintaining contacts with controlling authorities are the most important activities[52].

2.2.4 Relevant areas of Marti IAV´s value chain (Norway)

In figure 21 the simplified value chain of the company Marti IAV is shown in accordance to Porter´s value chain. This thesis will handle specific processes which are located in the area of primary activities. These relevant processes are located between the production and the

[51] (Porter 2000) p.71
[52] (Porter 2000) p.71 ff.

inbound logistics of the company Marti IAV at the tunnel site Solbakk in Norway. A further sub-division can be seen in the practical part.

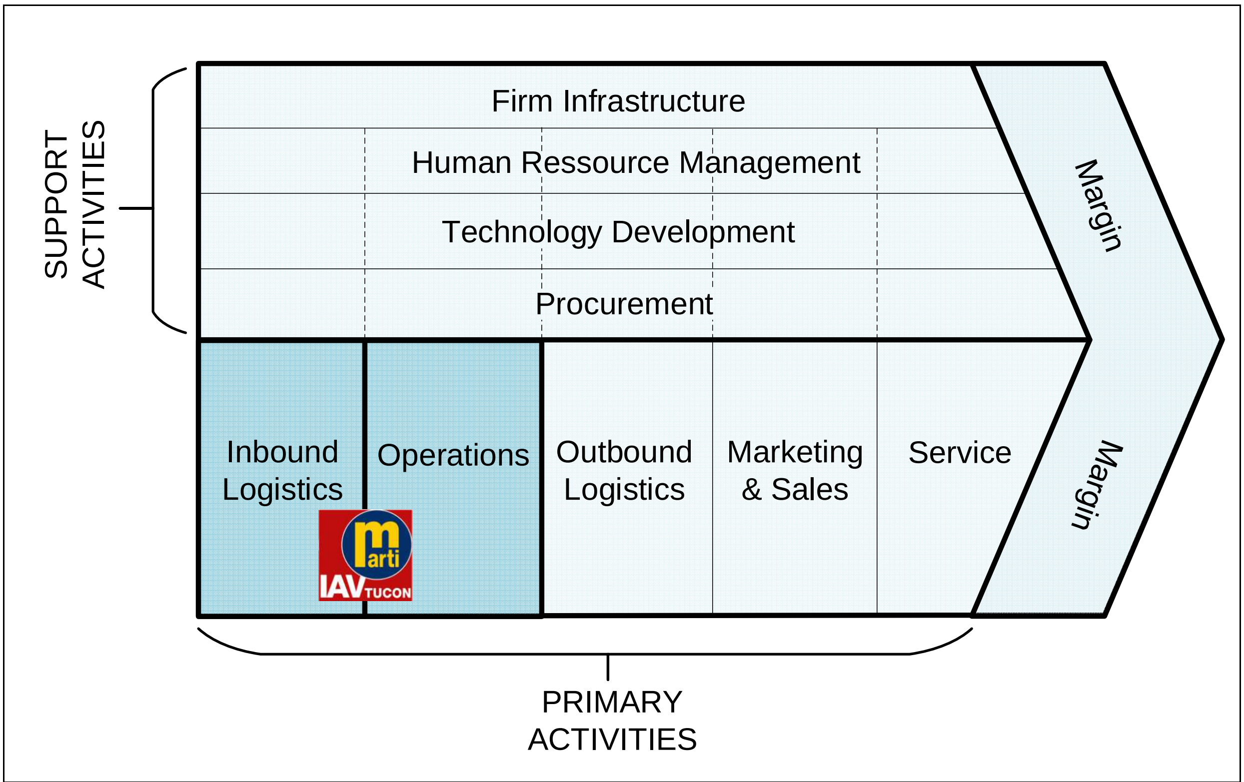


Figure 21: Marti IAV´s simplified value chain in accordance to Porter´s value chain[53]

According to Strassburger Porter´s value chain of a company can be break down into single products, activities or even into processes[54].

To analyze the relevant processes at the tunnel site Solbakk in Norway it is essential that the company Marti IAV is separated into different areas like in this value chain. Mental blockades can be avoided due to this point of view according to the author. The focus is exactly on the processes itself which is important for the whole thesis.

2.3 Process visualization

For this thesis it is important that all relevant processes will be visualized in order to see weak points within these existing processes. First step is to visualize the current situations of the existing processes and furthermore also the improved processes at the tunnel site in Norway. For a better understanding of all illustrations in the practical part it is essential to understand the different used graphical tools for the illustration of processes in general. Therefore an overview and explanation about these different graphical tools will be given in this sub-chapter. With this theoretical information it should be possible to follow all steps which were taken in the practical part of this thesis.

53 (Porter 2000) p.66
54 (Strassburger 2006) p.3

There are some important considerations for the illustration of processes. The following bullet points mention the relevant information for the creation of the specific processes on the tunnel site Solbakk in Norway according to Feldbrügge and Brecht-Hadraschek[55]:

- Adjust the illustrations to the requirements and the knowledge of the user from the process: Use just symbols which are known by the process users.

- Understandability and clearness comes before completeness: Occasionally it isn't possible to illustrate every detail or exceptions in one picture. Some text boxes on appropriate positions should be used.

- The meaning of the symbols must be clear: Symbols with the same meaning must always look equal. When the symbols have a different meaning they must look different. Just use new symbols if it is a profit for the whole illustration. Less is more.

- Use a clear arranged arrangement of the needed diagrams.

- Describing texts are good: Be careful because too much text descriptions are counterproductive. If more text is needed don't put it into the diagram. It should be described separate. The necessary information about the process for the user has to be either in the illustration or in the text.

- If it is possible use always the same format: Sometimes difficult because processes can be very complex.

- The reading direction of the pictures or diagrams is always from the left top to the right bottom if it is possible.

Also for the involved persons and workers in Norway it is important that they are able to understand and to read the used symbols and graphics. The content of the illustrations must be traceable and clear. If some symbols aren't known to the process owners it can be necessary to educate or train them directly on the site.

2.3.1 Process sequence

For the process optimization and especially for the process application a good process description or process sequence is very helpful. A well process sequence contains the correct cycle of the activities. Also the required inputs and the expected results of the process are listed in a good process description. A correct executed application of the process is also ensured due to a proper illustration of the process sequences[56].

[55] (Feldbrügge & Brecht-Hadraschek 2008) p.63 ff.
[56] (Schneider et al. 2008) p.46

A good process description has the following characteristics[57]:

- **Understandability:** The description of the process should be as easy as possible to ensure that the content will be understood by the involved people. Process descriptions which nobody can understand are senseless.

- **Shortness:** Process descriptions should be short and precise. Long instructions could discourage the users.

- **Suitable for daily use:** It is essential that the process instructions are near the reality. Unrealistic descriptions maybe won´t accepted by the users. Too theoretical process descriptions aren't really useful for the optimization of processes.

Also for the process descriptions at the tunnel site Solbakk these important characteristics must be considered in order to achieve process improvements. Demotivated workers due to inappropriate long or complicated process descriptions have to be avoided. Suitability for daily usage must be given.

2.3.2 Methods for business process modeling

For process documentation there are different methods available. Also the description of a process with a text would be possible. The description with a text is quite easy to perform but these texts can be very confusing. It can be hard or even impossible to see process improvements out of these descriptions. Process descriptions in table form are better for the clearness of processes compared to texts. But also with tables complex courses and dependencies cannot be described very well. Only a graphical modeling of processes enables to illustrate even complex cycles and dependencies in a clear way. There are diverse tools for process modeling on the market. It would be also possible to create an own tool for process modeling but this isn't usual in the praxis. To illustrate for instance processes on a low level of detail, a value chain diagram would be appropriate. The value chain diagram (VCD) is for the rough illustration of business processes in a process map. In the practical experience these value chain diagrams will be refined if it is possible and even necessary. With event driven process chains (EPC) the single business sub-processes can be refined further. With the visualization method of the event driven process chain it is possible to illustrate the steps of each process graphically with the associated information, systems and organizational units. Another tool for the visualization of processes is the business process model and notation (BPMN). The advantage of BPMN is that technical relationships can be better illustrated compared to EPC. The relationships between these three tools and their level of detail can be seen in figure 22 in accordance to Möhring and Vogel. Which method for modeling business processes or even for the graphical illustration of processes is used by a company depends on the purpose of modeling[58].

[57] (Schneider et al. 2008) p.47
[58] (Möhring & Vogel 2013) p.16 f.

In figure 22 it can be seen that the value chain diagram (VCD) has the lowest level of detail. That's why this tool is used to get a rough overview about a company's processes. According to this picture the event driven process chain (EPC) is located in the middle of the level of detail. But compared to the value chain diagram it is possible to describe processes on a more detailed level. The highest level of detail has the business process model and notation (BPMN). This notation goes very deep into detail and it is possible to illustrate also very complex processes. This is the reason why BPMN was chosen for the visualization of the relevant processes at the tunnel site in Norway. All generated illustrations with the suitable description can be seen in the practical part of this thesis. In the following the most important methods for business process modelling are explained.

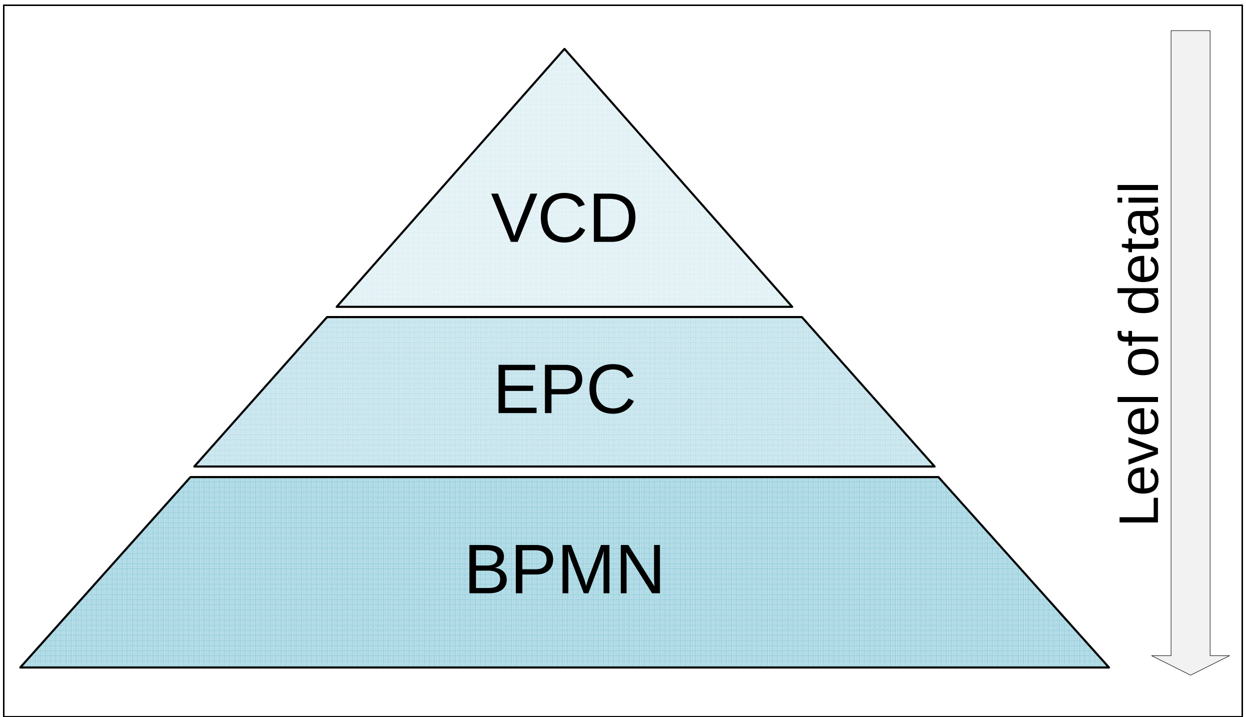


Figure 22: Hierarchy levels of business process modeling according to Möhring & Vogel[59]

2.3.3 Process map

Normally the whole process hierarchy, the so called process map, will be generated in process modeling and it isn't just modeling a single process. The process map is the topmost hierarchy level of the considered area. Between intermediate levels can be different models which allow further breakdown of processes. On the lowest level there can be also so called flow charts[60].

2.3.3.1 Function and essential questions

The highest process level can be illustrated in a process map. Main function of a process map is to get an overview about all primary processes in the considered area. Primary processes within such a process map will be well-defined and this is very important for the

59 (Möhring & Vogel 2013) p.18
60 (Schneider et al. 2008) p.48

overview. It is also possible to restrict the primary processes and to show existing interfaces inside the process map. There are some important questions for the creation of the process map[61]:

- Which bordering primary processes exist?
- Which primary processes belong to the organization?
- Which primary processes don't belong to the organization?
- Which relationships are between theses primary processes?

Also for the generation of the process map for the tunnel site Solbakk in Norway these questions were considered to ensure an appropriate illustration of the related processes on the top level of the process hierarchy of Marti IAV. The process map of Solbakk represents the primary processes of the tunnel site in Norway and can be seen in the practical part.

There is no standardized display format for the creation of process maps. Different graphical variants are available[61]. For the visualization of the process map in Norway an appropriate display format had to be found. Due to literature research the most suitable method for the illustration of a tunnel construction site must be found and applied.

2.3.3.2 Benefit of the process map

Benefits of a process map can be explained on three different levels. On the top level is the strategic level, in the middle is the tactical level with the optimization and on the lowest level is the operational level with all the information and transparency. Figure 23 shows the three benefits of a process map. An illustration as pyramid seems to be appropriate because the lowest level is the basis of this pyramid and the main focus is on the creation of transparency and the illustration of the information[62]. In the following the benefits will be explained in detail:

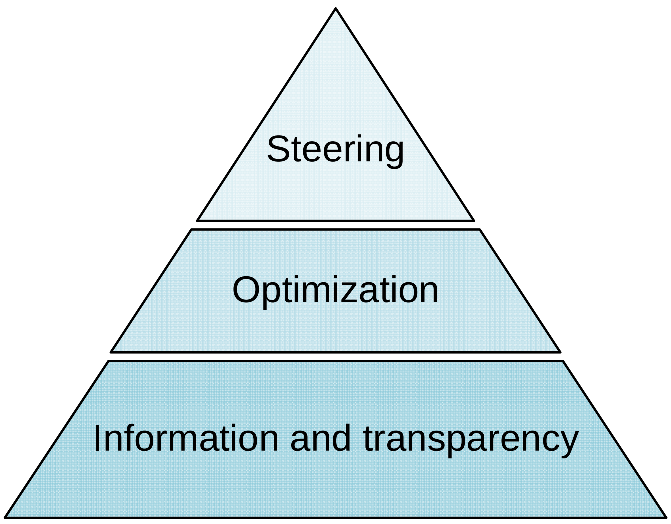


Figure 23: Benefits of the process map[63]

[61] (Schneider et al. 2008) p.97
[62] (Bayer & Kühn 2013) p.40 f.
[63] (Bayer & Kühn 2013) p.41

2.3.3.2.1 Steering

A process map can be used as a steering tool or as a management system for the guidance of processes. Also process control is possible due to the commitment of a process map. The process structure influences how an organization is structured and guided over processes. A structured illustration of the process architecture is very important for the acceptance and the visibleness of the process management in the organization[64].

2.3.3.2.2 Optimization

A process map offers the opportunity to identify cross-process potential for optimization. The optimization is located in the middle of the pyramid. With a kind of bird´s eye view it is possible to standardize existing processes[64].

2.3.3.2.3 Information and transparency

A good structured process overview enables a fast review about the business processes of a company. This map is a kind of a navigation tool because it allows a fast entrance into the process architecture of the company. Due to the fact that the process map offers all business processes it is suitable for the training of new employees. Also the possibility for searching special processes is given by process maps. This kind of visualization shows the transparency of the whole process organization of a corporation[64].

2.3.3.3 Configuration of a process map

Different attributes determine the configuration of a process map. Depending on the industry sector of a company the process attributes can be different. To define the attributes for the creation of a process map some steps have to be considered[64]:

- Identify the process attributes which are dependent on the line of business
- Arrange process attributes according to importance
- Decide which process attributes will lead to separate processes

For this thesis it is essential that all these steps will be considered due to creation of the process map of the tunnel site Solbakk. If some process attributes need a separate illustration outside the process map must be analyzed and implemented.

Figure 24 shows an example for structuring of a process map in accordance to Bayer and Kühn. The logic and the structure are related to an insurance company[65]. Not all processes will be explained in this figure because it isn’t relevant for this thesis. But in this picture the process conclusion of contract is broken down into its schematic single processes. These processes are shown in the left rectangular field. The upper process illustrates a serial connection of the sub-processes. That means if one process step is finished than the

[64] (Bayer & Kühn 2013) p.41 ff.
[65] (Bayer & Kühn 2013) p.43 f.

following process step will start. But processes can also be performed parallel. They will be executed at the same time. In this picture is also a specific sub-process shown. If it is necessary an additional illustration of this specific process can be made. All processes on the tunnel site in Norway have to be visualized. Whether some additional illustrations of processes are necessary must be analyzed and implemented if necessary. A bigger illustration of figure 24 is in appendix 4.

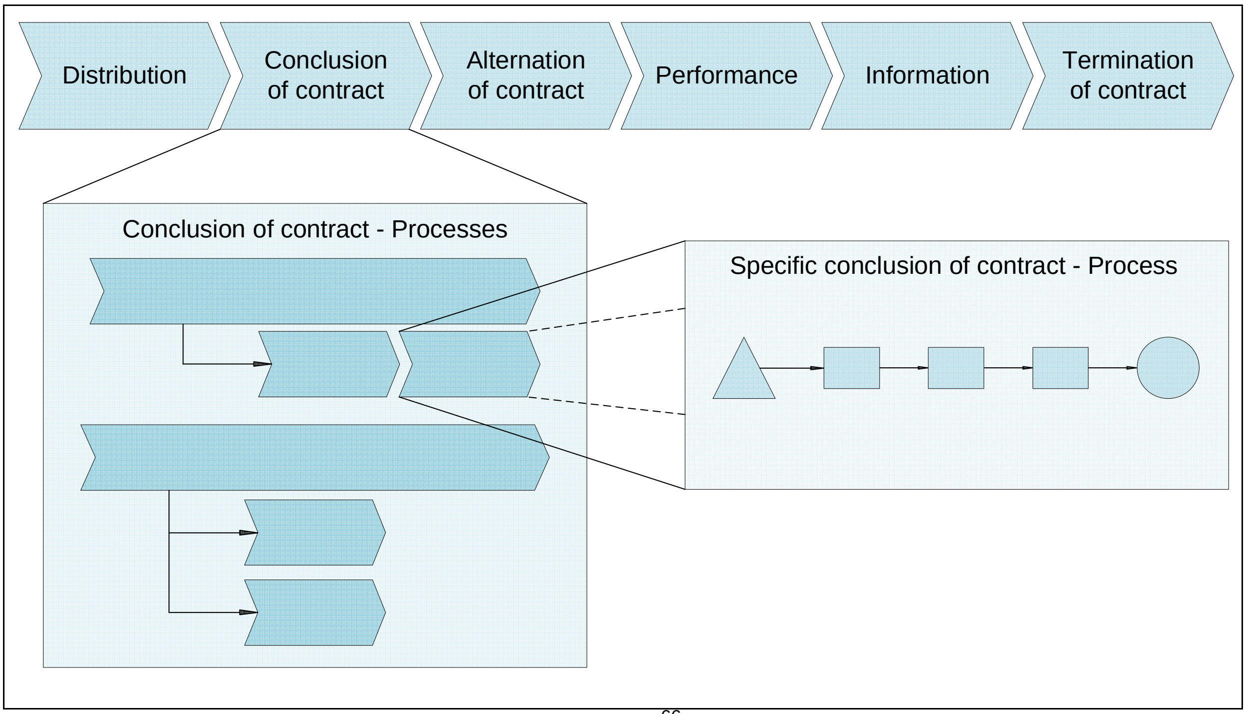


Figure 24: Example for structuring a process map[66]

2.3.4 Value chain diagram (VCD)

It was essential to get an overview about all important processes which are performed by the company Marti IAV in Norway. Therefore a process map with integrated value chain diagrams was established to get an overview about all relevant areas of the company. Due to the fact that this is a high level of abstraction it is quite easy to get a fast overview about these processes at the tunnel site in Solbakkk. The generation of this process map with the integrated value chain diagrams can be seen in the practical part of this thesis.

2.3.4.1 Definition of the value chain diagram

The value chain diagram can be traced back to Porter´s approach of the strategic business process analysis to achieve an advantage in competition. A value chain diagram shows the strategic importance of internal functions of a company. There is a distinction between primary and support activities. Further information about the value chain itself can be seen in chapter 2.2. These involved processes within the value chain diagram (VCD) are illustrated process-oriented. Modeling the process structure of a company with a value chain diagram enables the entrance into the process organization of a company on a high level. The

66 (Bayer & Kühn 2013) p.44

sequence modeling with a value chain diagram in accordance to Gadatsch isn't just representing the original value chain of Porter. In Fact it represents sequence modeling of functions on a high level[67].

2.3.4.2 Graphical illustration of the value chain diagram (VCD)

The notation of the value chain diagram can be seen in figure 25. A value chain diagram according to ARIS uses arrow symbols for the illustration of functions. It will be distinguished between start function and follow-up functions. Vertical arrows refer to parallel functions. These functions can be processed parallel to the upper main function. Dotted horizontal arrows refer to the next follow-up function. The following functions are on the same level and will be processed in series[67]. A larger image of this figure can be found in appendix 5.

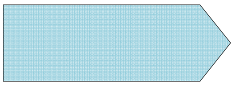
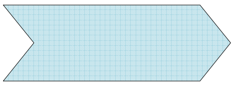
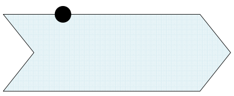
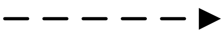
Symbol	Name	Description	Edge- / node type
	Start function	Description of a function which starts a process chain on a high level of abstraction	Activity node
	Follow-up function	Description on a previous function following function on a high level of abstraction	Activity node
	Itemization follow-up function	Marking of a function which will be detailed through a further model (Concept of hierarchy)	Activity node
	Follower	Control flow for follower. Links successional functions	Control flow edge
	Parallel process	Control flow of parallel functions. Links parallel running sub-functions of an higher main function	Control flow edge

Figure 25: Value chain diagram (Notation)[68]

2.3.5 Business process model and notation (BPMN)

Modeling of processes with business process model and notation is an international standard nowadays. The centers of BPMN are activities, messages, events and sequential cycles of processes. With these diagrams it is possible to formulate very detailed process models but also a rough concept on a high level of abstraction can be generated[69].

[67] (Gadatsch 2008) p.199 ff.
[68] (Gadatsch 2008) p.201
[69] (Leimeister 2012) p.214

This notation language was chosen in Solbakk for the illustration of detailed processes within the process map of this tunnel site in Norway. The process modeling can be seen in the practical part of this thesis.

2.3.5.1 Definition of the notation

Documentation and description is essential for managing business processes. But for more complex processes with data flow, events, rules for branching or executing organizational units this isn't enough. Therefore an appropriate notation is needed. A notation is a standardized language for describing business processes. If someone is able to read this language he can understand generated models from others. Through the standardized illustration it is also possible to analyze processes systematically. Also the dynamic behavior of a process can be simulated[70].

2.3.5.2 Graphical illustration of BPMN

Business processes can be modeled with BPMN because BPMN is a graphical notation language. The advantage of BPMN is that for all involved people, like the user or the developer, this language is easy to understand and even simple to use. So BPMN can be seen as the missing gap between business process implementation and business process modelling. Elements which are used in BPMN are classified into four categories and the graphical illustration occurs in a business process diagram (BPD). The elements which are explained afterwards are the basic elements of a business process diagram. These four categories of used elements are[71]:

- Flow objects
- Connecting objects
- Swim lanes and
- Artifacts

In the following the symbols of these elements will be illustrated and they will be explained in detail. This graphical explanation is essential to understand the created BPMN models which can be seen in the practical part of the thesis.

2.3.5.2.1 Flow objects

Flow objects are the basic elements which are used in the graphical illustration with BPMN. These objects can be divided into activities, events and gateways[71].

Table 1 shows flow objects of BPMN with the used symbols and a short description of each element. A bigger picture of this table can be found in appendix 6 at the end of the thesis.

[70] (Allweyer 2009) p.8
[71] (Krallmann et al. 2007) p.111 ff.

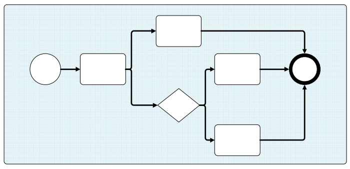
Event	An event is something what happens during a business process and it influences the cycle of the process. As a rule an event has a trigger and/or a result.	Start	Intermediate	End
Activity	An activity represents the work / action in a company. An activity can be a task or a sub process, which can consist out of more tasks.	Task	Sub-process (Collapsed)	
		 Sub-process (Expanded)		
Gateway	A gateway controls the flows. The way of control, for instance AND, OR, XOR, will be identified with an appropriate symbol. A gateway can be a decision point or merging and accordingly split up different, parallel flows.	Unspecified gateway		
		AND	OR	XOR

Table 1: Flow objects[72]

2.3.5.2.2 Connecting objects

These objects are connecting flow objects with each other. Connecting objects are classified into message flows, sequence flows and associations[72]. In table 2 the different connecting objectives are shown and explained. A bigger illustration of this table is also attached to appendix 7.

Sequence flow	With sequence flows the sequential arrangement between flow objects will be defined.	
Message flow	A message flow represents the communication between two process involved persons. For example in the swim lane illustration is every pool process involved.	
Association	With associations the allocation of artifacts like data objects or text annotations to flow objects is possible. They show the input or output of an activity.	

Table 2: Connection objects[73]

[72] (Krallmann et al. 2007) p.112
[73] (Krallmann et al. 2007) p.113

2.3.5.2.3 Swim lanes

With swim lanes it is possible to allocate different activities to their area of responsibility or swim lane. BPMN uses the elements lane and pool[74]. These elements are explained in table 3. Also the illustration of them is shown in this table. A large picture is in appendix 8.

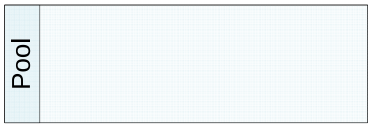
Pool	A pool is representing a process participant and is for the differentiation of activities among each other and for the allocation of activities in areas of responsibility.	
Swimlane	Lanes are divisions of a pool. With lanes it is possible to organize and categorize activities.	

Table 3: Swim lanes[74]

2.3.5.2.4 Artifacts

Artifacts are elements like groups, data objects or annotations. With artifacts it is possible to widen the notation elements context-dependent[74]. Table 4 shows these artifacts and a bigger illustration is added in appendix 9.

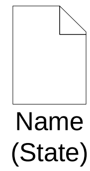
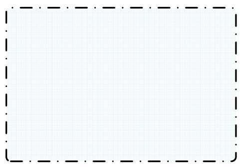
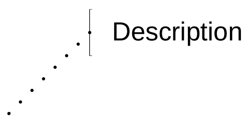
Data object	Data objects show which kind of data are created through an activity or which data is needed for an activity.	
Group	A group enables the possibility to allocate some optic to a group. The sequence flow will not be affected.	
Annotation	With annotations the modelling can show additional information in the diagram.	

Table 4: Artifacts[74]

[74] (Krallmann et al. 2007) p.113

For the processes on the tunnel-site in Norway it was also very important to add some additional information or even descriptions to raise the awareness of the workers to perform all the tasks as good as possible.

2.3.5.3 Definition of split- and merge gateways

To understand all steps which were done in the practical part of this thesis it is absolute necessary to study the following basic principles of BPMN gateways.

2.3.5.3.1 Split gateways

Split gateways are some kind of locations within a workflow. There the sequence flow can take two or more alternative paths. The following split gateways are different in the amount of possible paths which can be taken during the execution of the workflow. The difference between a XOR-split gateway and an OR-split gateway is that for a XOR-split gateway only one single path can be chosen. An OR-split gateway can have several outgoing flows. An AND-split gateway must have all outgoing flows activated. In BPMN there are different three different types of split gateways which can be seen in Table 5. Every type will be explained in detail with its corresponding behavior within this table[75].

A larger illustration can be found in appendix 10.

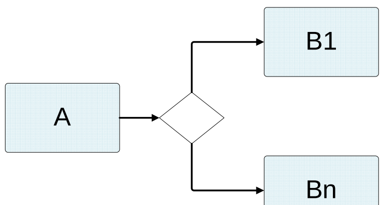
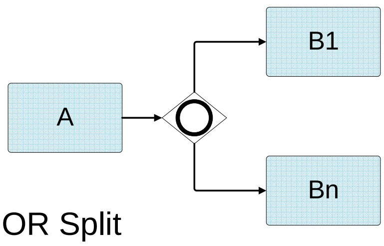
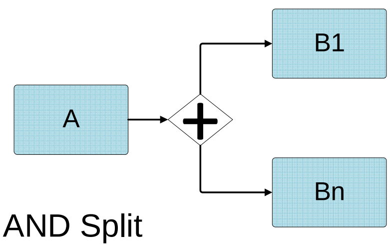
Split gateway	Process constraints
 XOR Split	- Only one of the B1 … Bn activities may be started - If A is completed, at least one of the B1 … Bn activities must be created before ending the case
 OR Split	- Since several B1 … Bn activities may be started, we just need to verify that if A is completed, at least one of the B1 … Bn activities is created before ending the case (like in XOR split above)
 AND Split	- If A is completed all B1 … Bn activities must be eventually started.

Table 5: Constraints for split gateways[75]

[75] (Engels et al. 2007) p.382

2.3.5.3.2 Merge gateways

For joining or synchronizing of alternative sequence flows in the process modeling with BPMN merge gateways are used. The definition of an XOR-merge gateway is that every time when a single incoming flow is completed than the outgoing activity may starts. An AND-merge gateway has to wait until all incoming flows are completed in order to synchronize them. The OR-merge gateway has to wait at least for one incoming flow to start the outgoing flow. BPMN distinguishes here also between three different types of merge gateways. In Table 6 these gateways can be seen with the related description of each single type of merge gateway[76].

The understanding of these different basic logical operations in the language of BPMN is necessary for the traceability of the process models which were created at the tunnel site in Norway. All generated models can be found in the practical part of this thesis. A bigger illustration of table 6 is added in appendix 11. In the following sub-chapter the event driven process chain is explained for the sake of completeness.

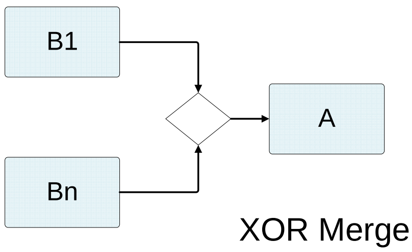
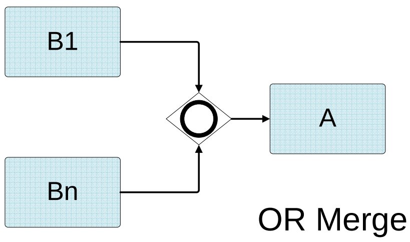
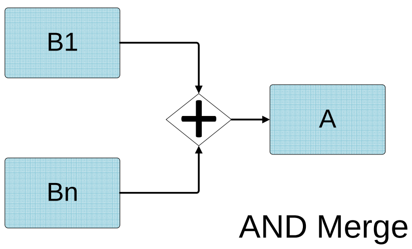
Merge gateway	Process constraints
	- All A activity instances have as a previous activity instance a completed acitvity instance of type B1 or … or Bn - Each B1 … Bn activity instance is followed by an A activity
	- An A activity instance must wait for at least an incoming flow
	- An activity instance of type A must wait for a set of activities B1 … Bn to be completed. - Each set of completed B1 … Bn activity instances must be related with an A activity instance.

Table 6: Constraints for merge gateways[76]

[76] (Engels et al. 2007) p.383 f.

2.3.6 Event driven process chain (EPC)

By reason that for this thesis the business process modeling notation (BPMN) was chosen and applied for the illustration of different processes on a detailed level at the site in Norway, the event driven process chain will be explained just compendiously.

2.3.6.1 Definition of EPC

Event driven process chains are able to describe process cycles. This modeling type illustrates the events of functions. It will be distinguished between triggered events and generated events. The simplest form of an EPC works just with events, logic branches and with functions. Also advanced event driven process chains are used in the practical experience. These advanced event driven process chains are working with additional objects like organizational units or with input and output data[77].

2.3.6.2 Graphical illustration of EPC

To understand the principle of the EPC in the following the most important symbols are shown. In table 7 and 8 the most common EPC symbols are illustrated with an appropriate explanation of each symbol. These pictures are also attached in appendix 12 and 13.

EPC-Symbol	Name	Description
Event	Event	An event indicates a state or a change in state. At the beginning and at the end of a process or branch of processes is an event.
Function	Function	Functions describe operations (Tasks, activities) which are executed during the course of the process.
→ Line (Edge)	Line (Edge)	Lines between events and functions are representing the logic flow of the process (Chronologically logic sequence).
V AND XOR XOR Λ OR	Branches in process sequences	Logic rules: • AND: All branches run through parallel. • XOR: Just one branch will be passed through. • OR: One or more branches will be ran through.

Table 7: EPC symbols with description[78]

[77] (Amrein 2012) p.85
[78] (Amrein 2012) p.86

EPC-Symbol	Name	Description
Org. unit	Organizational unit	Organizational unit which is responsible for the dedicated function.
Application system	Application system	Application system which is supporting a function.
Data file	Database or data file	Input or output of a function.
Document	Document	Input or output of a function.

Table 8: EPC symbols with description[79]

2.3.7 Used graphical tools

For the visualization of relevant processes at the tunnel site Solbakk in Norway the graphical tools process map with integrated value chain diagrams (VCD) and business process model and notation (BPMN) were chosen. With the process map it is possible to get an overview about the different specific processes at this tunnel site. All processes which need a high level of detail within this process map are illustrated with BPMN. In this sub-chapter the reasons and advantages for each tool are explained:

2.3.7.1 Process map with integrated value chain diagrams

With the process map it is possible to illustrate all processes which are performed by the company Marti IAV on the tunnel site Solbakk. The level of detail is low but the overview about all existing processes in Norway is given. This is important for a fast orientation on this graphical visualization map. The process map in combination with the VCD is also very easy to read and understand for different kind of workers and personal. This combination enables a fast entry into all relevant process areas of the company.

2.3.7.2 BPMN instead of EPC

The difference between business process model and notation (BPMN) and the event driven process chain (EPC) is in the technical or functional point of view in accordance to Jobst. BPMN has the advantage that its models are easy to generate and to read from a technical point of view. BPMN has a more technical focus compared to EPC. EPC is for the

[79] (Amrein 2012) p.87

professional description of business processes. A problem of EPC is that some object types have ambiguities and there is wiggle room for interpretation due to the fact that meaning of constructs isn't clearly specified[80].

The modeling technique BPMN was established with the goal to be easy to read and understandable for all different kind of persons which are involved in the creating and executing of BPMN processes. These persons are for instance the persons which make the functional modeling of the processes and of course the co-workers of the analyzed company. Co-workers are for example executing and controlling the processes. BPMN models are very understandable and appropriate for reusable technical questions[81].

Due to the fact that BPMN has the better technical focus compared to EPC in accordance to Jobst and it's also very easy to read and understand, this tool was chosen for the illustration of specific processes at the tunnel site Solbakk in Norway. Also miners, blacksmiths or other persons on this tunnel site have to understand their task within the process and the process itself. Therefore the notation with BPMN was successfully introduced and applied. A big advantage is also that the level of education of involved persons or process owners must not be very high. Compared to EPC, BPMN has a higher level of detail which was also an advantage and a reason for this tool. But the most important fact is that the people who work within the relevant processes are able to clearly understand the process itself and their task within this process. BPMN is a great tool for the visualization of very detailed processes and was successful applied at this site in Norway and accepted by the involved. All generated BPMN models as well as the process map with the included process chain diagrams can be seen in the practical part of this thesis.

2.3.7.3 Conclusion of the process visualization

For the tunnel site Solbakk the combination of a process map with included value chain diagrams (VCD) and BPMN was suitable for the process visualizations. With the process map and the diagrams it is possible to get a fast overview about the whole processes of the company Marti IAV at this tunnel site in Norway. These illustrations are also easy to read. Workers had no problem to understand the relations or the functions of the generated process map. BPMN was needed for the detailed processes among the process map of Solbakk. For the detailed sub-processes BPMN was essential on this site to illustrate the complex processes. The level of detail is high and the symbols of BPMN are clear without ambiguities. For the involved persons of the specific processes it was easy to understand the processes which were drawn with BPMN. The introduction of the process map with the included value chain diagrams in combination with BPMN drawings is a good combination to uncover all different kind of areas of the company. All illustrations which were established can be found in the practical part of this thesis.

[80] (Jobst 2010) p.92
[81] (Becker et al. 2009) p.70 f.

2.4 Internal analysis

A company is affected by its internal circumstances. Some internal circumstances are for example the human and material resources or even the corporate strategy of the company. Corporations are also affected by their environment or their branch. A company is surrounded by its internal environment, its branch environment and its macro environment. Figure 26 shows these different environments of a corporation. Due to a strategic analysis an internal and external analysis will be done. The internal analysis is defined just through the company itself. With the external analyses the company can identify its risks and chances in the external environment. Not every company has the same possibilities to react on these external chances and risks because this is depending on the strengths and weaknesses of the company. Goal of the internal analysis is to determine the strengths and the weaknesses of the corporation. The internal analysis of a company can just be determined through the company itself[82].

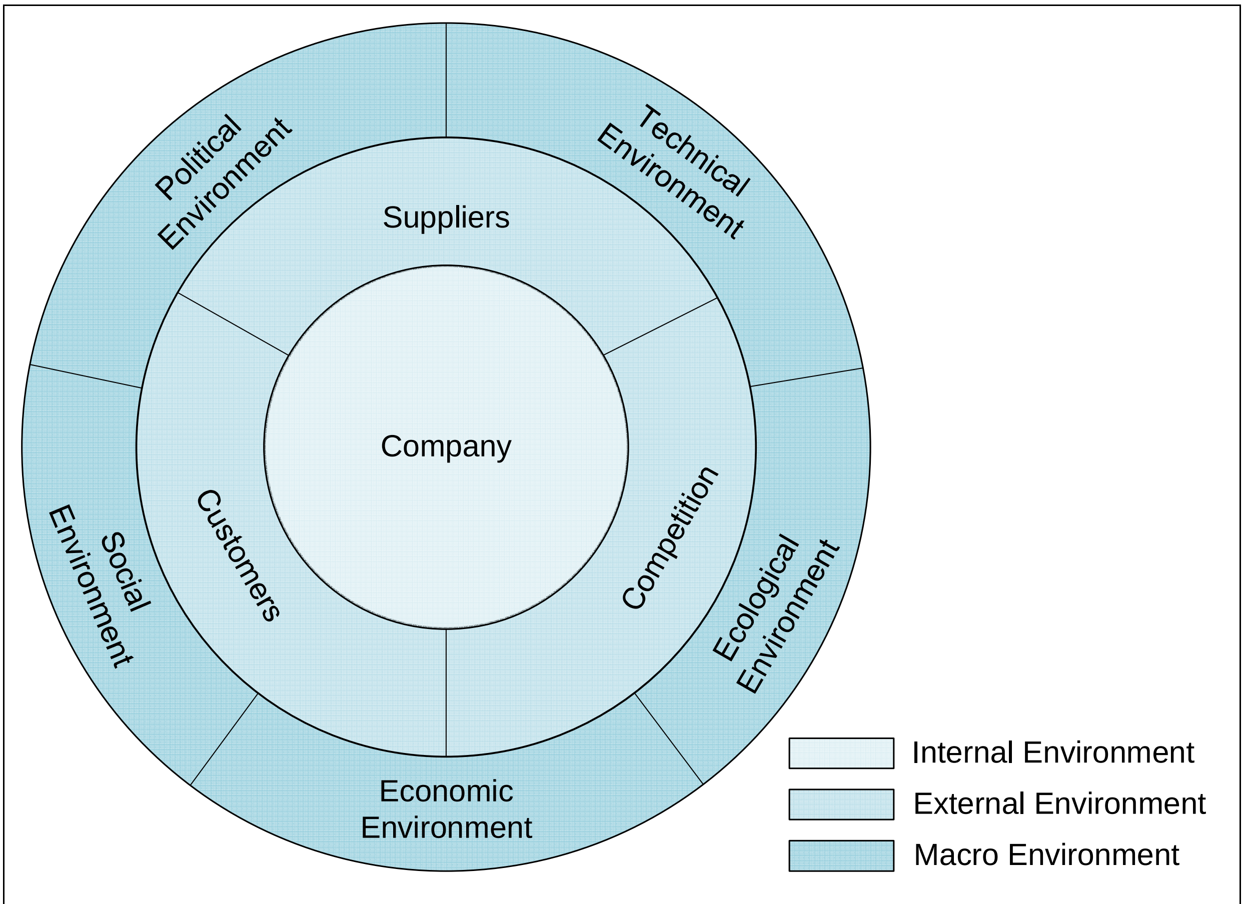


Figure 26: Levels and elements of an environmental analysis[82]

For the optimization of various processes at the tunnel site Solbakk in Norway the appropriate tool for the internal as well as external analysis of the company Marti IAV was the SWOT analysis. This analysis will be explained in the following sub-chapter. In the practical part of this thesis the SWOT analysis for the tunnel site Solbakk can be seen.

[82] (Nolte & Oppel 2008) p.49

2.4.1 SWOT analysis - Definition

The abbreviation SWOT stands for strengths, weaknesses, opportunities and threads of a company. With this analysis it is possible to determine the strengths and weakness or the threats and the opportunities of a corporation in relation to its competitors and especially its environment. Questions are for instance: “What make our competitors better than we make?” or “What do we make good?” Origin of this analysis is the strategic management. Such an analysis consists of an internal and an external part. The internal part includes the strengths and weaknesses of the company and the external part deals with the opportunities and the threads of the analyzed company. With this analysis the advantage in competition of a corporation can be found. At the internal analysis the strengths and the weaknesses of the company in comparison to competitive companies will be determined. The actual situation of the own company will be considered. At the external analysis the changes and the development of the company’s environment can be analyzed[83].

A big advantage of the SWOT analysis compared to other methods of strategic planning is in its clear arrangement and the integration of the internal and external perspective. The application of SWOT results in three steps[84]:

- Strengths / Weaknesses analysis (Internal analysis)
- Opportunities / Threats analysis (External analysis)
- Resume of the results in a matrix

2.4.2 Aim of the SWOT analysis

Aim of the internal analysis is to identify the own strengths and weaknesses of the company according to the company’s resources and abilities. This could be for instance capability characteristics of production or procurement. To measure the strengths and the weaknesses with competitors cannot be done absolute with SWOT, just relative measurements between the own and other companies is possible. The external analysis of SWOT identifies chances and risks of the company which are triggered through developments in the environment of the company. Companies cannot influence their environment. For example new procurement markets for political boundary conditions are unswayable for a company. Some results of SWOT are for instance low liquidity as weakness and a leading product technology as strength. A risk is for example political instability at procurement markets and a chance can be the growing demand on the Asian market. After elaborating the four fields the result must be written in a matrix. Single elements will be set into relationship and strategic course of actions can be derived out of it. In general the focus of a company is on the reduction of weaknesses and risks and on the usage of opportunities and own strengths. An advantage of the SWOT analysis is the low time requirement for the execution of this method[84].

[83] (Fueglistaller et al. 2008) p.255
[84] (Schuh 2014) p.106 f.

2.4.3 Example of a SWOT analysis

In figure 27 some opportunities or examples of a SWOT analysis in accordance to Pelz is shown.

Internal Strengths	Internal Weaknesses
• Technological competence • Good image • Financial resources • Personal • Loyal customer base	• Unclear strategic direction • Low market knowledge • Missing special skills • Costly processes • High costs
External Chances	**External Risks**
• New markets / Segments • Product design • Market penetration • Differentiation	• Law / Politics • New competitors / Products • Stagnating markets • Change in consumer buying habits • New distribution channels

Figure 27: SWOT analysis (Opportunities as a matter of principle) according to Pelz[85]

In this figure some examples of the company internal strengths and weaknesses as well as the external opportunities and risks can be seen.

2.4.4 Development of strategic options

With SWOT it is also possible and even important to establish strategy possibilities for a company. The graphical illustration takes also place in a matrix. This method searches or finds not the best strategy for a company but some possible strategy variants will be shown. From the previous sub-chapter the four key elements of SWOT are known. This new matrix consists of four additional fields for the different strategies of the company. These strategies are generated through the four key elements of SWOT. Next step is to write down the most important external chances and external risks of the company. Afterwards the most important internal strengths and internal weaknesses of the corporation must be written down. If these steps are completed some relevant strategies can be created out of the four key elements of SWOT[86]. Figure 28 shows the completed SWOT matrix with the additional fields for the different strategies. This SWOT analysis of the tunnel site Solbakk of the company Marti IAV can be seen in the practical part of this thesis.

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[85] (Pelz 2004) p.22
[86] (Sattes et al. 2001) p.44 ff.

SWOT Analysis	**S**trengths 1. 2. ...	**W**eaknesses 1. 2. ...
Opportunities 1. 2. ...	**SO** – Strategies 1. 2. ...	**WO** – Strategies 1. 2. ...
Threats 1. 2. ...	**ST** – Strategies 1. 2. ...	**WT** – Strategies 1. 2. ...

Figure 28: Scheme of the SWOT-Matrix[87]

For the development of a real SWOT matrix some steps have to be done in accordance to Sattes. First of all the internal strengths and weaknesses of the company should be listed. Afterwards the external chances and opportunities can be written down. With these entries the company should develop different strategies. At SO strategies the company can use its internal strength to use an external chance. With WO strategies a company will try to reduce its internal weakness through taking external chances. ST strategies parry the external threats through usage of the internal strengths. WT strategies have the aim to reduce or even avoid the internal weaknesses as well as the external threats. This new matrix shows all practicable strategies of the company. In general not all strategies will be implemented. Strategies which will improve the current situation of the company most efficient will be chosen. Focus is also on an easy realization of the selected strategies. After all steps and considerations the company has to choose the best strategy. It is important to derive some concrete measures out of the chosen strategies. A good strategy is simple and focuses on the internal strengths of the company. These strategies also attack the competitors where they are weak. Market and environment chances should be exploited[88]

In the practical part of this thesis a SWOT analysis of the company Marti IAV in Solbakk can be seen. Different strategies were established but not all of them were realized at this tunnel site in Norway. The SWOT analysis is a great tool because the focus is also directed on the external environment of the company and not just on internal aspects. Chosen strategy was the introduction of expert interviews with internal and external experts directly at this tunnel site. The results of these expert interviews can be also seen in the practical part.

[87] (Sattes et al. 2001) p.44
[88] (Sattes et al. 2001) p.44 ff.

2.5 Expert interviews and explorative interviews

For the illustration of the existing process sequences at the tunnel site Solbakk a lot of explorative interviews were necessary to obtain the required data and information. Also monitoring of processes and co-operating within different departments was essential to get a good overview about the various process sequences in Norway. To achieve process improvements it was totally important to make some expert interviews with internal and also external experts. With the knowledge of the external experts the own weak points of the company Marti IAV could be compensated. During different interviews an incredible knowledge about tunneling and administration of tunnel sites was recognizable. In this sub-chapter all necessary information for the understanding of the steps taken in the practical part is given.

2.5.1 Essential considerations

We must be aware that many interviewees tend to answers which they think it is desired from the society. People can give answers which are different than their real opinion. For an interview it must be considered that the whole questioning is codetermined through alternating expectations[89].

Also for the interviews in Norway this had to be considered within the established questionnaires in order to get real information. Explorative interviews were also absolutely necessary to get insights about different processes and this kind of interview is also explained in the following.

2.5.2 Definition of an expert

In sociology the term expert has especially to do with the participation at social design or decision processes. The role is determined through the social function of this person. Experts are for instance persons which have a special education and a social accepted access to a special area of operations like a doctor with a medical practice. Also scientists of universities, managers of corporations or public authorities can be seen as experts due to their participation in decision processes and their position in the company[90].

The definition of an expert is different in the psychology. Psychology has adjusted the main focus on the expertise of the person. Mentioned persons have acquired a special knowledge and appropriate skills to a specific topic. The interesting fact in this definition of an expert is that these persons don’t need a very high intelligence or memory. Most important is the longtime experience what these persons have. As a rule to achieve the necessary expertise it needs approximately 10 years of training and experience. But this kind of expert is restricted to his area of competence. His knowledge cannot be transferred into other areas[90].

[89] (Mieg & Näf 2005) p.4
[90] (Mieg & Näf 2005) p.6 f.

For this thesis the psychological definition of an expert is rather appropriate because the workers and miners at this tunnel site in Norway have in general not a very high education level but these people have gained valuable knowledge through their longtime commitments on different tunnel sites all over the world. All interviewed experts have worked more than ten years in the tunneling business. According to the author of this thesis an expert is someone who has a specific knowledge about tunneling because of this longtime experience at various tunnel sites. This unused knowledge and expertise of different experts is unused potential for improvement for the company Marti IAV. The know-how of the different workers on the tunnel site in Norway will be used for the creation of the desired target states of the relevant processes. All results of the interviews can be seen in the practical part of this thesis.

2.5.3 Explorative interviews

For this thesis also many explorative interviews were executed. These interviews were important to get useful data and information about the existing processes. With this information the current states of the interviews was illustrated. All illustrations can be found in the practical part. The definition of explorative interviews is the following:

The aim of explorative interviews is to get information about important issues to the relevant topic which is maybe unknown to the interviewer. It is essential to be aware of the aspects which the experts see as fundamental for a given subject because these persons have to fill out the questionnaire of the following expert interview or are asked about it. In such an explorative interview the interviewees can get open questions where they can speak free to the relevant topic. The interviewer should listen carefully to them in order to get to know possible unexpected aspects[91].

To get an insight into an unknown theme some explorative interviews with experts can be done. These interviewed experts should have a special knowledge about the specific topic. The sequence of the explorative interview is unstandardized and the interviewer can formulate own questions. These questions are open questions and the expert is able to answer them in his own words. Open questions allow the identification of problems. Also ideas as well as solution statements can be generated. The focus of explorative interviews should be on the complete collection of relevant information[92].

Explorative interviews are individual and verbal questionings. These interviews are used in general for obtaining first reference points regarding a special topic. The interviewer should steer the interview just as much as necessary in order to get open an honest answers of the interviewee. With this kind of interview it is also possible to get information about complicated range of topics. Another advantage is that the interviewer gets many different insights into the mindset and the feelings of the interviewees. A disadvantage of explorative interviews could be that the interviewer maybe has problems with the documentation of the interview

[91] (Aschemann-Pilshofer 2001) p.7
[92] (Wieseke 2004) p.175

due to restricted possibility of recording the interview. Loss of information could also happen especially for longer explorative interviews with less possibility for notices during the interview according to Schmidt[93].

During the execution of explorative interviews at the tunnel site in Norway some important and also unexpected aspects were detected. All these aspects can be seen in the practical part. The author of this thesis made always notices during these explorative interviews to avoid loss of data and information. All these notices are at hand of the author.

2.5.4 Expert interviews

For the improvement of existing processes in Norway it was essential to make various expert interviews directly on this tunnel site. With the received information and solution statements it was possible improve the existing processes in Norway. Therefore an accurate preparation of the expert interview guideline respectively expert interview questionnaire was mandatory. All relevant theoretical steps are mentioned in this sub-chapter. The finished expert interview questionnaires can be seen in the practical part.

2.5.4.1 The expert interview – Qualitative data acquisition

Essential for the expert interview is that the experts can answer in a free way of speaking. It is very important that the interview guideline doesn't simulate answer categories because this is negative for the free speech of the expert. Compared to quantitative social researches expert interviews have a small amount of interviewees. Sometimes it can also be that just one person is interviewed. The expert interview counts to the qualitative methods of data acquisition due to the openness of the questions. An interview is a social interaction between an inquiring and an interviewed person. We have to be aware that these persons have personal problems and own interests. The most important is that the result of the scientific interview can be understood. A good preparation for the interview is necessary. Recording the interview with a voice recorder is very recommendable. All statements of the expert or the interviewee are some kind of data. With the voice recorder it is possible to look back at the interview at any time. When some notices aren't readable or missing it's also very helpful to complete the whole interview. For a functional interview it is fundamental that the expert sees an able dialog partner in the interviewer. The interviewer has to know the basics in the area of expertise of the expert[94].

2.5.4.2 Requirements and problems of the expert interview

A simple definition of an expert interview is that an expert is just asked about his knowledge. The interviewer and the expert are discussing a topic in a constructive way. The motivation for the expert is that he can show and illustrate his knowledge to the interviewer. Bad for the whole expert interview is when the expert isn't a real expert or has not the needed experience or knowledge about the specific topic. It is also poor if the interviewer hasn't the

[93] (Schmidt 2007) p.76 ff.
[94] (Mieg & Näf 2005) p.4 ff.

required expertise about the theme. But it can also happen that the interview isn't a real expert interview because of the three following reasons[95]:

- The expert interview is finished and the interviewer will ask at the end additional questions about total different areas. This is not in the knowledge area of the expert and even forbidden to ask the expert about his opinion.

- If the interviewer has a problem and he knows an expert which hasn't the appropriate knowledge about this problem than he shouldn't try to ask this question because the expert hasn't the specific knowledge and then it isn't a real expert interview.

- An unprepared discussion is also not a real expert interview. The problem is the inadequate objectivity at data acquisition.

2.5.5 Generation of expert interviews

In this sub-chapter all required steps which were necessary for the creation of expert interviews which were performed at the tunnel site in Norway are mentioned.

2.5.5.1 Preparation for the questionnaire

Don't start with the questionnaire before the clear definition of the questions is elaborated. It can happen that really needed information will not be asked. For better structuring of the questions a mind map is very helpful. In the middle of the mind map is the rough topic written down, for instance the title of a diploma thesis. The first step is to make a brainstorming to obtain important aspects which must be implemented in the questionnaire. These aspects must be implemented in the creation of the mind map. This combination of brainstorming and mind map is very helpful for the collection of ideas for the interviews. Further ideas could be gained out of explorative interviews with people or out of the literature. The accurate and structured approach is very important to collect the most essential aspects. If an important aspect isn't mentioned now it can be that the interviewer will never get an answer to this aspect. Before the creation of questionnaires also some explorative interviews can be done to get more information about a topic. Also some unexpected aspects could occur[96].

All established relevant mind maps which were essential for the questionnaires at the tunnel site in Norway can be seen in the practical part.

2.5.5.2 Important frame conditions for the interviews

At the beginning of the questionnaire should be a short but clear introduction about the sense and the expectations of the interview. Different aspects of the expert interview must be asked in different questions and the situation for the interviewed persons during the interview

[95] (Mieg & Näf 2005) p.6 ff.
[96] (Aschemann-Pilshofer 2001) p.4 ff.

should be as comfortable as possible. A pleasant situation is for instance when the interviewer provides enough time for the interview[97].

2.5.5.3 Establishing the guideline for expert interviews

In this sub-chapter the interview guidelines are explained. Also for the expert interviews in Norway an accurate approach was mandatory in order to get real important information to improve the existing relevant processes at the tunnel site Solbakk. Therefore the finished guidelines and the evaluation respectively the results of the process improvements can be found in the practical part of the thesis.

2.5.5.3.1 Formation of the guideline

A guideline for interviews is a rough structured scheme for the orientation of the interviewer. Not every detail must be included but a rough structure should be visible. With the guideline it is ensured that no important questions will be missed. Key questions can be marked if they need to be urgent answered. The expert interview guideline consists of three parts: introduction, main part and conclusion. In the introduction there are some opening questions, in the main part there are some question blocks regarding to topics and sub-topics and in the conclusion is a thanks to the expert and a review or forecast. In the following the introduction and the main part are explained[98].

Introduction of the interview guideline:

An appropriate introduction for the interview is recommendable. This introduction should contain at least the following points[99]:

- An explanation of the purpose and the goal of the interview.
- A short introduction of the interviewer and his institution.
- Confirmation of absolute anonymity of the interview.
- An appeal to honest answers. There is no right or wrong answer.
- The expression that every answered question is important for improvements.
- Thanks to the expert for taking his time for the interview.

Main part of the interview guideline:

In the main part appropriate questions and hypotheses concerning to the specific topic must be formulated. The most important topic block or questions should come at the beginning of the guideline. A reason therefore is that it could be that the expert interview will be disturbed or finished unexpected. The interviewer must consider possible answers of the interviewees. If the answer is totally clear it is no benefit of information for the interviewer. These kinds of questions must be new formulated and reconsidered. Repetitive or unclear defined questions

[97] (Aschemann-Pilshofer 2001) p.9
[98] (Mieg & Näf 2005) p.14 f.
[99] (Aschemann-Pilshofer 2001) p.12

must be avoided because they will interrupt the flow of the expert interview. The most relevant and common types of questions are[100]:

- **Direct questions** to a central topic.
- To concretize general statements the following **specific questions** are useful: Who…, what…, when…, how…, what for…, with what…, why…?
- **Questions for confirmation** like for instance: "Is it really that …?"
- **Questions for examples** like: "Could you give me please an example?"

2.5.5.3.2 Format of the questions

It will be distinguished between open and closed questions. Open questions have the advantage that the expert isn't restricted to the given answer categories of the interviewer. The interviewee can say his real opinion. But this could be also a disadvantage if the expert cannot express himself in an adequate way. Closed questions will be answered without own words of the expert. In general these questions will be marked with crosses on a sheet. Also hybrid forms between open and closed questions are possible. The form of the address must be the same during the interview. The questions have to be simple and clear for open and closed questions. Complicated questions must be avoided[101].

2.5.5.3.3 Layout of the expert interview guideline

For this thesis the most essential requirements to an interview guideline are[102]:

- The guideline shouldn't contain too much questions. This would mean less time for open questions.
- Openness for the answers of the interviewee must be given.
- The guideline must be formal well-arranged and shouldn't confuse the experts.
- Questions with longer answers should come at the beginning of the interview. Open questions with short expected answers can be at the end of the expert interview.
- Top priority has the spontaneous produced story of the interviewee. That's why a good interview guideline for expert interviews doesn't contain too much questions.

2.5.5.3.4 Pretest of the interview guideline

A pretest of the established guideline is urgent necessary. This can be done with well-known persons out of the circle of friends. These persons must know that this is a pretest in order to avoid misunderstandings. From the problems which have been occurred at the pretest can be learned a lot, for instance some very important points are[103]:

[100] (Mieg & Näf 2005) p.14 ff.
[101] (Aschemann-Pilshofer 2001) p.14 ff.
[102] (Helfferich 2011) p.180
[103] (Mieg & Näf 2005) p.16 f.

- Avoid or correct technical problems before the real interviews start.
- Leave out unnecessary questions.
- Estimate the approximate length of the expert interview.
- Clarify misunderstandings.
- Bring the questions in an associated logical structure.

2.5.5.4 Instruction manual for expert interviews

The whole expert interview should be made well-structured and in a scientific way. Therefore it is necessary to have an appropriate instruction manual. In the following an introduction of six methodical steps for the development of expert interviews is given and explained according to Mieg and Näf[104]:

2.5.5.4.1 From the leading research question to the hypotheses

At the beginning the interviewer has to ensure that he has enough knowledge about the specific topic in order to ask essential questions and to obtain useful information of the expert. Also literature research to relevant topics can be useful. Relevant steps are:

- First the interviewer hast to pre-structure the topic.
- The leading research question must be established.
- Hypotheses should be formulated.

If the leading research question is established the hypotheses can be derived. Hypotheses are unscreened theoretical assumptions according to a certain circumstance. The form “If…”, “then…” is widely used for hypotheses.

2.5.5.4.2 Selection of the experts

The question is which persons have the required knowledge about a specific topic. These persons should be able to answer the hypotheses of the interviewer. If the expert doesn’t accept his role as expert or the expert hasn’t the appropriate expertise it isn’t an expert interview. Also the function or the position of the expert in the analyzed company must be considered by the interviewer. If the interviewer cannot find an expert for the overall question he has to split the question into sub-questions. Afterwards he needs for every sub-question an own expert for the interview. Expert interviews have to be executed always with just one expert.

2.5.5.4.3 Generate a guideline

In the third step the expert interview guideline will be established. Some important points are the following:

- At the beginning should be some opening questions. In the main part must be the question blocks divided by topic and sub-topics. Finally at the end comes an acknowledgement to the expert.

[104] (Mieg & Näf 2005) p.10 ff.

- The question blocks must be asked in a logical sequence.
- Some interesting questions: How is the reaction of the expert regarding the interview or to the interviewer? What are the expectations of the expert?
- Use direct and clear questions. If questions are clear, out of the pretest, the interviewer has to find new one.
- Between the questions on the questionnaire should be some space for the answers.

2.5.5.4.4 Planning of the expert interview

The agreement of the expert is needed before the interview can start. Following points should be followed:

- It can be an advantage if the expert gets some pre-information or questions before the real interview starts because he can make some thoughts about the topic.
- The needed duration of call and the date must be fixed. Duration of call is in general one hour. If time pressure is available the date should be better shifted to another day.

2.5.5.4.5 Execution of the expert interview

Most relevant and essential points are:

- Record the whole interview. A voice recorder should be used in combination with a handwritten protocol. Before the voice recording starts absolute anonymity and the sense of the recorder must be explained to the expert. Start of the voice recorder should be after the introduction of the own person, the approximately time duration and so on. Time and location of the expert interview must be also written down.
- Important notices like new questions or disturbances should be written down.
- At the end the expert should have the possibility to ask also some questions to the interviewer.
- All sheets of paper must be stitched together in order to keep the arrangement.
- The sequence of the questions can be changed if necessary.
- If the expert disturbs or dominates the interview the interviewer must ask him to stay businesslike. The interviewer must hold on his guideline.

2.5.5.4.6 Evaluation of the interview

Some questions regarding to the finished interviews could be:

- Are the hypotheses answered?
- Is the leading research question answered?
- Are there useless answers of the expert?
- Have some new scientific questions occurred during the interview?
- In every expert interview genial citations can appear.

These interviews are supported by hypotheses. The best hypothesis would be one which could be answered with “Yes” or “No”. But this is nearly impossible in the practical experience. If the preparation of the interview is clear than the effort of evaluation will be smaller. All steps of the evaluation are explained more in detail in the next sub-chapter.

2.5.6 Evaluation of expert interviews

After all expert interviews at the tunnel site Solbakk were done the evaluation of them could be started. Therefore a systematical approach is necessary. In the following the appropriate method paraphrasing will be explained. With this method it was possible to evaluate the interviews in Norway and to achieve process improvements in Solbakk. All process improvements and results can be seen in the practical part.

2.5.6.1 Goal of the evaluation

If some or all interviews are finished it is necessary to clarify the relationships between these interviews. The subjective theory of the interview partners delivers information about trends, results and conditions of processes[105].

The evaluation of the obtained qualitative data results from an interpretative strategy for evaluation of expert interviews. Goal is to detect similarities or patterns of interpretations out of the different expert interviews. The evaluation of the expert interviews is restricted to the expert knowledge. It is a kind of analysis and comparison of the received expert knowledge. The orientation of the evaluation is according to the associated but scattered text passages through all finished interviews. In general the interest of the evaluation is directed to the obtained information or themes but not on the person of the expert itself. A further advantage of the expert interview guideline is that the whole interview can be focused on the interesting topics and a thematic comparability of the different expert statements is possible. To enable the evaluation of the different expert interviews it is necessary to transliterate every recorded interview close and complete[106].

Through thematically comparisons it should be possible to show similarities and differences of various experts. Main focus is given to the associated content of widespread text passages. Breaking the logic structure of texts within passages is allowed. It can be also necessary because not the intrinsic logic of a single case is the item of the evaluation but the collective divided context of all experts. Comparability is ensured. Depending on the research interest the scientist can choose the experts for the interviews. In summary it can be said the goal of the evaluation of these interviews is that relationships of minds will be linked to theories[107].

All transliterated expert interviews from the tunnel site in Norway are at hand of at the author.

[105] (Gläser & Laudel 2009) p.248
[106] (Tonhäuser 2010) p.116
[107] (Funken 2004) p.129

2.5.6.2 Paraphrasing of expert interviews

For the evaluation of the expert interviews a paraphrasing can be done. The paraphrasing consists of five steps. These steps will be explained in the following:

2.5.6.2.1 Step 1 – Paraphrasing

The received data or material will be concentrated in the first step. Contents of statements related to a specific topic must be highlighted by the interviewer and the whole content of the conversation will be described in own words. Attention must be paid that also some new aspects or topics can occur which weren't considered before. It isn't allowed to add or deform the information. Overhasty classification can lead to the reduction of complexity. The transliterated text must be read again and the most important text paragraphs of interest will be excerpted. Afterwards there are some sentences with the most relevant content standing on the paper[108].

2.5.6.2.2 Step 2 – Thematic sequencing

Compaction of the text material is the next step which has to be done. The paraphrased text passages must be dedicated to themes in the form of headings. Normally the text passages will be concentrated to a topic because the interview guideline is used. But it can also happen that the interviewee comes back to a discussed topic or he could foreclose a topic. Paragraphed passages must be dedicated to headlines respectively to themes. Similar text passages of the interview will be combined and dedicated to the relevant topic. It is important that in this step all information and themes are out of one single interview[108].

2.5.6.2.3 Step 3 – Thematic comparison

In the third step all similar text passages of all interviews are compiled and the headlines will be standardized. The headlines out of different expert interviews will be summarized. At the compression of data some essential information can get lost if wrong interpretations were made or an overhasty summary was created. A continuous inspection of the classification must be done. Therefore it is useful to list the related passages[108].

2.5.6.2.4 Step 4 – Conceptualization

Differences and similarities will be formulated in a scientific language. Generalizations must be made but restricted to the expert interviews. Terms and definitions out of everyday speech must be replaced with accurate technical terms[109].

2.5.6.2.5 Step 5 – Theoretical generalization

Just in the last step some theories will be included. The single translated themes will be also classified theoretically in their internal relation. It is important that no step out of these five steps will be leaved out because they build up on each other. Occasionally it can be necessary to go back to a previous step in order to control if the generalization is suitable[109].

[108] (Mayer 2006) p.49 ff.
[109] (Mayer 2013) p.54f.

3 Practical approach

With the knowledge about the most relevant fundamentals of processes and their graphical visualization as well as the basics of the internal company analysis out of the theoretical part it is possible to transfer and implement the theory into the practical part.

First the individual sub-goals of the different processes are solved with the appropriate measures. Explorative interviews, monitoring and co-operation at the site in Norway were essential in order to solve the given sub-problems of these three different processes. Afterwards the current situations of each process are illustrated with a process map of the tunnel site Solbakk in combination with value chain diagrams and further BPMN models. After this procedure a SWOT analysis was done in order to improve the existing processes with the chosen method expert interviews. With the obtained expert knowledge the target states of each process are illustrated and resulting cost savings are shown at the end of this chapter.

3.1 Solution of the individual sub-goals

In this sub-chapter the individual sub-goals of each single process are explained and solved with the appropriate measurements. In this phase of the thesis the needed information or data was received through explorative interviews as well as through active participation directly at the tunnel site in Norway in order to get the necessary information about the specific problems of the different processes in Solbakk.

3.1.1 Process 1 - Workshop administration process

All problems, sub-problems, goals, sub-goals and measurements for process 1 which is located in the workshop of the tunnel site can be seen in chapter 1. In this sub-chapter the individual sub-goals of each single process could be achieved through explorative interviews with workers and experts directly on the tunnel construction site in Norway. Also co-operating within these processes especially in the workshop area and in the tunnel was essential to get the specific knowledge and overview about the different problems of each process. The visualization of process 1 as well as the visualization of every process Marti IAV executes at this construction site can be seen later in the practical part of this thesis.

3.1.1.1 Sub-goal 1

Process 1 has the sub-problem that the mechanics and blacksmiths in the workshop are unsatisfied and complaining about high searching times for tools and spare parts. It isn't known how much time the workers spend on searching for different tools and spare parts. Figure 29 shows the current conditions in the workshop. Tools are lying on the floor and a lot of different stuff is put on movable tool boxes. Tool kits or even remote controllers are deposited on the ground of the workshop hall. The awareness for clean or appropriate working conditions in a tunnel workshop leaves a lot to be desired here.

Figure 29: Disorder in the workshop hall in Norway

Due to the fact that the average hours of the searching procedure aren't known it was essential to identify the average searching hours of all workers in the workshop. Therefore some explorative interviews with all involved workers, some blacksmiths and some mechanics, were done in Norway in order to get the current amount of searching hours of every member of the workshop team. All interviews were performed absolute anonymous and every worker was willing to participate in the interview. In table 9 the average time of all workers as well as the sum of them all for searching tools and spare parts out of the interviews can be seen. All interviews were done in May 2014 on the site Solbakk.

Date	Name	Min / day	Min / 6 days	Min / month
12.05.2014	Worker 1	**120**	720	2880
13.05.2014	Worker 2	**90**	540	2160
13.05.2014	Worker 3	**180**	1080	4320
14.05.2014	Worker 4	**120**	720	2880
15.05.2014	Worker 5	**60**	360	1440
16.05.2014	Worker 6	**120**	720	2880
17.05.2014	Worker 7	**150**	900	3600
17.05.2014	Worker 8	**120**	720	2880
19.05.2014	Worker 9	**150**	900	3600
	Average time [min]	**123**	**SUM / Month [min]**	**26640**
	Average time [h]	**2,1**	**SUM / Month [h]**	**444**

Table 9: Searching times for tools and spare parts in the workshop

The average searching time for tools and spare parts on the tunnel construction site Solbakk per worker is about 2,1 hours per day (123min). Also some negative emotions of the workers about the bad situation were recognizable. An improved situation would be desirable for the most of the workers and a few of them said they would have to improvise a lot during execution of their tasks. The workshop has three shifts: one day shift, one night shift and one shift is always at home. Every shift consists of three workers. That means that there are always six workers in the workshop area per day. Table 10 shows the searching times for tools and spare parts per month for these six persons which are available every day from Monday to Saturday.

Time / day [h]	Time / week [h]	Time / month [h]
12,3	74	296

Table 10: Searching times for tools and spare parts per two shifts per month

Time values out of the explorative interviews are rounded. The time per day is calculated by multiplying the average time out of nine workers multiplied with six persons because every day from Monday to Saturday there are six workers on this construction site. The sum of the searching time for tools and spare parts of six workers in the workshop Solbakk is **about 300 hours** calculated with the average searching time per person. This incredible amount of wasted hours must be urgent reduced due to this thesis. Also the unexplainable loss of tools must be visible through the internal analysis of the company and in combination with the visualization of all processes. Therefore it is necessary to visualize the whole processes of Marti IAV on this site in Norway in order to find the basic weak points within each single process. The visualization of the processes will come a little bit later in the practical part.

Because the overview about the storage containers in the workshop is bad, some labels were introduced and fixed in the workshop hall. With the new labels it is also for new mechanics or blacksmiths clear where the different tool or spare part containers are located. Figure 30 shows the top view of the workshop hall in Norway with the new labeling. A bigger illustration can be found in appendix 14.

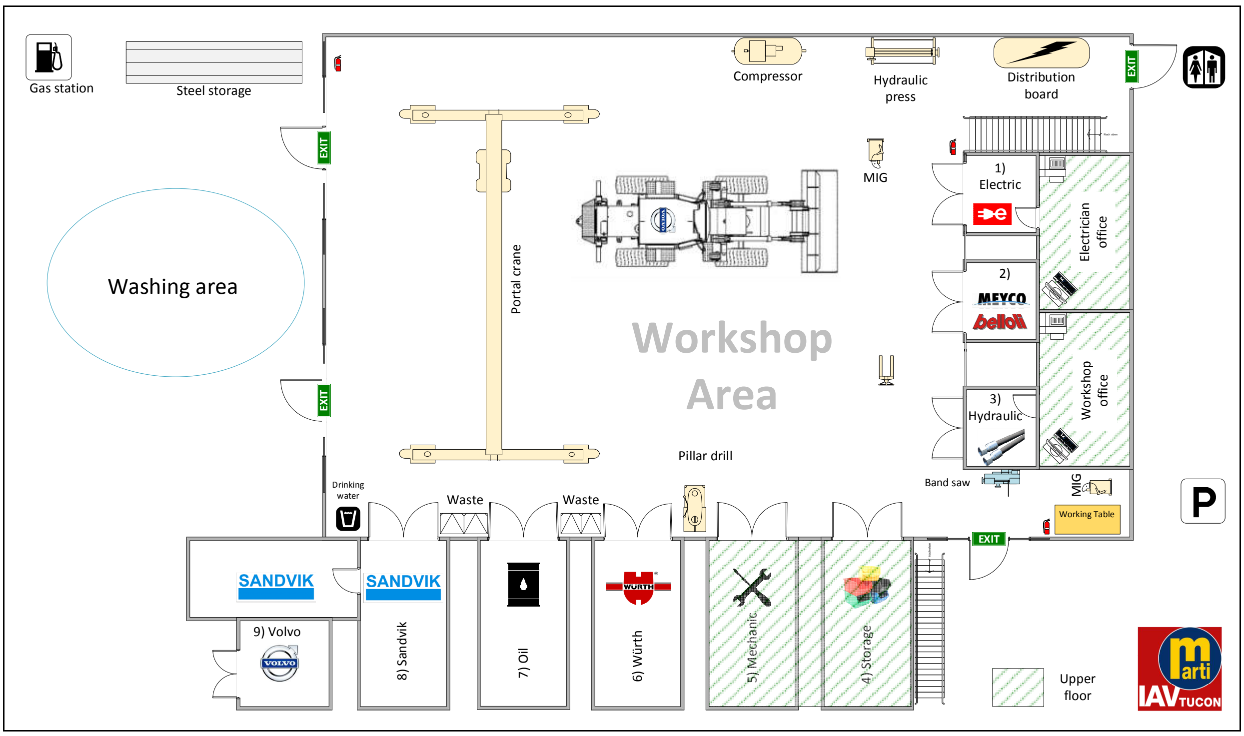


Figure 30: Plan view of the workshop hall with labels (Own illustration)

3.1.1.2 Sub-goal 2

Due to co-operation and observation on this tunnel construction site in the workshop it was possible to analyze the long ways of the steel material flow of the blacksmiths. There are long distances between the only working table and the steel storage outside of the workshop hall or the pillar drill. With the existing arrangement of the machines the times for the transportation of steel profiles and materials were taken. These times of the three main ways of a blacksmith in Solbakk can be seen in figure 31. The red arrows show the needed distance and the time for carrying heavy steel profiles from the steel storage into the workshop hall to the band saw or to the pillar drill.

It isn't clear if a new arrangement of the existing machines is possible or even more efficient. The long ways of the material flow mean loss of time and money. To ensure a good output and smooth working conditions in the workshop it is necessary to have a short flow of material. Through expert interviews the cost saving potential and the possibility for a new arrangement of the existing machines should be analyzed and if possible implemented. This will be shown later in the practical part of the thesis.

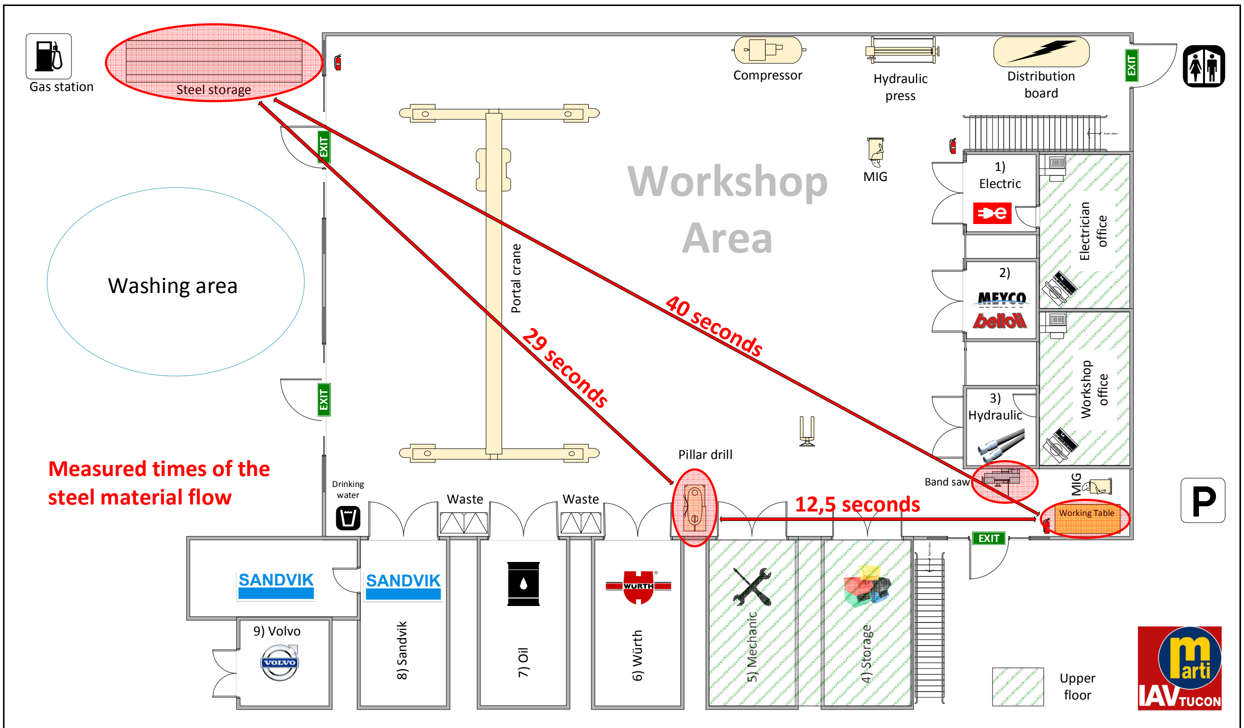


Figure 31: Needed time for transportation of steel profiles or materials in the workshop

3.1.1.3 Sub-goal 3

Last sub-problem of process 1 is that it isn't clear if the workers are disturbed through the incoming goods in the workshop hall. Also the time for removing palettes and boxes or spare parts isn't known. When suppliers are blocking the main entrance of the workshop hall the additional time must be added to the time for cleaning and removing if it is severe. Figure 32 shows some boxes and unremoved palettes in the workshop of Solbakk. In May 2014 there was no real responsible storekeeper for removing these incoming goods. The results were missing spare parts or increased ordering of identical material due to the missing overview about these materials.

Figure 32: Unremoved boxes and palettes in the workshop of Solbakk

Due to the fact that the average hours of removing these incoming goods in combination with the waiting times during the time when suppliers block the main entrance of the workshop hall with their trucks aren't known. So it was important to identify the average times of all workers in the workshop for removing and waiting because of the goods income in the workshop hall. Therefore some explorative interviews were done in Norway. All interviews were performed absolute anonymous and every worker agreed to the interview. In table 11 the needed average time of nine workers in the workshop as well as the sum of them for removing incoming goods in is shown.

Date	Name	Min / day	Min / 5 days	Min / month
17.05.2014	Worker 1	15	75	300
19.05.2014	Worker 2	10	50	200
19.05.2014	Worker 3	25	125	500
20.05.2014	Worker 4	15	75	300
20.05.2014	Worker 5	10	50	200
20.05.2014	Worker 6	15	75	300
21.05.2014	Worker 7	20	100	400
21.05.2014	Worker 8	10	50	200
21.05.2014	Worker 9	15	75	300
	Average time [min]	**15**	**SUM / month [min]**	**2700**
	Average time [h]	**0,3**	**SUM / month [h]**	**45**

Table 11: Time for removing incoming goods in the workshop

The average time through the disturbance per day is about 15 minutes per person. It was recognizable that fewer workers complained about the incoming goods in the workshop. There are always just two shifts with three workers each shift on the construction site in

Norway. The needed time of six persons for removing incoming material can be seen in table 12. These time values are also rounded and received through explorative interviews. The time per day is calculated with the average time of nine persons multiplied with six workers. This value multiplied with five working days results as time per week and so on. Attention must be paid to the delivery days in Norway. The main deliveries are coming very frequently from Monday to Friday with trucks on the construction site.

Time / day [h]	Time / week [h]	Time / month [h]
1,5	7,5	30,0

Table 12: Time for removing incoming goods per two shifts per month

The sum of the required time through the entire disturbance takes **30 hours** for six persons per month. Compared to the needed hours for searching material this average value for removing is rather small. Also the workers weren't emotional troubled like with the situation of the searching times. With explorative interviews it is possible to get a feeling about the attitude or the opinion or even the emotions of each single worker. Sometimes it can happen that some great and unexpected ideas for improvement will be mentioned by a worker. It must be found out if another opportunity for storage of material or goods income is available or even urgent needed.

3.1.2 Process 2 - Operating instruction process

A lot of mistakes and scrap occurs on the tunnel construction site Solbakk in Norway because of verbal instruction- and communication errors. Before the author came to this tunnel site the main instruction method for producing steel assemblies was the verbal instruction to the blacksmiths at the tunnel area and in the workshop. Also for frequently used steel assemblies there were no appropriate drawings with the bill of material (BOM) available on this site. Inaccurate hand sketches of foremen are also not state of the art nowadays.

3.1.2.1 Construction of frequently used steel assemblies with BOM

Marti IAV has a lot of different steel assemblies which are used frequently on every construction site and will be even used for future projects. Occasionally appropriate CAD drawings are totally missing at the workshop level. During this thesis the author drew some very important steel constructions with 3D-CAD. In the following sub-chapters some of them are explained shortly.

3.1.2.1.1 Construction of 3D-CAD stone crusher wear plates

The company uses a mobile stone crusher in the tunnel for crushing the big stones into small stones. After the massive explosion due to the drill and blast excavation method the miners muck the stones with a wheel loader into the stone crusher. The stone crusher crushes the stones and then they are transported with a conveyor belt out of the tunnel and are mucked into the sea. Figure 33 shows a wheel loader filling big stones into the mobile stone crusher. During co-operation in the tunnel and some explorative interviews the importance of new wear plates for stone crusher was recognized because a better material for the wear plates was urgent needed due to heavy wear of the old wear plates. Also the gaps between the old crusher wear plates weren’t suitable for this kind of hard rock. New constructed crusher wear plates with improved gaps and geometry were needed. A better material had to be chosen. All these considerations aren’t relevant for this thesis.

Figure 33: Wheel loader filling the mobile stone crusher

Measurements inside the mobile stone crusher had to be done. First all jammed stones had to be removed. After taken all required measurements the new crusher wear plates were drawn. Attention was given to the new gaps between the plates in order to avoid jamming of the stones between the plates. Figure 34 shows some jammed stones inside of the stone crusher because of inappropriate gaps between the wear plates.

Figure 34: Jammed stones inside the mobile stone crusher

A construction drawing of one single wear plate was made and can be found also in appendix 15. Also an assembly drawing of all wear plates was constructed directly on-site. All detailed construction and assembly drawings with the suitable bill of material were given to the workshop manager in Norway. Step-Files were generated in order to give these files to another company for laser cutting. Blacksmiths can weld the new plates on the existing acceptance. Without the usage of CAD it would be impossible to make fast changes on the existing 3D-CAD wear plates. Now some new plates can be ordered easily by the workshop manager. Figure 35 shows an assembly drawing of the crusher wear plates with blinded out under construction. The colored steel plates are for a better overview about the four different types of plates. Wear resistance of the new plates is about one to one and a half month. A successful standardization of the different stone crusher wear plates was done.

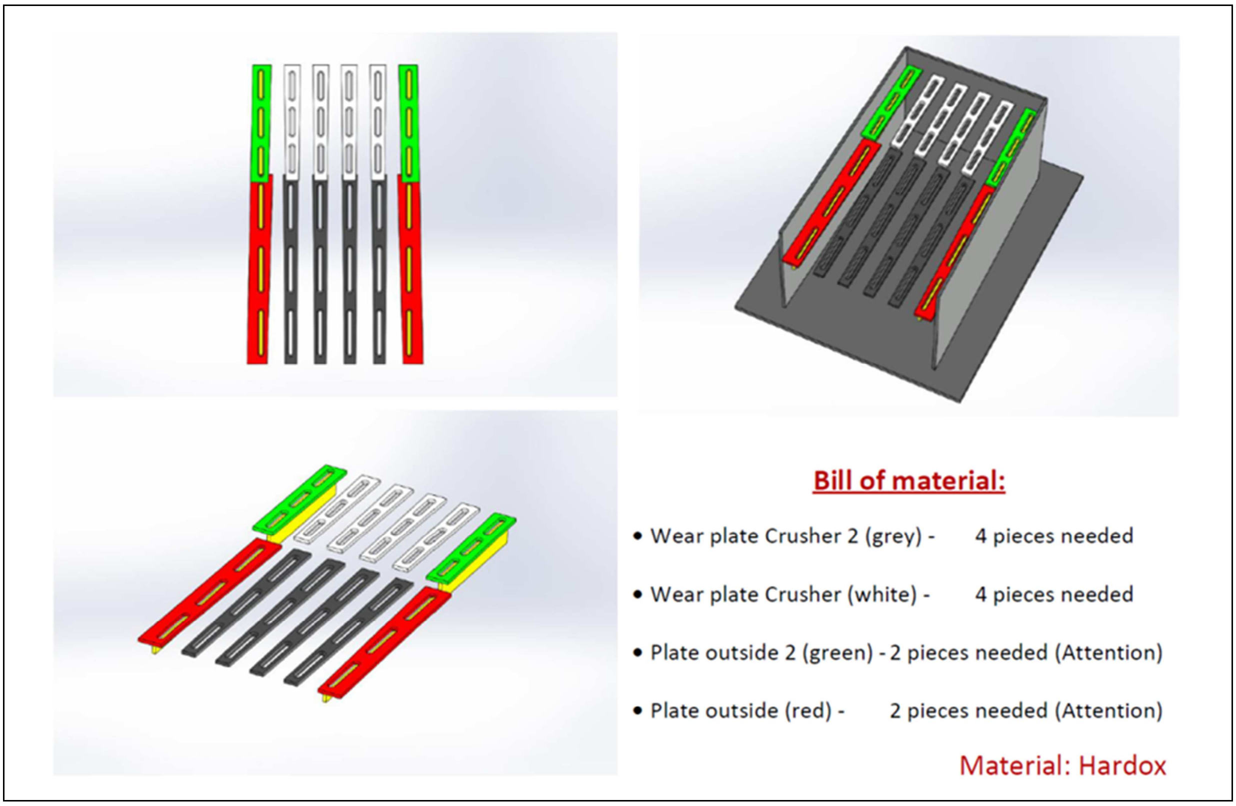


Figure 35: 3D-CAD drawing of the stone crusher wears plates

3.1.2.1.2 Movable working table

In this sub-chapter it was necessary to find out if the blacksmiths at the construction site in Norway would be able to work with given CAD construction drawings. Therefore an urgent needed steel assembly was created with CAD on the computer. Because there is just one single working table in the workshop it is always a mess on this table. Workers have to wait until a coworker has finished his task on the table. Occasionally the blacksmiths or mechanics work without this single table. They put their stuff on a palette or somewhere else. Figure 36 shows a mechanic in the workshop of Solbakk working on the floor. He put the steel plate of a wheel loader on a pallet on the floor and drills some holes in it with a bad bend over position. A black stripe in the face ensures anonymity of the worker. The reason that there is just one single working table forces the workers occasionally to work in such unhealthy working positions. Such circumstances must be avoided by the responsible management.

Figure 36: Bad working position of a blacksmith in the workshop

Therefore the construction of a new movable welding table was necessary in order to raise the flexibility of all workers in the workshop and to avoid such horrible working positions. The main measurements of the existing table were taken and the table was constructed with CAD. Figure 37 shows the assembly drawing of the movable working table. The movable rolls had to be ordered.

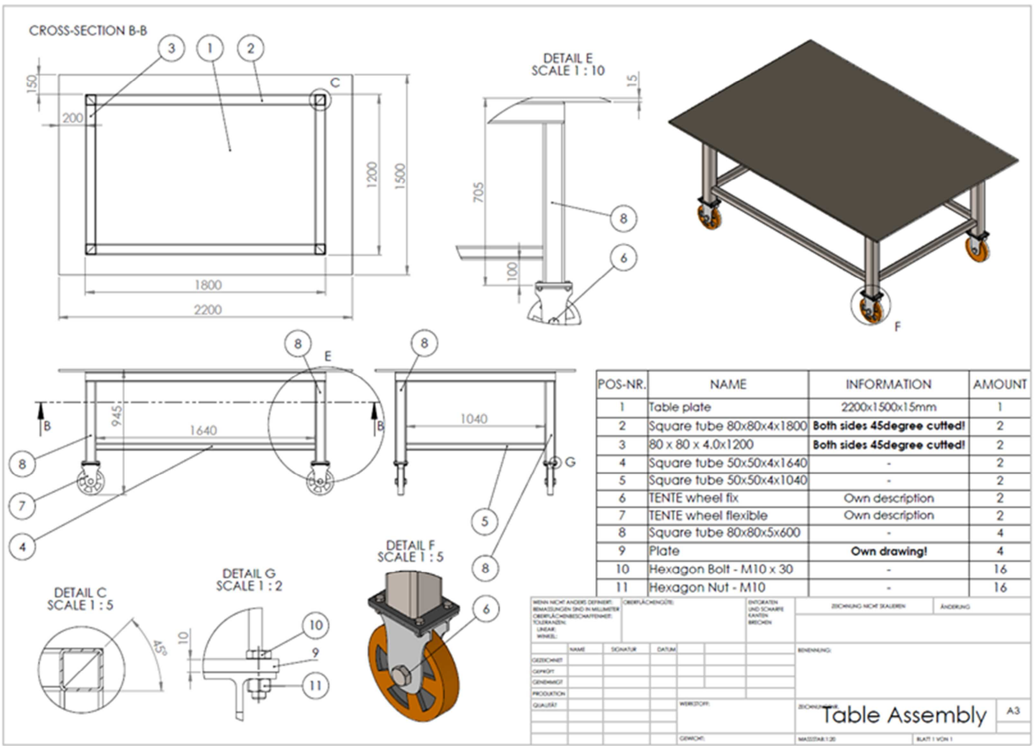


Figure 37: Movable working table for the workshop

In the bill of material also some comments about how to cut the steel profiles as well as the suitable single part drawings are given. The assembly drawing with the bill of material is attached in appendix 16. All necessary single part drawings are given to the workshop manager in Solbakk. With this drawing set it was important to find out if the blacksmiths in Norway can work autonomous.

Therefore the full drawing set was given to the blacksmiths at the tunnel site Solbakk in Norway. With explorative interviews they were asked to assume their needed time for the production of this steel table. Compared was the assumption to produce the steel table with the fix drawing set and on the other side to get just the verbal instruction or even a fast hand sketch like it was done before. Table 13 shows the result of these interviews. This picture is also attached in the appendix. For this process the additional costs for the program and the constructing engineer had not to be considered. It was important to see if the efficiency of the blacksmiths in the workshop can be raised through the introduction of CAD drawings.

Production:	Worker 1		Worker 2		Worker 3		Worker 4		Worker 5	
	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.
Needed time - minutes for:										
Measurements total	10	30	20	45	35	110	30	80	25	90
Cutting steel profiles	60	60	70	90	60	90	55	65	70	80
Cutting table plate	60	60	45	50	35	50	65	70	55	60
Drilling plates (4#)	30	30	25	25	55	90	45	65	50	55
Time for welding	120	120	95	95	110	150	130	140	110	110
Time for screwing / ass.	15	15	35	35	25	25	20	20	30	30
Time for thinking	75	120	15	55	30	120	45	80	40	65
Prepare material	30	60	30	45	40	90	20	70	25	80
Prepare tools / equipment	30	30	20	25	35	35	30	30	25	25
SUM [min]	**430**	**525**	**355**	**465**	**425**	**760**	**440**	**620**	430	595
TIME SAVING / Worker [h]	**1,6**		**1,8**		**5,6**		**3**		**2,8**	
AVERAGE TIME SAVING [h]	**3,0**									
Worker in % faster with CAD drawing	525	100	465	100	760	100	620	100	595	100
	430	x	355	x	425	x	440	x	430	x
	x	81,9	x	76,3	x	55,9	x	71,0	x	72,3
Worker in % faster with CAD drawing	**18,1 % faster**		**23,7 % faster**		**44,1 % faster**		**29,0 % faster**		**27,7 % faster**	
Worker in % faster with CAD drawing	Average of 5					Abbreviations:		CAD	Computer Aided Design	
AVERAGE PERCENTAGE FASTER	**28,5 % faster**							BOM	Bill of Material	

Table 13: Comparison of CAD drawings (BOM) with common hand sketches in Solbakk

Five workers were asked in an interview to make assumptions about the needed time for preparing material and devices, some needed measurements and diverse production steps. Compared was the assumption to produce the table with the given drawing set with the appropriate bill of material and the assumption to get a verbal instruction or even a hand sketch in that way what they would have to expect. The average time saving for the production of one movable working table is about 3 hours rounded out of five persons. On average the workers are **nearly 30 percent faster** with the given instruction materials. *"Such instruction materials would be very desirable for us"*, said a Slovakian blacksmith according to the given drawing sets. In Appendix 17 another steel construction with the comparison between CAD and verbal instruction can be seen. In this example the blacksmiths are 40 percent faster according to their own assumptions.

The question if such CAD drawings could raise the efficiency in a tunnel workshop is now answered. For more complicated steel constructions the saved time and achieved efficiency would raise enormous. Also the positive feedback about such accurate computer drawings with the correct length ration and even a colored 3D-CAD model on the paper would be very helpful for the blacksmiths in the tunnel workshop of Solbakk. Figure 38 shows the produced working table in the workshop. This working table was produced absolute autonomous by a blacksmith. The table was produced without any questions of workers. Flexibility of the workers with the movable working table has increased. If a mechanic for instance wants to repair something besides a tunneling vehicle he can move the table in the best possible position. Bad working positions on the floor should be past. All given instruction materials were accepted and successfully executed by the workers in Norway.

Figure 38: Produced movable working table

3.1.3 Process 3 - Drill steel administration process

The third process is located between tunnel area and workshop area. Marti IAV had no experienced data about the grinding process of the three different types of drill bits. An appropriate grinding machine is available at this construction site in Norway. Through practical grinding of the used drill bits it was possible to get the necessary data and parameter about this grinding process.

Table 14 shows an abstract of the scientific grinding statistic. In appendix 18 the full table without headline, start time and end time is shown. It was essential that different people were grinding the bits to ensure a better arithmetical mean of the obtained results. The grinding process was performed from mid-March to the end of May 2014. Some outliers are noticeable in this table. Reason therefore is a higher wear of the single drill bit. It is important that this procedure was done over a certain period to achieve real values for this grinding process.

SANDVIK **Grinded drill bits** Add grinding job

Date	Name	Start	End	Used time	# drill bits 48mm	# drill bits 54mm	# drill bits 102mm	min / bit 48mm	min / bit 54mm	min / bit 102mm
14-Apr-14	Sandvik 1	13:00:00	14:10:00	1:10:00		13			0:05:23	
14-Apr-14	Sandvik 1	10:00:00	12:00:00	2:00:00	20			0:06:00		
12-Apr-14	Sandvik 2	16:00:00	17:05:00	1:05:00		10			0:06:30	
12-Apr-14	Sandvik 2	10:00:00	16:00:00	6:00:00	40			0:09:00		
10-Apr-14	Sandvik 2	17:00:00	19:00:00	2:00:00			4			0:30:00
8-Apr-14	Auernig Daniel	16:05:00	18:10:00	2:05:00	19			0:06:35		
8-Apr-14	Auernig Daniel	15:00:00	16:05:00	1:05:00		12			0:05:25	
8-Apr-14	Auernig Daniel	14:00:00	15:00:00	1:00:00			3			0:20:00
7-Apr-14	Sandvik 2	10:00:00	16:00:00	6:00:00	50			0:07:12		
3-Apr-14	Auernig Stefan	15:00:00	17:30:00	2:30:00	20			0:07:30		
2-Apr-14	Auernig Daniel	14:00:00	16:10:00	2:10:00	20			0:06:30		
2-Apr-14	Auernig Daniel	16:20:00	16:55:00	0:35:00			2			0:17:30
31-Mar-14	Sandvik 2	15:00:00	19:00:00	4:00:00	20			0:12:00		
29-Mar-14	Sandvik 2	14:00:00	17:00:00	3:00:00	10			0:18:00		
28-Mar-14	Auernig Daniel	17:15:00	18:05:00	0:50:00		10			0:05:00	
28-Mar-14	Auernig Daniel	15:30:00	17:15:00	1:45:00	15			0:07:00		
27-Mar-14	Sandvik 2	16:30:00	19:00:00	2:30:00	19			0:07:54		
26-Mar-14	Auernig Stefan	16:40:00	16:55:00	0:15:00			1			0:15:00
26-Mar-14	Auernig Stefan	16:15:00	16:35:00	0:20:00		4			0:05:00	
26-Mar-14	Auernig Stefan	15:00:00	16:12:00	1:12:00	10			0:07:12		
25-Mar-14	Auernig Stefan	14:30:00	15:15:00	0:45:00		8			0:05:37	
25-Mar-14	Auernig Stefan	13:00:00	14:25:00	1:25:00	11			0:07:44		
21-Mar-14	Auernig Daniel	17:05:00	17:28:00	0:23:00			1			0:23:00
21-Mar-14	Auernig Daniel	14:25:00	17:05:00	2:40:00	21			0:07:37		
20-Mar-14	Auernig Stefan	16:20:00	16:40:00	0:20:00			1			0:20:00
20-Mar-14	Auernig Stefan	14:00:00	16:15:00	2:15:00	18			0:07:30		
19-Mar-14	Auernig Daniel	17:20:00	18:00:00	0:40:00		8			0:05:00	
19-Mar-14	Auernig Daniel	10:00:00	12:20:00	2:20:00	20			0:07:00		
18-Mar-14	Auernig Daniel	15:00:00	16:20:00	1:20:00	13			0:06:09		
18-Mar-14	Auernig Daniel	14:15:00	14:40:00	0:25:00			2			0:12:30
18-Mar-14	Auernig Daniel	13:30:00	13:58:00	0:28:00		8			0:03:30	
18-Mar-14	Auernig Daniel	11:30:00	12:00:00	0:30:00		8			0:03:45	
18-Mar-14	Auernig Daniel	10:00:00	11:20:00	1:20:00	15			0:05:20		
14-Mar-14	Auernig Daniel	14:15:00	17:15:00	3:00:00	33			0:05:27		
13-Mar-14	Auernig Daniel	14:30:00	17:00:00	2:30:00	27			0:05:33		
				182:47:00	**1005**	**173**	**58**	**0:08:36**	**0:05:07**	**0:25:07**

Table 14: Abstract of the grinding statistics (Own illustration)

At the end of this recording it can be said that the needed time for grinding a 48mm drill bit takes 8min36s, for a 54mm drill bit 5min07s and for the large 102mm reaming bit it takes 25min7s on average. Total time of all grinders just for the grinding process of these bits without preparation of needed grinding cups or tools was nearly 183 hours. With this table it is possible to select the needed grinders or some specific days in order to conclude to the individual grinding performance of the grinder or to see in which period some values were significant different. By creation of a button on the top it is possible to sign in some new entries. After an introduction into this program all grinders were able to make own entries into this grinding table due to easy handling of this statistics.

In appendix 18 there is also a time target table attached. This time target shows how long a grinder would have to grind per day to achieve the maximum needed daily amount of used drill bits. Maximum refers to an ideal day of the miners in the tunnel. They would need 50 small bits, 8 middle-sized bits and 2 large reaming bits. With the average values out of table 14 a grinder would need maximum 9 hours per day at the moment in order to fulfill the maximum needed amount.

The grinding machine, new drill bits, used drill bits or re-grinded drill bits are located in the grinding or storage container on the tunnel site. Normally all foremen must write down if they take or bring some drill bits into the container or into the tunnel to the drilling jumbos. Therefore the company has prepared a sheet for writing down the flow of the bits in order to keep the overview about these bits. During grinding and through explorative interviews it was recognizable that the foremen who were coming into the grinding container weren't really sure what they should write. Some explorative interviews with the guys from Sandvik (Drill steel and drilling jumbo) were made. It was found out that the prepared sheets aren't clear to the foremen. Figure 39 shows an example of these sheets. In appendix 19 some examples of the sheets can be seen.

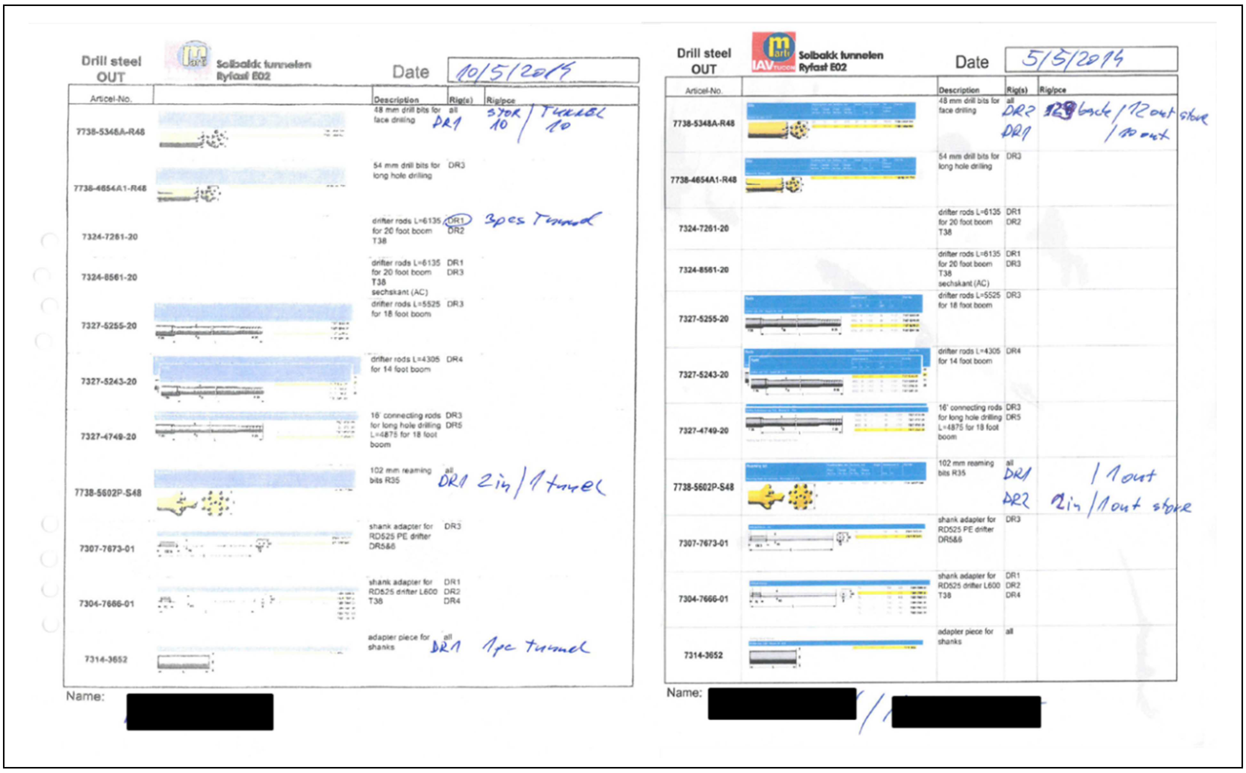
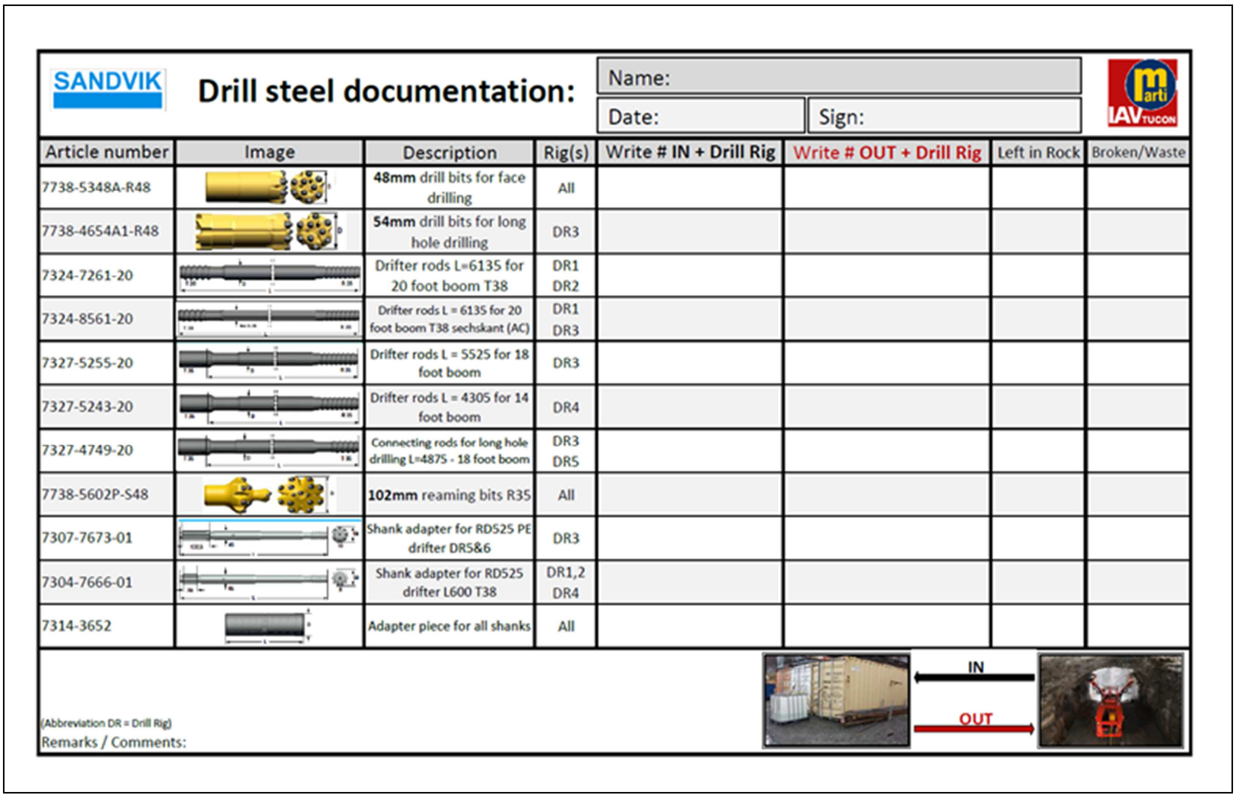


Figure 39: Sheets for writing down drill steel (IN / OUT)

In general foremen must write down the taken and brought drill steel or even drill bits. Also the drilling jumbo must be written into this sheet in order to know or to follow the needed drill steel per shift and drilling jumbo. There are four Sandvik drilling jumbos in usage at this tunnel construction site. The abbreviation is DR and this stands for drill rig or drilling jumbo. This thesis focuses especially on the flow of drill bits on the site in Norway. The problem is that the foremen have different opinions about IN and OUT. It isn't clear what is in and what is out. In figure 39 the foreman on the left sheet means that OUT is into the tunnel and the foremen on the right sheet mean that OUT is into the storage container. Here are total different views of IN and OUT. There will be no correct values of this drill steel flow with these sheets. Such sheets for documentation of the drill steel are very unsatisfactory due to wrong obtained data of the whole drill steel flow. It was essential to improve this situation immediately.

Therefore a new sheet was established in Norway. This sheet contains also some space for writing down the broken or damaged drill bits. Occasionally it can happen that some drill bits remain in the rock of the tunnel. With the new sheet this can be remarked too. To avoid mistakes due to different views of IN and OUT a small picture is on the right lower position of the sheet. Now it is obvious what should be in and out of the tunnel or the storage container. There is also some space for remarks or some important information. A picture of each drill bit or drill steel with the correct description ensures correct entries. Figure 40 shows this improved sheet. This sheet was established through explorative interviews with external experts at the construction site. During the interviews it was recognizable that these external experts have a huge knowledge about drill steel administration. In general these experts were very motivated and willing to give a lot of useful information to the author.



SANDVIK	Drill steel documentation:			Name:			
				Date:	Sign:		
Article number	Image	Description	Rig(s)	Write # IN + Drill Rig	Write # OUT + Drill Rig	Left in Rock	Broken/Waste
7738-5348A-R48		48mm drill bits for face drilling	All				
7738-4654A1-R48		54mm drill bits for long hole drilling	DR3				
7324-7261-20		Drifter rods L=6135 for 20 foot boom T38	DR1 DR2				
7324-8561-20		Drifter rods L = 6135 for 20 foot boom T38 sechskant (AC)	DR1 DR3				
7327-5255-20		Drifter rods L = 5525 for 18 foot boom	DR3				
7327-5243-20		Drifter rods L = 4305 for 14 foot boom	DR4				
7327-4749-20		Connecting rods for long hole drilling L=4875 - 18 foot boom	DR3 DR5				
7738-5602P-S48		102mm reaming bits R35	All				
7307-7673-01		Shank adapter for RD525 PE drifter DR5&6	DR3				
7304-7666-01		Shank adapter for RD525 drifter L600 T38	DR1,2 DR4				
7314-3652		Adapter piece for all shanks	All				

(Abbreviation DR = Drill Rig)
Remarks / Comments:

Figure 40: Improved sheets for writing down drill steel (IN / OUT)

In the column “Rig(s)” the appropriate drilling jumbo for each kind of drill steel is marked. For instance DR3 stands for the drill rig or drilling jumbo number 3. 54mm drill bits are just for the drill rig number 3. With this drilling jumbo the miners drill the armature boreholes for the rock consolidation. If “All” stands in this field it is possible to mount this type of drill steel in every drill rig. A bigger picture of this sheet can be found in appendix 20. An additional picture was fitted on the wall in the grinding container to ensure that everybody understands the directions of the drill steel flow. In figure 41 this documentation guideline can be seen.

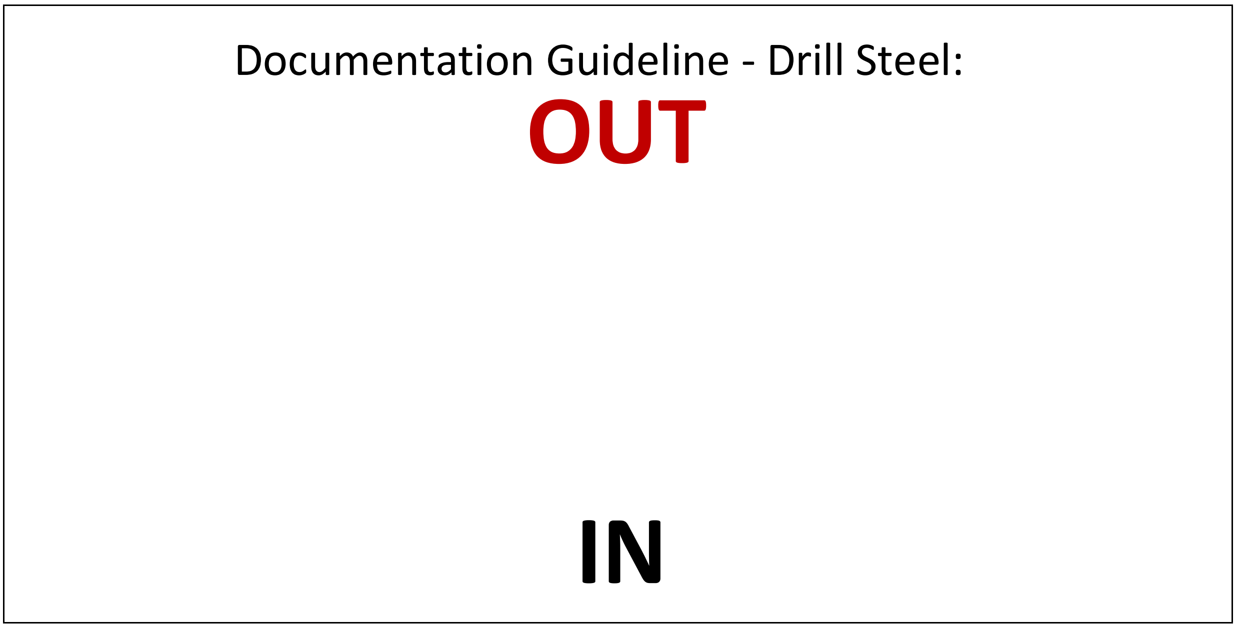


Figure 41: Documentation guideline for the flow of drill steel

In agreement with the workshop manager of Solbakk some spot tests in two-week intervals were made. In these two-week intervals 400 drill bits got lost. This means that **per month are 800 drill bits missing** according to the workshop manager in **October 2014**. This loss of drill bits will be uncovered later in the practical part. Therefore the visualization of this process must be made in order to detect the weak points in the drill bits flow. The process will be improved afterwards through the introduction of expert interviews.

3.2 Graphical visualization of the current states

After the sub-goals of each individual single process were finished it was essential to begin with the illustration of the current states of the processes in order to get an overview about the whole tunnel construction site in Norway. In this sub-chapter all illustrations of the current states are from May 2014.

3.2.1 Visualization of all processes as value chain diagrams (VCD)

The value chain of the company can be seen in the theoretical part of the thesis. This chain represents the primary and support activities of a corporation. This thesis is focusing on the processes which are located mainly in the fields of operations and inbound logistics and these activities are called primary activities. These activities are responsible for the value creation of a corporation. For analyzing the relevant processes in Norway it was important that the company Marti IAV was divided into different areas of processes like in a value chain. Now the focus is exactly on all processes of the company. Figure 42 shows the relevant detail of the value chain of Marti IAV. All three relevant processes are located in the dark blue fields.

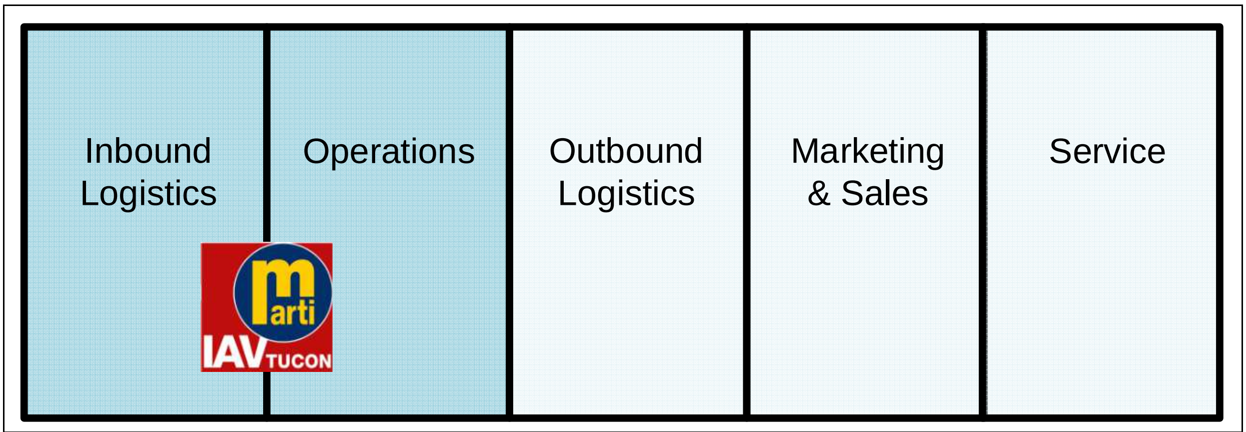


Figure 42: Detail from Marti IAV´s value chain

Through explorative interviews, monitoring and co-operation directly on the site it was possible to generate the different process types below inbound logistics and operations. It will be distinguished between three different types of processes. There are management, core and support processes. Figure 43 shows the sub-division of the inbound logistics and operations. This thesis will handle just the core processes and the support processes of Marti IAV because the management processes aren’t relevant for the tasks of this master thesis.

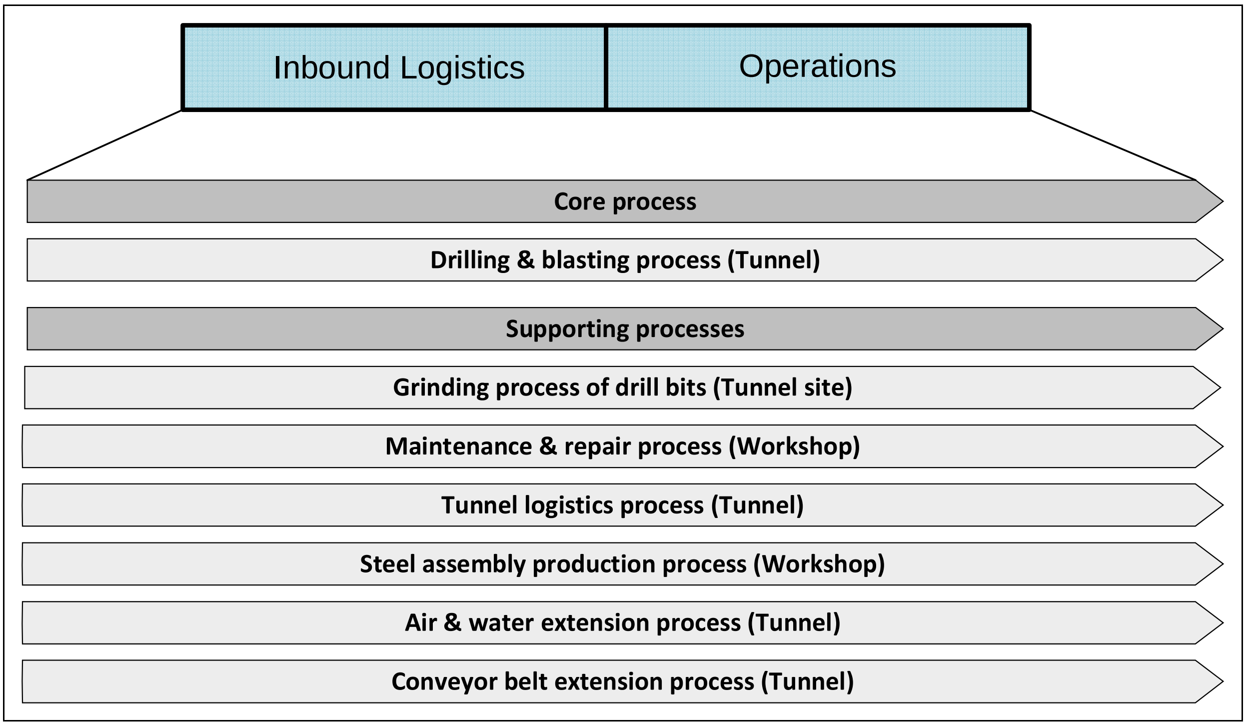


Figure 43: Detail from Marti IAV´s value chain at the tunnel site Solbakk

The core process of the company is the drill and blast process in the tunnel. This process creates the direct value for Marti IAV. Below there are the supporting processes. These supporting processes are supporting the core processes and they are indirect involved in the value creation of the company. All supporting processes are performed parallel to the core process. Also the location of the individual processes can be seen in this figure. Without these support processes it would be nearly impossible to make a drill and blast excavation on this tunnel construction site. In the following all single processes are complete visualized as value chain diagrams and explained. All processes are repeatable.

3.2.1.1 Core process – Drill and blast process

The core process of Marti IAV is the drill and blast process in the tunnel. Value is created through all of these activities performed by the miners in the tunnel. Figure 44 shows a picture of the whole drill and blast process as a value chain diagram.

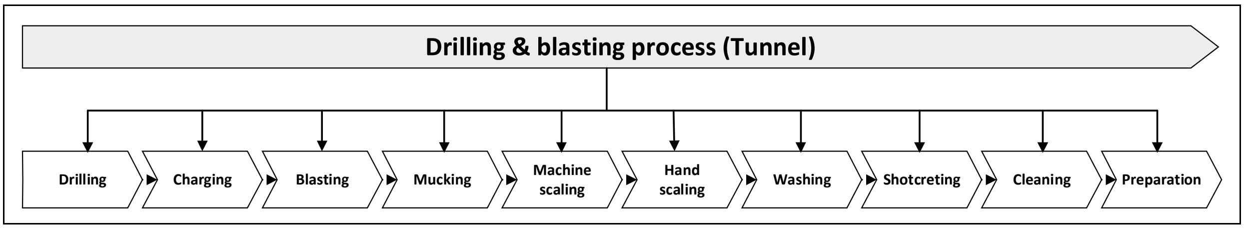


Figure 44: Sequence of the drill and blasting process

First the miners have to drill the boreholes with the drill steel and the drilling jumbos in the tunnel. Afterwards the explosive agent comes into the holes and will be blown up. The miners will transport the stones into the stone crusher with the wheel loaders and the material will be mucked into the sea. Loose material will be removed with excavators due to machine scaling. Hand scaling is done with forklifts and miners in a metal basket. The workers have iron rods and they remove the loose stones and material with their hands. Afterwards the surface will be washed and after this step the shotcrete for rock consolidation is sprayed on the tunnel walls and surfaces. Thereafter the miners clean again the tunnel face and prepare for the next step.

3.2.1.2 Support processes

Support processes are supporting the core processes and they are indirect involved in the value creation of the company Marti IAV. But without them it would be almost impossible to produce a tunnel. These processes are also illustrated as value chain diagrams.

3.2.1.2.1 Grinding process of drill bits

The grinding or storage container is located at the construction site but the flow of drill bits goes into the tunnel and back again into the storage container. All necessary process steps can be seen in figure 45.

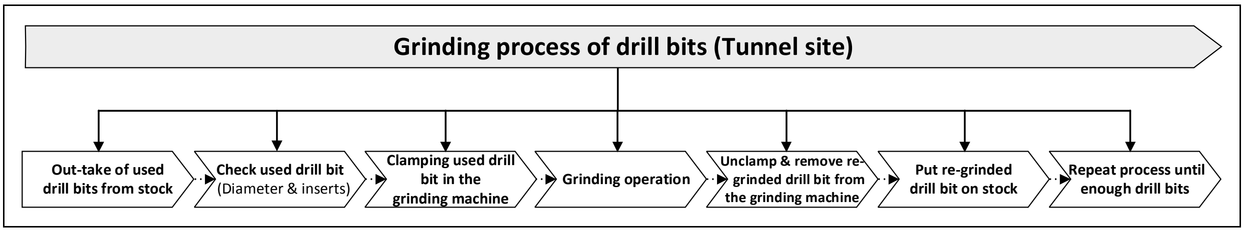


Figure 45: Sequence of the drill bits grinding process

A grinder takes the used drill bits out from the drill bits stock. Afterwards he has to check the drill bit according to damage of defect inserts. Also the minimum diameter must be checked. In the next step the used drill bit is fixed into the grinding machine. Grinding itself can be started. When the whole drill bit is re-grinded the grinder has to remove the drill bit out of the machine. The re-grinded drill bit will be put on stock. This process will be performed until enough drill bits for the drill and blast shifts are available.

3.2.1.2.2 Maintenance and repair process

This process is located in the workshop of the tunnel site. Mechanics are responsible for the repair and service tasks at the tunneling vehicles. Figure 46 shows the complete process.

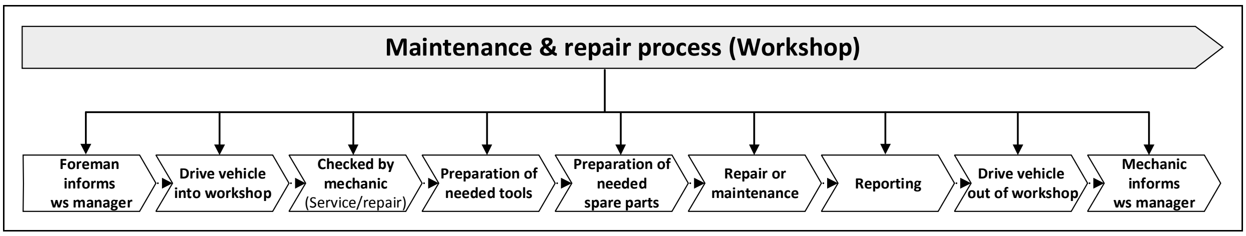


Figure 46: Sequence of the maintenance and repair process

First of all the workshop manager (ws manager) is informed by his foremen about the vehicles which are brought into the workshop. Normally miners drive the tunneling vehicles out of the tunnel into the workshop hall if it is possible. A mechanic checks the vehicle and decides to make a service or a repair task. Therefore he has to prepare the needed tools or spare parts in the following process steps. If everything is available the repair or maintenance task will be performed. Afterwards a report will be written by the mechanic. The tunneling vehicle can drive back into the tunnel if the vehicle is needed there or somewhere else at the site. In the last step the mechanic informs at least the workshop manager.

3.2.1.3 Tunnel logistics process

To ensure permanent material supply for the drill and blast excavation in the tunnel it is necessary that a responsible worker on the site brings them the needed materials. Figure 47 shows this process.

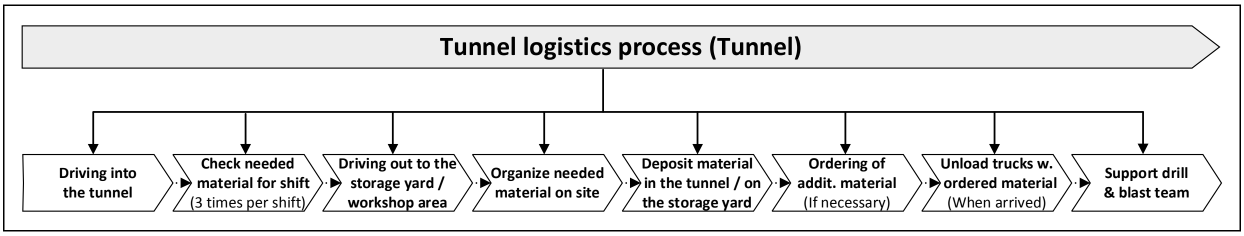


Figure 47: Sequence of the tunnel logistics process

Every day one workers is driving three times into the tunnel and checks the needed material for the miners. After these steps he drives out of the tunnel to the workshop area or storage yard and organizes the required materials. In the next step the worker brings the material into the tunnel when it is needed there. If necessary this person has to order additional material to avoid supply shortfall in the production of the tunnel. When trucks arrive at the site he has to unload them. Also supporting the drill and blast team in the tunnel is a task of this person if he has completed his logistics tasks.

3.2.1.4 Steel assembly production process

This process is located mainly in the workshop hall of Solbakk. The blacksmiths on the site are performing this process which can be seen in figure 48. In this figure all necessary steps of a blacksmith are shown.

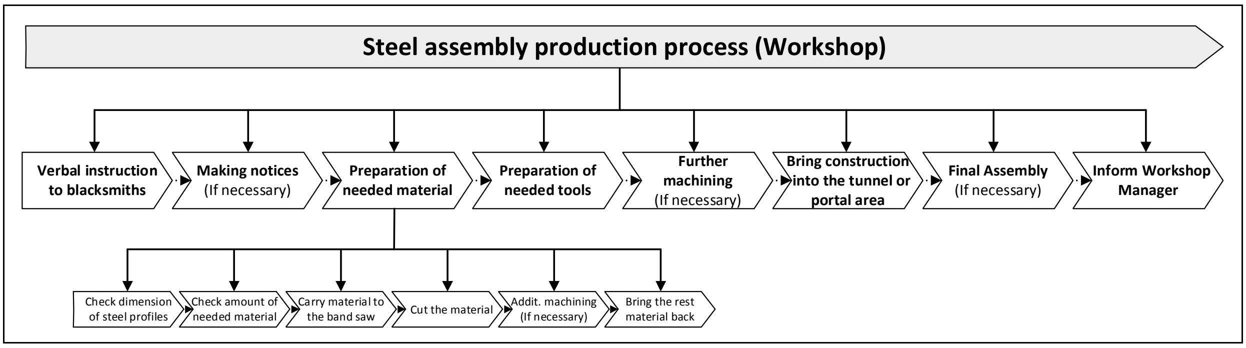


Figure 48: Sequence of the steel assembly production process

In general the foremen or the workshop manager gives verbal instructions to the blacksmiths. If necessary the blacksmiths or even the foremen or the workshop manager makes some hand notices. The next step of the blacksmith is to prepare the needed material and the tools for the task. Some machining tasks will follow if it is required. Sometimes the finished steel constructions are brought into the tunnel or even somewhere else at the site. If the steel construction isn't finished assembled the workers assemble it directly on the intended location. When this step is completed the workshop manager will be informed. The function preparation of needed material consists also of some single steps. First the blacksmith has to check the dimensions and the amount of the needed steel profiles at the steel storage. Afterwards he has to carry the material in the workshop hall to the band saw and cuts the material. If no additional machining is required the worker brings the material rest material back to the steel storage. These steel material ways are quite long and can be seen in the previous sub-chapter.

3.2.1.5 Air and water extension process

Every tunnel needs fresh air and a water supply. Therefore the following process is required. This process is performed in the tunnel of Solbakk. Figure 49 shows all important steps.

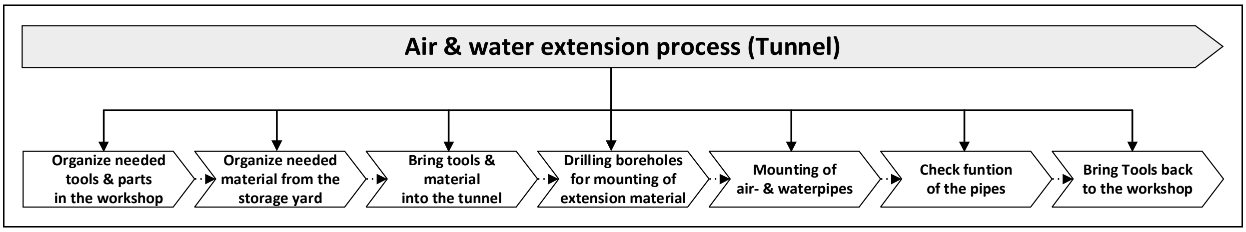


Figure 49: Sequence of the air and water extension process

At the beginning some miners organize needed tools and parts in the workshop. In the next step they search for additional materials on the storage yard. Afterwards they drive with all the materials into the tunnel. Boreholes will be drilled in the tunnel to mount the extension material for water and air. If all holes are finished the workers mount the water pipes and air pipes. Immediately afterwards the function will be checked. If it is alright the tools will brought back into the workshop hall.

3.2.1.6 Conveyor belt extension process

After blasting the miners put the huge stones with wheel loaders into the stone crusher. The crusher crushes the large stones into small stones and these small stones are transported outwards of the tunnel and will be thrown into the sea automatically with a conveyor belt. Figure 50 shows this process.

First the miners have to prepare the mobile stone crusher in the tunnel. This sub-process consists of excavation of a new cross section for the crusher. Afterwards the area must be cleaned and the crusher basement must be concreted. If the concrete is hard enough the crusher will be driven to its new place. If some additional tools are needed the miners drive into the workshop in order to organize missing tools. Then the crusher will be adjusted and the function will be checked. At the end of this sub-process the tools should be brought back into the workshop hall.

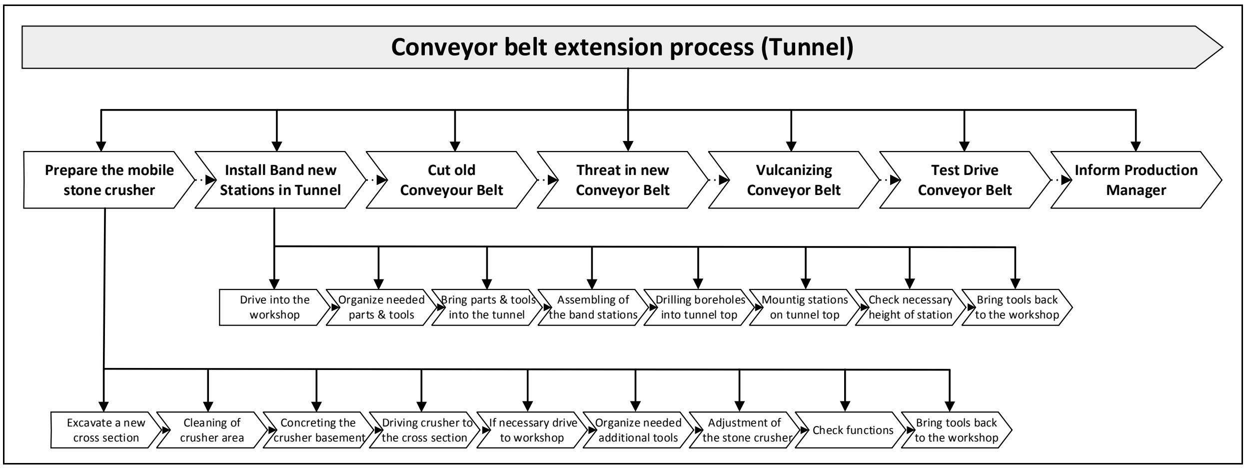


Figure 50: Sequence of the conveyor belt extension process

After preparation of the stone crusher the new conveyor belt stations will be installed in the tunnel. This sub-process has in the first step the task to drive into the workshop and organize needed tools and parts. The workers bring all materials back into the tunnel and the band stations will be assembled. Again some boreholes must be drilled for the new stations. Afterwards the new band stations will be mounted under the tunnel top and the function will be checked immediately. It the check was successful the miners bring all tools back into the workshop. Large pictures of all support and core processes can be seen within two parts in appendix 21.

3.2.2 Generation of the process map for the tunnel-site Solbakk

After creation of all single value chain diagrams of all relevant processes performed on the tunnel construction site in Norway it was essential to combine them within a process map. This enables a total overview about all processes performed by Marti IAV in Solbakk. The whole process organization of the company can be seen on a high level. To get all necessary information about each single process a lot of explorative interviews had to be executed.

3.2.2.1 Process map of Marti IAV

All single value chain diagrams (VCD) of the company were combined and illustrated within the process map of Solbakk. Figure 51 shows the process map of the company in Norway. All support processes run in parallel to the core process. With this process landscape it is possible to get a fast overview about all performed processes on this site. Especially for new workers it is easy too to get a feeling about each single process. Process maps offer the topmost hierarchy level of the considered areas. Some important questions must be asked and answered during the generation of this process map. In the theoretical part all questions for the creation of process maps can be seen. This process landscape shows the transparency of the whole process organization of the company Marti IAV. A bigger picture is in appendix 22. For the process map of Solbakk it was important to identify all relevant process attributes which are dependent on the line of business. The decision about process attributes which lead to separate processes are shown in the next sub-chapter of the thesis.

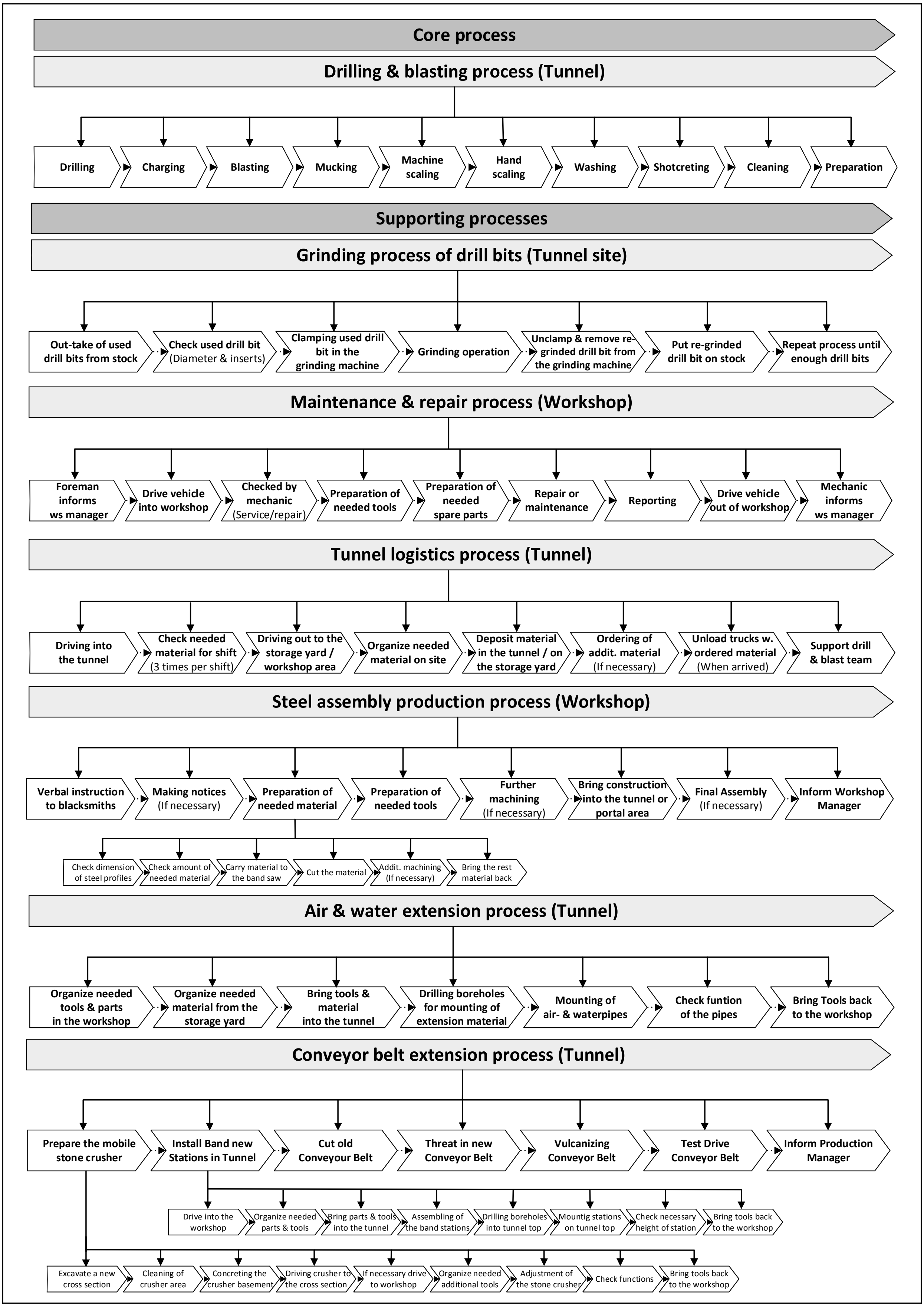


Figure 51: Process map of the tunnel site Solbakk

3.2.2.2 Location of the three specific processes

With the obtained process map of the tunnel construction site in Norway a good overview at a high level is given. Next task is to exclude relevant sub-processes or to find relationships between them within this process map. Start and end points must be determined. It was necessary to find out where the three relevant processes, which must be improved, are located. Therefore many explorative interviews and monitoring were required to get important information about all processes. It was essential to interview miners of the tunnel, blacksmiths or mechanics in the workshop or even the workshop manager or the foremen at this site. Also the opportunity to co-operate with different kind of workers was important to get the total overview about the relevant processes. It can be said that every expert on the site was willing to give a lot of information according to the questions of the explorative interviews. For many of them an improvement of the existing processes would be desirable. The author had the feeling that especially workers and miners were proud that they had the chance to contribute with their experience and knowledge. At nearly all workers the willingness to give information was really strong and fascinating.

Figure 52 shows the legend of the location of the three thesis-relevant sub-processes. The used colors are needed in order to understand and to see their distribution within the established process map of this tunnel construction site in Norway. For process 1 and process 2 an additional BPMN illustration was created for the purpose of showing the relations and the weak points within these processes. Also for process 3 an additional BPMN graphic was necessary in order to see why and where are so many drill bits missing. These BPMN drawings can be seen a little bit later in the practical part of this thesis.

Location of relevant processes:

- Process 1

Workshop administration process

[Additional BPMN (A)]

- Process 2

Operating instruction process

[Additional BPMN (A)]

- Process 3

Drill steel administration process

[Additional BPMN (B)]

Figure 52: Legend of the process map Solbakk

Figure 53 shows the actual location of these relevant sub-processes within the process map of Solbakk. For instance in all red fields tools and spare parts are involved.

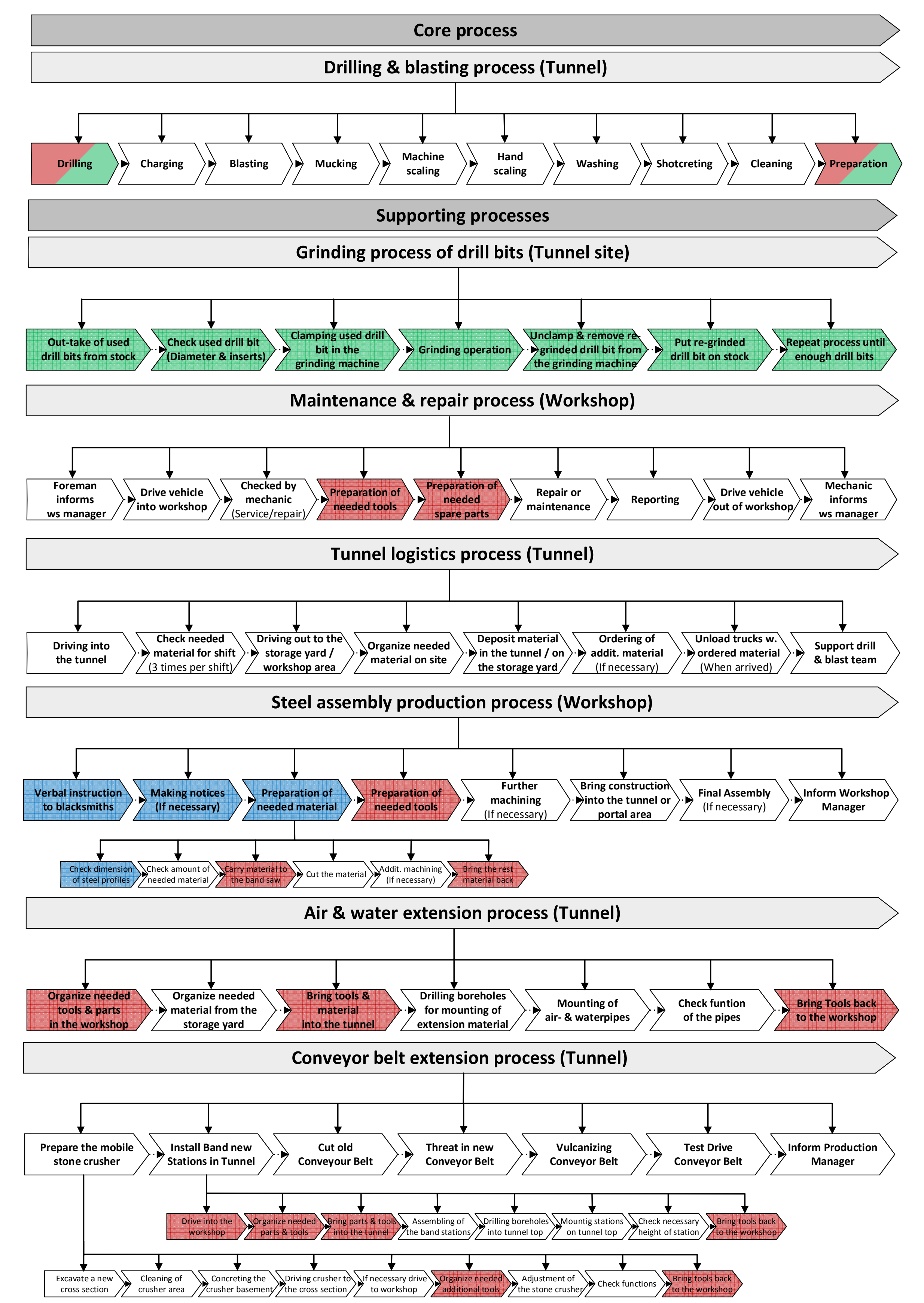


Figure 53: Process map of the tunnel site Solbakk with distribution of relevant processes

In figure 53 it can be seen that the three analyzed processes are distributed within this process map of Solbakk. A bigger illustration can be seen at appendix 23. For the workshop administration process the unexplainable loss of tools must be figured out. In this illustration the red arrows show the steps which have to do with the process of borrowing tools. Because the process map hasn’t the necessary deepness of detail it was important to create some business process modeling notations (BPMN´s). Also for the drill steel process it can be seen that this process is a cross-process and the related arrows are green. The flow of the whole drill bits is between drill steel storage container and the tunnel. Why so many drill bits are missing cannot be found out with this illustration. Also for this process an additional BPMN model was necessary. The work instructions to the blacksmiths can be seen due to blue arrows. With the established BPMN models it should be possible to get an exact overview about these relevant aspects of each individual process. These models can be seen in the next sub-chapter.

3.2.3 BPMNs of the tunnel site Solbakk

Business process model and notation (BPMN) offers the highest level of detail according to the theoretical part of the thesis. With this kind of modeling processes it is possible to create very detailed process models but also rough process concepts can be established. Therefore this method was needed to uncover the weak points which couldn’t be seen in the process map of the construction site in Norway.

To get the necessary information about especially the loss of tools in process 1 and the loss of drill bits in process 3 it was essential to make many explorative interviews on the tunnel construction site in Norway. It was important to ask different groups of workers to guarantee a correct illustration of the processes within the process map.

3.2.3.1 Generation of single BPMNs of different workgroups in the workshop

Co-operating and performing explorative interviews with much different kind of workers on this site was important for the visualization of each single sub-notation. In the following sub-chapters various types of workers were asked directly on-site for the exact illustration of the BPMN processes. Used colors refer to the processes and fit also to the process map.

3.2.3.1.1 BPMN for Process 1 and 2

Unexplainable loss of tools and disorder in the workshop hall causes searching hours of about 300 hours per month. Especially with explorative interviews in combination with the generated BPMN process these weak points must be detected. Therefore different kind of workers in the workshop and the tunnel were asked in some explorative interviews:

Blacksmiths in the workshop hall

All blacksmiths in the workshop were willing to participate in the explorative interview. It was found out that the main instruction method to them is the verbal instruction through a foreman or the workshop manager. Many of them said that they would have sometimes problems to understand the task which has to be performed by them. Than they get a fast but unfortunately occasionally bad hand sketch from the foreman. Also some complaints about the long ways of the steel storage to the band saw were mentioned sometimes. But all blacksmiths have access to the tool container in the workshop. If the needed tools aren't inside they will ask co-workers or even the foreman of the workshop. When all these efforts don't bear fruits to get the required tools the blacksmiths occasionally have to improvise in performing their task. Sometimes it is just impossible. Figure 54 shows the single BPMN model of the blacksmiths in the workshop. A bigger illustration is added in appendix 24.

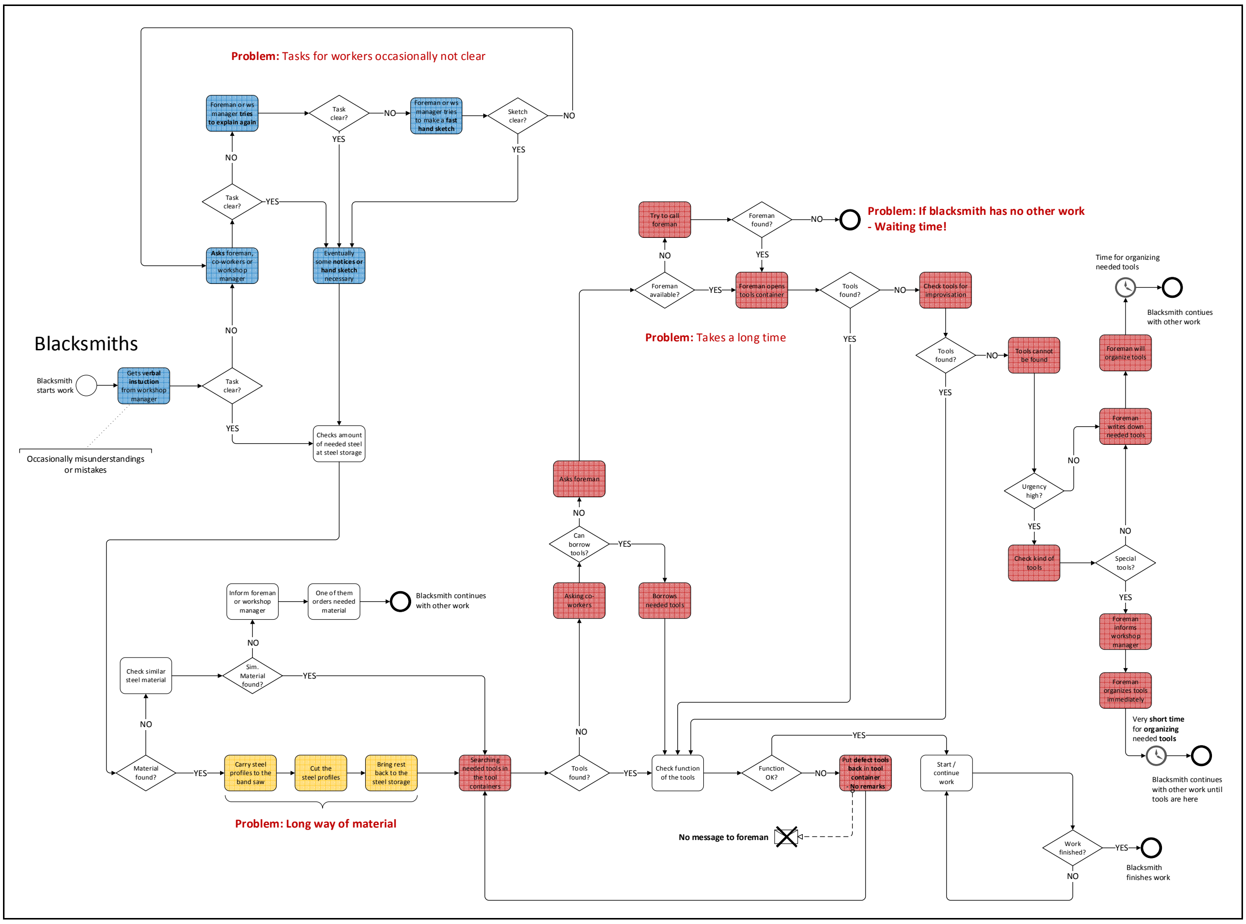


Figure 54: BPMN model of the blacksmiths in the workshop

All blue tasks have to do with the work instruction process (Process 2). Problem here is that sometimes the given task aren't clear to the blacksmiths in the workshop and this can cause scrap due to misunderstandings. Eventually asking again or some notices with fast hand sketches could be necessary deepening on the task. If the worker knows what is to do he will search the needed steel material. The yellow tasks represent the long ways of the steel material transport in the workshop. After the correct or similar material is found the blacksmith will begin to search the needed tools. All red tasks are related to the tools (Process 1) for instance borrowing at co-workers and so on. At least the foreman will be asked and if necessary he will order the required tools immediately if there is high urgency. Some waiting time will occur if the foreman isn't available. A big problem was detected during the explorative interviews with the responsible foremen in the workshop: Broken or defect tools will be put back into the tool container by the workers in the workshop without remarks or information to the foreman. This causes huge troubles at urgent tasks! The small clock symbols are representing the time needed for ordering. If the blacksmith doesn't get the required tools he will continue with another work.

Mechanics in the workshop hall

Also the mechanics were interviewed with explorative interviews in order to get necessary information about their tasks within the workshop. Every day the mechanics get information from the workshop manager or a foreman about the incoming tunneling vehicles. Figure 55 shows the BPMN model of the mechanics. The red boxes show all tasks where tools are involved (Process 1). A larger picture is in appendix 25.

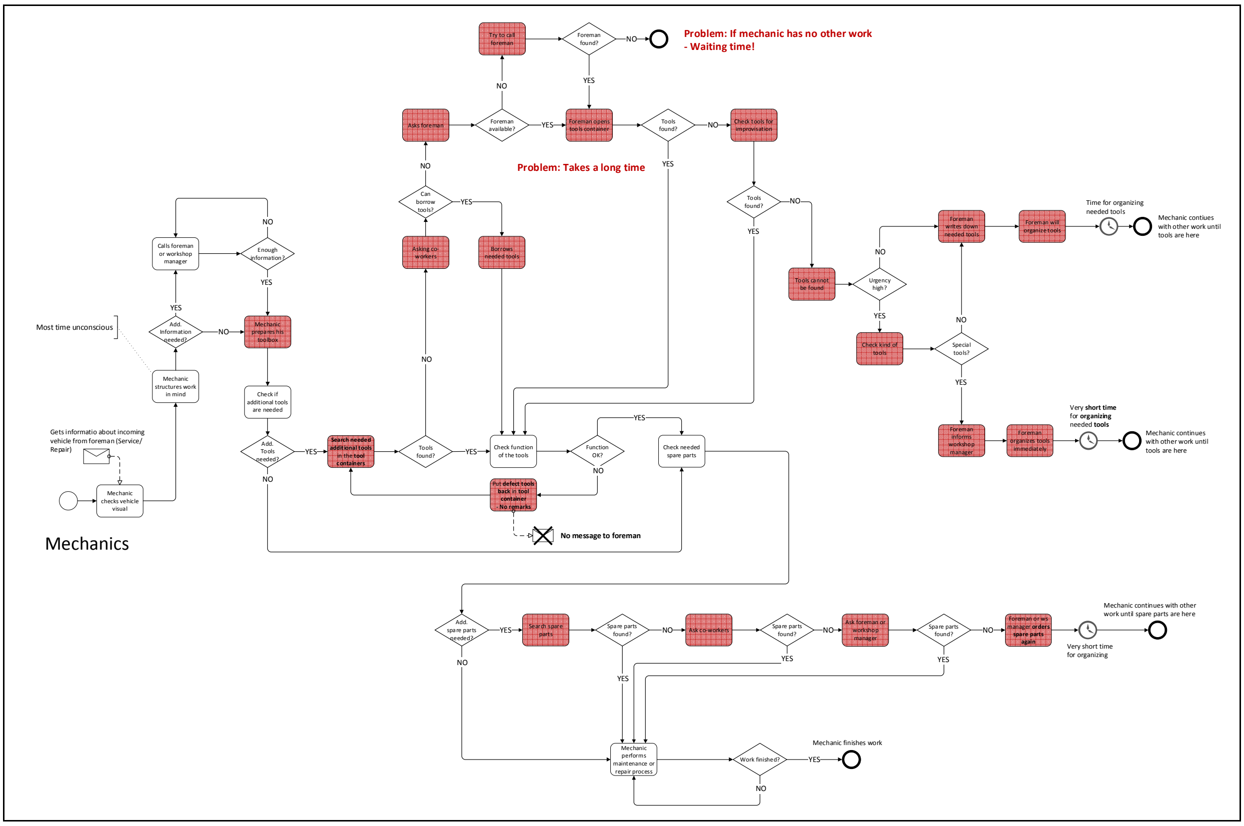


Figure 55: BPMN model of the mechanics in the workshop

Normally every shift mechanic has an own tool box. But if additional tools are needed the mechanic can also go into the tool storage container in the workshop. Maybe he will ask some co-workers and at least the foreman about needed tools. Explorative interviews with leading personal in the workshop hall showed a big problem: Also mechanics put broken or defect tools back into the tool container without inform the foremen. At urgent repair or service tasks this can be a huge problem! When the foreman also cannot find the required tools he will order it. If it is very important he will immediately organize standard tools. Special tools need the allowance of the workshop manager. Mechanics also need spare parts in order to make the required services at the tunneling vehicles. When needed spare parts cannot be found the mechanic will ask co-workers and the foreman or even the workshop manager. On this site there is no real storekeeper. That means that a lot of material and parts will be unpacked by a worker of the day or night shift. Occasionally these materials are put somewhere into a container and aren't easy to find. This causes additional ordering of spare parts and delays the repair and maintenance unnecessarily. Whether mechanics aren't able to get the needed spare parts they will continue with another task.

Miners from the tunnel drive into the workshop hall

Also the miners in the tunnel need some tools for execution of their tasks. If additional tools are needed they drive immediately into the workshop and organize tools by themselves. Through explorative interviews it was found out that everybody has access to the tool storage container in the workshop. Figure 56 shows the BPMN of the miners in Solbakk. A bigger illustration can be found in appendix 26. Red tasks represent tasks where the tools are involved (Process 1).

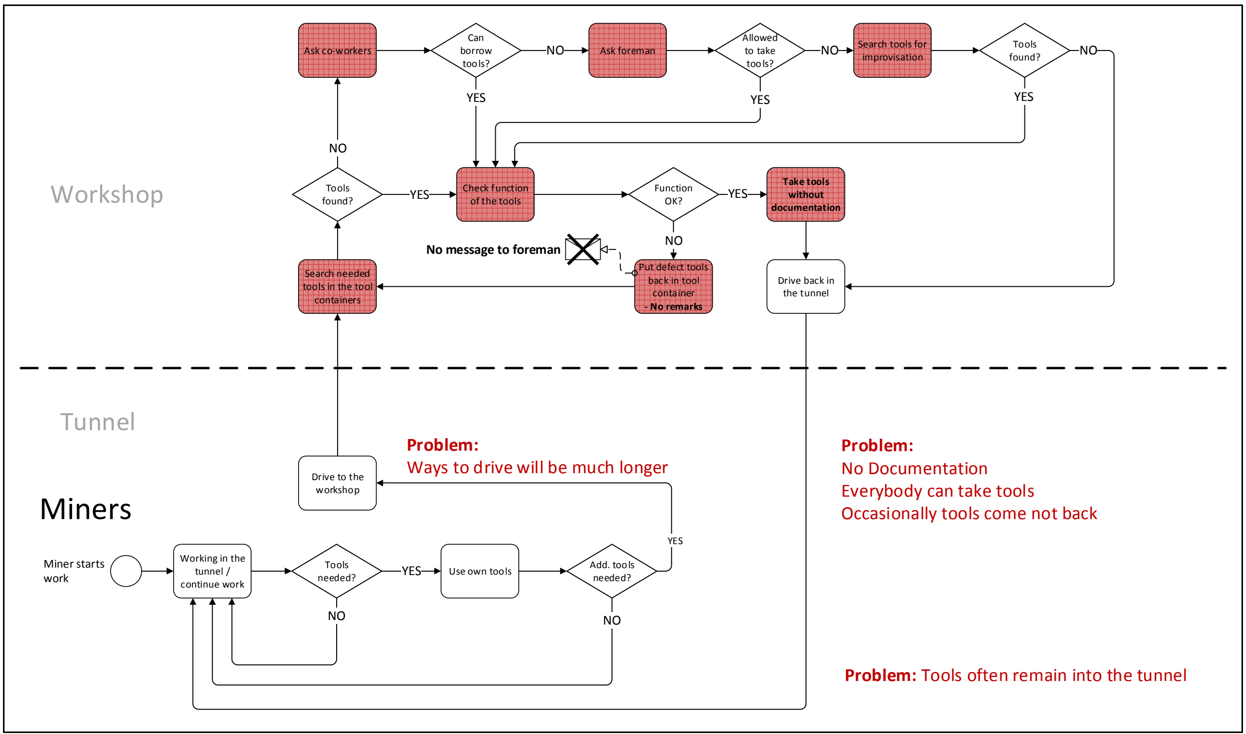


Figure 56: BPMN model of miners between tunnel and workshop

The dotted lines represent the border between tunnel and workshop. Miners start their work in the tunnel which is the lower field in this figure. They use their own tools but if some additional tools are needed they will drive immediately into the workshop hall. There they search the required tools. Also co-workers will be asked or even tools for improvisation will be searched. At least the foreman will be asked if the tools are important for performing their tasks. It also can happen that the foreman isn't available and no tools for improvisation can be found than the miners drive back into the tunnel without tools. Also here the problem is that defect tools aren't remarked and there is no message to the foreman. Another big problem is according to the interviews that a lot of tools remain in the tunnel and there is also no documentation about these tools.

Different suppliers drive into the workshop hall

At the construction site Solbakk a lot of different suppliers arrive mainly from Monday to Friday. Their trucks will be parked in front of the workshop hall. Figure 57 shows the BPMN model of the initial situation of the unloading process and is also added in appendix 27.

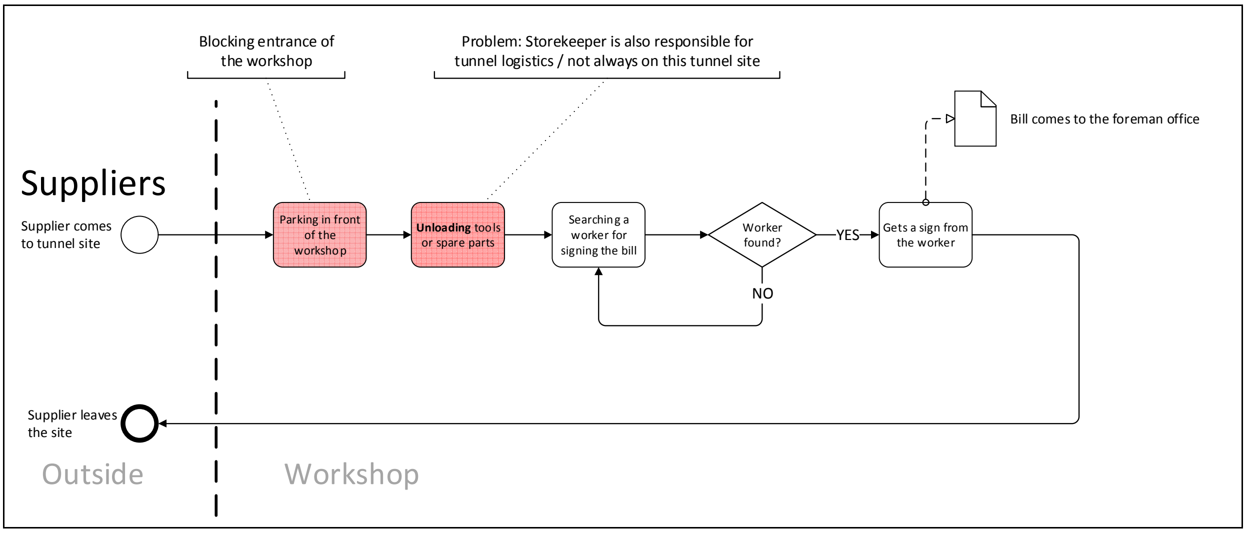


Figure 57: BPMN model of suppliers in front of the workshop

The dotted line represents the border between the workshop hall and outside of the workshop hall. Through explorative interviews it was found out that the parking in front of the hall isn't really disturbing the workers of the workshop. All light red tasks have to do with the goods income (Process 1). The supplier unloads his palettes and boxes and searches for a worker which gives him a sign for the delivery. Data object or the bill will be given to the foreman or put into his office by the worker. Afterwards the supplier leaves the site. With explorative interviews it was recognized that on this tunnel construction site there is no real storekeeper for removing the incoming goods. This person is also responsible for the tunnel logistics. A further problem will occur with increasing length of the tunnel. That worker will have less time for removing all the incoming goods. A solution therefore would be desirable.

3.2.3.1.2 Combination of the established BPMNs into one main BPMN

To get an overview about all different groups of workers it is essential to put the single BPMNs into pools and lanes. In figure 58 the BPMN model of the current states including process 1 and 2 can be seen. It is called BPMN (A). In this BPMN model all different kind of work groups in and around the workshop hall can be seen. A large illustration is added in appendix 28. The red boxes represent tasks which have to do with the tools and spare parts (Process 1). Light red tasks represent the goods income in the workshop hall by the different suppliers (Process 1). Blue tasks are showing the work instruction tasks (Process 2) to the blacksmiths. The yellow boxes represent the long ways of steel material flow of the blacksmiths (Process 1). At the moment it isn't clear if these long ways can be improved. With expert interviews later in the practical part an answer to this question will be given.

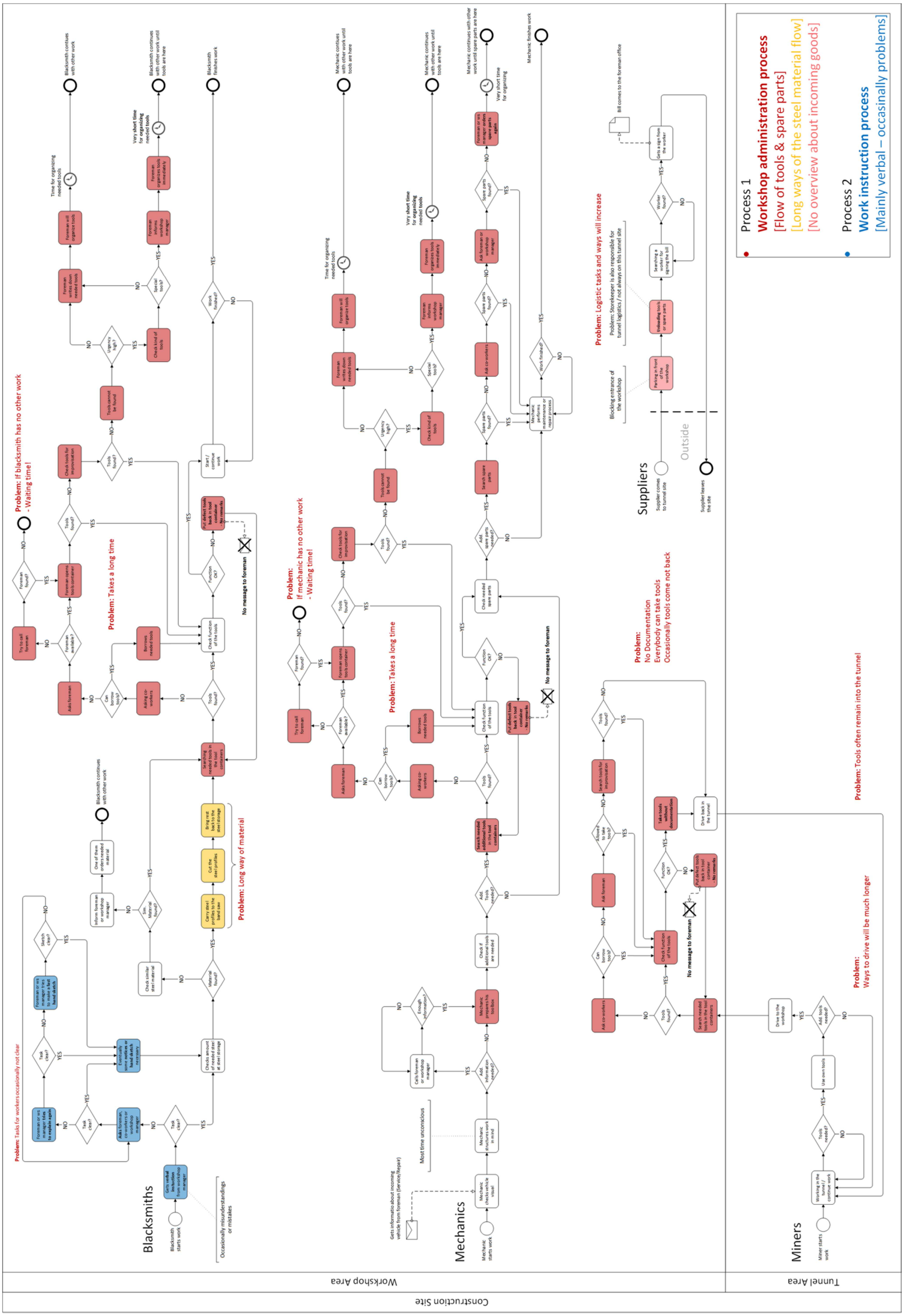


Figure 58: BPMN (A) of the current states including process 1 and 2

In this main BPMN model the current states according to May 2014 of each worker group is shown. Main pool is the construction site in Solbakk. Sub-pools are the workshop area and the tunnel area. All red boxes deal with the tools of the workshop. Unfortunately there is no documentation about borrowed or defect tools. A big problem is that everybody even other companies have access to the tool container. Many tools remain in the tunnel or somewhere else because there is no responsible storekeeper or documentation about these circumstances. Broken or defect tools aren't claimed. The workers put them just back without information to a foreman. Light red tasks show the incoming goods of various suppliers. Sadly there is no overview regarding to the incoming goods in the workshop hall because the person who is responsible for that is also responsible for the tunnel logistics. With increasing length of the tunnel this will be a big problem. The blue boxes represent the way of the verbal task introduction to the blacksmith in the workshop.

3.2.3.2 Generation of single BPMNs of different workgroups at the tunnel area

To illustrate the loss of drill bits it was necessary to make some explorative interviews with miners and with foremen. Also important explorative interviews with mechanics of the company Sandvik (Drilling jumbos and drill steel) were done. In the following the different work groups were interviewed and their ideas were visualized with BPMN. Afterwards all processes were combined into a main process. The used green colors for the tasks refer to the drill bits or flow of the drill bits in order to show their flow on this tunnel construction site.

3.2.3.2.1 BPMN for Process 3

After agreement with the workshop manager of Solbakk some spot tests in two-week intervals were made. In these two weeks there were 400 drill bits lost on average. This means that **per month are 800 drill bits missing** according to the workshop in October 2014. The unexplainable loss of drill bits must be shown with a BPMN illustration in order to detect the weak points in the existing drill bits flow. With BPMN in combination with co-operation and especially explorative interviews the reasons for this unexplainable loss of bits must be uncovered. Therefore different kinds of workers in the tunnel and on the site were interviewed:

Extern Sandvik mechanic

Mechanics of the company Sandvik are responsible for the service and repair tasks on the four drilling jumbos at this construction site. But also the inventory of the drill bits in the grinding or storage container will be done by them. According to the explorative interviews with them it was recognizable that there are many drill bits aren't coming back into the storage or grinding container. Figure 59 shows the BPMN model of the weekly inventory process of the extern mechanics. In appendix 29 a large illustration can be seen. The whole inventory process is done in the grinding or storage container. First the worker has to count the small drill bits. Afterwards he has to check how many drill bits are needed per day. If enough 48mm drill bits are available he will count the 54mm drill bits. In case of less 48mm drill bits the Sandvik mechanic writes down the amount of 48mm drill bits which must be ordered at Sandvik drill steel. Normally the extern mechanics write down new, re-grinded and used drill bits in a map in order to keep an overview about the usage behavior of Marti IAV´s miners (March 2014). The same procedure is done for the drill bits with the diameter 54mm and for the reaming bits 102mm. Through explorative interviews it was found out that there are many drill bits to order and the needed or wasted amount has increased dramatically according to the extern mechanics. After counting and writing down all needed or available drill bits the mechanic checks his order. If the order is complete he will order the required drill bits at his company Sandvik. Then the worker drives to the office of Marti IAV and he will inform the production manager about the ordering. After that he will continue with another work.

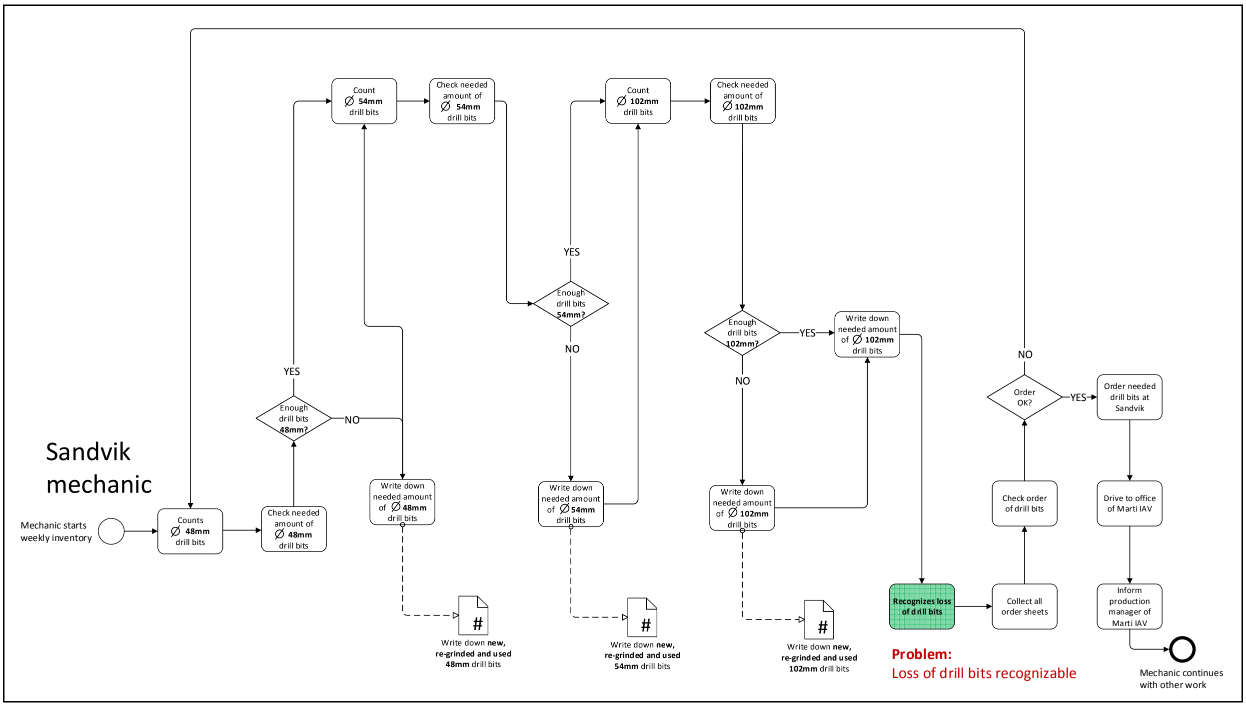


Figure 59: BPMN model of a Sandvik mechanic in the grinding container

Grinder in the grinding or storage container

In February 2014 there were no responsible workers of Marti IAV for re-grinding the used drill bits. The mechanics of Sandvik did this when they had some waiting time. Even the needed time or the grinding parameters weren’t known to the company Marti IAV. So the author of this thesis got a short introduction into the grinding process by the Sandvik mechanics. After this introduction the times for grinding the different types of drill bits were taken and a scientific analysis was established in order to get the average needed time per drill bit. This statistics can be seen at the beginning of the practical part. In the grinding container is a box for the used drill bits. Normally the foremen should take the used drill bits out of the tunnel and put them into this box in the storage container. In figure 60 the whole grinding process of a grinder can be seen. The green boxes show the problematic task within this process of the individual drill bits. This information was obtained through explorative interviews and through execution of the grinding process itself. Appendix 30 shows a larger illustration of this process.

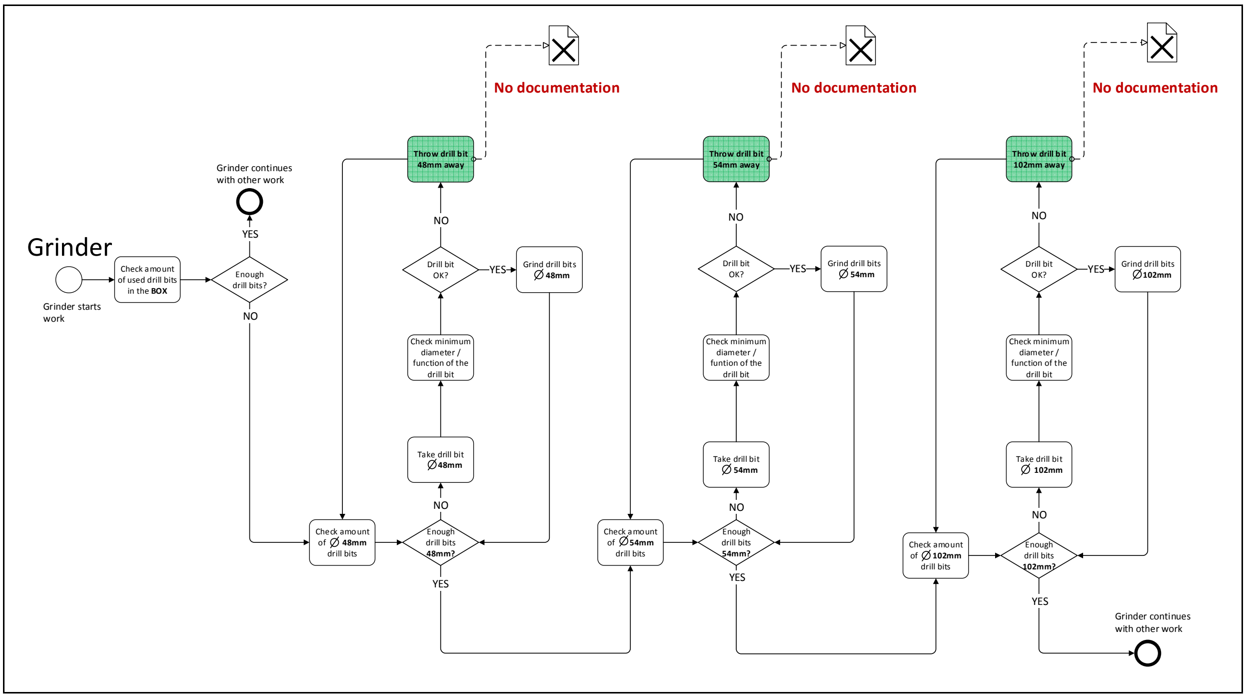


Figure 60: BPMN model of a grinder in the storage container

When the grinder goes into the grinding container he will first check the amount of used drill bits in the box. If there aren't drill bits he will continue with another work. When there are a lot of used drill bits in the box he will first check the amount of the 48mm drill bits on stock because on a good day the miners need 50 pieces of them. If there are enough 48mm drill bits on stock the grinder will check the available amount of 54mm drill bits. In case of less 48mm drill bits the grinder will take a drill bit and he has to check the minimum diameter and also the functionality of the drill bit. If this drill bit is alright the grinder will start to grind these kinds of bits until there are enough on stock. A problem here is that broken or too small drill bits can be thrown away without any documentation because the production management is not interested in a documentation of the unused or damaged drill bits. This grinding procedure is repeated and performed with all three types of drill bits until there are enough on stock. The major problem especially in October 2014 is that there are nearly no drill bits coming back for grinding. This causes high costs which will be calculated later in the practical part. According to the Sandvik mechanics these drill bits can be re-grinded minimum five times before they are too small.

Miners drive out from the tunnel to the grinding container

Miners need every day drill bits for the drill and blast process. New or re-grinded drill bits can be taken by the tunnel foremen. When they take or bring drill bits the foremen must write the amount of the brought or taken drill bits. Also the drilling jumbo must be written down in order to keep the overview about the drill bits flow at the site. The maximum needed drill bits per day are 50 pieces of 48mm drill bits, 8 pieces of 54mm drill bits and 2 pieces of 102mm reaming bits. Figure 61 shows the BPMN model of miners at the tunnel construction site in Norway. In appendix 31 a bigger illustration of this BPMN model is available.

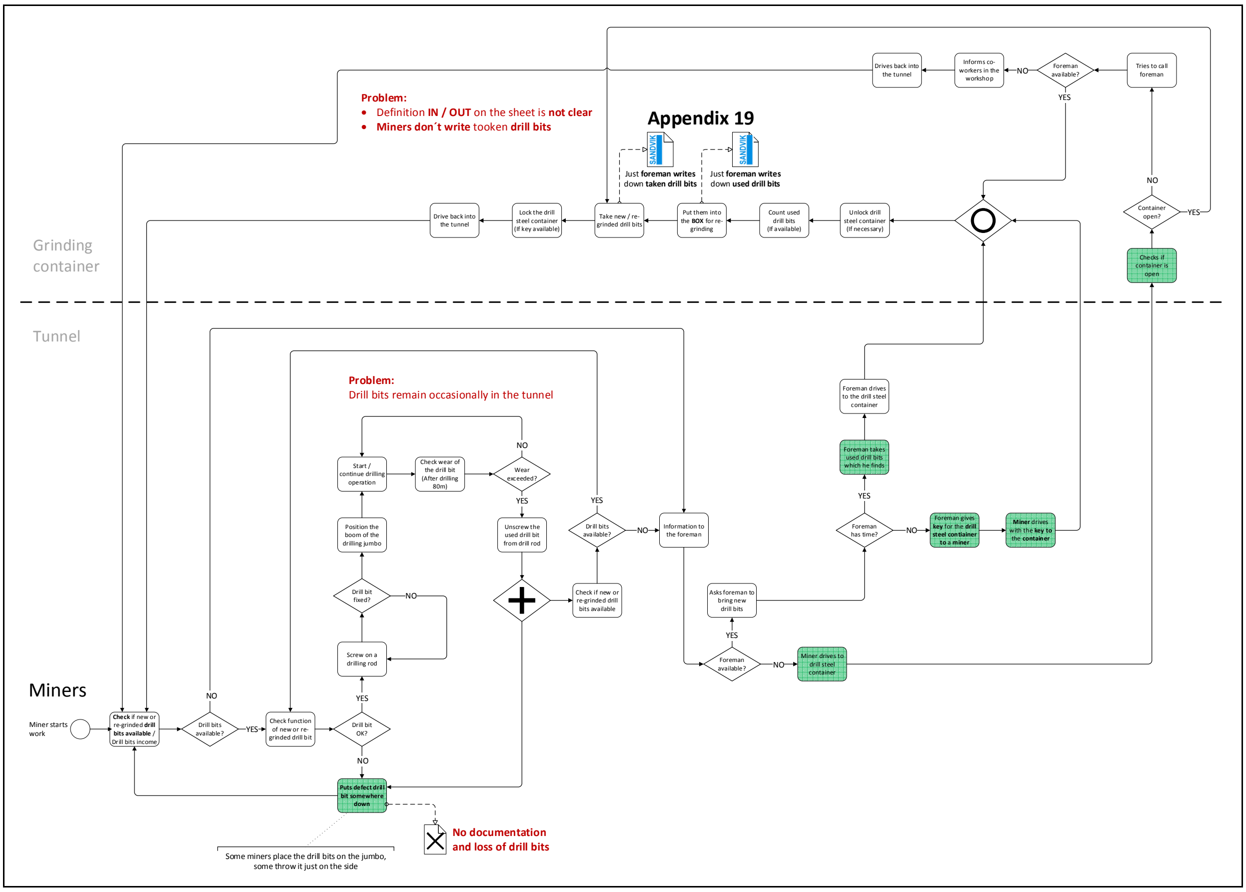


Figure 61: BPMN model of miners between tunnel and grinding container

When miners start their work they check first the availability of the needed drill bits. If the appropriate bits are available they inspect the function of each used drill bit. Through explorative interviews with the extern Sandvik mechanics it was found out that the miners regularly throw away used but re-grind able drill bits. Some of them throw them somewhere on the side in the tunnel. A few place them on the side of the drilling jumbo. When a miner or the mechanic from Sandvik drives out with the drill rig all the used drill bits fall to the ground in the tunnel. The awareness for bringing them back or be careful in usage is totally missing according to an extern mechanic. There is also no documentation about missing drill bits (May 2014). If the wear of a drill bit is exceeded nearly all of them are loosen in the tunnel. According to the workshop manager of Solbakk 800 pieces are missing on average. This would mean that nearly all of them remain in the tunnel. The costs therefore will be calculated in the next sub-chapter. If the drill bit is alright a miner screws it on the drilling rod and drills until the wear is exceeded. While enough drill bits are available this procedure continues. In the case that drill bits run out the miners will ask the foreman to organize new bits for them because just the foremen and the mechanics of Sandvik have the appropriate keys for the grinding container. If the foreman isn’t in the tunnel one miner drives on his own to the storage or grinding container. A big problem occurs when the container is open because the miners go inside the container and take drill bits without writing down into the sheet. This sheet can be seen in appendix 19. When the miners find a foreman and he drives to the container the foreman should also bring the used drill bits with him. This is unfortunately not always the case according to explorative interviews with different workers. A big problem is that the foreman isn’t able to write down the taken and brought drill bits due to the bad sheets. The IN / OUT definition isn’t clear enough. In the previous sub-chapter the improved sheets for the drill bits can be seen. With explorative interviews it was also recognizable that the foremen occasionally give the key to the miners and the miners can unlock the container by themselves. Because they don’t even write this is very bad for the whole documentation of the drill bits flow.

3.2.3.2.2 Combination of the established BPMNs into one main BPMN

After all different kind of work groups have been illustrated with single BPMNs it was important to bring all these single visualizations into a main BPMN. This main BPMN shows the current state of process 3. This main BPMN, which is called BPMN (B), can be seen in figure 62 and a bigger illustration can be found in appendix 32. All required information was obtained through explorative interviews and co-operating on the tunnel construction site Solbakk in Norway. Green boxes represent tasks which are critical for the documentation, flow and especially loss of drill bits (Process 3). In this figure also the pools and lanes can be seen. Loss of drill bits was recognizable through co-operating on the tunnel site and found out especially through explorative interviews with extern mechanics and workers of Marti IAV. Drill bits can be thrown away without documentation by a grinder. Also this situation will improve if the new introduced sheets (Appendix 20) are in usage. These improved sheets for the drill steel documentation were established in combination with explorative interviews. Miners from the tunnel also have access to the drill steel container. If this storage container is open they just go inside and take new drill bits with them. Occasionally miners don’t write taken and brought drill bits because it is not their task. Normally the foreman should write down the taken and brought drill bits. The foreman also has to write down the taken and brought drill bits in combination with the number of the drilling jumbo in order to ensure an exact documentation of the drill steel. In the previous chapter it can be seen that the old sheets of Marti IAV aren’t accurate enough for the drill steel flow documentation (Appendix 19). Existing IN and OUT definition problems were solved with the new documentation sheets (Appendix 20). Through explorative interviews it was also found out that some foremen give their key for the drill steel container to a miner in order that the miner can drive outside of the tunnel and bring the needed drill bits or drill steel into the tunnel. Through explorative interviews it was also recognized that the miners just throw away the used drill bits in the tunnel according to external experts. There is no documentation about the drill bits which are just thrown somewhere on the side in the tunnel. The costs for these drill bits are quite high and in the next sub-chapter the loss and the arising expenses therefore will be calculated. Later in this thesis the new solution as well as the cost savings, which were made and found out through expert interviews, can be seen.

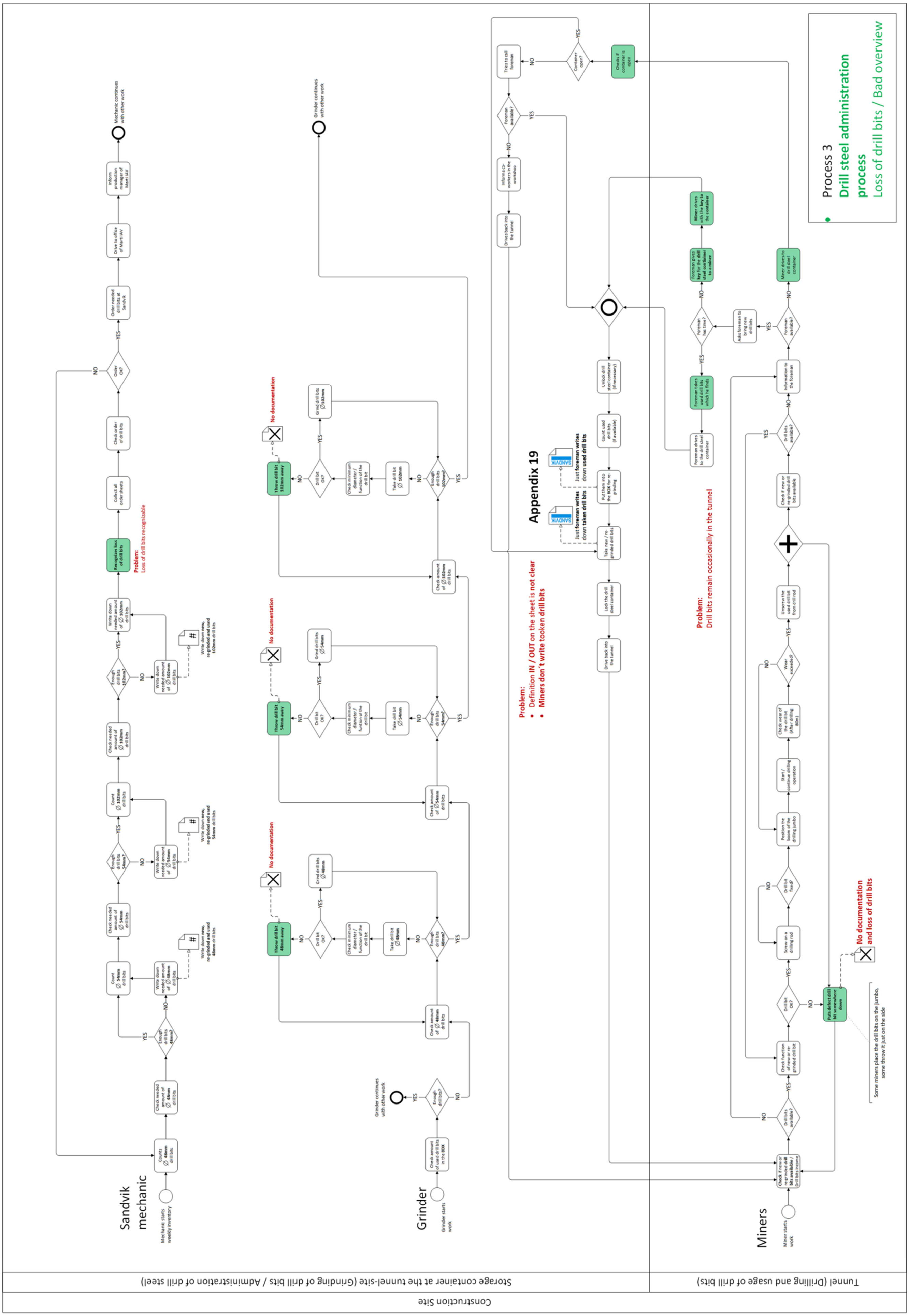


Figure 62: BPMN (B) of the current states including process 3

3.2.4 Current costs of the relevant processes

This thesis contains three processes. For process 1 and process 3 a cost calculation and especially a cost reduction must be made. In this sub-chapter the current costs of these two processes are shown. Process 2 showed that it is possible to increase the efficiency of the blacksmiths in the workshop hall of Solbakk by the introduction of 3D-CAD drawing sets. Arising costs for the introduction of CAD as well as the constructing engineer hadn't to be considered. It was required to see if the efficiency of the steel production itself can be raised because it was not even clear if the Slovakian blacksmiths are accepting the introduced drawing sets.

3.2.4.1 Current costs for process 1

The sum of the searching times calculated with the average searching time of all workers in the workshop hall in Norway can be found in chapter 3.1.1.1. For one month this sum is 296 hours rounded for six workers. The sum of the needed time for removing incoming goods takes 30 hours rounded per month and the calculation out of the explorative interviews can be also seen in this sub-chapter. These two times are added:

$$296h + 30h = 326h$$

The sum of these two required times is **326 hours** per month. Wage rate of a Slovakian blacksmith or mechanic is 267 NOK/h. This is **32,51€/h** according to the exchange rate of the European Central Bank (ECB 05.04.14 22:40). This wage rate is pre-tax and was received for this calculation from the commercial manager of the tunnel site Solbakk. With this value the calculation has to be made according to Marti IAV.

$$326h * \left(\frac{32{,}51€}{h}\right) = 10.598{,}26€$$

$$\frac{10598{,}26€}{month} * 12months = 127.179{,}12€$$

$$\frac{127179{,}12€}{year} * 5years = 635.895{,}6€$$

Sum of the average searching- and removing time per month per available workers multiplied with the wage rate of a Slovakian worker produces overall costs of **10.598,26€/month**. According to five years of production this would cause **635.895,6€/5years**. These costs will be reduced with the improvement of this process. Therefore some explorative interviews were necessary. With experts on this tunnel construction site in Norway the process weak points and improvements were clarified due to the introduction of expert interviews. All necessary steps according to the relevant processes can be seen later in the practical part.

3.2.4.2 Current costs for process 3

In table 15 three different drill bit types with the needed amount per day and also the price for each bit are shown. The smallest drill bits with 48mm have a price of 59,37€ per piece and the company needs maximum 50 pieces per day. For the drill bits with diameter 54mm the company pays 94,00€ and from this type of drill bit are 8 pieces used per day. The reaming bits with 102mm diameter have a price of 230,06€ per piece. From this type are maximum two pieces per day needed by Marti IAV. Producer of the drill bits is the company Sandvik and all prices are company intern prices what Marti IAV gets. According to an explorative interview with the workshop manager the loss of drill bits is about 800 pieces altogether per month. These current costs will be calculated in this chapter.

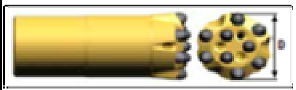
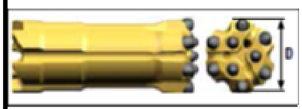
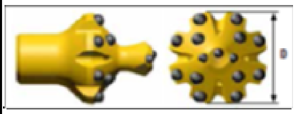
SANDVIK	Diameter	Max. # / day	Price / #
	Ø 48mm	50/day	59,37 €
	Ø 54mm	8/day	94,00 €
	Ø 102mm	2/day	230,06 €

Table 15: Prices and maximum needed amount of each drill bit type

Assumption: 60 pieces of drill bits are used every day. With an account settlement the percentage of needed 48mm drill bits is 83,33%, of 54mm drill bits is 13,33% and the 102mm reaming bits have an percentage of 3,33% according to 60 pieces and their used frequency. This means for the 800 missing bits per month that the percentages have to be multiplied with 800 in order to obtain the loosed amount of each type of drill bit.

$$800\ \# * 83{,}33\% = 667\ \#\ 48mm\ drill\ bits$$

$$800\ \# * 13{,}33\% = 107\ \#\ 54mm\ drill\ bits$$

$$800\ \# * 3{,}33\% = 27\ \#\ 102mm\ drill\ bit$$

Out of the total sum of the lost drill bits per month the partial amount of 48mm bits is 667 drill bits, of 54mm bits is 107 pieces and of 102mm reaming bits is 27 drill bits. All these values were rounded.

In the following the needed amount of each drill bit type is multiplied with its price per drill bit and the sum of all three types which are lost is build:

$$\left(667\# * 59{,}37\frac{€}{\#}\right) + \left(107\# * 94{,}00\frac{€}{\#}\right) + \left(27\# * 230{,}06\frac{€}{\#}\right) = 55.869{,}41€$$

The total costs for lost drill bits according to the random tests of the workshop manager in Solbakk are **55.869,41€ per month.**

$$\frac{55869{,}41€}{month} * 12months = 670.432{,}92€$$

$$\frac{670432{,}92€}{year} * 5years = 3.352.164{,}6€$$

For **five years of drill and blast excavation** the total costs would be **3.352.164,6€** at this tunnel construction site in Norway. A reduction of these costs will be achieved through the improvements of this process. Therefore an internal analysis was essential and all required steps can be seen in the following sub-chapters.

3.3 Internal analysis

The goal of the internal analysis is to determine the strengths and the weaknesses of a company. For the optimization of processes on the construction site Solbakk in Norway the tool SWOT was chosen for this analysis. Theory and aims of the SWOT analysis can be read in the theoretical part of this thesis. To get some strategic options a SWOT analysis was done in Norway and can be seen in the next sub-chapter.

3.3.1 SWOT analysis of the tunnel site Solbakk

In figure 63 the most relevant aspects of the internal SWOT analysis of the tunnel site Solbakk are shown. Related theory can be seen in the theoretical part of this thesis. Main aspect is given to the possibility of process improvement directly on this construction site in Norway.

SWOT Analysis	**S**trengths • Long lasting experience in tunneling • Many experts on this tunnel-site • Good educated leading personal • Experienced mechanics and blacksmiths of different countries • Know how • Different background of the workers	**W**eaknesses • Communication problems • Bad information flow between upper management and low level workers • Inefficient processes • Costly process sequences • Partly inefficient employees
Opportunities • Get follow-up projects of building owner • Establish in Norway • Enter new markets all over Scandinavia • Good reputation • Well-known company in Scandinavia	**SO** – Strategies Use existing knowledge and long lasting as well as different experience of own experts like mechanics, foremen and blacksmiths. Measures: **Expert interviews with own workers**, further training and education of workers	**WO** – Strategies Improve existing communication problems and use the knowledge of company extern experts like the mechanics of Sandvik. Measure: **Expert interviews with own and extern experts**, hire people which know the environment
Threats • Increasing competition in this sector • Rising transportation costs • Increasing wages & raw material prices • Dissatisfied building owner • Supply problems • Bad reputation on the Norwegian market	**ST** – Strategies Make processes more efficient through process optimizations! Use knowledge to reduce waste of time and costs. Measures: **Expert interviews with own management and business partners**, frequent production meetings and continuous improvements	**WT** – Strategies Improve communication problems. Raise awareness of own people for efficient execution of processes. Eventually training of them. Measures: **Expert interviews with Norwegian experts**, Co-operation with Norwegian companies + exchange

Figure 63: SWOT analysis of the tunnel site Solbakk in Norway

In this figure company intern strengths and weaknesses can be seen as well as the extern threats and opportunities of the company Marti IAV. Some important measures are shown for every type of strategy. It can be seen that the expert interview occurred in every strategy type for the optimization of existing processes. These interviews can be made with own workers, leading personal and also extern experts can be interviewed in order to get important information for the optimization of existing processes in Solbakk. That is the reason why expert interviews were executed in Norway. In the next sub-chapter all relevant details of the interviews are shown.

3.3.2 Expert interviews at the tunnel site

In this sub-chapter all essential steps which were necessary for the creation of expert interviews are shown and explained:

3.3.2.1 Preparation of the questionnaires

In this sub-chapter all preparations for the expert interviews are shown. For process 1 and 3 it was essential to establish questionnaires to execute expert interviews directly on-site in Norway. For process 2 it wasn't relevant to execute explorative interviews. All relevant theory for the generation of expert interviews can be read in the theoretical part of this thesis.

3.3.2.1.1 Mind maps

To avoid loss of really important information it is very helpful to make a good structuring of the relevant topic or aspects which are important for expert interviews. Out of the theory it can be said that this structuring with a mind map should be done before the creation of the questionnaires. Also some explorative interviews can be done before to get more needed or unexpected information about a specific topic. For process 1 and 3 it was essential to create first a mind map for a good structure of the following questions. In combination with required literature research the figures 64 and 65 were generated in Norway and they show the established mind maps for process 1 and process 3. The mind map of process 1 can be found also in appendix 33 of the thesis. With this mind map the specification of the questions within the questionnaires was done.

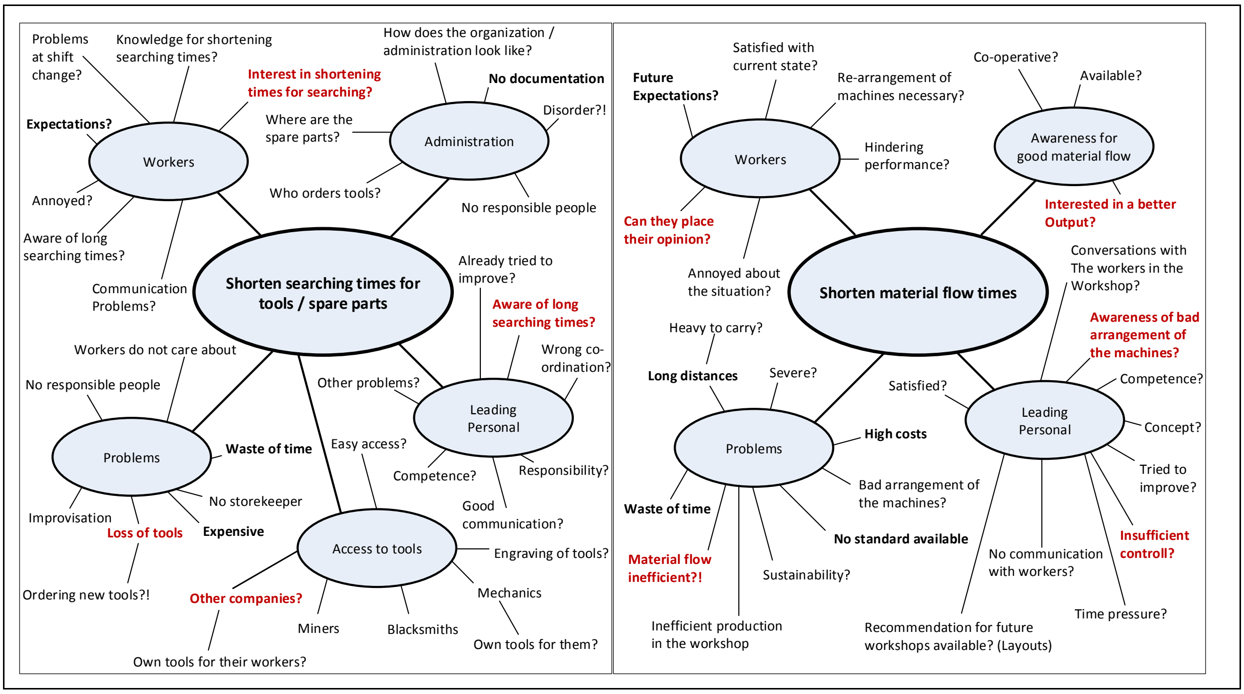


Figure 64: Mind map for structuring of questionnaire of process 1

Very important and needed answers were expected from the red or bolt written statements in the mind map. Before the mind map was generated a brainstorming was performed. Information out of the brainstorming is included in this mind map. All created brainstorming's are at the hand of the author. Figure 65 shows the created mind map for the drill steel administration process (Process 3) between the tunnel and the workshop area in Solbakk. Very helpful information is expected of the extern mechanics of the company Sandvik. Sandvik is the producer of the drilling jumbos and also of the drill bits. They have high extern knowledge due to their long experiences as partners for different tunneling companies on diverse tunnel-sites all over the world. Appendix 34 shows a larger image of this mind map. Important questions are written bolt or even red to show their high importance. These aspects should be implemented urgent into the questionnaire for the drill bits process. It was recognizable that the mind maps were really helpful for generating the questionnaires.

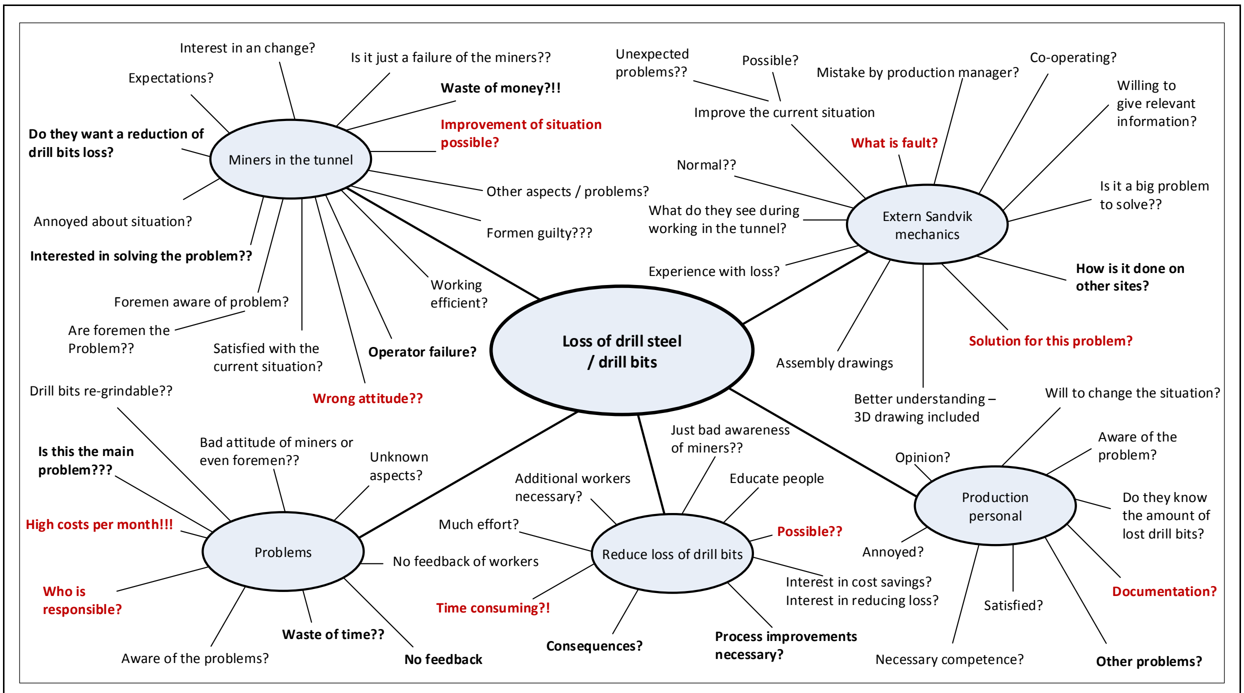


Figure 65: Mind map for structuring of questionnaire of process 3

3.3.2.1.2 Pretest at the tunnel site Solbakk

In order to estimate the length of the expert interviews and to avoid mistakes due to technical failures it was essential to make a pretest with the questionnaire. It was required to bring all questions into a logical structure and to clarify misunderstandings. Also with the established expert interviews in Norway the pretest was made. The results out of the pretest were integrated into the finished expert interview guidelines and can be seen in the next sub-chapter.

3.3.2.1.3 Leading research question and hypotheses of the master thesis

The leading research question of this master thesis is the following: “Is it possible to increase the efficiency of processes at the tunnel site Solbakk through expert Interviews“? After the execution and evaluation of the expert interviews it should be possible to answer this question.

In the following the two hypotheses of process 1 and 3 are shown:

Hypothesis for process 1 is: “If the experts bring in their knowledge about this process then it is possible to achieve significant cost savings in the workshop of the tunnel site Solbakk“.

Hypothesis for process 3 is: “With the experience and the knowledge of the interviewed experts it is possible to reduce the drill bits loss dramatically in order to achieve significant cost savings”.

3.3.2.1.4 Expectations of the interviewer

With the knowledge of different experts at this tunnel site in Norway it should be possible to improve process 1 and 3 of the master’s thesis. The experts are working every day on this construction site or in the workshop area and they will know how to improve the current situations. Also the willingness of all experts to participate in the interview should be high because the experts will feel honored to contribute to an improvement at this tunnel site. The result should be a standardization of the process and significant cost savings for the company Marti IAV. A recommendation for future tunnel workshops should be given. The interviewer is looking forward to perform the interviews in Solbakk.

Important questions of the interviewer:

- Are they willing to give a lot of information?
- Do they accept the voice recorder?
- How is the feedback of the experts according to the interview?
- Will new solution statements be visible?
- Is it possible to raise the efficiency of processes through expert interviews?
- Are there communication problems on this tunnel site?
- Is a standardization of the processes possible?

For expert interviews it is also important to write down possible answers or solutions of the interviewed experts. Further information can be found in the theoretical part of this thesis.

Possible answers for the process 1 could be:

- Write down of token tools or spare parts
- Hire an own storekeeper
- Re-arrange the machines and the equipment of the workshop
- Re-arrange also the tool containers in the workshop
- Clear instructions for the workers how to deal with the tools
- Own tools for the different teams (Mechanics, miners, …)
- Engraving of all tools for clear identification to avoid loss of tools
- New storage system for tools and spare parts

Possible answers for process 3 could be:

- Raise the awareness concerning high costs for loosing drill bits of miners
- Educate foremen in order to avoid the loss of drill bits
- Introduction of a documentation
- Bonus payments for careful dealing with the bits

3.3.2.1.5 Finished expert interview questionnaires

All interviewed experts were selected by the author of this thesis. Figure 66 shows the start page of the questionnaire for improvement of process 1. In appendix 35 all twelve blank sheets of the questionnaire for process 1 without answers are added. It can be seen that between the questions is a lot of space for making some notices during the interview. Before recording the expert interview the experts had to agree to the voice recorder. On the start sheet is also a short introduction and some general information for the interviewees. For the improvement of process 1 there are six main questions in this questionnaire. Further questions are added in order to ask more detailed questions and that no important question or aspect will be forgotten.

In page 8 and 9 of this expert interview questionnaire, which can be seen in appendix 35, the top view of the workshop hall in Norway is shown with the needed times for the main ways of the blacksmiths and the mechanics. With these illustrations the experts should try to draw improvements of the existing arrangement of the machines. At the end of the interview it is important to thank each expert for his time and knowledge. The experts had the opportunity to ask also some questions regarding to the interview or the interviewer if they had some. Questions about the feeling of the expert during the interview and important points which maybe have not been considered by the interviewer will be asked afterwards to ensure high quality of the whole questionnaire. After the interviews were finished the interviewer filled out some sheets according to the entire atmosphere of the single expert interview. Mood or body language of the expert was also written down. It can be said that all interviewed experts were quite good in mood and willing to tell as much as they knew. This is really a lot of knowledge and potential for the company Marti IAV. At least some information about problems which maybe have been occurred or space for improvement is given.

Graz University of Technology TU Graz
Institute of Business Economics and Industrial Sociology

Expert Interview – Process 1

BWL

Expert Interview:

(Introduction – Main part – Conclusion)

Introduction:

The interviewer (Auernig Daniel) writes his Master-Thesis for the Institute of Business Economics and Industrial Sociology at the University of Technology in Graz - Austria. For him you have an expert status due to your experience which you have gained on tunnel sites. The goal of this interview is to reduce the searching times for tools and spare parts in the workshop of the tunnel site Solbakk. Loss of tools and spare parts should be avoided. Also the long ways of the material flow should be reduced. He appreciates every answered question from you because it is a great opportunity for him to get important information from an expert. With your knowledge you will help to improve the working conditions for all workers in the workshop on this tunnel site in Norway.

With the results a recommendation for future tunnel sites should be given. The motivation for you to participate in this interview should be that with this obtained information the productivity in the workshop Solbakk will be raised. Time and cost savings for the company Marti IAV will be the result.

General information:

- Selection of the expert done by the interviewer
- **This interview is absolute anonymous!**
- No wrong or right answers – just honest answers please
- Your answers will help to improve the working conditions for the workers in the workshop

Framework requirement:

- Personal expert interview (Recording + hand notices by interviewer)
- Agree to record the interview? (For preventing data loss) ☐YES ☐NO
- Expert interview with guideline and open questions

Facts of the interview:

- Duration about 45min
- PART 1 – Questions about the searching times of tools and spare parts in the workshop
- PART 2 – Questions about the goods income and the way of material flow in the workshop

Personal facts:

- Age: [ ]
- Are you working in the tunneling workshop of Solbakk? ☐YES ☐NO
- Area of responsibility on this tunnel site:
- Qualification / Position in the company:
- Tunneling workshop experience: [ ] Years of experience

Comments / questions:

Expert #1 Site Solbakk - Norway Date: Time:

1

Figure 66: Start page of the expert interview (Process 1)

Figure 67 shows the first sheet of the expert interview questionnaire for process 3. The goal of this interview is to uncover the weak points in the drill steel documentation and in the drill bits flow. In appendix 36 the rest of the questionnaire can be seen.

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Institute of Business Economics and Industrial Sociology

Expert Interview – Process 3

Expert Interview:

(Introduction – Main part – Conclusion)

Introduction:

The interviewer (Auernig Daniel) writes his Master-Thesis for the Institute of Business Economics and Industrial Sociology at the University of Technology in Graz - Austria. For him you have an expert status due to your experience which you have gained on tunnel sites. The goal of this interview is to uncover the unexplainable high loss of drill bits at the tunnel-site Solbakk. With your experience and knowledge in this branch this circumstances will be improved. The interviewer appreciates every answered question from you because it is a great opportunity for him to get important information from a tunneling expert. With your knowledge you will help to avoid the high loss of drill bits.

With the results a recommendation for future tunneling projects of Marti IAV will be given. The motivation for you to participate in this interview should be that with this obtained information the extreme high loss of drill bits at the tunnel-site Solbakk will be decreased. Cost savings for the company Marti IAV will be achieved.

General information:

- Selection of the expert done by the interviewer
- **This interview is absolute anonymous!**
- No wrong or right answers – just honest answers please
- Your answers will help to improve the working conditions for the workers in the workshop

Framework requirement:

- Personal expert interview (Recording + hand notices by interviewer)
- Agree to record the interview? (For preventing data loss) ☐YES ☐NO
- Expert interview with guideline and open questions

Facts of the interview:

- Duration about 40min
- Questions about loss of drill bits, the documentation and possibilities for improvement

Personal facts:

- Age: [ ]
- Are you working for Marti IAV at the tunnel-site Solbakk? ☐YES ☐NO
- Area of responsibility on this tunnel site:
- Qualification / Position in your company:
- Tunneling experience: [ ] Years of experience

Comments / questions:

Expert #1 Site Solbakk - Norway Date: Time:

1

Figure 67: Start page of the expert interview (Process 3)

The questionnaire for process 3 also has a short introduction and the general information. Experts also must be asked if they agree to the voice recorder. This expert interview contains four main questions and also some sub-questions. These sub-questions guarantee that no important aspect or further question will be missed.

3.3.2.2 Execution of the expert interviews

For process 1 two intern blacksmiths, two intern mechanics and one extern expert had to be asked and interviewed in order to get various opinions and solutions for the relevant problems and questions of this process. According to process 3 two extern mechanics, an intern foreman and an intern leading personal was interviewed. Every expert agreed to the voice recorder and all expert interviews were recorded. These files are at hand of the author because absolute anonymity was promised to the experts. With voice recordings it is possible to complete the handwritten protocol if necessary. Also disturbances or new questions or aspects were written down and implemented into the questionnaire for the next expert interview. It is essential to write down the date and the time of the expert interview.

Remarkable aspect of expert interviews is that the feelings or emotions of experts according to the specific topics are available. Concerning the searching times in the workshop most of the experts were really annoyed if they are also working with these tools. Goods income wasn't really seen as problematic by the involved experts. The extern mechanics were shocked about the amount of the lost drill bits compared to other construction sites. All in all the atmosphere of every single expert interview was pleasant. The interviewer had the feeling that the experts were also a little bit proud to be asked about their own opinion. Willingness to tell was great and after all expert interviews it can be said that this is a great opportunity for the interviewer to get a lot of essential information. But therefore the structure and the questionnaire guideline must be well prepared to ensure a smooth sequence of each single interview. In summary it can be said that on the tunnel construction site in Solbakk is a huge knowledge of different persons and it was important to get this relevant information for the improvement of process 1 and 3. All experts seemed to be very motivated and also their body language showed high interest in solving the existing problems.

3.3.2.3 Evaluation of the expert interviews

In general there was nearly no useless information of an expert regarding to a question or a problem. Especially with the pretest of the expert interview guideline the questionnaires were improved quite well and the experts were quite impressed by the logical structure and the clear questions. After finishing the expert interviews the hypotheses and the leading research question can be answered due to the well-prepared questionnaires.

3.3.2.3.1 Answer of the leading research question and the hypotheses

With all obtained information and data it was obvious that the leading research question of this master thesis can be answered with a big "Yes". It is possible to increase the efficiency of processes at the tunnel site in Solbakk through the introduction of expert interviews! Many interesting and not considered aspects were mentioned by the different experts.

Also the hypotheses for process 1 and for process 3 can be answered after the interviews:

Regarding process 1 it was recognized that it is possible to achieve significant cost savings in the workshop of the tunnel site Solbakk because the different experts gave good solution statements and great ideas for improvement of the existing problems. For them it was totally clear that this can be achieved.

Also for process 3 it can be said that the loss of drill bits can be reduced in order to achieve significant cost savings through the obtained information and solution statements of the experts.

Also some genial citations appeared during the expert interviews. For instance at the expert interview for process 1 the third expert, which is just known to the author, made the following statement: *"I hate it to search hours and hours for tools in the workshop and a lot of tools are missing too. Marti should find immediately a solution therefore because without tools you cannot make any work[110]".* Out of this statement the emotions of this expert can be seen. This dissatisfaction was also recognizable due to some explorative interviews which were made before the questionnaire of the interview.

3.3.2.3.2 Goal of the evaluation

After finishing all expert interviews it was important to find some similar trends or results of all statements of the different experts. The received data or information of each single expert will be compared with the statements of the other experts in order to make a meaningful conclusion. Therefore it was necessary to write down all text passages of each single interview. In this case the voice records are very helpful otherwise it wouldn't be possible to reconstruct the expert interviews in an accurate way. The interest of the evaluation is just on the obtained information and not on the person of the expert. Through usage of the interview guideline the comparability of all text passages of the different experts is given because of the focus onto specific topics. All transliterated interview material of nine completed expert interviews from the construction site Solbakk in Norway is at hand of the author. Breaking the logic structure of the different text passages enabled a better comparability.

3.3.2.3.3 Paraphrasing of the expert interviews of the tunnel site Solbakk

First it was necessary to write down all statements of every expert in their own words. It isn't allowed to deform or add information. Afterwards the transliterated texts had to be read again and the most important text paragraphs of interest had to be excerpted. All these transliterated text passages are also at hand of the author. In the second step it was important to combine similar text passages of just one and to dedicate them to the relevant topic. Attention: In this step all information is collected from one expert. At the third step all similar text passages of all experts are compiled and the headlines will be standardized. Afterwards the headlines of all expert interviews were summarized. A continuous inspection of the classification had to be done in order to avoid data loss or wrong interpretation.

[110] Statement of an expert at the tunnel site Solbakk (Location: 11min27s at voice record 3 – at the authors hand)

Therefore the related passages were listed. In the fourth step it was important to formulate differences and especially similarities of these compressed data and information. Now it was important to make generalizations but just restricted to the executed expert interviews. Understandability and accurate technical term explanations must be considered. Step five allowed including some theory and the theoretically classification of the single translated themes according to their internal relation. All themes and texts which were translated are at hand of the author. In the following the most relevant and important aspects and measures out this expert interview material for process 1 and for process 3 are shown:

<u>Paraphrasing of process 1 – most relevant measures and generalizations:</u>

- Reduce searching times for tools and spare parts
    - Introduction of a storekeeper who is responsible for ordering, repair and documentation of tools
    - Restrict access of miners and extern workers to the tool container of Marti IAV because they have their own tools
    - Engraving of tools for each working shift to avoid burglary among workers

- Shorten the way of the steel material flow
    - This situation is bad but the arrangement of the machines in Solbakk cannot be changed anymore because there is less space besides portal crane rail
    - Space is limited even if huge tunneling vehicle drive into the workshop

- Improve the situation with the goods income
    - Introduction of a storekeeper which can also remove and order the spare parts
    - Large spare parts and material must be unloaded in the new storage tent

<u>Paraphrasing of process 3 – most important aspects and measures:</u>

- Drill bits loss – Problem:
    - Four foreman have a key for the storage container
    - Normally 1 or 2 persons give out the needed drill bits
    - Foremen occasionally take new instead of re-grinded drill bits
    - No or wrong documentation of the drill bits flow
    - Much more drill bits go out than in the storage container
    - Often foremen give their key to miners and the miners don't write the drill bits
    - Occasionally miner throw away the used but re-grind able drill bits
    - Bad awareness and attitude of the foremen

- Solution:
    - A responsible person must give out the required and take back the used drill bits twice per day to the foremen at 05:30 and at 17:30 for a half hour to overlap the two tunnel shifts
    - A work shift gets maximum 30 pieces of drill bits for twelve hours

- o Foremen have to bring back the used drill bits after drilling to the responsible person in order to get new drill bits at the beginning of the new shift
- o To improve the bad documentation a new sheet must be made, which also includes damaged, lost or even wasted drill bits (Already done: Appendix 19)
- o Educate the miners and foremen to save money and to bring back the bits

3.3.3 Implementation of the expert solution statements

With the received information out of the expert interviews according to process 1 and 3 it was important to redraw the existing business process modeling notations BPMN A and BPMN B under consideration of the main key points of paraphrasing.

3.3.3.1 Target state of BPMN (A)

Out of the expert interviews with different experts it was recognized that all experts had the same opinion that an own storekeeper is urgent missing at the tunnel site Solbakk. This is the main weak point of the existing process. Everybody had access to the tool container and nobody documented borrowed tools. Removing of incoming goods did every worker and occasionally these boxes and palettes couldn't be found by others. Result was that some orders were ordered twice because there was no overview about the incoming goods in the workshop hall of Solbakk. With the introduction of a storekeeper this problems will disappear. The storekeeper would be also responsible for removing the incoming goods and for ordering needed spare parts or even tools. This person has a key position in the eyes of different experts at this tunnel site. Also the access of the miners into the tool container must be restricted in order to keep the overview about borrowed tools. The miners can come into the workshop hall but if they need tools they have to ask the storekeeper. If they borrow additional tools the storekeeper will make notices about these tools and the person which takes the tools. Also blacksmiths or mechanics have to ask the storekeeper if they need additional or special tools. It can be seen that the storekeeper is the central person within the workshop. Even if a mechanic needs some spare parts he will not have to search on his own because the storekeeper is than responsible for ordering and storing the incoming goods and also spare parts. Much better overview will be the result because there is finally one responsible person for these tasks. According to the experts just with the introduction of a new guy this situation can be changed. This new storekeeper will work inside and around of the workshop hall. If workers urgent need tools and the storekeeper can't be seen they can call him on his phone. All required tools and spare parts will be ordered just by the storekeeper. The blue boxes represent the operating instruction process (Process 2). This procedure wasn't changed. The yellow boxes represent the long ways of the steel material flow. According to the expert interviews this situation can't be changed anymore because of less space due to the portal crane rail in the workshop. But there is room for improvement especially for generating new workshop layouts for future tunneling projects. This thesis will not handle the improvements of better workshop layouts for tunnel sites. A recommendation for the company is that all heavy incoming parts and goods should be stored in the storage tent besides the workshop hall. For all ordering and removing processes the storekeeper will be responsible. He has the key positon and the overview about the flow of tools, spare parts and incoming goods. Figure 68 shows the improved BPMN (A) model for process 1. A bigger illustration can be seen in appendix 37. All grey tasks involve a new storekeeper which should be available on this tunnel site. This is a recommendation for the company Marti IAV.

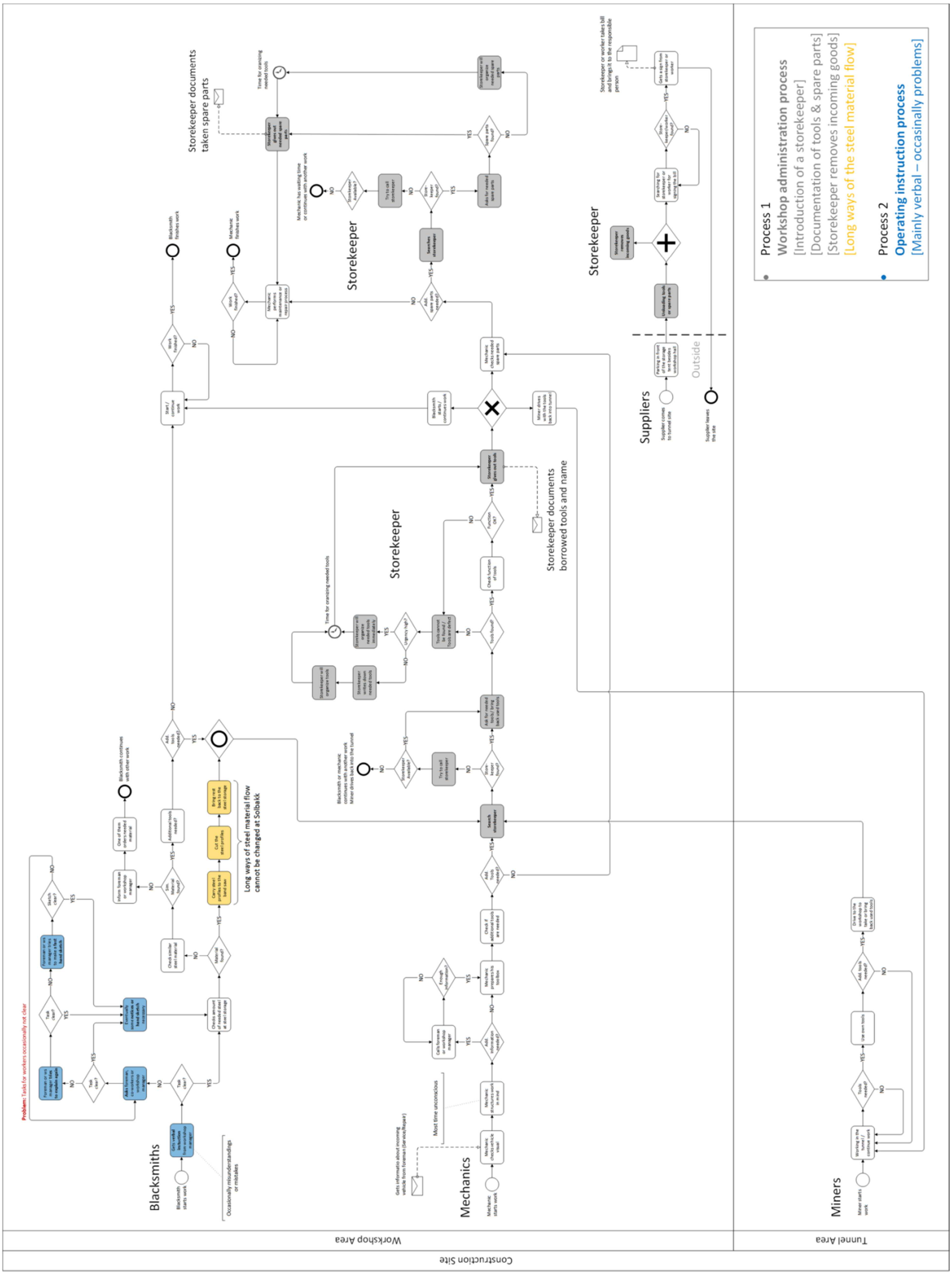

Figure 68: BPMN (A) of the target state including process 1 and 2

3.3.3.2 Target state of BPMN (B)

For the drill steel administration process some significant problems were detected through the execution of the expert interviews. For instance four foremen had access to the drill steel grinding or storage container. On other tunnel sites there are one or maximum two people which give out the drill bits according to the extern experts. At the tunnel site Solbakk a big problem is also that some foremen gave their key to their miners and these miners drove out of the tunnel to take new drill bits. The miners didn't write down the taken drill bits and were not interested to bring back the used drill bits. Also the foremen had difficulties to fill out the old drill steel documentation sheets (Appendix 19). Through explorative interviews this sheet had been improved (Appendix 20). Now it is possible to write down also lost, broken or other drill bits which remained in the stone of the tunnel. According to the workshop manager the loss of drill bits is about 800 pieces per month (Status October 2014). Out of the expert interviews it can be said that the awareness especially of the foremen leaves a lot to be desired in this case. Through their leading function they should set a good example. In the target state the miners aren't allowed to throw away the used drill bits because they are very expensive and can be re-grinded minimum five times according to the extern experts. The awareness of the miners and their foremen must be urgent raised in order to improve the existing problems. Marti IAV hired an own grinder in October 2014 but there aren't many drill bits coming back into the storage or grinding container. Solution therefore is that this person must give out and take back the needed drill bits per day. This person is also responsible for the documentation of the drill bits flow. Of course the used drill bits will be re-grinded by the grinder too. In fact that every day two shifts are working in each tunnel there must be opening times in the storage container and the grinder will be responsible for the outgo and the income of the drill bits. Opening times could be from 05:30 to 06:00 and from 17:30 to 18:00 from Monday to Saturday. This person which grinds and documents the drill bits has a very important function for the company Marti IAV. A generalization out of the expert interviews according to process 3 also showed that the awareness of the miners and the foremen must be raised to achieve cost savings. After the shift is over the foremen must bring back the used drill bits immediately to the storage container where the grinder is awaiting them. High loss of drill bits would be easy visible and not be accepted anymore by the company Marti IAV. The awareness will be high to bring back all drill bits according to the experts because otherwise the foremen will not get new drill bits. A box for putting in the used or even broken drill bits makes the transportation of the drill bits much easier. The documentation about the flow of drill bits could be done by the grinder too because he is every day in the storage or grinding container. Marti IAV needs a responsible person for supervising the flow of drill bits and the grinder can do the documentation besides his work. In accordance to the time target of appendix 18 the needed hours for re-grinding the maximum required amount of drill bits per day takes nine hours with the average taken times per drill bit. This person has the capacity to make the documentation besides grinding.

In figure 69 the improved target state of the BPMN for process 3 can be seen. In appendix 38 a larger image of this BPMN (B) can be seen. In this case the purple boxes are tasks where the grinder is involved. Brown tasks represent a box where the used or new drill bits put into and will be transported by foremen in and out of the tunnel.

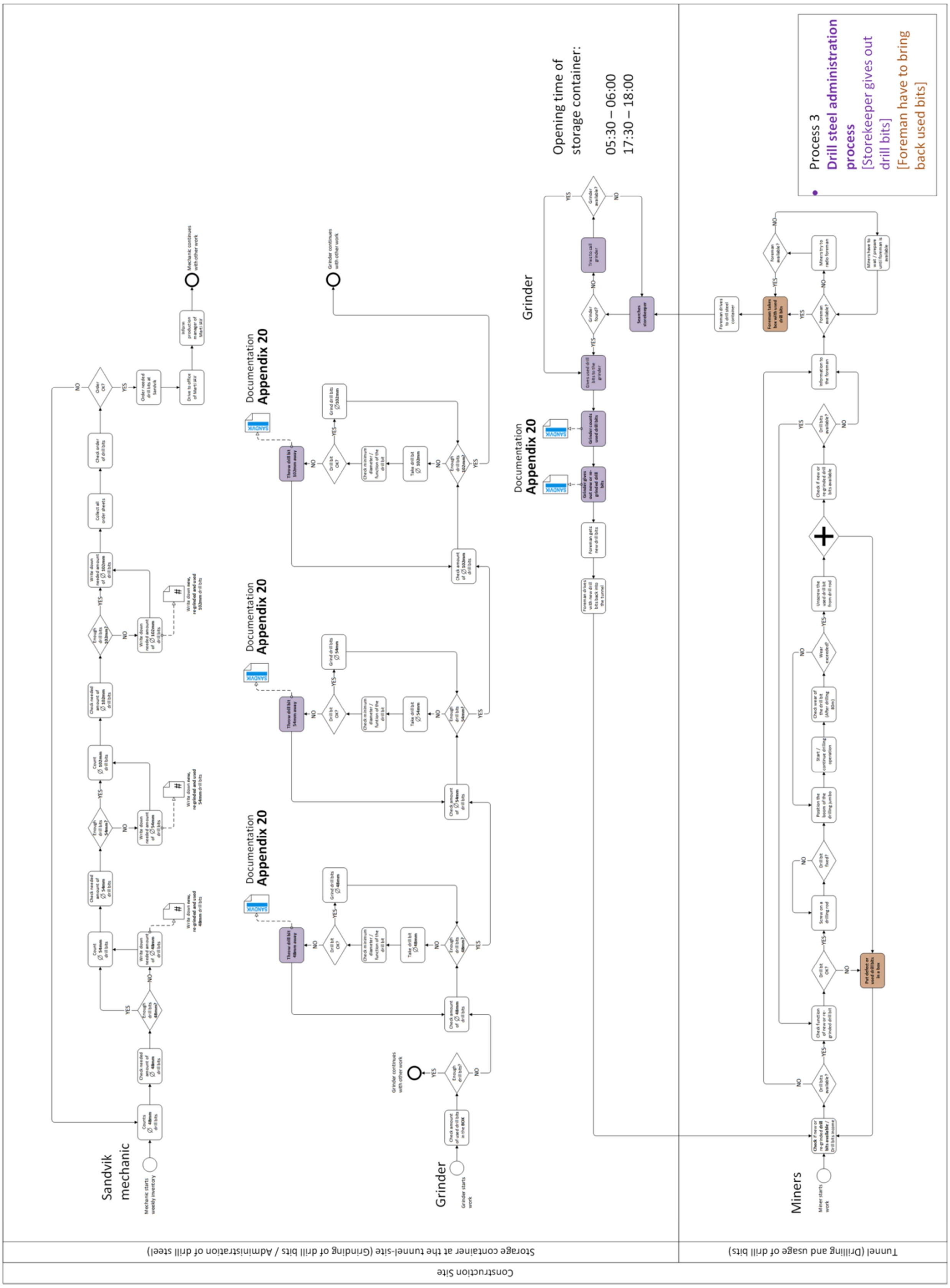

Figure 69: BPMN (B) of the target state of process 3

In this illustration it can also be seen that the grinder has to write down also the broken or too small drill bits into the new sheet for documentation (Appendix 20). These defect or too small drill bits weren't written down before. Normally the grinder will be always available in the storage or grinding container. Just foremen are now allowed to drive into the storage container and they have to bring back the used drill bits because otherwise they will not get new one. The awareness for bringing back the used drill bits will be high by the foremen because Marti IAV will not tolerate such high loss of bits anymore.

3.3.3.3 Target costs of the improved processes

These improved BPMN models were shown to the workers and experts at the tunnel site in Norway. In this sub-chapter the target costs for process 1 and for process 3 will be analyzed.

3.3.3.3.1 Target costs for process 1

The main improvement of the workshop administration process is the introduction of a new storekeeper. This person will have a key function on this tunnel construction site because the storekeeper will give out and take back the needed tools for the workers. Also the documentation of the borrowed tools will be done by this person. The storekeeper will also have the total overview about the incoming goods and the spare parts. Ordering of tools and spare parts is also in his area of responsibility. All experts which were interviewed in the expert interviews had the same opinion that this person is urgent needed at this site in Norway. The improved BPMN (A) model was shown and explained to the workers of the workshop (Appendix 37). Through explorative interviews the same workers had to make estimations how long they would search for tools and spare parts if there would be a responsible storekeeper at this site. Table 16 shows the estimated time of the workers in the workshop. According to these experts a time reduction for this procedure will occur in Solbakk. Most of them agreed immediately that this is a great idea for improvement.

Date	Name	Min / day	Min / 6 days	Min / month
31.07.2014	Worker 1	**20**	120	480
31.07.2014	Worker 2	**15**	90	360
31.07.2014	Worker 3	**30**	180	720
01.08.2014	Worker 4	**20**	120	480
31.07.2014	Worker 5	**25**	150	600
25.07.2014	Worker 6	**35**	210	840
01.08.2014	Worker 7	**20**	120	480
01.08.2014	Worker 8	**15**	90	360
01.08.2014	Worker 9	**25**	150	600
	Average time [min]	**23**	**SUM / Month [min]**	**4920**
	Average time [h]	**0,4**	**SUM / Month [h]**	**82**

Table 16: Target searching times for tools and spare parts in the workshop

With the introduction of a storekeeper the average searching time for tools and spare parts on the tunnel site Solbakk would be 23 minutes per worker per day. Out of these interviews the urgency for the introduction of a real responsible storekeeper was recognizable. There are always just two of three shifts at this tunnel site with three workers per shift. That means that there are always six workers available per day in the workshop from Monday to Saturday. Table 17 shows the target searching time for tools and spare parts per two shifts per month. The time for searching would be 55 hours per month. This value is rounded and was calculated by multiplying the average searching time per person, which is 0.4 hours in average, with the amount of six workers per day. This result was multiplied with six because there are six working days per week. The sum for the searching time for tools and spare parts of six workers in the workshop per month would be 55 hours.

Time / day [h]	Time / week [h]	Time / month [h]
2,3	14	55

Table 17: Target searching times for tools and spare parts per two shifts per month

Target costs would be these 55 hours multiplied with the wage rate of a Slovakian mechanic or blacksmith. This wage rate is 32,51€/h according to the exchange rate of the European Central Bank (ECB 05.04.14 22:40). The wage rate is pre-tax and was received for this calculation from the financial manager of the tunnel site Solbakk. Because just the storekeeper would be responsible for removing the incoming goods all other workers in the workshop would not be disturbed anymore.

$$55h + 0h = 55h$$

The sum of the estimated searching times of all workers in the workshop of Solbakk would be **55 hours** per month. Wage rate of a Slovakian blacksmith or mechanic is 267 NOK/h. This is **32,51€/h.**

$$55h * \left(\frac{32{,}51€}{h}\right) = 1.788{,}05€$$

$$\frac{1.788{,}05€}{month} * 12months = 21.456{,}6€$$

$$\frac{21.456{,}6€}{year} * 5years = 107.283€$$

Sum of the average searching time per month per available workers multiplied with the wage rate of a Slovakian worker produces overall costs of **1.788,05€/month**. According to five years of production this would cause **107.283€/5years**. In chapter 3.3.4 the resulting cost savings can be seen. Also the additional costs for hiring a new storekeeper will be considered in this sub-chapter.

3.3.3.3.2 Target costs for process 3

The improved BPMN (B) model was shown to some experts and with explorative interviews it was found out that with these improvements the loss of drill bits would be 50 pieces on average. These experts were quite sure that this would be possible because the foremen must bring back the used or broken drill bits in order to get new one of the grinder in the storage container. If some drill bits are remaining in the rock of the tunnel the foreman has to explain that to the grinder and he will notice that. The grinder will have an overview about the entire flow of these drill bits and should also be responsible for the documentation of them. Also the foremen and their miners must be educated about the importance of bringing the drill bits back into the storage container. If the loss should increase the grinder has to alarm the responsible production managers of Marti IAV.

Assumption: 60 pieces of drill bits are used every day. With an account settlement the percentage of needed 48mm drill bits is 83,33%, of 54mm drill bits is 13,33% and the 102mm reaming bits have an percentage of 3,33% according to 60 pieces and their used frequency. This means for the 50 missing bits per month that the percentages have to be multiplied with 50 in order to obtain the loosed amount of each type of drill bit.

$$50\ \# * 83{,}33\% = 42\ \#\ 48mm\ drill\ bits$$

$$50\ \# * 13{,}33\% = 7\ \#\ 54mm\ drill\ bits$$

$$50\ \# * 3{,}33\% = 2\ \#\ 102mm\ drill\ bit$$

Out of the total sum of the lost drill bits per month the partial amount of 48mm bits is 42 drill bits, of 54mm bits is 7 pieces and of 102mm reaming bits is 2 drill bits. All these values were rounded. In the following the needed amount of each drill bit type is multiplied with its price and the sum of all three types is build:

$$\left(42\# * 59{,}37\frac{€}{\#}\right) + \left(7\# * 94{,}00\frac{€}{\#}\right) + \left(2\# * 230{,}06\frac{€}{\#}\right) = 3.611{,}66€$$

The target total costs for lost drill bits according to the estimation is **3.611,66€ per month.** But also the costs for the grinder have to be considered like in the following:

$$\frac{3.611{,}66€}{month} * 12months = 43.339{,}92€$$

$$\frac{43.339{,}92€}{year} * 5years = 216.699{,}6€$$

For **five years of drill and blast excavation** the target total costs would be **216.699,6€** under consideration of these improvements. In the following sub-chapter the cost savings according to five years of drill and blast excavation will be shown.

3.3.4 Cost savings at the tunnel site Solbakk

Finally the resulting cost savings of process 1 and process 3 for Marti IAV will be calculated in this sub-chapter.

3.3.4.1 Cost savings for process 1

The costs for the old process of Marti IAV caused 10.598,26€ per month. In this calculation the long searching times with the additional time for removing of the incoming goods are integrated and this calculation can be seen in chapter 3.2.4.1. With the improvements of this process the monthly target costs would be 1.788,05€ according to the obtained information out of explorative interviews. This calculation can be seen in chapter 3.3.3.3.1. To achieve these lower costs it is also necessary to take the additional storekeeper into account:

$$10.598{,}26 - 1788{,}05 = 8.810{,}21€\ cost\ savings\ /\ month\ without\ consideraiton\ storekeeper$$

But therefore the storekeeper must be subtracted. As assumption Marti IAV could take a Slovakian worker with the wage rate is 32,51€/h according to the exchange rate of the European Central Bank (ECB 05.04.14 22:40).This person works five days per week and has eight hours per day:

$$8.810{,}21 - \left(\frac{32{,}51€}{h} * 8h * 5d * 4\right) = 3.608{,}61€\ cost\ savings\ per\ month$$

Under these assumptions the **cost savings** are **3.608,61€ per month.** In the following the calculation is continued for a year and for five years of drill and blast excavation:

$$\frac{3.608{,}61€}{month} * 12months = 43.303{,}32€\ cost\ savings\ per\ year$$

$$\frac{19.896{,}12€}{year} * 5years = 216.516{,}6€\ cost\ savings\ per\ five\ years$$

Accumulated to a year these cost savings will be 43.303,32€. For **five years of drill and blast excavation** this means **cost savings** of about **216.516,6€** at the tunnel site Solbakk. All workers and miners should come to the storekeeper within his working times. Also the responsible foreman of the shift must get a key for the tool container if the storekeeper isn't available. These guys must cooperate and the foreman must also write down all borrowed tools. If many tools aren't written down or even lost the storekeeper must inform the management of the company Marti IAV. Most important improvement in this process is that the storekeeper has the necessary overview about the tools and spare parts in the tunnel workshop of Solbakk.

3.3.4.2 Cost savings for process 3

According to the status of October 2014 there are 800 drill bits missing on average. This causes costs of 55.869,41€ per month. Marti IAV hired already in October a grinder for grinding of the drill bits. This person must be responsible for the outgo and intake of the drill bits in order to avoid such a high loss. Also the documentation could be done besides his regular job. With these improvements the target costs for lost drill bits would be 3.611,66€ per month. Cost savings per month would be following:

$$\frac{55.869{,}41€}{month} - \frac{3.611{,}66€}{month} = 52.257{,}75€\ cost\ savings\ per\ month$$

Cost savings per month would be 52.257,75€. The additional expenses for the grinding personal must be also included. The grinder will have to work five days with twelve hours each day. As assumption Marti IAV should take a Slovakian worker with the wage rate of 32,51€/h.

$$52.257{,}75€ - \left(\frac{32{,}51€}{h} * 12h * 5d * 4\right) = 44.455{,}35€\ cost\ savings/month\ with\ grinder$$

In the following this calculation is continued for a year and for five years of drill and blast excavation:

$$\frac{44.455{,}35€}{month} * 12months = 533.464{,}2€\ cost\ savings\ per\ year$$

$$\frac{533.464{,}2€}{year} * 5years = 2.667.321€\ cost\ savings\ per\ five\ years$$

Accumulated to a year these cost savings for process 3 would be 533.464€. In accordance to five years of drill and blast excavation this would cause incredible cost savings of about 2.667.321€.

ATTENTION: A further consideration must be done according to some extern experts. If new drill bits are thrown away after one single usage there will be much more costs for the company because these new drill bits can be re-grinded minimum five times according to extern experts of the company Sandvik. In that case this would mean that if the **drill bits** are used for the first time they could be **re-grinded additional four times**. This means that all **cost savings** which are calculated in this sub-chapter must be **multiplied** with the **factor 4.** These costs are the real costs which could be saved.

$$44.455{,}35€\frac{cost\ savings}{month} * 4 = 177.821{,}4€\ real\ cost\ savings\ per\ month$$

$$533.464,2€ \frac{cost\ savings}{year} * 4 = 2.133.856,8€\ real\ cost\ savings\ per\ year$$

$$2.667.321€ \frac{cost\ savings}{5\ years} * 4 = 10.669.284€\ real\ cost\ savings\ per\ five\ years$$

According to the repetitive grind-ability of the drill bits the real **cost saving**s for Marti IAV according to **five years of drill and blast excavation** would be **10.669.284€.**

3.3.4.3 Total cost savings according to five years of drill and blast excavation

The cost savings for process 1 and process 3 can be added in order to get the total cost savings for this thesis at the tunnel site in Norway:

$$43.303,32€ \frac{cost\ savings}{year} + 2.133.856,8€ \frac{cost\ savings}{year} = 2.177.160,12€\ cost\ savings\ /\ year$$

Under consideration of all improvements and solution statements out of the expert interviews the **total cost savings** for the company Marti IAV would be **2.177.160,12€ per year.** For five years of drill and blast excavation the total cost savings regarding process 1 and process 3 are calculated in the following:

$$216.516,6€ \frac{cost\ savings}{5\ years} + 10.669.284€ \frac{cost\ savings}{5\ years} = 10.885.800,6€\ cost\ savings/\ 5years$$

Total cost savings of process 1 and process 3 regarding to **five years of drill and blast excavation** in Solbakk would be altogether **10.885.800,6€.** Main part of these cost savings could be achieved through the improvements in process 3.

4 Summary and conclusion

In the last chapter of this thesis there will be a short summary about the results which were achieved at the tunnel construction site Solbakk in Norway. Afterwards an outlook as well as some recommendations for handling future tunneling projects will be shown.

4.1 Summary of the thesis

This thesis handled three different processes which are located at the construction site Solbakk in Norway. In the following sub-chapters the summary of each single process is given:

4.1.1 Summary workshop administration process (Process 1)

Due to explorative interviews and co-operation at this construction site it was possible to detect the weak points within the workshop administration process. With BPMN the existing flow of tools and spare parts was drawn and can be found in appendix 28. Through explorative interviews the weak points were evaluated. Main weak point within this BPMN (A) was that everybody had access to the tool container in the workshop. With the introduction of expert interviews this process was improved with the solution statements of all different experts. Main improvement was the new storekeeper in the workshop hall. The improved BPMN (A) model can be seen in appendix 37 at the end of this thesis. According to the process improvements the **cost savings** for this process would be **216.516,6€ per five years of drill and blast excavation** at this tunnel site in Norway. Central person of interest within this process for ordering and administering of tools and spare parts will be the new introduced storekeeper at this tunnel construction site. All other improvements and recommendations can be seen in previous chapters.

Long ways of the steel material flow can be seen in figure 31. During expert interviews it was found out that it isn't possible to improve the current arrangement of the machines. Main problem is the portal crane rail and less space at the side of the rail. For future tunneling projects the company should establish some appropriate layouts in order to increase the efficiency of the workshop team and to save further costs.

4.1.2 Summary operating instruction process (Process 2)

For the operating instruction process it can be said that the efficiency of blacksmiths in Solbakk can be raised also for simple steel constructions like in this thesis. In chapter 3.1.2 the increase in efficiency can be seen. The blacksmiths accepted the introduced CAD drawing sets and the feedback of the workers in Norway was quite positive. With drawing sets in combination with the appropriate bill of material it is possible to achieve tremendous increase in efficiency of the blacksmiths. The costs for the program and the constructing engineer hadn’t to be considered for this thesis. Before an introduction of a new CAD program all relevant factors should be considered by Marti IAV.

4.1.3 Summary drill steel administration process (Process 3)

An essential improvement of the drill steel documentation sheet (Appendix 19) was made through some explorative interviews at the site. The upgraded sheet can be found in appendix 20. All unknown grinding parameter of the grinding process were obtained through practical grinding of the different drill bits. The scientific analysis of the grinding statistics can be seen in the appendix. Due to explorative interviews and cooperating at this construction site it was also possible to draw the BPMN (B) model which can be seen in appendix 32. Within this process illustration it was possible to see the weak points of the drill steel flow at this site. Afterwards some expert interviews were made for the purpose of improving this BPMN model. With the obtained information and solution statements of the experts at the site this process was successfully improved and this improved BPMN (B) model can be found in appendix 38. With the improvements of process 3 significant cost savings can be made. The **cost savings** for **five years of drill and blast excavation** at the tunnel site Solbakk are **10.669.284€.** According to the experts this sum can be saved with the measures what must be transferred at this construction site.

4.2 Recommendation for future tunneling projects of Marti IAV

Main part of the cost savings could be achieved through process improvements of the drill steel administration process. The company Marti IAV should focus especially on these improvements which were figured out due to this thesis in order to achieve significant cost savings in future tunneling projects. For the workshop administration process the cost savings are compared to the drill steel administration process rather small but the urgency for the introduction of a new storekeeper was recognizable during this thesis. In general the workers in the workshop were quite unsatisfied with the high searching times and the missing overview about the tools and spare parts at this tunnel construction site. Marti IAV should also consider that the factor motivation of workers in the workshop could be raised if the company would hire a responsible person for the administration of the required tools and spare parts.

A further recommendation for Marti IAV is that the company should make some workshop layouts for future tunneling workshops. With explorative interviews it was found out that there are no predefined layouts for tunnel workshops at hand. Also the long ways of the steel material flow must be shortened in order to increase the efficiency of the workshop personal. If proper defined workshop layouts will be developed and used in future a high increase in efficiency of the whole workshop unit will be achieved and further significant cost savings will be the result.

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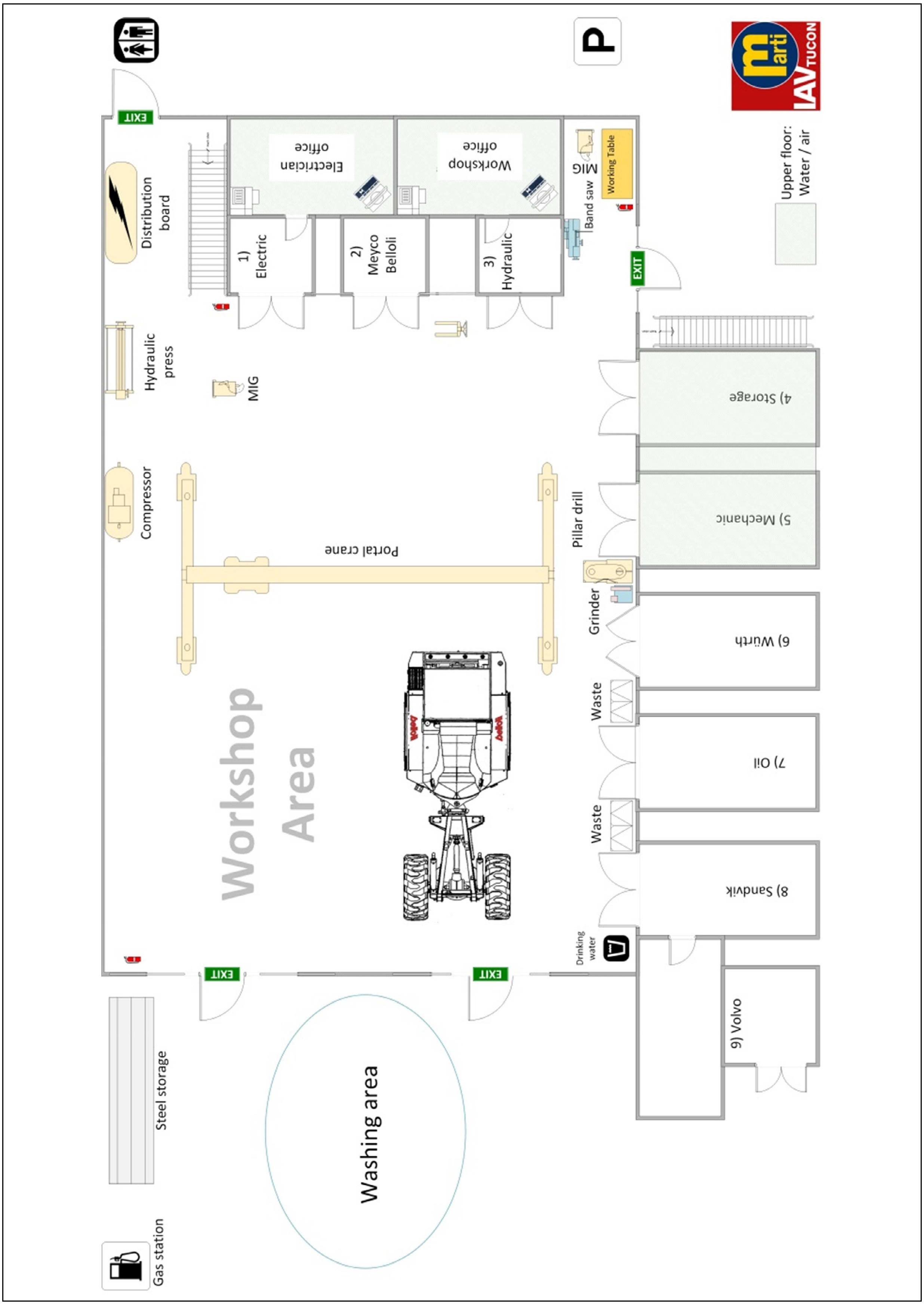
Table of abbreviations

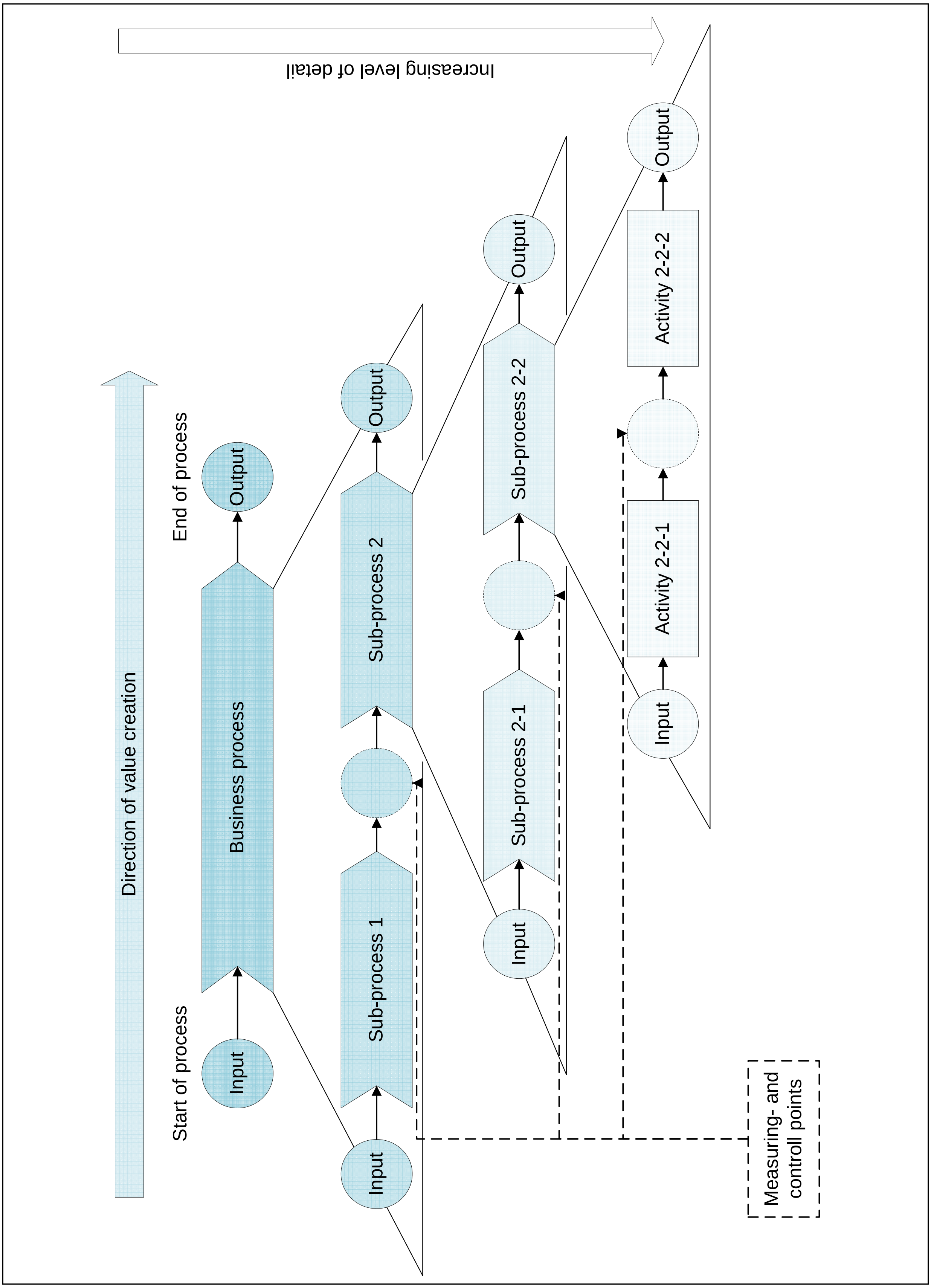
BOM	Bill of material
BPD	Business process diagram
BPMN	Business process model and notation
CAD	Computer aided design
DR	Drill rig
EPC	Event driven process chain
€	Euro
HR	Human resource
PO	Process objective
TBM	Tunnel boring machine
VCD	Value chain diagram

Appendix

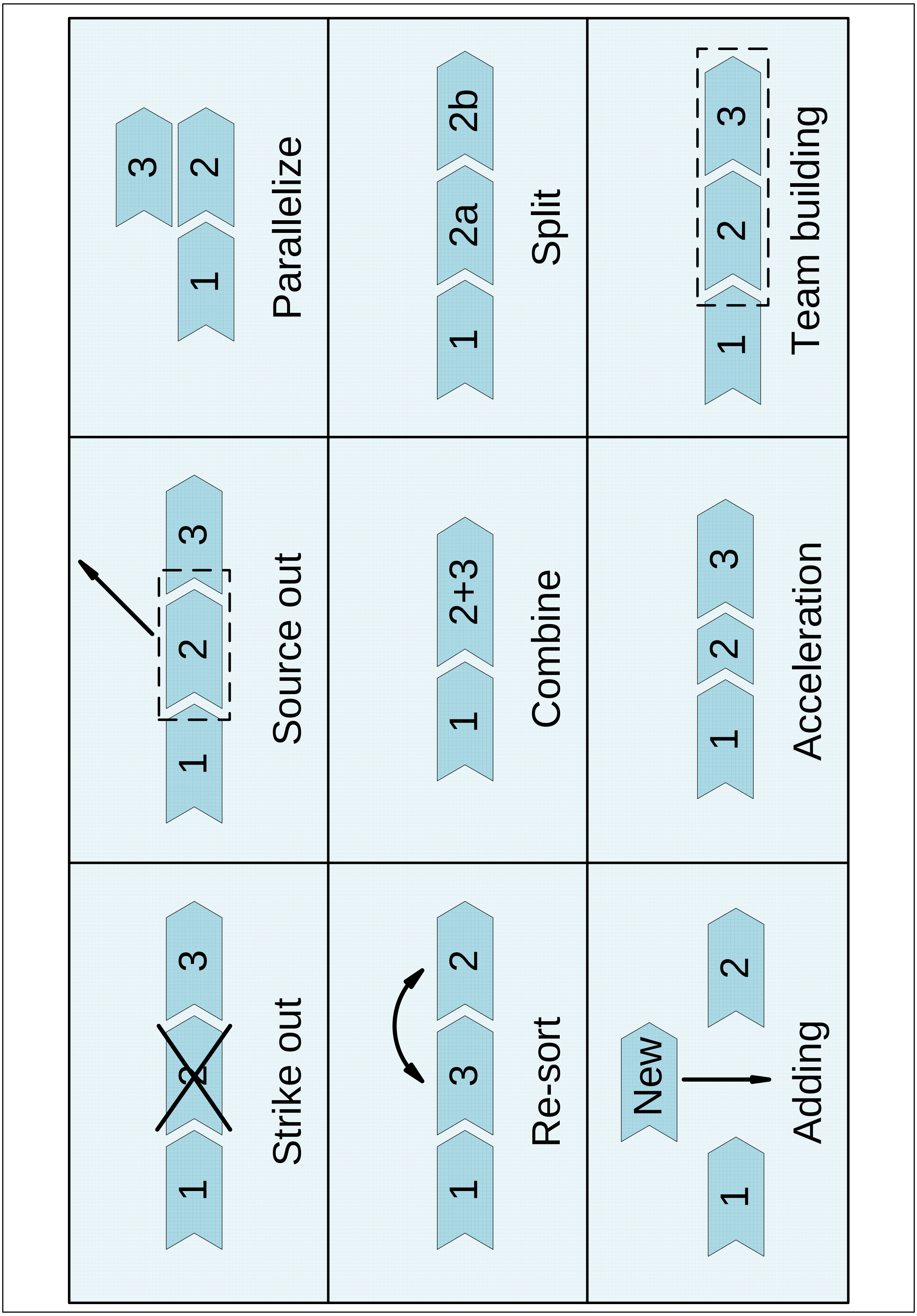
Appendix 1: Plan view of the workshop hall in Norway in May 2014



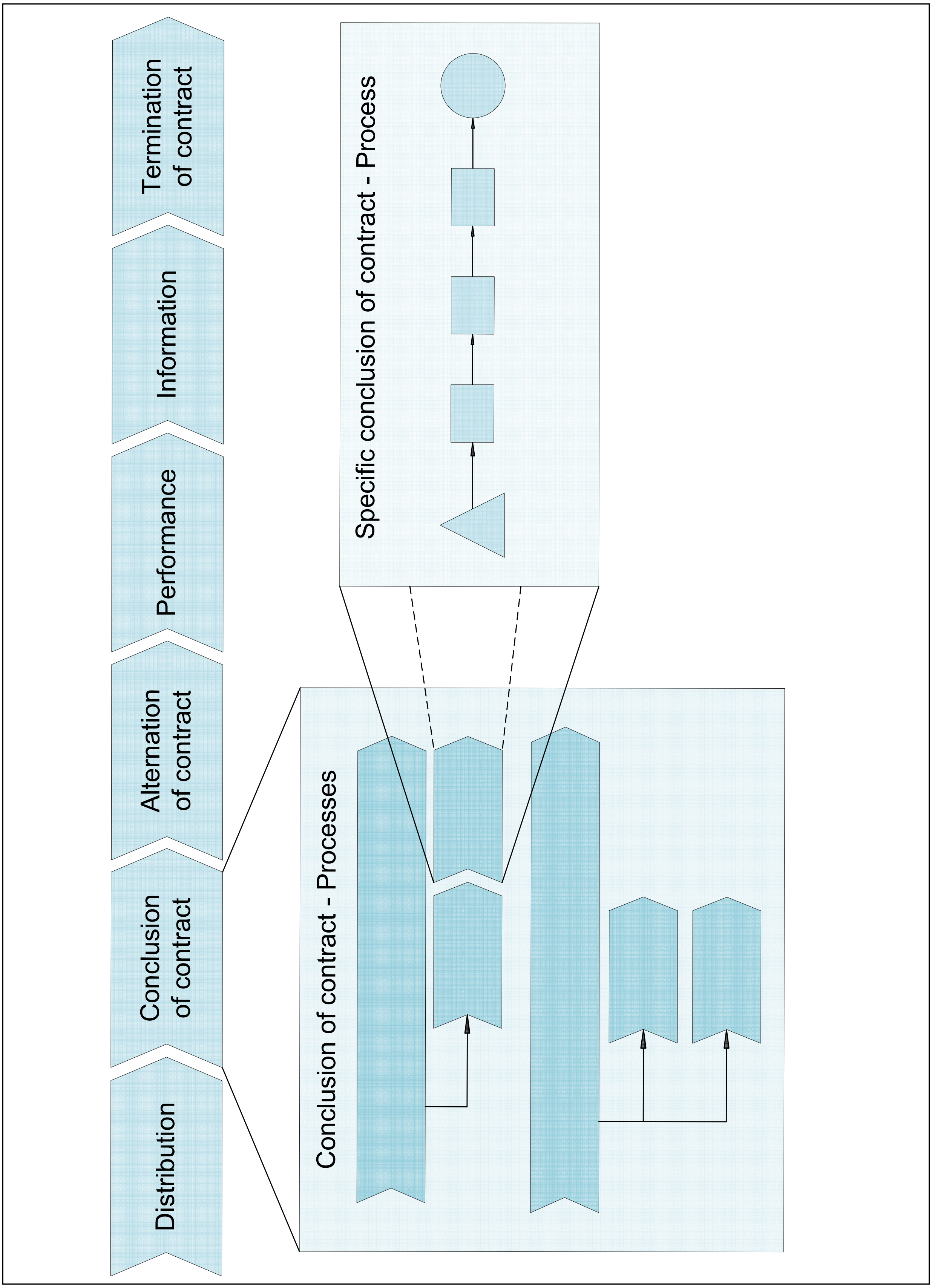
Appendix 2: Business process with refinements



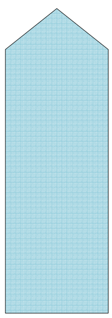
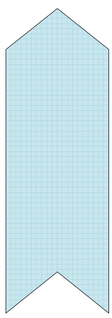
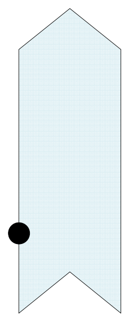
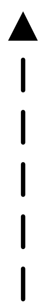
Appendix 3: Improvement opportunities between processes



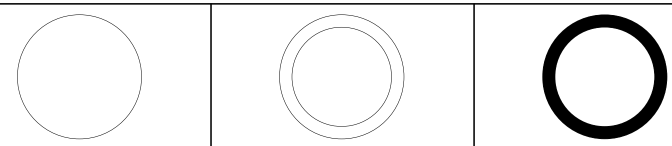
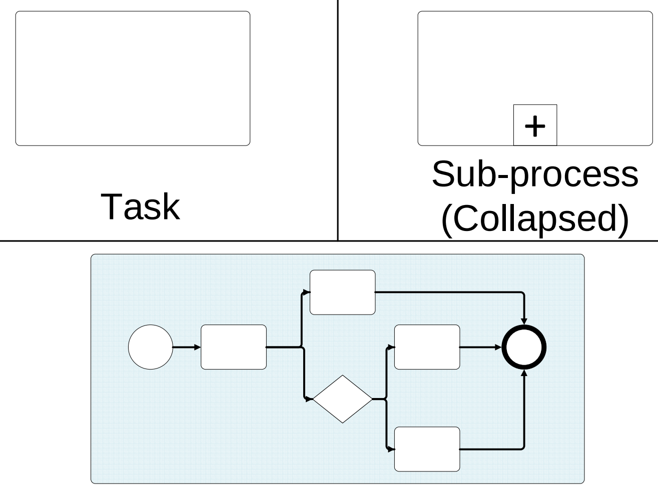
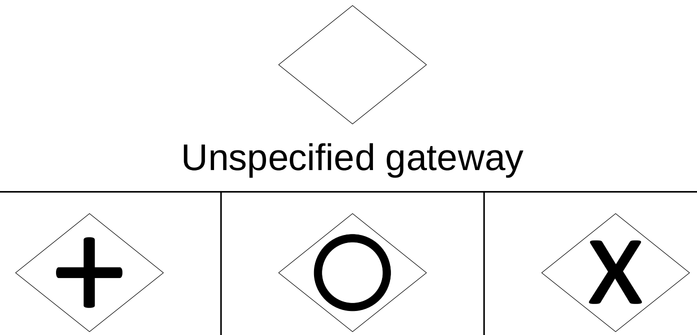
Appendix 4: Example for structuring a process map



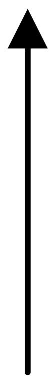
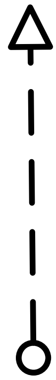
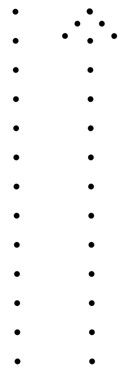
Appendix 5: Value chain diagram (Notation)

Symbol	Name	Description	Edge- / node type
	Start function	Description of a function which starts a process chain on a high level of abstraction	Activity node
	Follow-up function	Description on a previous function following function on a high level of abstraction	Activity node
	Itemization follow-up function	Marking of a function which will be detailed through a further model (Concept of hierarchy)	Activity node
	Follower	Control flow for follower. Links successional functions	Control flow edge
	Parallel process	Control flow of parallel functions. Links parallel running sub-functions of an higher main function	Control flow edge

Appendix 6: Flow objects

Event	An event is something what happens during a business process and it influences the cycle of the process. As a rule an event has a trigger and/or a result.	
Activity	An activity represents the work / action in a company. An activity can be a task or a sub process, which can consist out of more tasks.	
Gateway	A gateway controls the flows. The way of control, for instance AND, OR, XOR, will be identified with an appropriate symbol. A gateway can be a decision point or merging and accordingly split up different, parallel flows.	

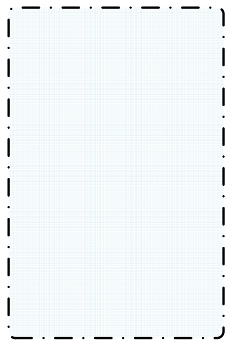
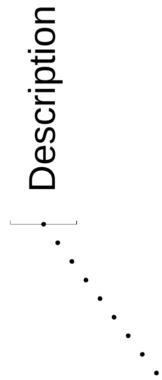
Appendix 7: Connecting objects

Sequence flow	With sequence flows the sequential arrangement between flow objects will be defined.	
Message flow	A message flow represents the communication between two process involved persons. For example in the swim lane illustration is every pool process involved.	
Association	With associations the allocation of artifacts like data objects or text annotations to flow objects is possible. They show the input or output of an activity.	

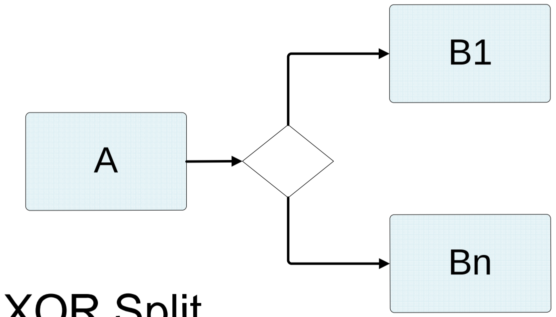
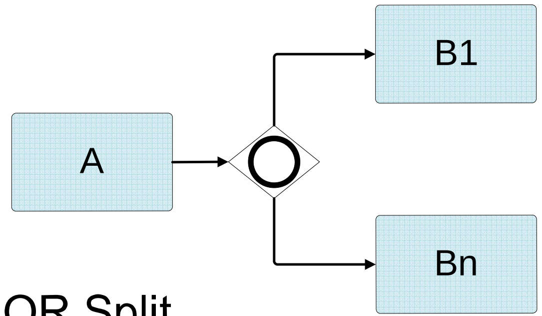
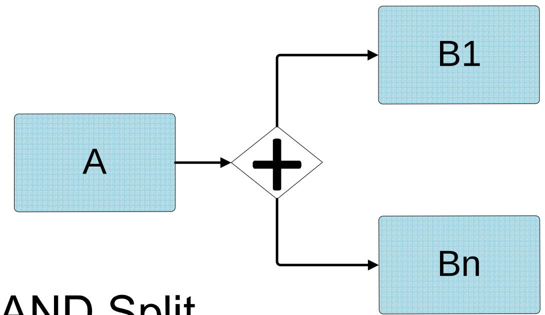
Appendix 8: Swim lanes

Pool	A pool is representing a process participant and is for the differentiation of activities among each other and for the allocation of activities in areas of responsibility.	
Swimlane	Lanes are divisions of a pool. With lanes it is possible to organize and categorize activities.	

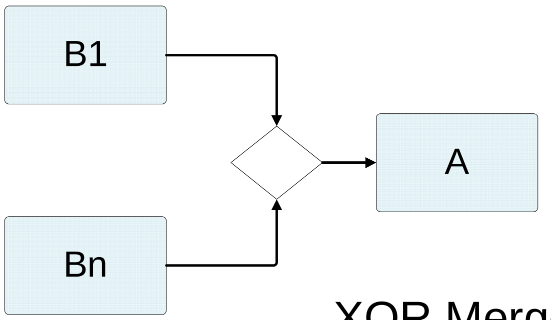
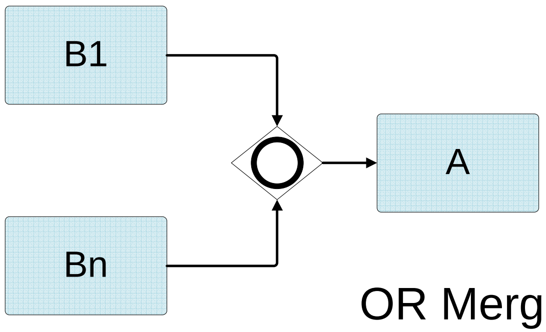
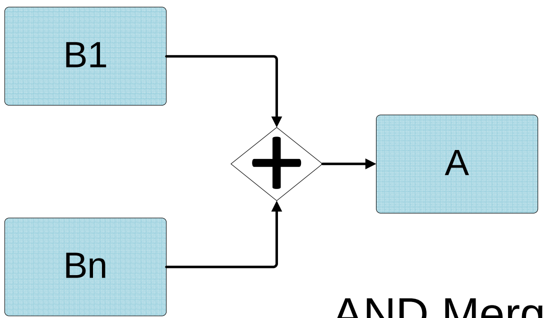
Appendix 9: Artifacts

Data object	Data objects show which kind of data are created through an activity or which data is needed for an activity.	
Group	A group enables the possibility to allocate some optic to a group. The sequence flow will not be affected.	
Annotation	With annotations the modelling can show additional information in the diagram.	

Appendix 10: Constraints for split gateways

Split gateway	Process constraints
 XOR Split	- Only one of the B1 … Bn activities may be started - If A is completed, at least one of the B1 … Bn activities must be created before ending the case
 OR Split	- Since several B1 … Bn activities may be started, we just need to verify that if A is completed, at least one of the B1 … Bn activities is created before ending the case (like in XOR split above)
 AND Split	- If A is completed all B1 … Bn activities must be eventually started.

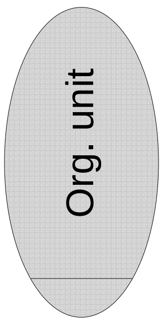
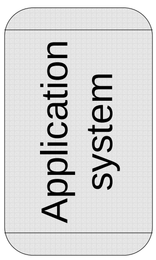
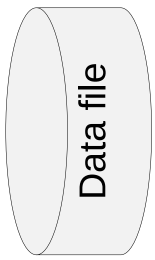
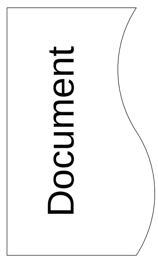
Appendix 11: Constraints for merge gateways

Merge gateway	Process constraints
 XOR Merge	- All A activity instances have as a previous activity instance a completed acitvity instance of type B1 or … or Bn - Each B1 … Bn activity instance is followed by an A activity
 OR Merge	- An A activity instance must wait for at least an incoming flow
 AND Merge	- An activity instance of type A must wait for a set of activities B1 … Bn to be completed. - Each set of completed B1 … Bn activity instances must be related with an A activity instance.

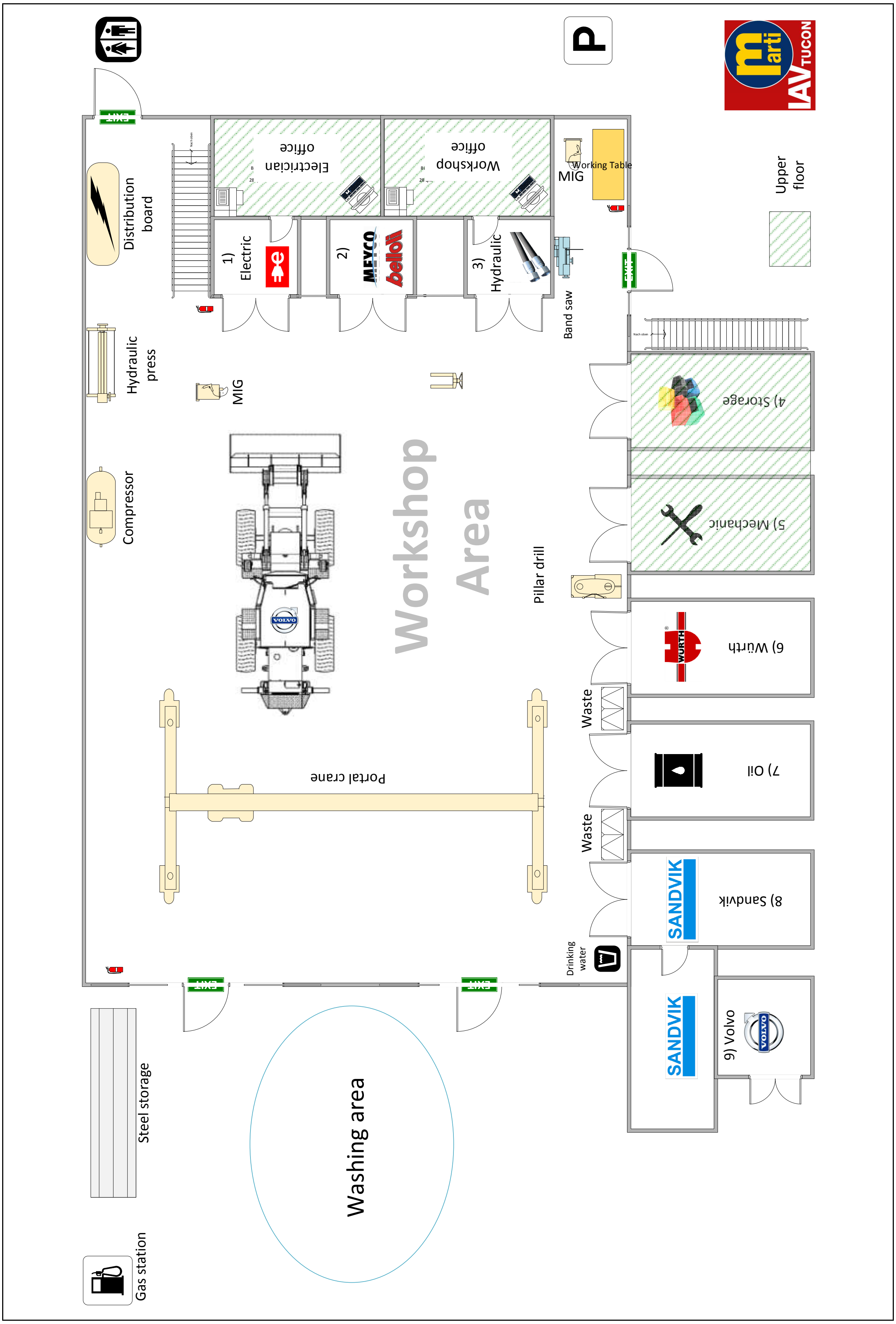
Appendix 12: EPC symbols with description

EPC-Symbol	Name	Description
Event	Event	An event indicates a state or a change in state. At the beginning and at the end of a process or branch of processes is an event.
Function	Function	Functions describe operations (Tasks, activities) which are executed during the course of the process.
Line (Edge)	Line (Edge)	Lines between events and functions are representing the logic flow of the process (Chronologically logic sequence).
V AND XOR XOR Λ OR	Branches in process sequences	Logic rules: • AND: All branches run through parallel. • XOR: Just one branch will be passed through. • OR: One or more branches will be ran through.

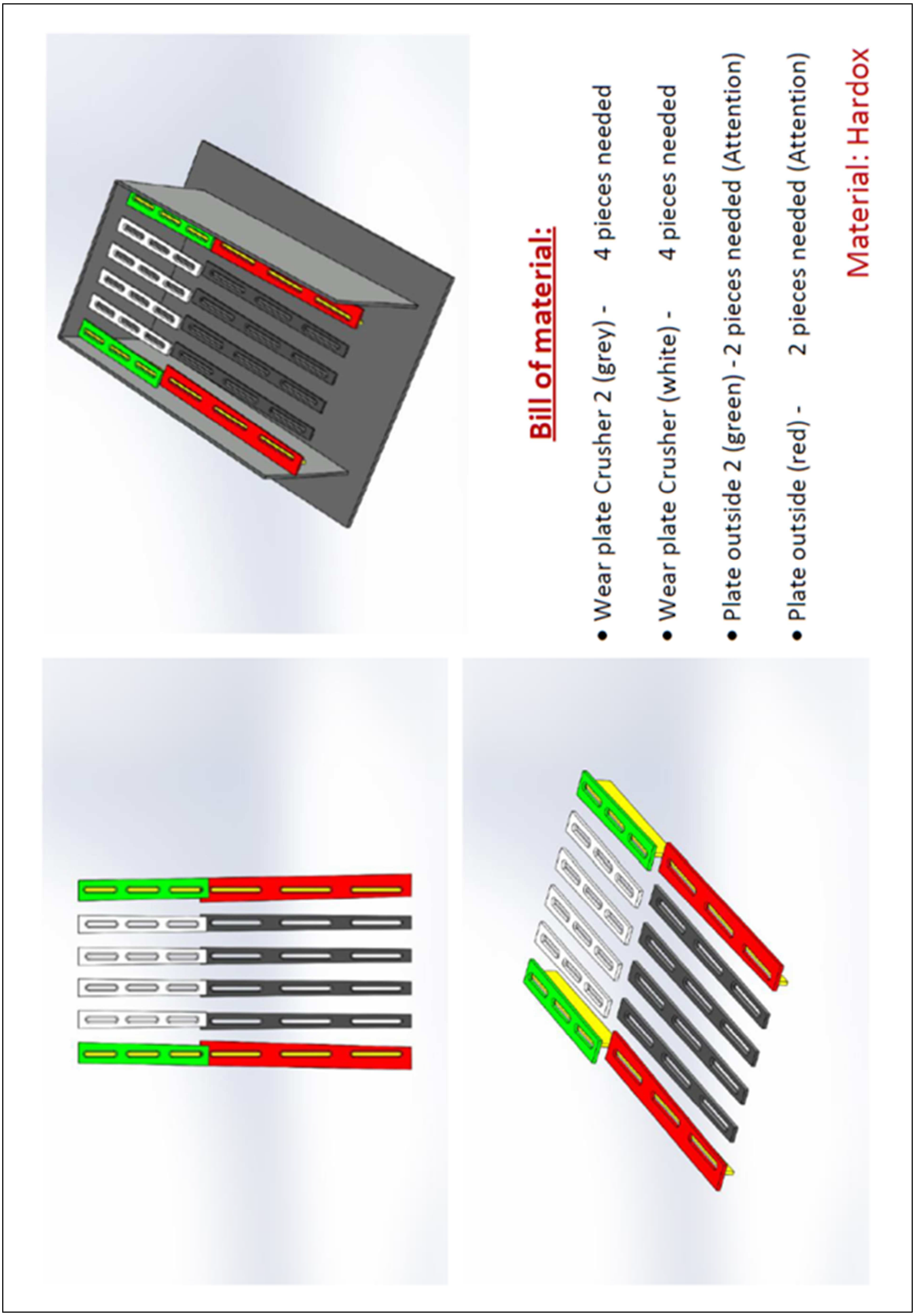
Appendix 13: EPC symbols with description

EPC-Symbol	Name	Description
	Organizational unit	Organizational unit which is responsible for the dedicated function.
	Application system	Application system which is supporting a function.
	Database or data file	Input or output of a function.
	Document	Input or output of a function.

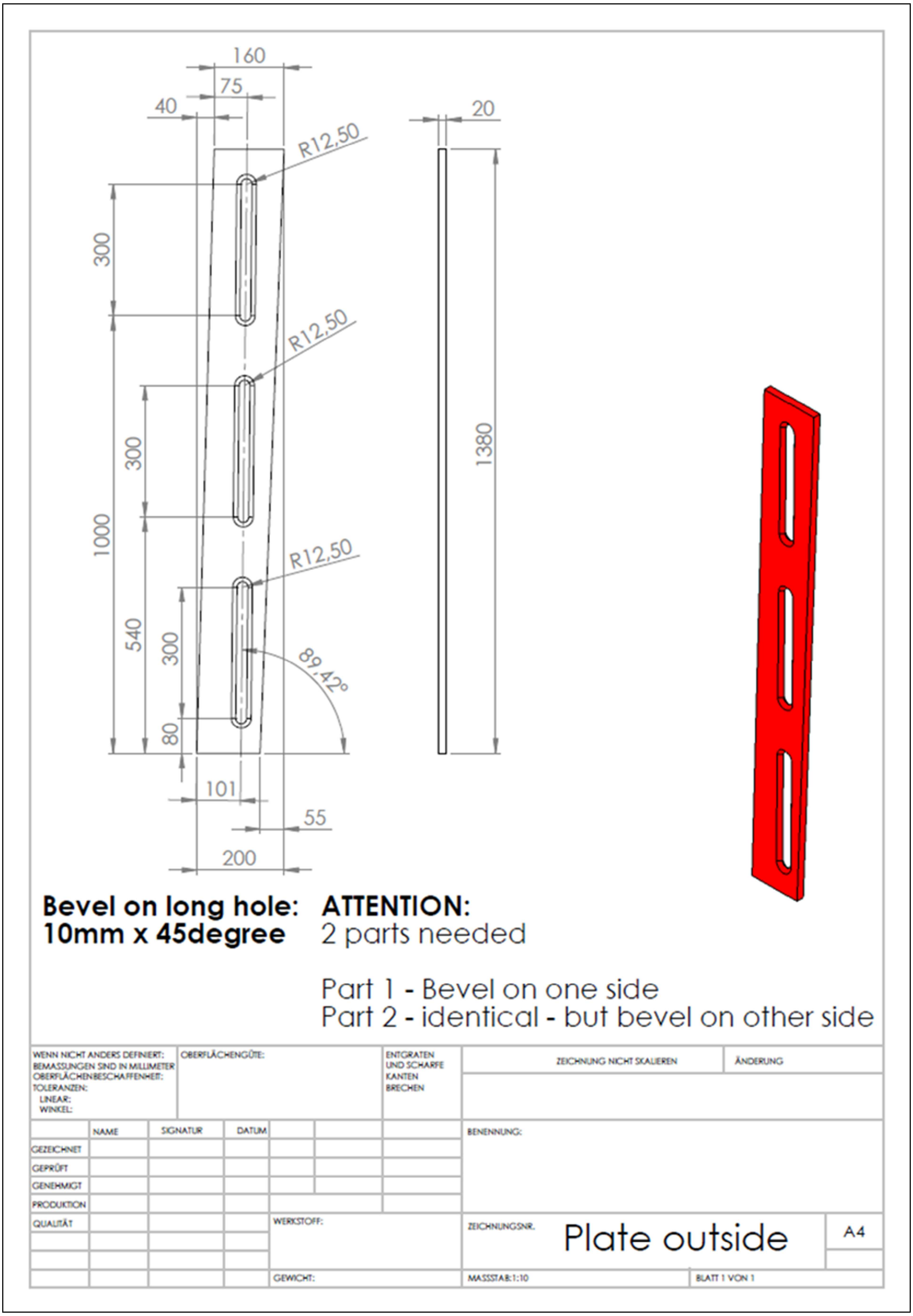
Appendix 14: Plan view of the workshop hall with labels



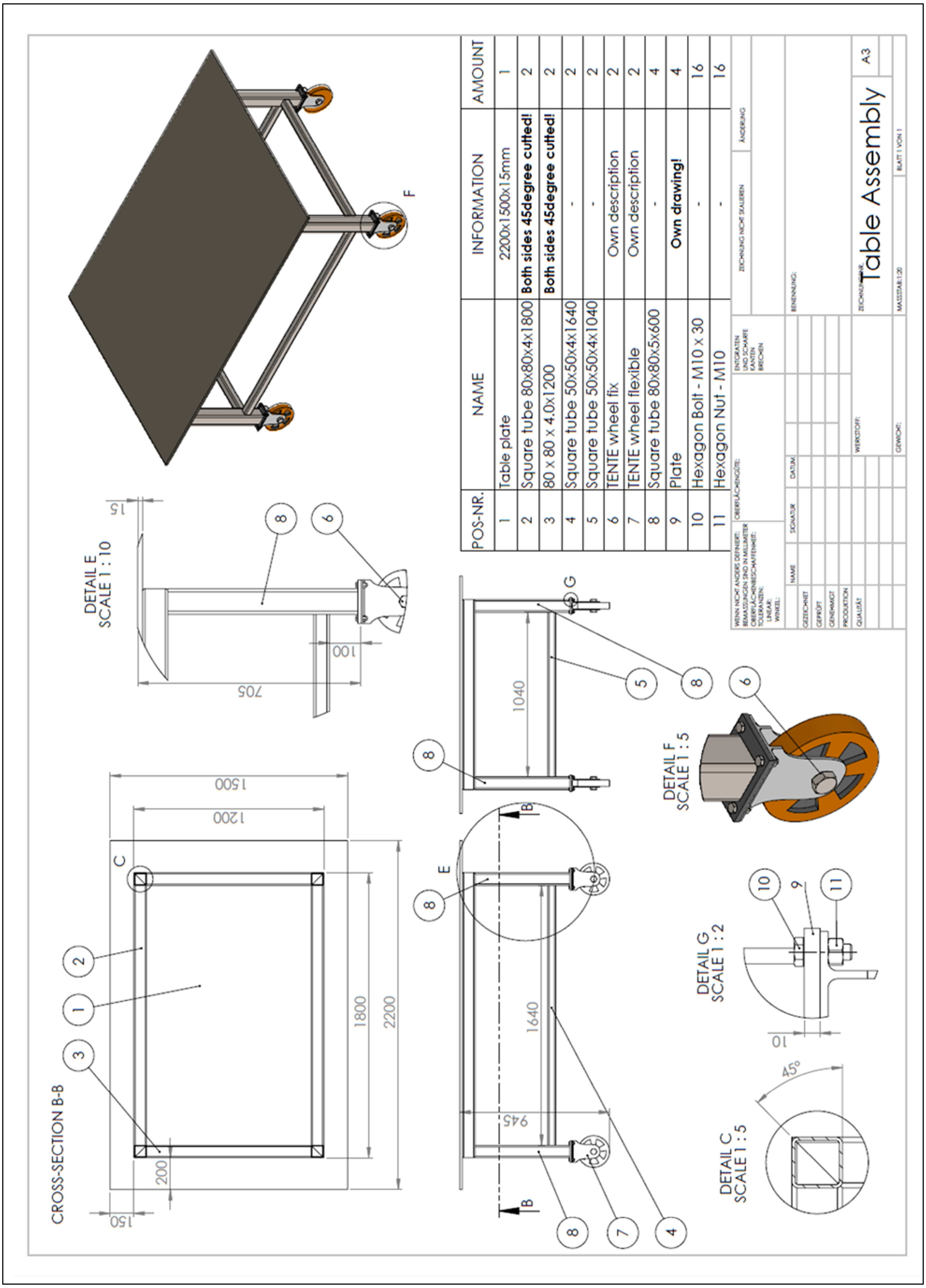
Appendix 15: CAD assembly drawing of the crusher wear plates



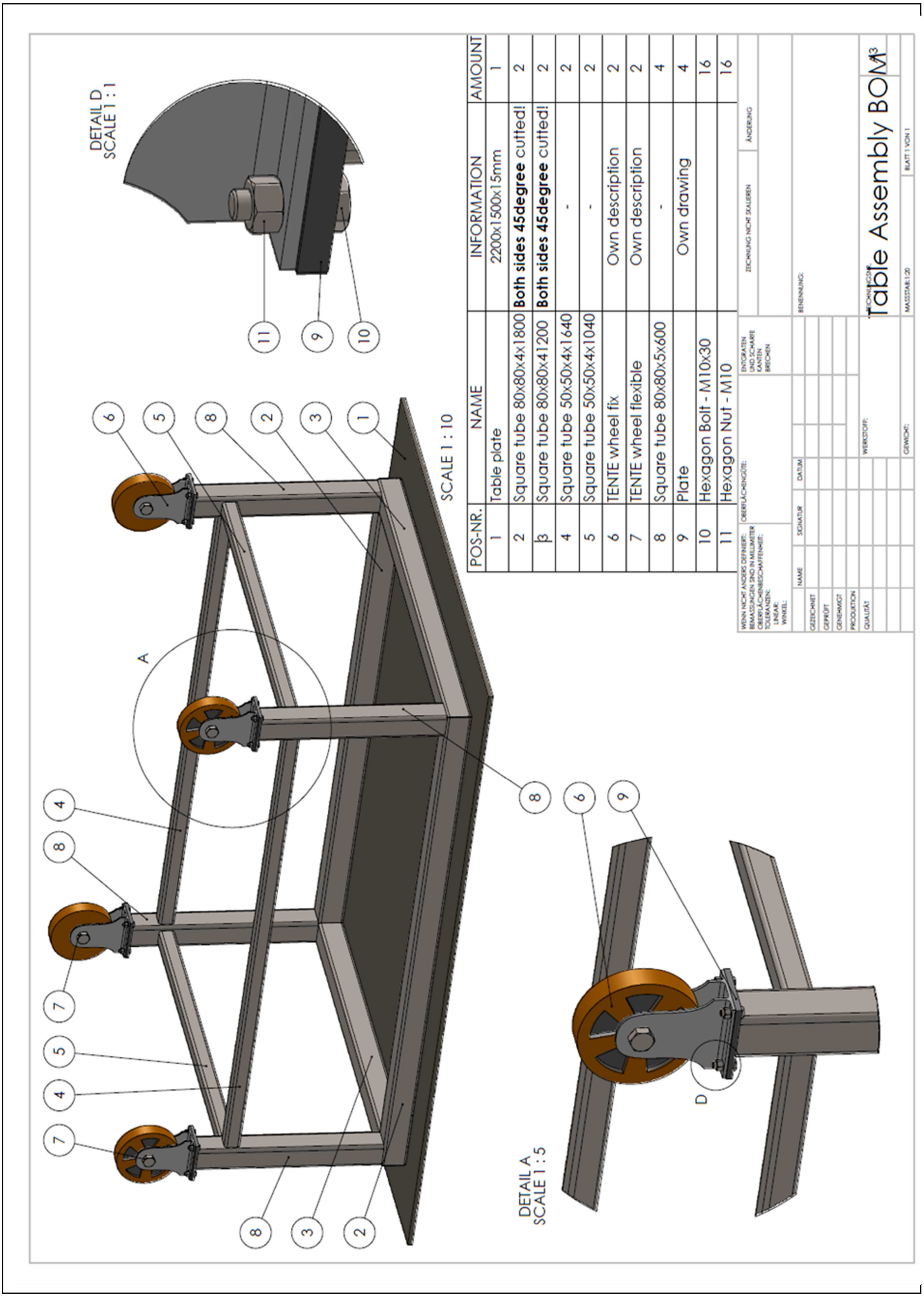
Appendix 15: CAD part drawing of one crusher wear plate



Appendix 16: CAD assembly drawing of the movable working table



Appendix 16: CAD assembly drawing of the movable working table



POS-NR.	NAME	INFORMATION	AMOUNT
1	Table plate	2200x1500x15mm	1
2	Square tube 80x80x4x1800	**Both sides 45degree** cutted!	2
3	Square tube 80x80x41200	**Both sides 45degree** cutted!	2
4	Square tube 50x50x4x1640	-	2
5	Square tube 50x50x4x1040	-	2
6	TENTE wheel fix	Own description	2
7	TENTE wheel flexible	Own description	2
8	Square tube 80x80x5x600	-	4
9	Plate	Own drawing	4
10	Hexagon Bolt - M10x30		16
11	Hexagon Nut - M10		16

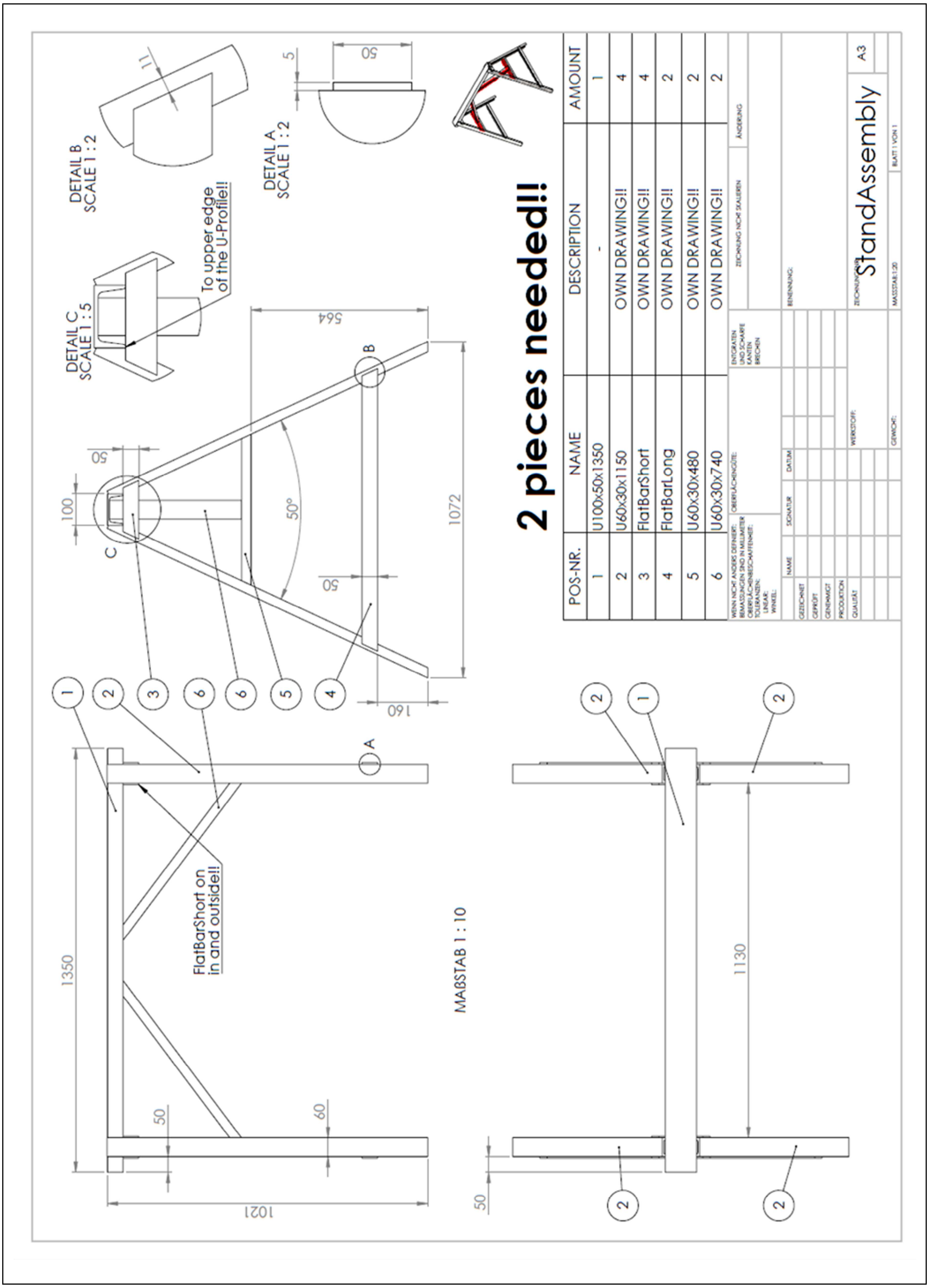
Appendix 16: Comparison of CAD drawings with verbal instructions

Production:	Worker 1		Worker 2		Worker 3		Worker 4		Worker 5	
	CAD + BOM	**Verbal Instr.**	**CAD + BOM**	**Verbal Instr.**	**CAD + BOM**	**Verbal Instr.**	**CAD + BOM**	**Verbal Instr.**	**CAD + BOM**	**Verbal Instr.**
Needed time - minutes for:										
Measurements total	10	30	20	45	35	110	30	80	25	90
Cutting steel profiles	60	60	70	90	60	90	55	65	70	80
Cutting table plate	60	60	45	50	35	50	65	70	55	60
Drilling plates (4#)	30	30	25	25	55	90	45	65	50	55
Time for welding	120	120	95	95	110	150	130	140	110	110
Time for screwing / ass.	15	15	35	35	25	25	20	20	30	30
Time for thinking	75	120	15	55	30	120	45	80	40	65
Prepare material	30	60	30	45	40	90	20	70	25	80
Prepare tools / equipment	30	30	20	25	35	35	30	30	25	25
SUM [min]	**430**	**525**	**355**	**465**	**425**	**760**	**440**	**620**	430	595
TIME SAVING / Worker [h]	**1,6**		**1,8**		**5,6**		**3**		**2,8**	
AVERAGE TIME SAVING [h]	**3,0**									
Worker in % faster with CAD drawing	525	100	465	100	760	100	620	100	595	100
	430	x	355	x	425	x	440	x	430	x
	x	81,9	x	76,3	x	55,9	x	71,0	x	72,3
Worker in % faster with CAD drawing	**18,1 % faster**		**23,7 % faster**		**44,1 % faster**		**29,0 % faster**		**27,7 % faster**	
Worker in % faster with CAD drawing	**Average of 5**									
AVERAGE PERCENTAGE FASTER	**28,5 % faster**									

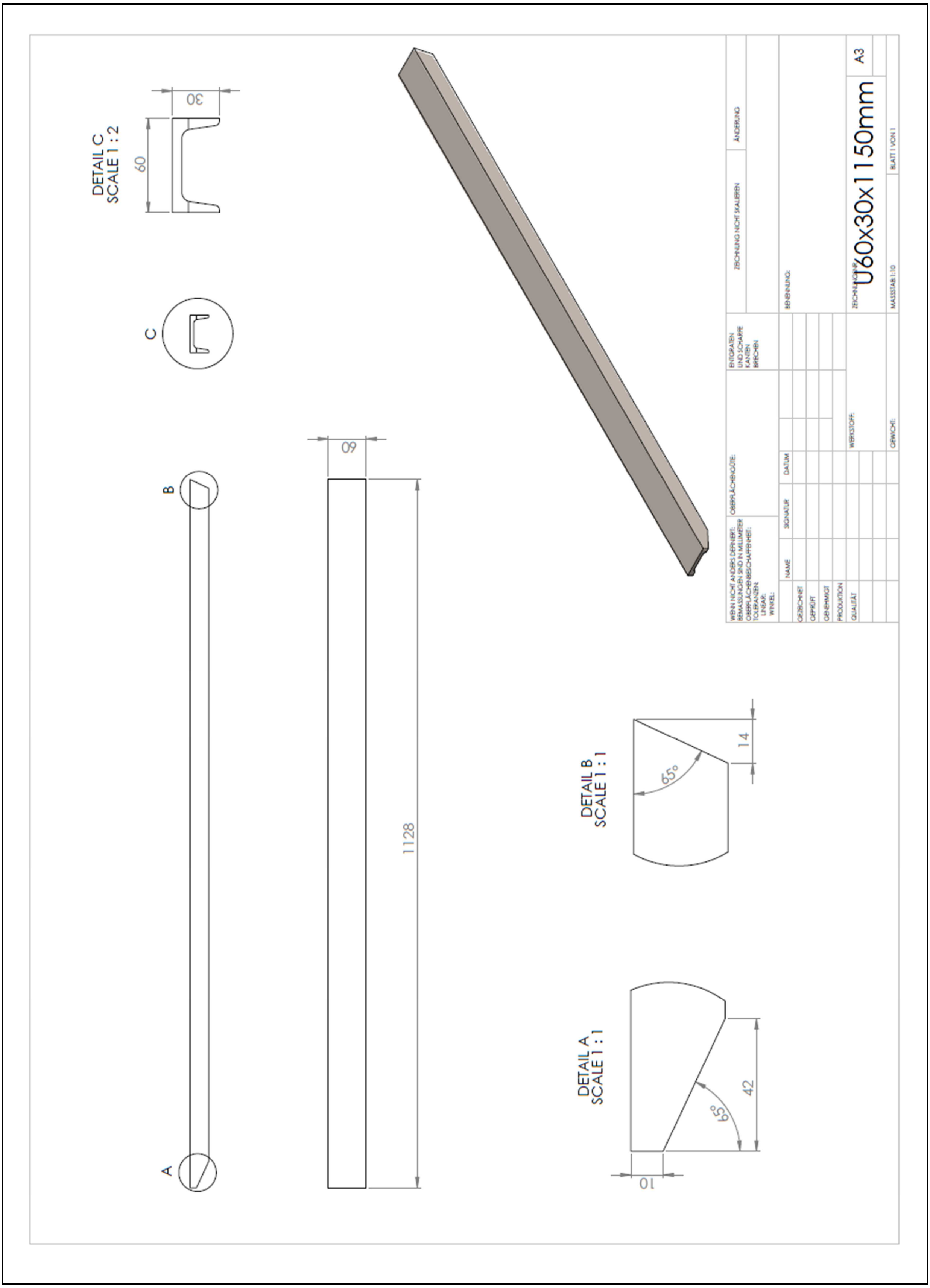
Abbreviations:

CAD	Computer Aided Design
BOM	Bill of Material

Appendix 17: CAD assembly drawing of working stands



Appendix 17: CAD single part drawing for the working stands



Appendix 17: Comparison of CAD drawings with verbal instructions

Production:	Worker 1		Worker 2		Worker 3		Worker 4		Worker 5	
	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.	CAD + BOM	Verbal Instr.
Needed time - minutes for:										
Measurements total	30	60	35	90	60	135	45	75	50	85
Cutting steel profiles	90	180	50	50	90	150	100	130	90	125
Time for welding	60	60	100	100	60	60	70	70	85	85
Time for thinking	15	60	15	90	10	75	12	65	10	70
Prepare material	30	60	30	55	30	60	25	70	20	55
Prepare tools / equipment	30	30	20	20	30	45	25	30	20	20
SUM [min]	**255**	**450**	**250**	**405**	**280**	**525**	**277**	**440**	**275**	**440**
TIME SAVING / Worker [h]	**3,3**		**2,6**		**4,1**		**2,7**		**2,8**	
AVERAGE TIME SAVING [h]	**3,3**									
Worker in % faster with CAD drawing	450	100	405	100	525	100	440	100	440	100
	255	x	250	x	280	x	277	x	275	x
	x	56,7	x	61,7	x	53,3	x	63,0	x	62,5
Worker in % faster with CAD drawing	**43,3 % faster**		**38,3 % faster**		**46,7 % faster**		**37,0 % faster**		**37,5 % faster**	
Worker in % faster with CAD drawing	**Average of 5**									
AVERAGE PERCENTAGE FASTER	**40,6 % faster**									

Abbreviation:

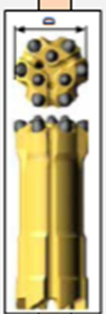
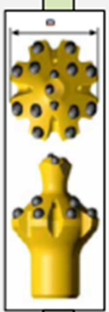
CAD	Computer Aided Design
BOM	Bill of Material

Appendix 18: Abstract of the grinding statistics

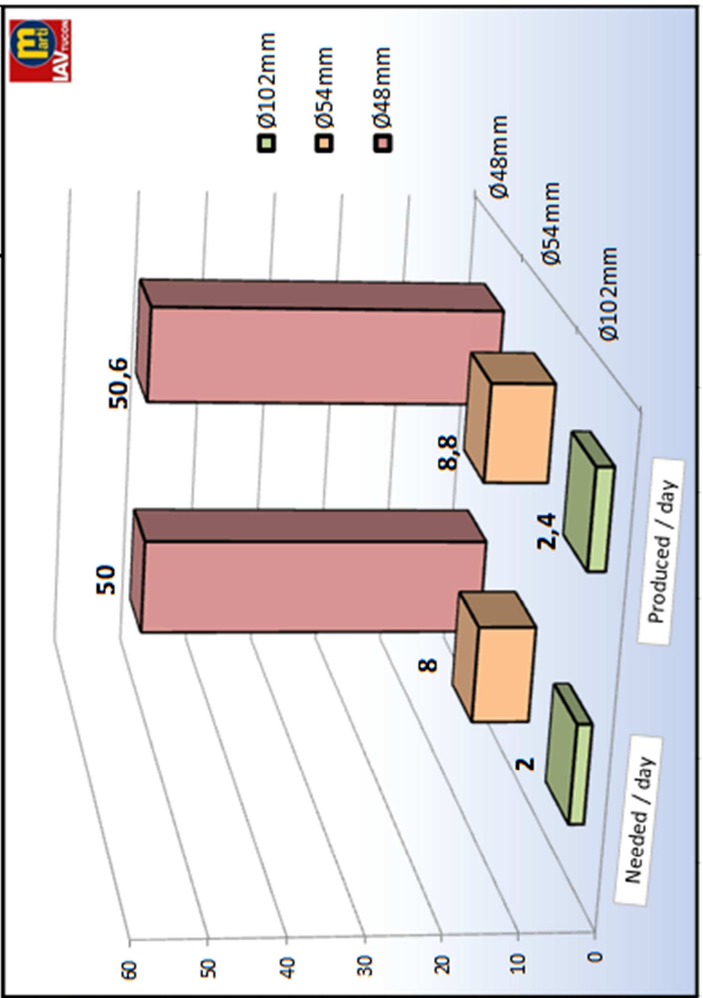
Date	Name	Used time	# drill bits 48mm	# drill bits 54mm	# drill bits 102mm	min / bit 48mm	min / bit 54mm	min / bit 102mm
30-May-14	Auernig Daniel	2:00:00			5			0:24:00
29-May-14	Auernig Daniel	3:30:00	20			0:10:30		
26-May-14	Krško Matúš	4:31:00	31			0:08:45		
25-May-14	Auernig Daniel	2:00:00		23			0:05:13	
24-May-14	Krško Matúš	6:40:00	38			0:10:32		
23-May-14	Krško Matúš	4:15:00	23			0:11:05		
22-May-14	Krško Matúš	4:20:00	24			0:10:50		
22-May-14	Auernig Daniel	4:05:00	26			0:09:25		
21-May-14	Krško Matúš	1:49:00	10			0:10:54		
20-May-14	Krško Matúš	3:30:00	22			0:09:33		
20-May-14	Auernig Daniel	2:25:00			4			0:36:15
19-May-14	Krško Matúš	2:22:00	15			0:09:28		
19-May-14	Auernig Daniel	1:00:00		12			0:05:00	
19-May-14	Auernig Daniel	0:55:00			2			0:27:30
19-May-14	Auernig Daniel	2:00:00	20			0:06:00		
17-May-14	Krško Matúš	2:27:00	16			0:09:11		
16-May-14	Krško Matúš	2:56:00	18			0:09:47		
16-May-14	Auernig Daniel	1:00:00		12			0:05:00	
16-May-14	Auernig Daniel	2:05:00			3			0:41:40
16-May-14	Auernig Daniel	2:20:00			4			0:35:00
15-May-14	Krško Matúš	2:03:00	12			0:10:15		
15-May-14	Krško Matúš	1:11:00	8			0:08:53		
14-May-14	Krško Matúš	1:09:00	8			0:08:37		
14-May-14	Auernig Daniel	1:00:00	9			0:06:40		
14-May-14	Auernig Daniel	1:00:00		13			0:04:37	
13-May-14	Krško Matúš	2:04:00	12			0:10:20		
13-May-14	Krško Matúš	1:02:00		10			0:06:12	
12-May-14	Auernig Stefan	4:00:00	31			0:07:45		
12-May-14	Auernig Stefan	4:00:00	29			0:08:17		
10-May-14	Sandvik 2	2:00:00			5			0:24:00
10-May-14	Sandvik 2	5:00:00	30			0:10:00		
9-May-14	Auernig Daniel	3:05:00			5			0:37:00
9-May-14	Auernig Daniel	1:05:00			3			0:21:40
9-May-14	Auernig Daniel	2:05:00	13			0:09:37		
9-May-14	Auernig Daniel	2:00:00			5			0:24:00
8-May-14	Auernig Daniel	2:00:00	15			0:08:00		
8-May-14	Auernig Stefan	4:00:00	26			0:09:14		
7-May-14	Auernig Stefan	2:00:00		22			0:05:27	
7-May-14	Auernig Stefan	1:55:00			5			0:23:00
6-May-14	Auernig Stefan	7:10:00	62			0:06:56		
3-May-14	Sandvik 2	7:00:00	45			0:09:20		
2-May-14	Auernig Stefan	6:55:00	41			0:10:07		
14-Apr-14	Sandvik 1	1:00:00			3			0:20:00
14-Apr-14	Sandvik 1	1:10:00		13			0:05:23	
14-Apr-14	Sandvik 1	2:00:00	20			0:06:00		
12-Apr-14	Sandvik 2	1:05:00		10			0:06:30	
12-Apr-14	Sandvik 2	6:00:00	40			0:09:00		
10-Apr-14	Sandvik 2	2:00:00			4			0:30:00
8-Apr-14	Auernig Daniel	2:05:00	19			0:06:35		
8-Apr-14	Auernig Daniel	1:05:00		12			0:05:25	
8-Apr-14	Auernig Daniel	1:00:00			3			0:20:00
7-Apr-14	Sandvik 2	6:00:00	50			0:07:12		
3-Apr-14	Auernig Stefan	2:30:00	20			0:07:30		
2-Apr-14	Auernig Daniel	2:10:00	20			0:06:30		
2-Apr-14	Auernig Daniel	0:35:00			2			0:17:30
31-Mar-14	Sandvik 2	4:00:00	20			0:12:00		
29-Mar-14	Sandvik 2	3:00:00	10			0:18:00		
28-Mar-14	Auernig Daniel	0:50:00		10			0:05:00	
28-Mar-14	Auernig Daniel	1:45:00	15			0:07:00		
27-Mar-14	Sandvik 2	2:30:00	19			0:07:54		
26-Mar-14	Auernig Stefan	0:15:00			1			0:15:00
26-Mar-14	Auernig Stefan	0:20:00		4			0:05:00	
26-Mar-14	Auernig Stefan	1:12:00	10			0:07:12		
25-Mar-14	Auernig Stefan	0:45:00		8			0:05:37	
25-Mar-14	Auernig Stefan	1:25:00	11			0:07:44		
21-Mar-14	Auernig Daniel	0:23:00			1			0:23:00
21-Mar-14	Auernig Daniel	2:40:00	21			0:07:37		
20-Mar-14	Auernig Stefan	0:20:00			1			0:20:00
20-Mar-14	Auernig Stefan	2:15:00	18			0:07:30		
19-Mar-14	Auernig Daniel	0:40:00		8			0:05:00	
19-Mar-14	Auernig Daniel	2:20:00	20			0:07:00		
18-Mar-14	Auernig Daniel	1:20:00	13			0:06:09		
18-Mar-14	Auernig Daniel	0:25:00			2			0:12:30
18-Mar-14	Auernig Daniel	0:28:00		8			0:03:30	
18-Mar-14	Auernig Daniel	0:30:00		8			0:03:45	
18-Mar-14	Auernig Daniel	1:20:00	15			0:05:20		
14-Mar-14	Auernig Daniel	3:00:00	33			0:05:27		
13-Mar-14	Auernig Daniel	2:30:00	27			0:05:33		
		182:47:00	1005	173	58	0:08:36	0:05:07	0:25:07

Appendix 18: Abstract of the grinding statistics

Time target for grinding drill bits

Type of drill bit		Calculated minutes per bit	Output / hour	Choose hours 7,50 Output in choosen hours	Max. needed bits / day
Ø48mm		0:08:36	7,0	52,3	50
Ø54mm		0:05:07	11,7	88,0	8
Ø102mm		0:25:07	2,4	17,9	2

	Hours	Output
Choose hours Ø102mm	1,00	2,4
Choose hours Ø54mm	0,75	8,8
Choose hours Ø48mm	7,25	50,6
Needed hours / day	9	



Appendix 19: Sheets for writing down drill steel (IN / OUT)

Drill steel OUT — Solbakk tunnelen Ryfast E02 — Date: 5/5/2014

Articel-No.	Description	Rig(s)	Rig/pce
7738-5348A-R48	48 mm drill bits for face drilling	all DR2 DR1	[illegible] back / 12 out store / 10 out
7738-4654A1-R48	54 mm drill bits for long hole drilling	DR3	
7324-7261-20	drifter rods L=6135 for 20 foot boom T38	DR1 DR2	
7324-8561-20	drifter rods L=6135 for 20 foot boom T38 sechskant (AC)	DR1 DR3	
7327-5255-20	drifter rods L=5525 for 18 foot boom	DR3	
7327-5243-20	drifter rods L=4305 for 14 foot boom	DR4	
7327-4749-20	16' connecting rods for long hole drilling L=4875 for 18 foot boom	DR3 DR5	
7738-5602P-S48	102 mm reaming bits R35	all DR1 DR2	1 out / 2 in / 1 out store
7307-7673-01	shank adapter for RD525 PE drifter DR5&6	DR3	
7304-7666-01	shank adapter for RD525 drifter L600 T38	DR1 DR2 DR4	
7314-3652	adapter piece for shanks	all	

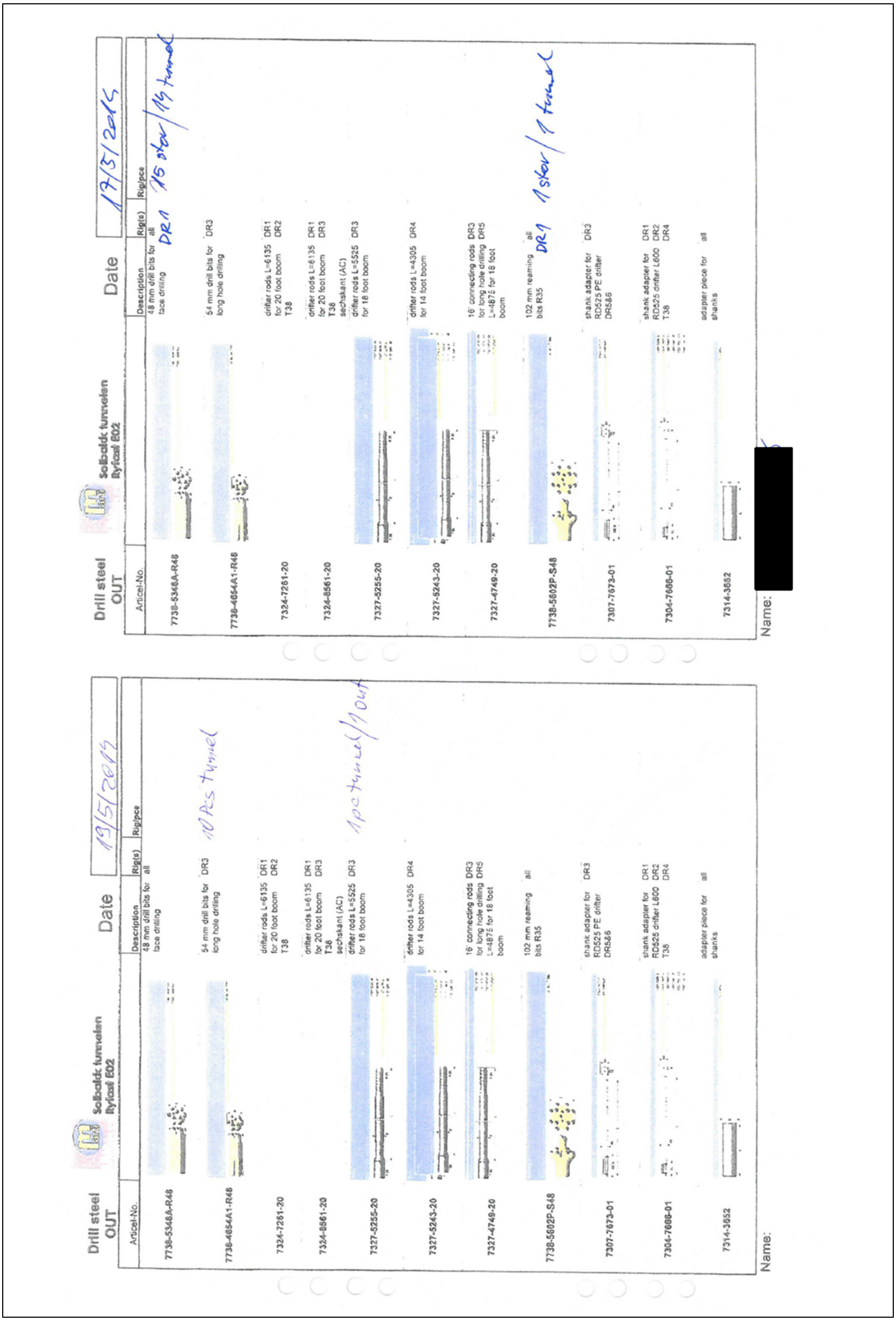
Name: [redacted]

Drill steel OUT — Solbakk tunnelen Ryfast E02 — Date: 10/5/2014

Articel-No.	Description	Rig(s)	Rig/pce
7738-5348A-R48	48 mm drill bits for face drilling	all DR1	STOR 10 / Tunnel 10
7738-4654A1-R48	54 mm drill bits for long hole drilling	DR3	
7324-7261-20	drifter rods L=6135 for 20 foot boom T38	DR1 DR2	3pcs Tunnel
7324-8561-20	drifter rods L=6135 for 20 foot boom T38 sechskant (AC)	DR1 DR3	
7327-5255-20	drifter rods L=5525 for 18 foot boom	DR3	
7327-5243-20	drifter rods L=4305 for 14 foot boom	DR4	
7327-4749-20	16' connecting rods for long hole drilling L=4875 for 18 foot boom	DR3 DR5	
7738-5602P-S48	102 mm reaming bits R35	all DR1	2 in / 1 tunnel
7307-7673-01	shank adapter for RD525 PE drifter DR5&6	DR3	
7304-7666-01	shank adapter for RD525 drifter L600 T38	DR1 DR2 DR4	
7314-3652	adapter piece for shanks	all DR1	1pc tunnel

Name: [redacted]

Appendix 19: Sheets for writing down drill steel (IN / OUT)



Appendix 19: Sheets for writing down drill steel (IN / OUT)

Drill steel OUT — Solbakk tunnelen Ryfast E02 — Date: 6/5/2014

Article-No.	Description	Rig(s)	Rig/pce
7738-5348A-R48	48 mm drill bits for face drilling	all	DR2 – 12 out; DR3 – (2 out); 15 in / 4 out
7738-4654A1-R48	54 mm drill bits for long hole drilling	DR3	—
7324-7261-20	drifter rods L=6135 for 20 foot boom T38	DR1 DR2	2 out
7324-8561-20	drifter rods L=6135 for 20 foot boom T38 sechskant (AC)	DR1 DR3	
7327-5255-20	drifter rods L=5525 for 18 foot boom	DR3	
7327-5243-20	drifter rods L=4305 for 14 foot boom	DR4	
7327-4749-20	16' connecting rods for long hole drilling L=4875 for 18 foot boom	DR3 DR5	3 out
7738-5602P-S48	102 mm reaming bits R35	all	1 out / 1 in
7307-7673-01	shank adapter for RD525 PE drifter DR5&6	DR3	2 out
7304-7666-01	shank adapter for RD525 drifter L600 T38	DR1 DR2 DR4	
7314-3652	adapter piece for shanks	all	2 out

Name: [redacted]

Drill steel OUT — Solbakk tunnelen Ryfast E02 — Date: 8/5/2014

Article-No.	Description	Rig(s)	Rig/pce
7738-5348A-R48	48 mm drill bits for face drilling	all	DR1 18pcs back
7738-4654A1-R48	54 mm drill bits for long hole drilling	DR3	
7324-7261-20	drifter rods L=6135 for 20 foot boom T38	DR1 DR2	
7324-8561-20	drifter rods L=6135 for 20 foot boom T38 sechskant (AC)	DR1 DR3	
7327-5255-20	drifter rods L=5525 for 18 foot boom	DR3	
7327-5243-20	drifter rods L=4305 for 14 foot boom	DR4	
7327-4749-20	16' connecting rods for long hole drilling L=4875 for 18 foot boom	DR3 DR5	
7738-5602P-S48	102 mm reaming bits R35	all	DR1 2pcs back
7307-7673-01	shank adapter for RD525 PE drifter DR5&6	DR3	
7304-7666-01	shank adapter for RD525 drifter L600 T38	DR1 DR2 DR4	
7314-3652	adapter piece for shanks	all	

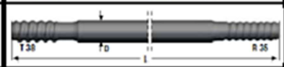
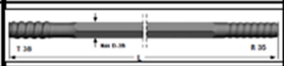
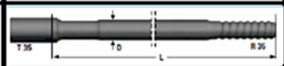
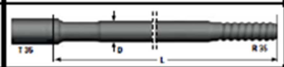
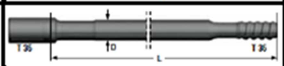
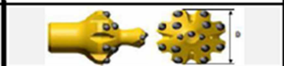
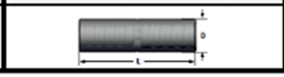
Name: [redacted]

Appendix 20: Improved sheets for writing down drill steel (IN / OUT)

SANDVIK

Drill steel documentation:

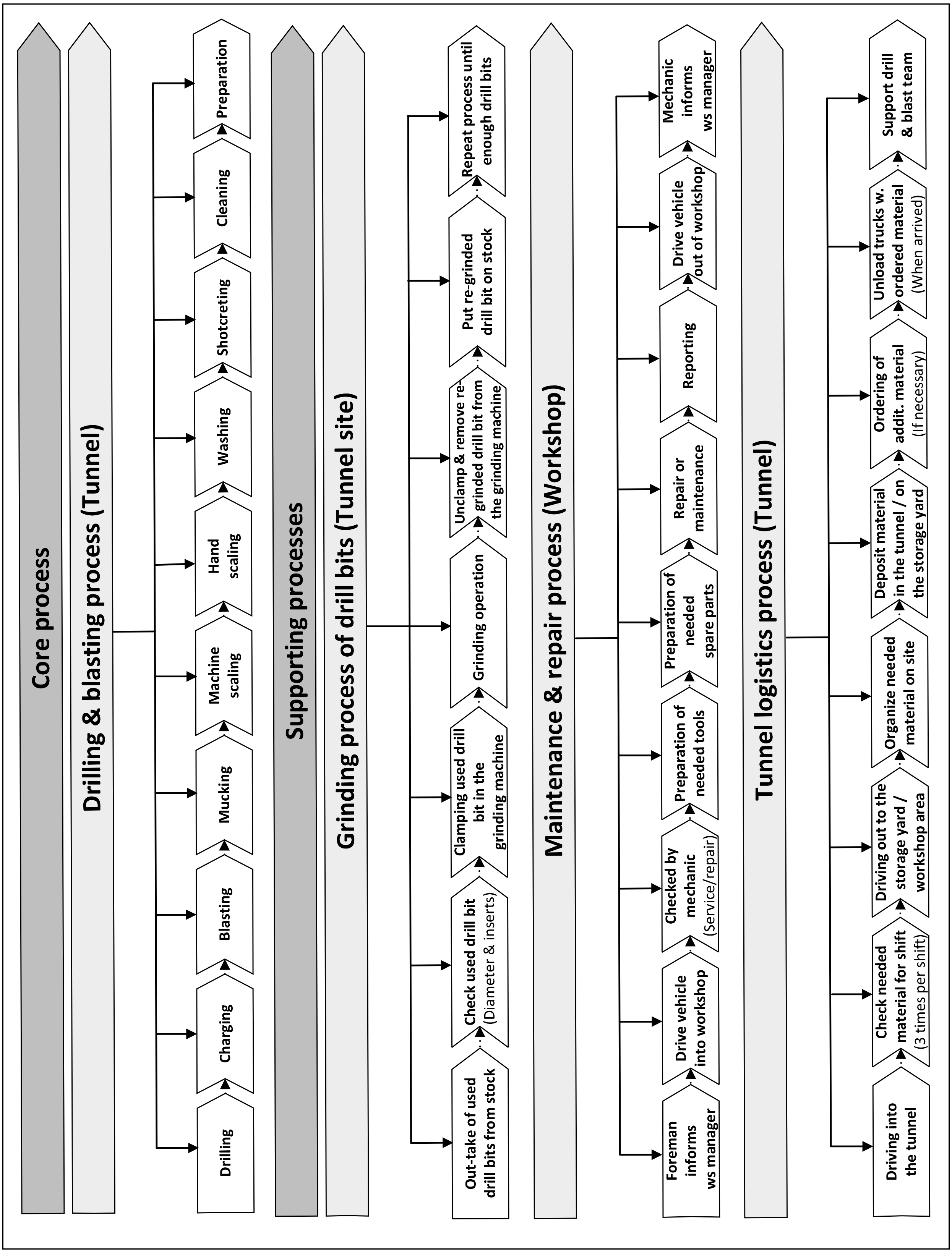
Name:	
Date:	Sign:

Article number	Image	Description	Rig(s)	Write # IN + Drill Rig	Write # OUT + Drill Rig	Left in Rock	Broken/Waste
7738-5348A-R48		**48mm** drill bits for face drilling	All				
7738-4654A1-R48		**54mm** drill bits for long hole drilling	DR3				
7324-7261-20		Drifter rods L=6135 for 20 foot boom T38	DR1 DR2				
7324-8561-20		Drifter rods L = 6135 for 20 foot boom T38 sechskant (AC)	DR1 DR3				
7327-5255-20		Drifter rods L = 5525 for 18 foot boom	DR3				
7327-5243-20		Drifter rods L = 4305 for 14 foot boom	DR4				
7327-4749-20		Connecting rods for long hole drilling L=4875 - 18 foot boom	DR3 DR5				
7738-5602P-S48		**102mm** reaming bits R35	All				
7307-7673-01		Shank adapter for RD525 PE drifter DR5&6	DR3				
7304-7666-01		Shank adapter for RD525 drifter L600 T38	DR1,2 DR4				
7314-3652		Adapter piece for all shanks	All				

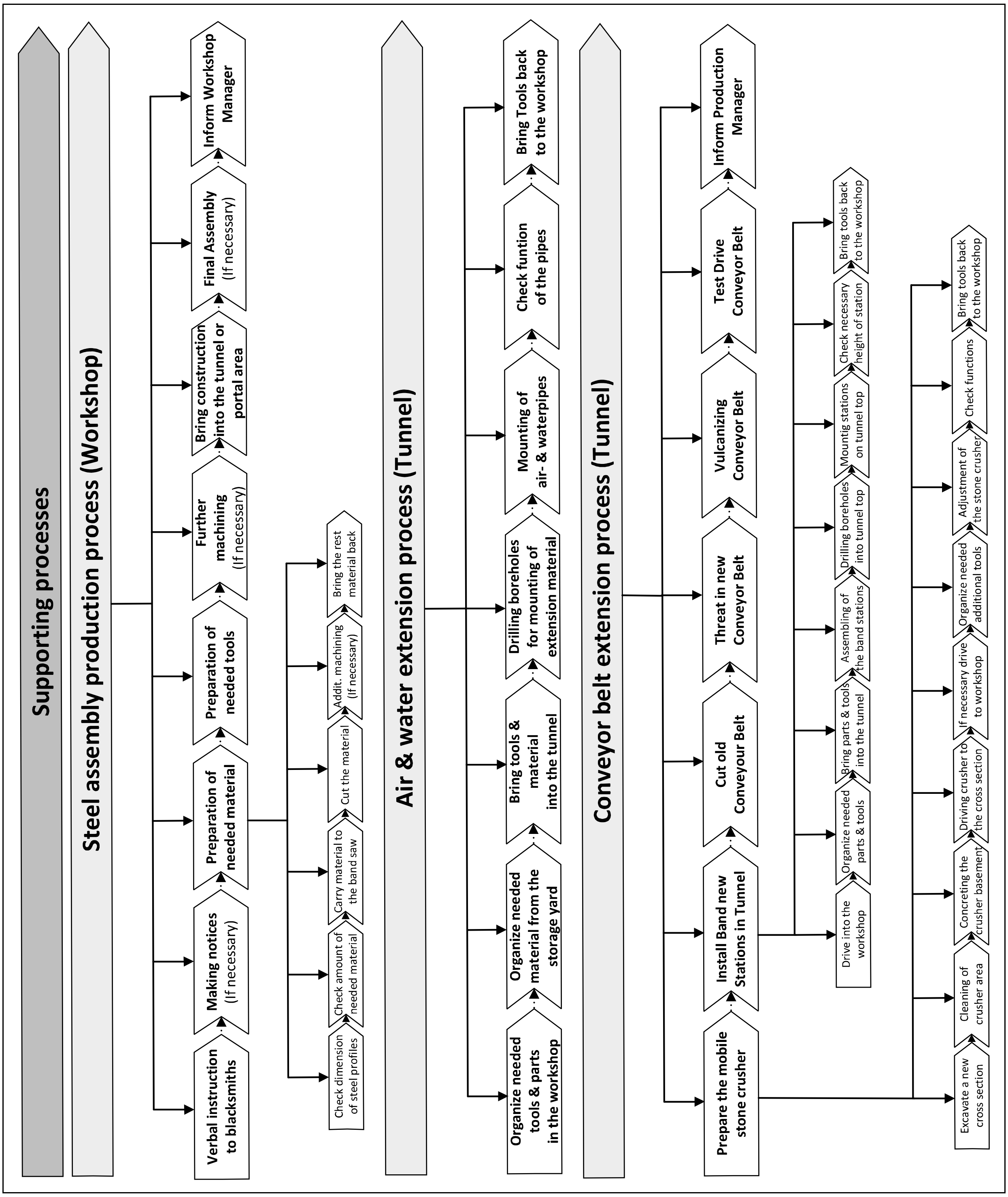
(Abbreviation DR = Drill Rig)
Remarks / Comments:

IN
OUT

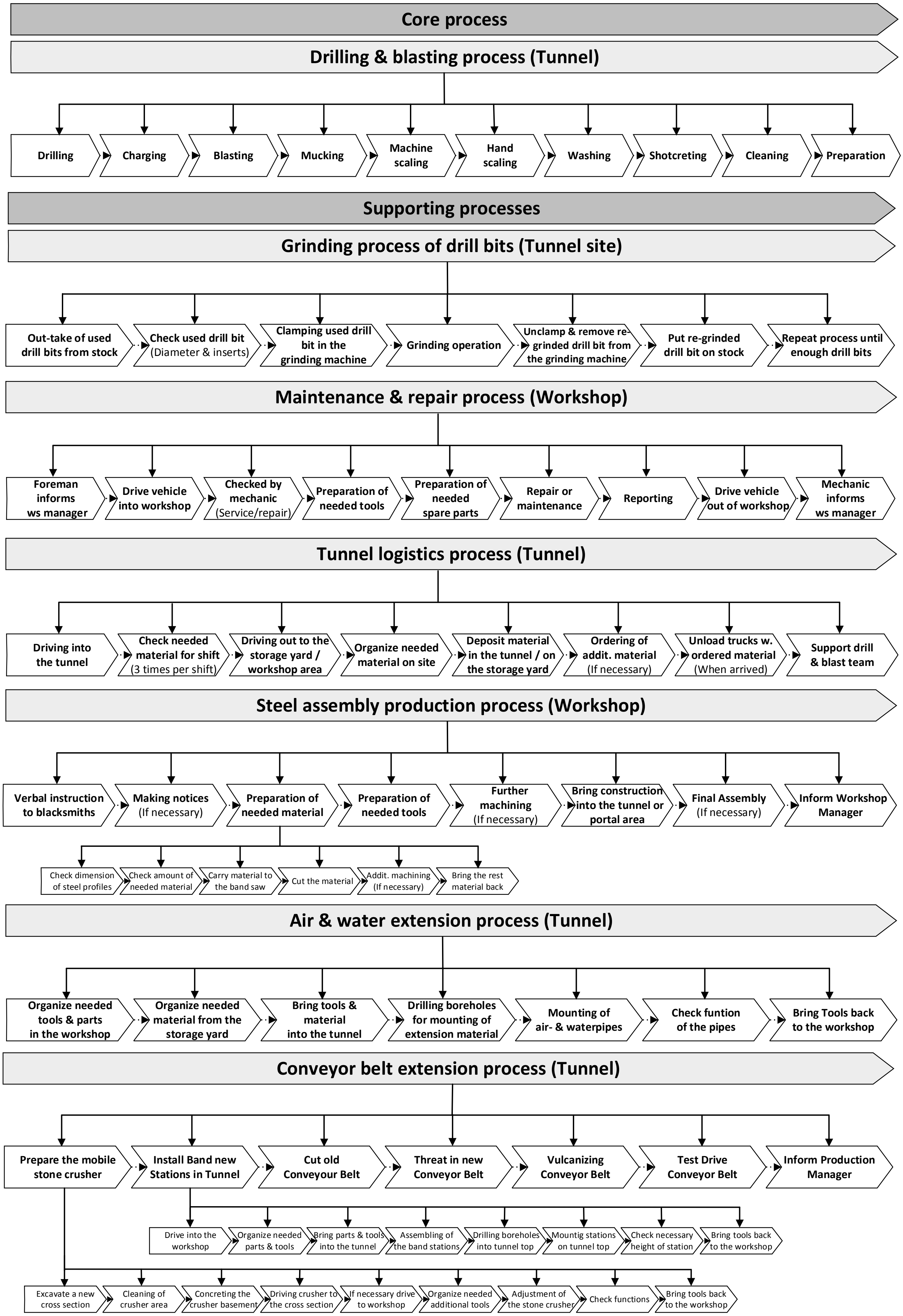
Appendix 21: Core- and support processes Solbakk (Part 1/2)



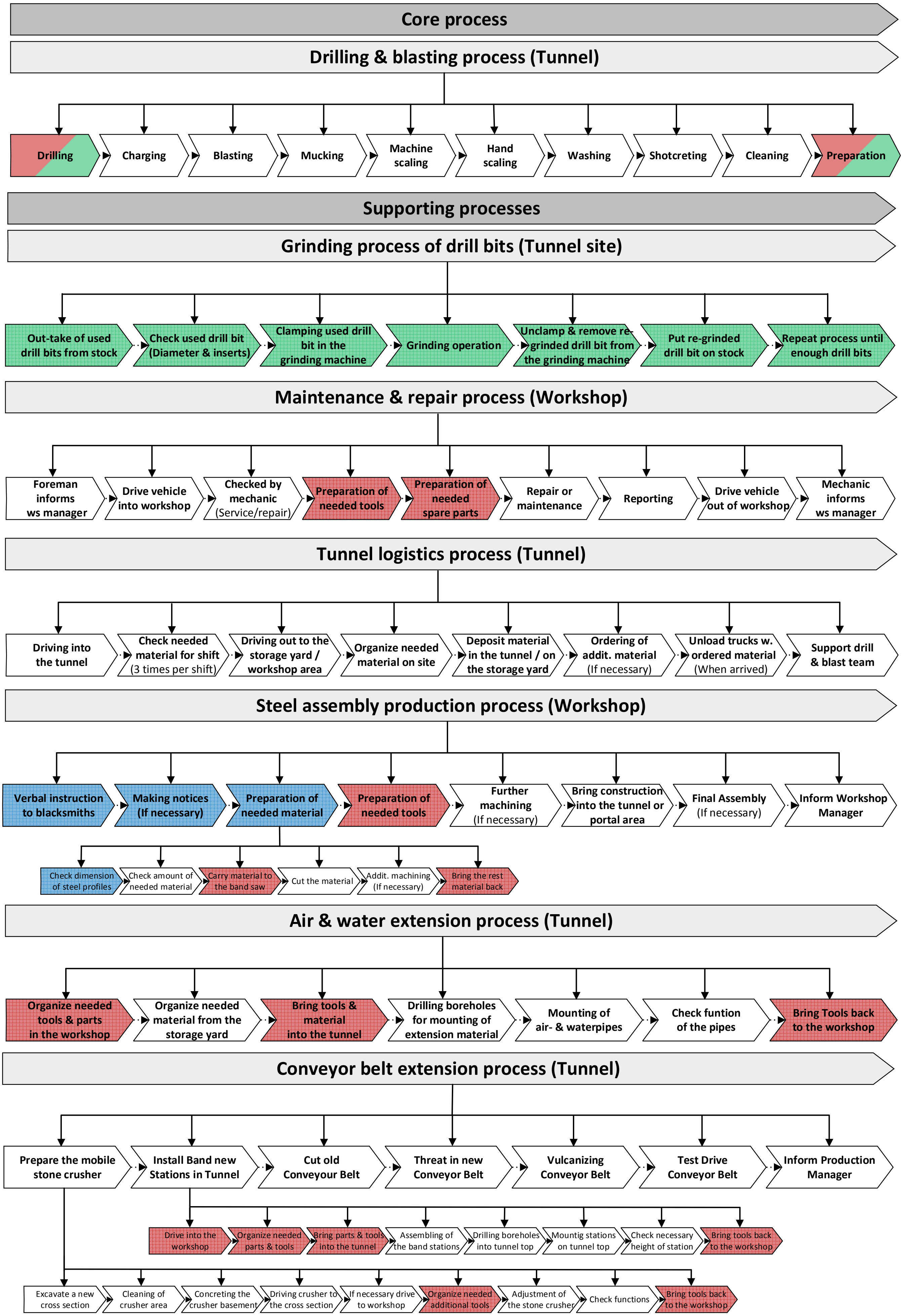
Appendix 21: Core- and support processes Solbakk (Part 2/2)



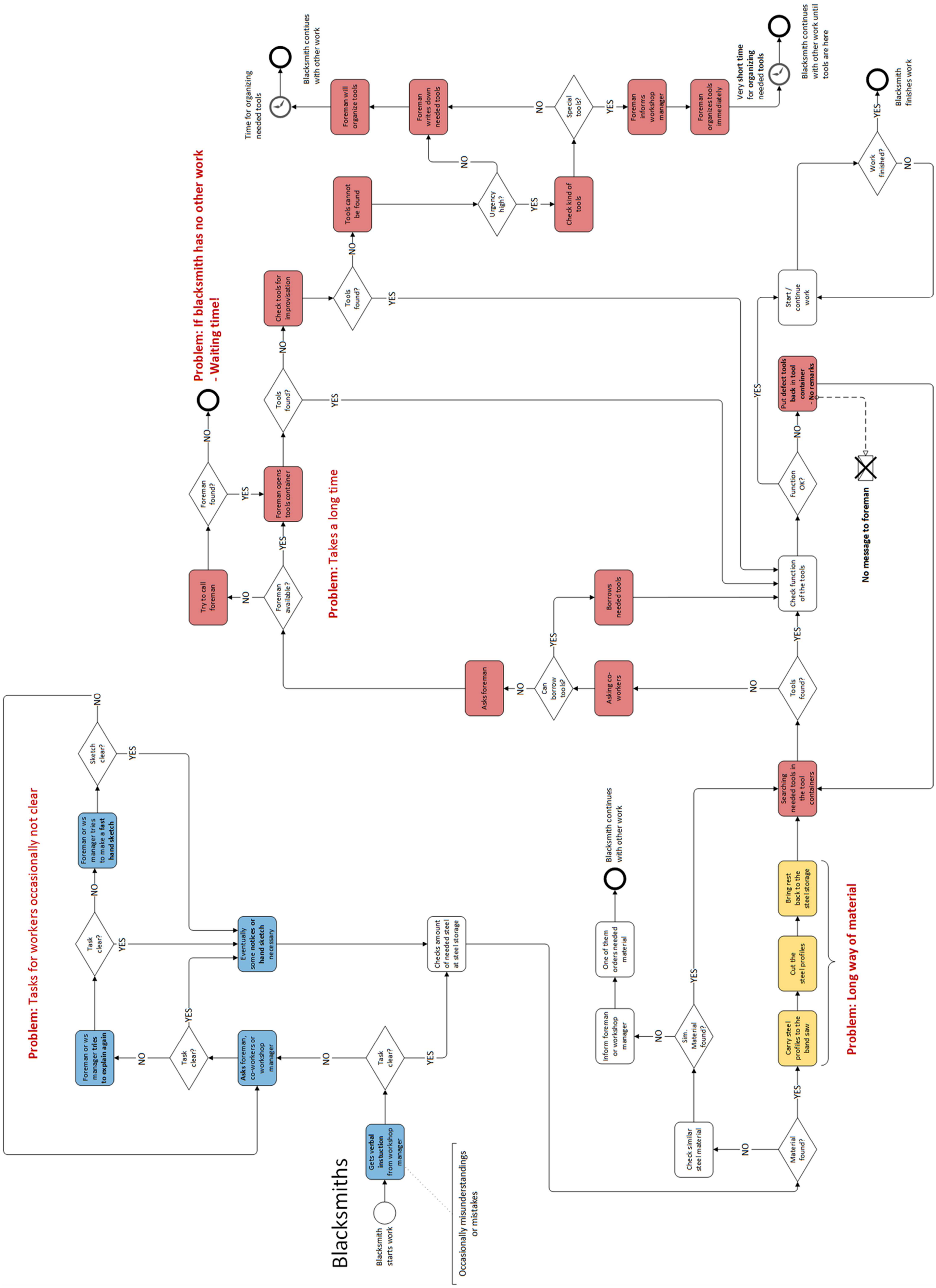
Appendix 22: Process map of the tunnel-site Solbakk



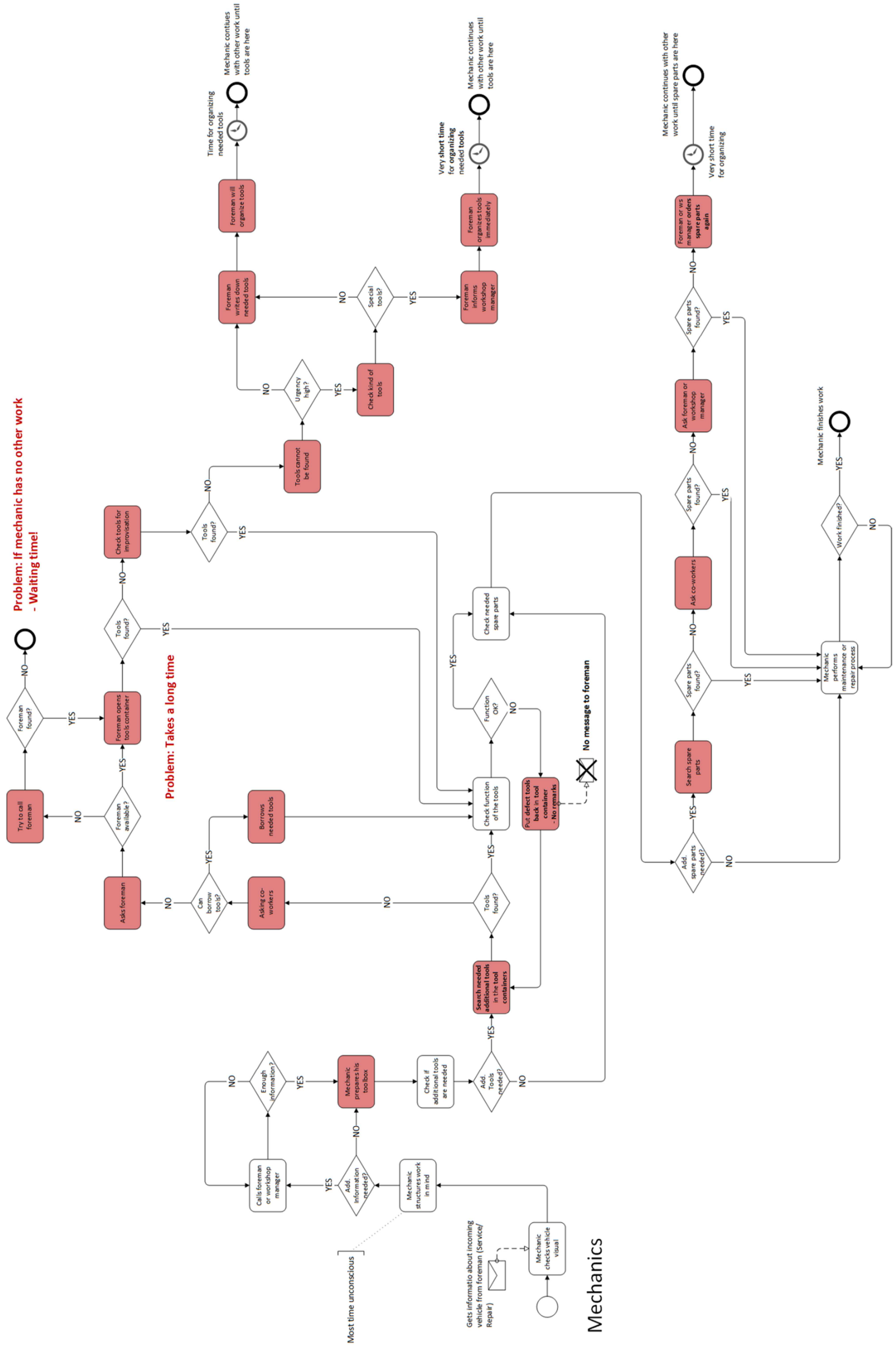
Appendix 23: Process map with distribution of relevant processes



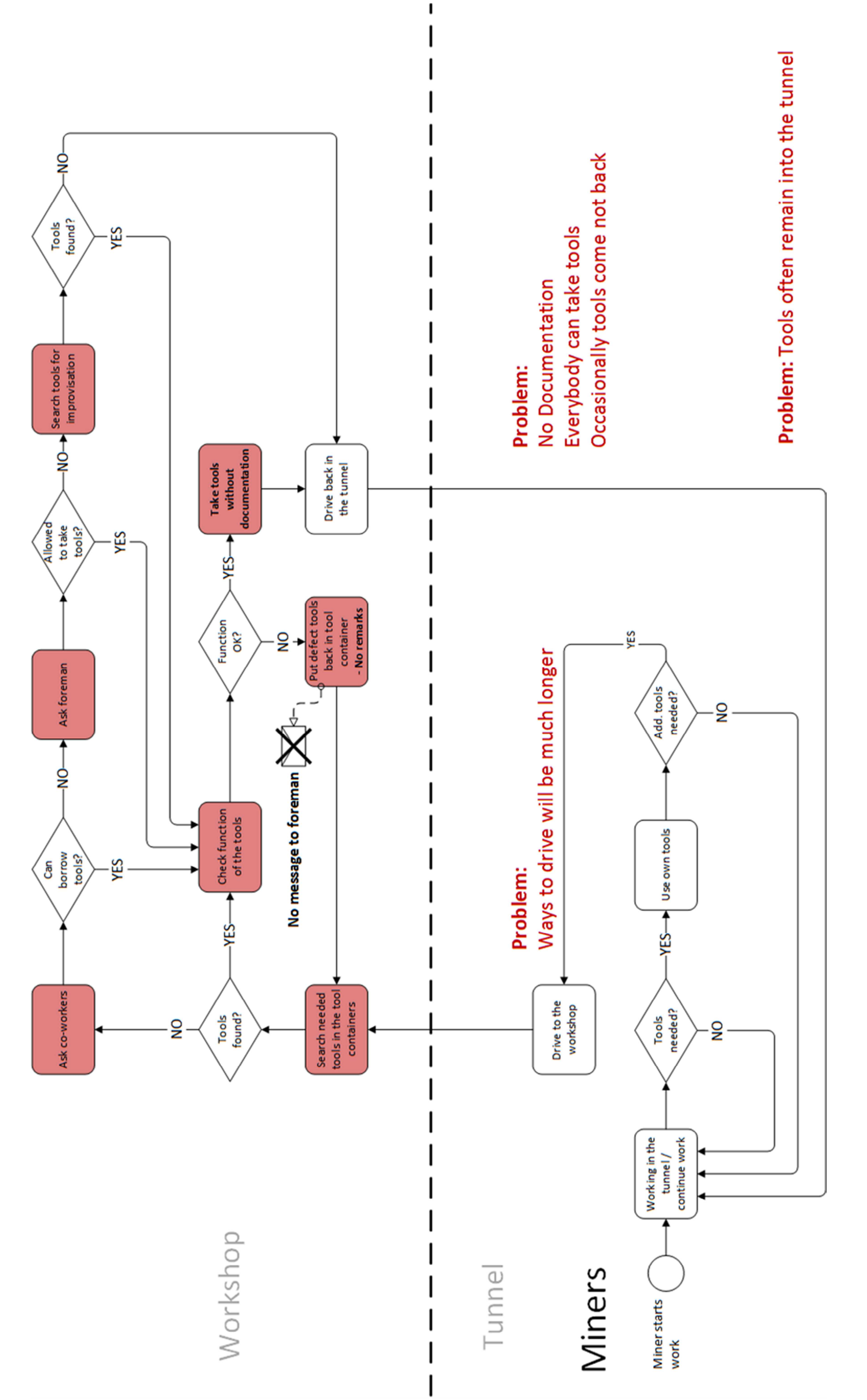
Appendix 24: BPMN model of the blacksmiths in the workshop



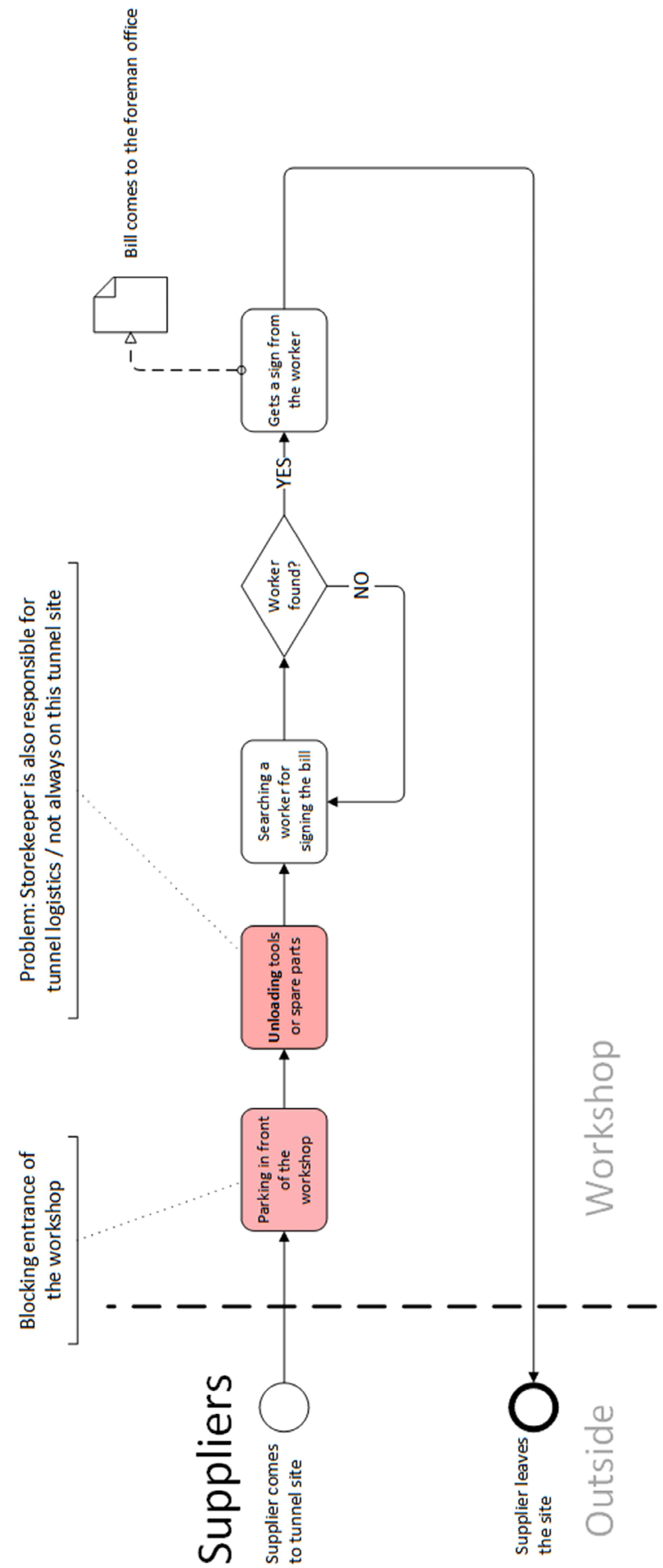
Appendix 25: BPMN model of the mechanics in the workshop



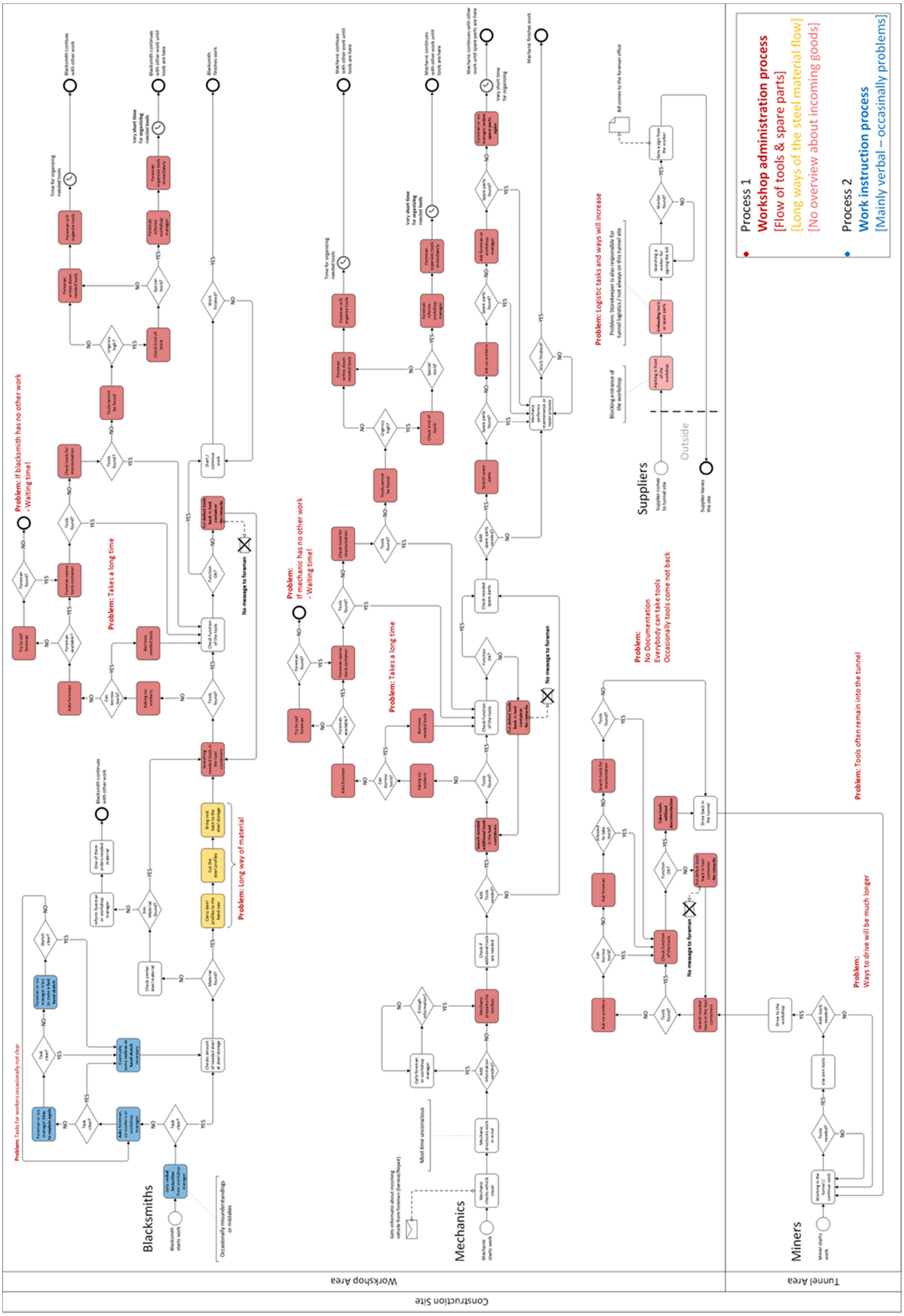
Appendix 26: BPMN model of miners between tunnel and workshop



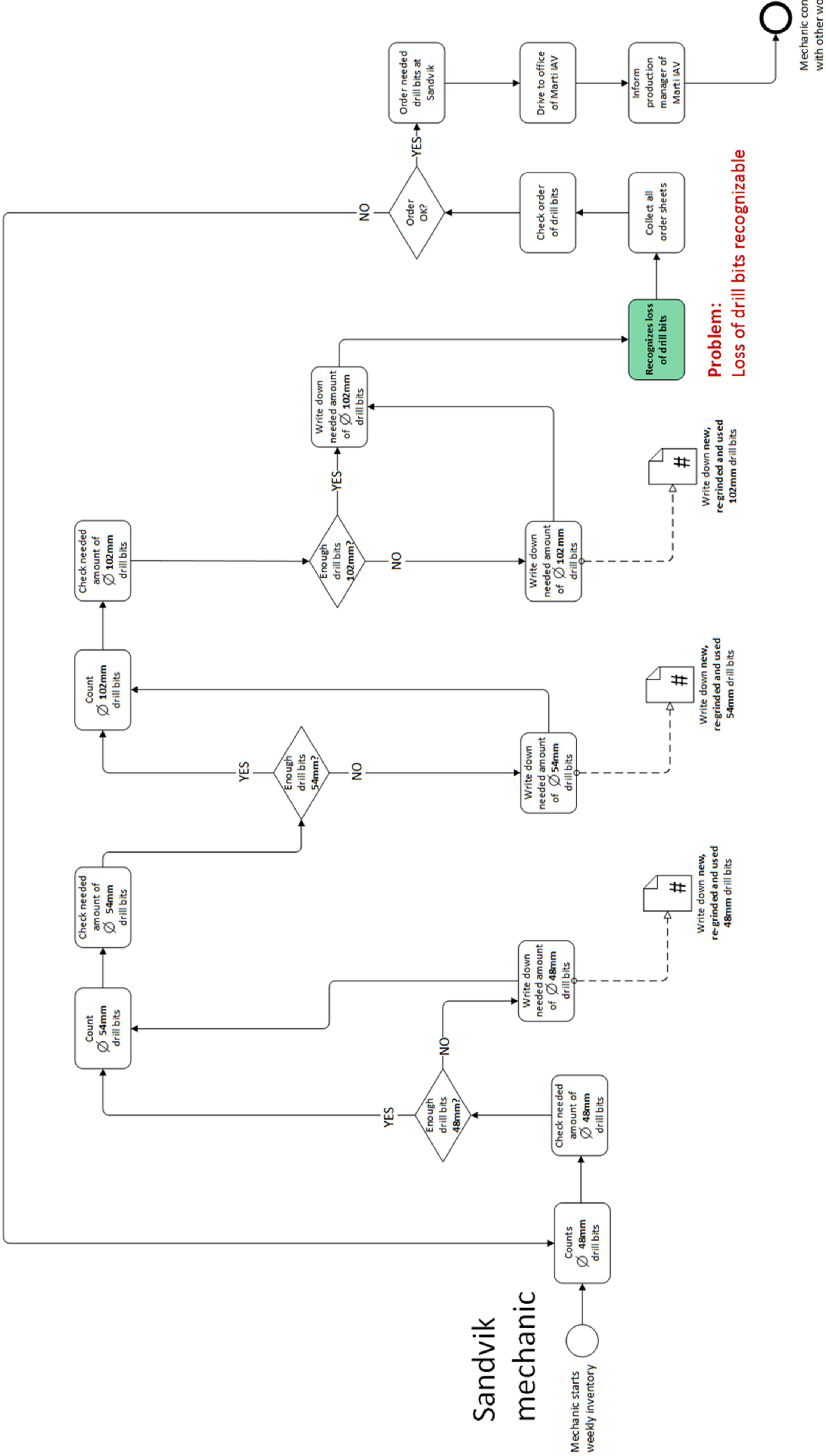
Appendix 27: BPMN model of suppliers driving to the workshop



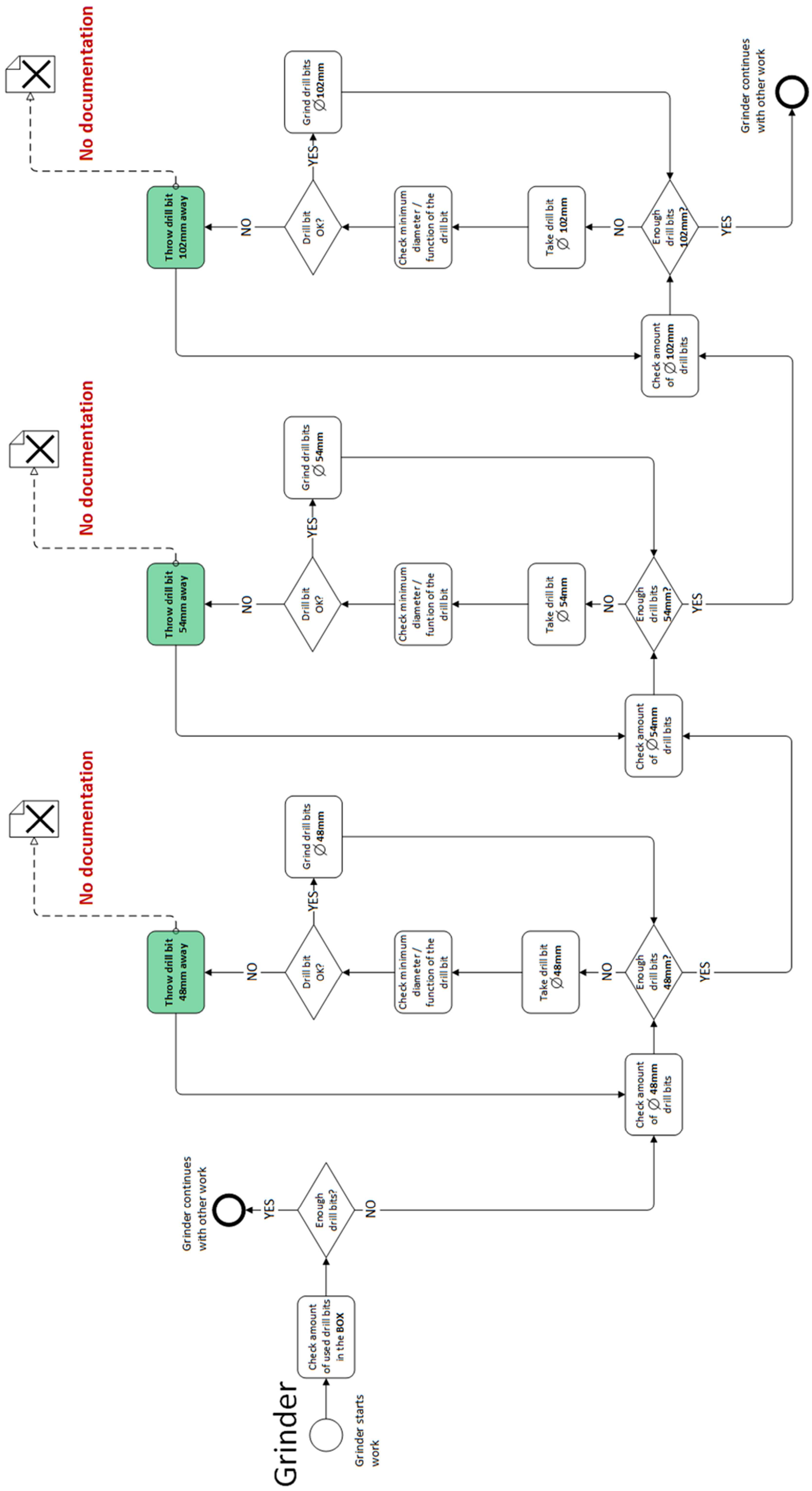
Appendix 28: BPMN (A) of the current states including process 1 & 2



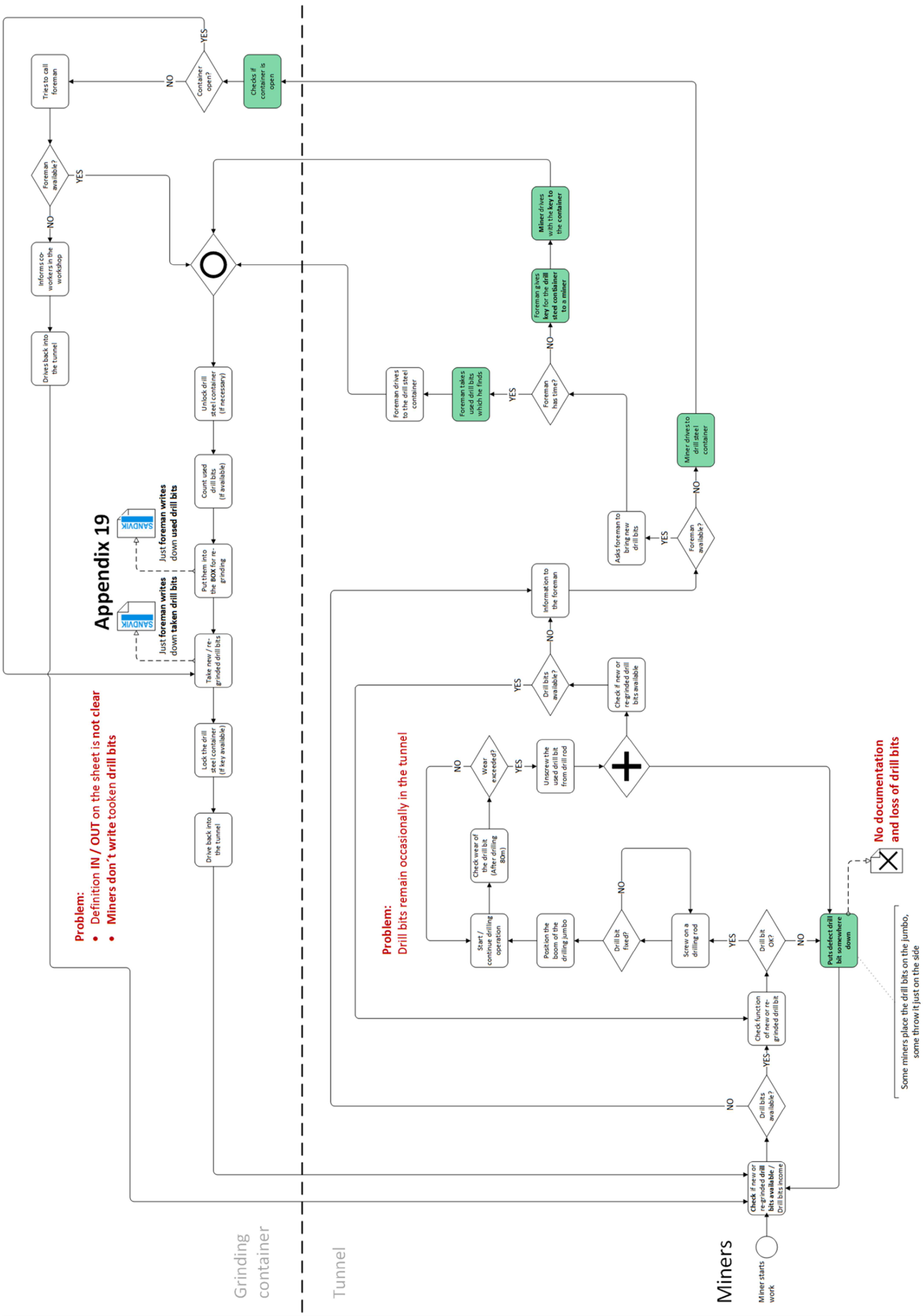
Appendix 29: BPMN model of a Sandvik mechanic



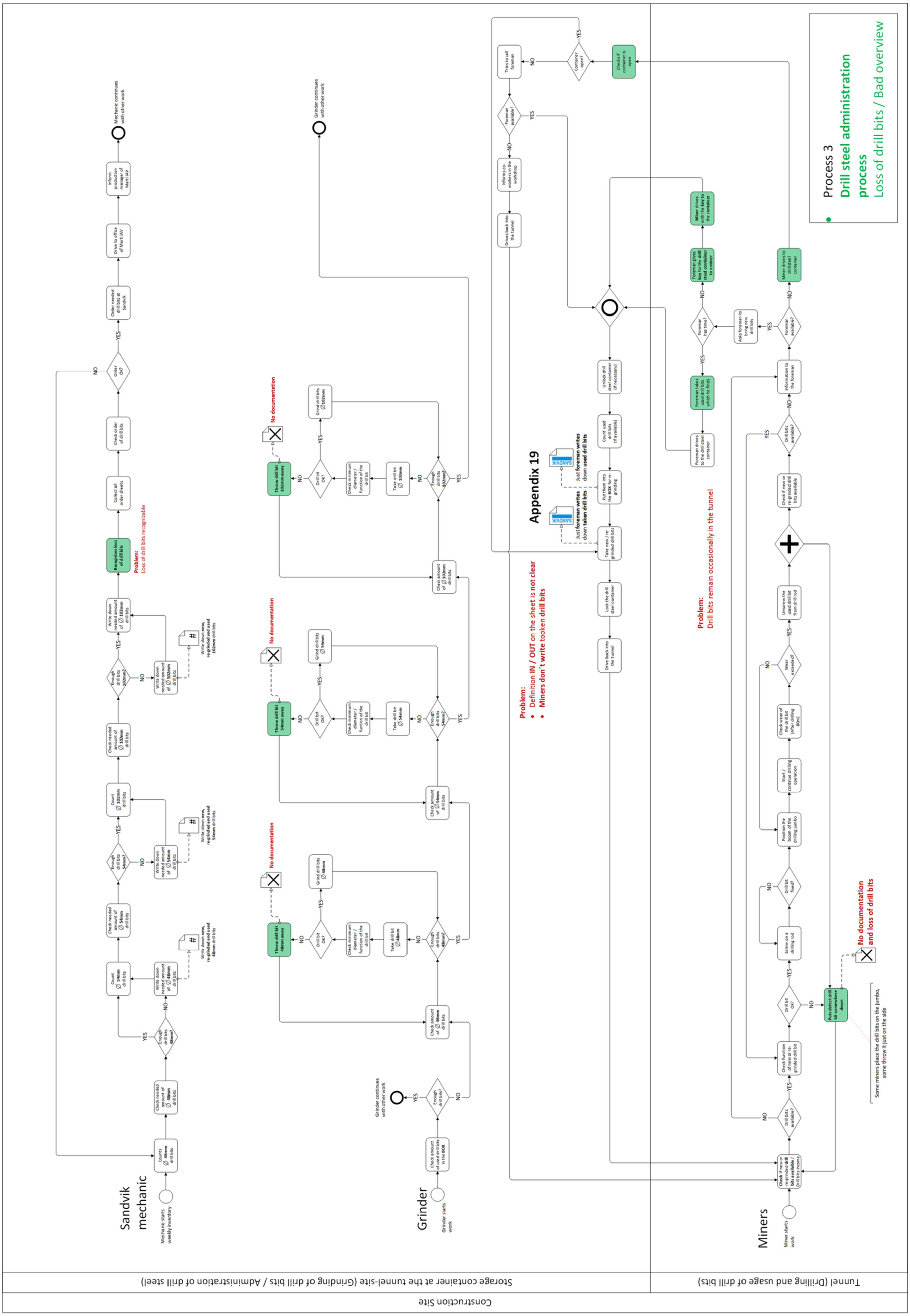
Appendix 30: BPMN model of a grinder in the storage container



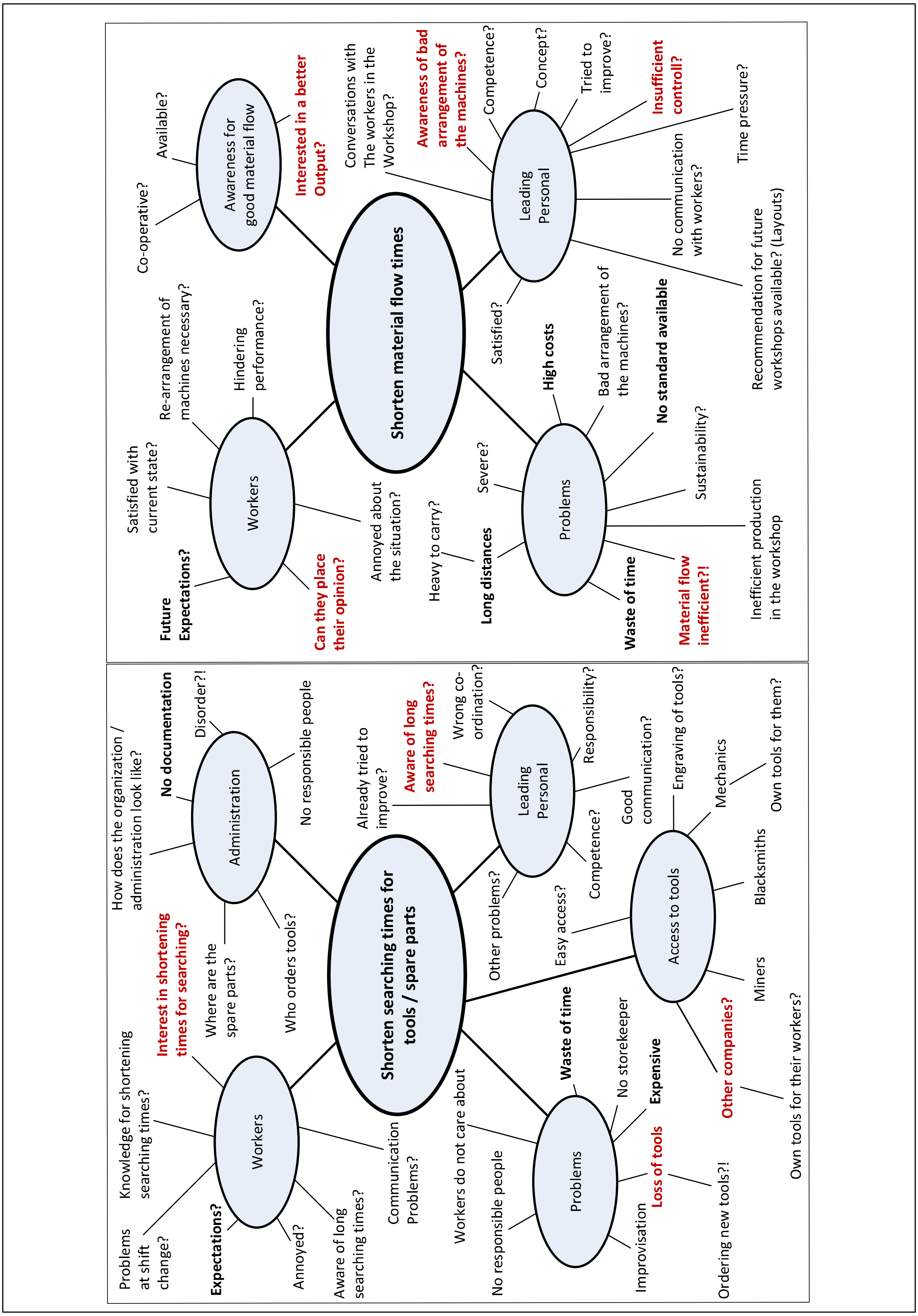
Appendix 31: BPMN model of miners between tunnel / grind. Container



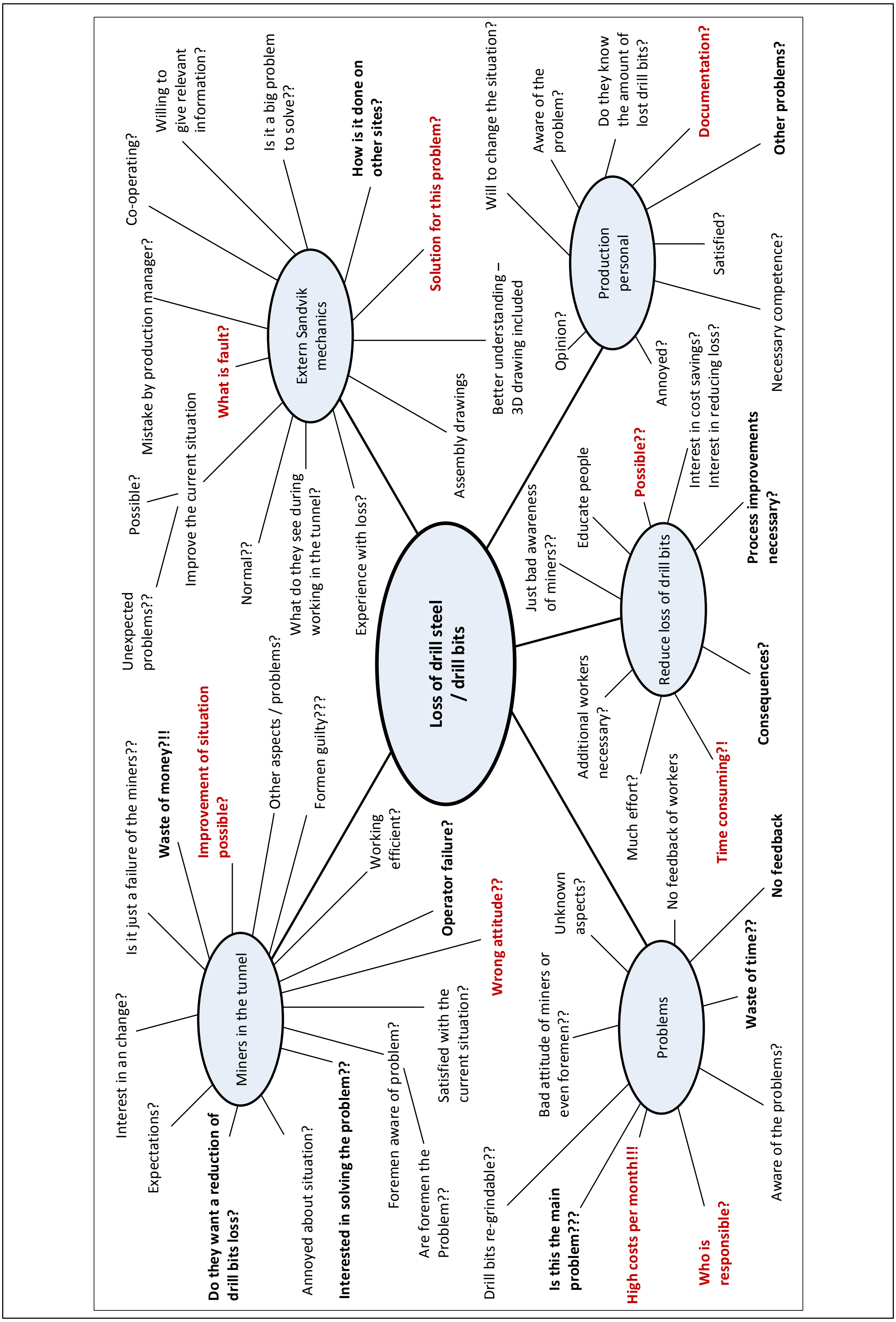
Appendix 32: BPMN (B) of the current states including process 3



Appendix 33: Mind map for structuring the questionnaire of process 1



Appendix 34: Mind map for structuring the questionnaire of process 3



Appendix 35: Questionnaire of the expert interview (Process 1)

Graz University of Technology
Institute of Business Economics and Industrial Sociology

Expert Interview:

(Introduction – Main part – Conclusion)

Introduction:

The interviewer (Auernig Daniel) writes his Master-Thesis for the Institute of Business Economics and Industrial Sociology at the University of Technology in Graz - Austria. For him you have an expert status due to your experience which you have gained on tunnel sites. The goal of this interview is to reduce the searching times for tools and spare parts in the workshop of the tunnel site Solbakk. Loss of tools and spare parts should be avoided. Also the long ways of the material flow should be reduced. He appreciates every answered question from you because it is a great opportunity for him to get important information from an expert. With your knowledge you will help to improve the working conditions for all workers in the workshop on this tunnel site in Norway.

With the results a recommendation for future tunnel sites should be given. The motivation for you to participate in this interview should be that with this obtained information the productivity in the workshop Solbakk will be raised. Time and cost savings for the company Marti IAV will be the result.

General information:

- Selection of the expert done by the interviewer
- **This interview is absolute anonymous!**
- No wrong or right answers – just honest answers please
- Your answers will help to improve the working conditions for the workers in the workshop

Framework requirement:

- Personal expert interview (Recording + hand notices by interviewer)
- Agree to record the interview? (For preventing data loss) ☐YES ☐NO
- Expert interview with guideline and open questions

Facts of the interview:

- Duration about 45min
- PART 1 – Questions about the searching times of tools and spare parts in the workshop
- PART 2 – Questions about the goods income and the way of material flow in the workshop

Personal facts:

- Age: [ ]
- Are you working in the tunneling workshop of Solbakk? ☐YES ☐NO
- Area of responsibility on this tunnel site:
- Qualification / Position in the company:
- Tunneling workshop experience: [ ] Years of experience

Comments / questions:

Appendix 35: Questionnaire of the expert interview (Process 1)

IF NO QUESTIONS LEFT – STARTING OF VOICE RECORDER

Comments:

Main part:

The interviewer made some explorative interviews on this tunnel site before and found out that the searching times for tools and spare parts are about 2 hours on average per person every day.

1.) How is the workshop organized?

a. Who is responsible for ordering the tools / spare parts?

b. What happens if that person is not available (e.g. holiday, …)?

2.) Why are the searching times for tools and spare parts so high in the workshop?

Appendix 35: Questionnaire of the expert interview (Process 1)

c. What is the problem therefore?

d. Who can take tools out from the workshop? (Workers form other companies too?)

e. Are borrowed tools brought back and documented? (Why not?)

3.) How could the situation in the workshop be improved? (How is it solved on other sites?)

f. Would a documentation of tools help? (Writing IN / OUT?, what else?)

Expert #1 Site Solbakk - Norway Date: Time:

Appendix 35: Questionnaire of the expert interview (Process 1)

g. What do you think about engraving of all tools for a clear identification?

h. Do responsible people know about the long searching times of the workers in the workshop? If yes, why nothing happens? (Co-workers, foremen, workshop manager)

i. How much could the searching time per person of about 2 hours every day be reduced with those improvements?

[ ] minutes

Part 1 is now finished. Do you want to add something important? Have you recognized some important points for improvement which the interviewer maybe hasn't considered?

Appendix 35: Questionnaire of the expert interview (Process 1)

PART 2 – General questions about the material ways and goods income in the workshop:

Comments:

Through explorative interviews the interviewer found out that the workers in the workshop are complaining about inappropriate ways of the material flow and a disturbing goods income. The time for removing incoming goods (e.g. pallets, ...) due to the suppliers and the additional waiting time through the parking vehicles in front of the workshop are about 15 minutes per person every day.

4.) Are you satisfied with the ways of steel material flow in the workshop? (Why / why not?)

5.) How could the way of the material flow in the workshop be improved? Could you afterwards please make a new arrangement of the machines / equipment on page 10 and 11? *(Expert gets a pen)*

Appendix 35: Questionnaire of the expert interview (Process 1)

6.) Disturbing goods income in the workshop: How could this situation be improved?

j. Who is responsible for removing incoming goods?

k. What happens if this person is not available (e.g. holiday, ...)

l. Is it a good idea to shift all the incoming goods into the new storage tent? (Why not?)

Appendix 35: Questionnaire of the expert interview (Process 1)

m. Would an own storekeeper for removing pallets, etc. make sense?

n. How much could the times for sorting the incoming goods and waiting of 15 minutes per day be reduced?

[ ] minutes

Comments:

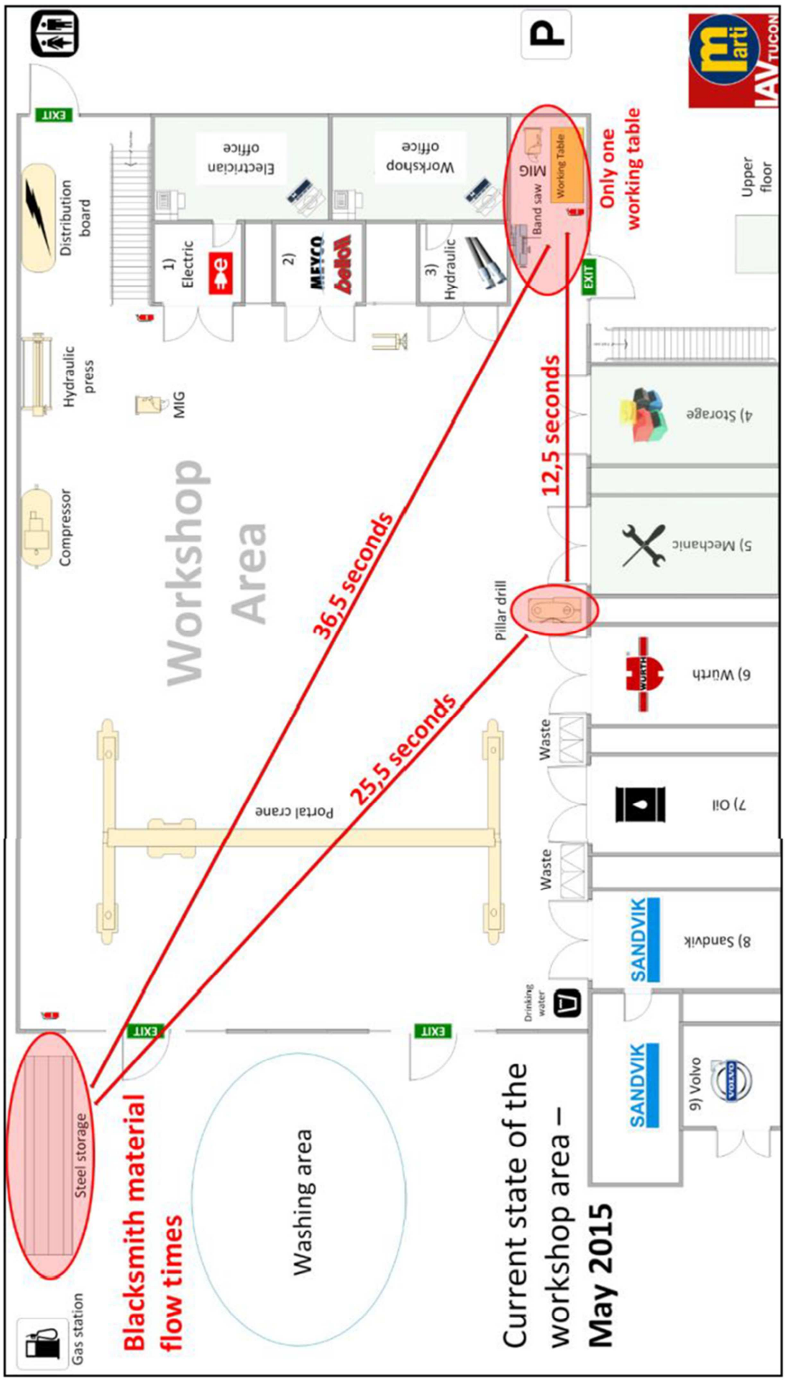
Appendix 35: Questionnaire of the expert interview (Process 1)

Graz University of Technology — Expert Interview – Process 1

Institute of Business Economics and Industrial Sociology

PLEASE SKETCH A NEW ARRANGEMENT OF THE MACHINES ON THIS PAGE:

Information: The red arrows are the existing ways / times of the workers (Point in time: August 2014)



Expert #1 — Site Solbakk - Norway — Date: — Time:

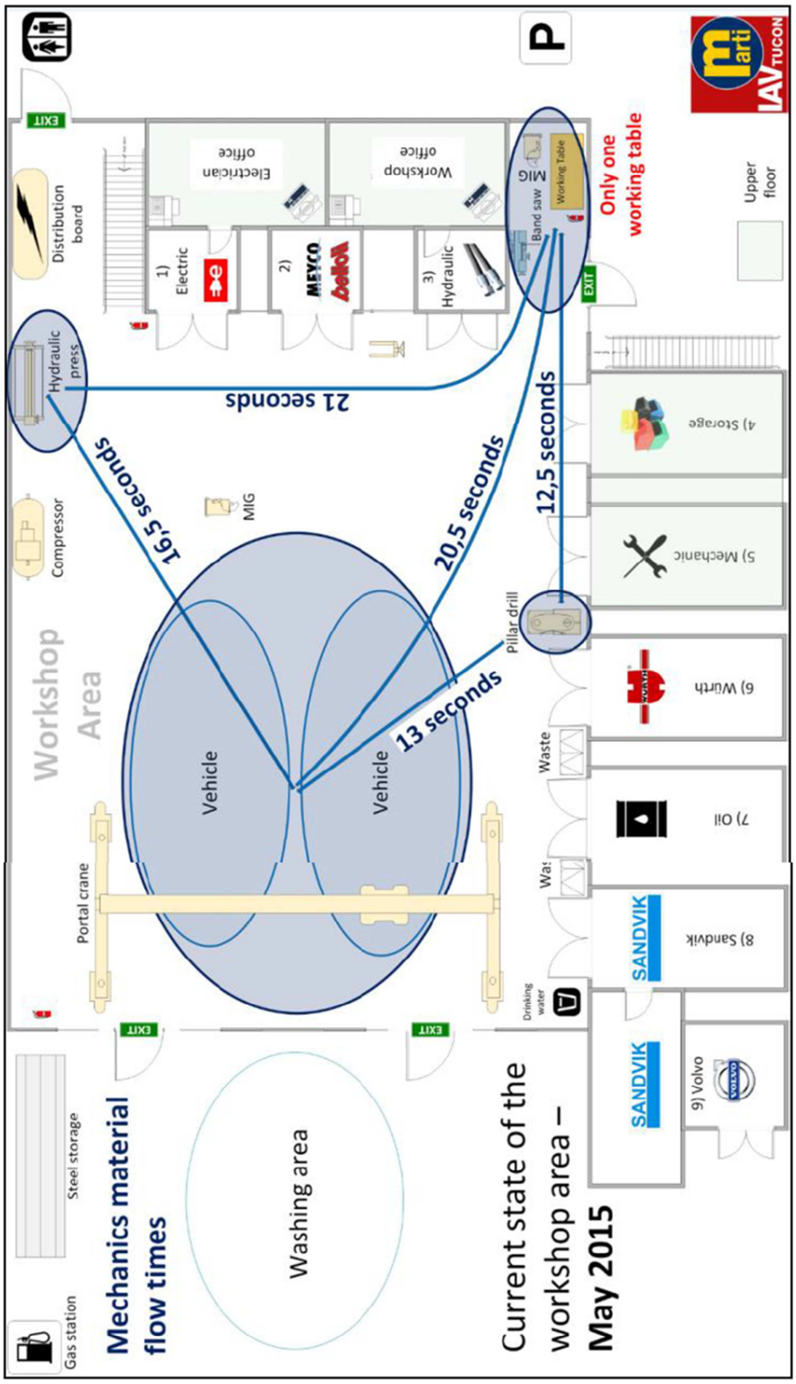
Appendix 35: Questionnaire of the expert interview (Process 1)

Graz University of Technology
Institute of Business Economics and Industrial Sociology

Expert Interview – Process 1

PLEASE SKETCH A NEW ARRANGEMENT OF THE MACHINES ON THIS PAGE:

Information: The red arrows are the existing ways / times of the workers (Point in time: August 2014)



Expert #1 Site Solbakk - Norway Date: Time:

Appendix 35: Questionnaire of the expert interview (Process 1)

Conclusion:

THANK YOU VERY MUCH FOR PARTIZIPATING!

With your professional answers the interviewer will make an evaluation of the whole interview. Therefore the recording is also very important to avoid data loss. With these results he will try to implement your ideas for raising the productivity in the workshop of the company Marti IAV in Solbakk. The interviewer will make an analysis of the resulting times and cost savings. If these measurements are successful they will be implemented on future tunnel sites.

- Do you have questions to the interview / to the interviewer?

- How was your feeling during the interview?

- Have you recognized some important points for improvements in this interview which the interviewer maybe hasn't considered?

Appendix 35: Questionnaire of the expert interview (Process 1)

- How do you like this questionnaire? (Improvements?)

- Was every question clear for you? If not, which question was not clear?

Comments:

Appendix 35: Questionnaire of the expert interview (Process 1)

REMARKS TO THIS INTERVIEW – WILL BE FILLED OUT BY THE INTERVIEWER AFTER THIS INTERVIEW:

- Atmoshere?
- Willingness of the expert to tell? (Does expert accept the expert role?)
- Mood / Body language (e.g. tired, excited, motivated,…)?
- Something strange during the interview? (Problems?)
- Room for improvement of the questions?

Appendix 36: Questionnaire of the expert interview (Process 3)

Graz University of Technology TU Graz
Institute of Business Economics and Industrial Sociology

Expert Interview – Process 3

BWI

Expert Interview:

(Introduction – Main part – Conclusion)

Introduction:

The interviewer (Auernig Daniel) writes his Master-Thesis for the Institute of Business Economics and Industrial Sociology at the University of Technology in Graz - Austria. For him you have an expert status due to your experience which you have gained on tunnel sites. The goal of this interview is to uncover the unexplainable high loss of drill bits at the tunnel-site Solbakk. With your experience and knowledge in this branch this circumstances will be improved. The interviewer appreciates every answered question from you because it is a great opportunity for him to get important information from a tunneling expert. With your knowledge you will help to avoid the high loss of drill bits.

With the results a recommendation for future tunneling projects of Marti IAV will be given. The motivation for you to participate in this interview should be that with this obtained information the extreme high loss of drill bits at the tunnel-site Solbakk will be decreased. Cost savings for the company Marti IAV will be achieved.

General information:

- Selection of the expert done by the interviewer
- **This interview is absolute anonymous!**
- No wrong or right answers – just honest answers please
- Your answers will help to improve the working conditions for the workers in the workshop

Framework requirement:

- Personal expert interview (Recording + hand notices by interviewer)
- Agree to record the interview? (For preventing data loss) ☐YES ☐NO
- Expert interview with guideline and open questions

Facts of the interview:

- Duration about 40min
- Questions about loss of drill bits, the documentation and possibilities for improvement

Personal facts:

- Age: [ ]
- Are you working for Marti IAV at the tunnel-site Solbakk? ☐YES ☐NO
- Area of responsibility on this tunnel site:
- Qualification / Position in your company:
- Tunneling experience: [ ] Years of experience

Comments / questions:

Expert #1 Site Solbakk - Norway Date: Time:

1

Appendix 36: Questionnaire of the expert interview (Process 3)

IF NO QUESTIONS LEFT – STARTING OF VOICE RECORDER

Comments:

Main part:

Due to random tests the loss of drill bits was evaluated. At the moment there are about 800 drill bits missing per month.

1.) What is the problem therefore?

a. Who has access to the storage or grinding container? (Who has a key? Miners also?)

b. Do you think burglary is the problem?

2.) Why is the loss of drill bits so high at this tunnel-site?

Appendix 36: Questionnaire of the expert interview (Process 3)

c. Is there documentation of the taken and brought drill bits?

d. Is there a problem with the documentation?
(Why? Writes every worker into the sheets? What happens with broken drill bits?)

e. Who is responsible for bringing back the used drill bits? (Foremen or also miners?)

f. Is there any other problem?

Appendix 36: Questionnaire of the expert interview (Process 3)

3.) How could the situation with the lost bits be improved? (How is it solved on other sites?)

g. Would a better documentation the drill bits help? (Writing IN / OUT?)

h. Does the responsible production manager know about the high loss?
(If yes, why nothing happens?)

i. What else would you suggest?

Appendix 36: Questionnaire of the expert interview (Process 3)

4.) Could the improvements be realized? (Problems?)

j. Which amount of loosen drill bits would be acceptable per month with these improvements?

[ ] pieces

Conclusion:

THANK YOU VERY MUCH FOR PARTIZIPATING!

With your professional answers the interviewer will make an evaluation of the whole interview. Therefore the recording is also very important to avoid data loss. With these results he will try to implement your ideas for raising the productivity in the workshop of the company Marti IAV in Solbakk. The interviewer will make an analysis of the resulting times and cost savings. If these measurements are successful they will be implemented on future tunnel sites.

- Do you have questions to the interview / to the interviewer?

- How was your feeling during the interview?

Appendix 36: Questionnaire of the expert interview (Process 3)

- Have you recognized some important points for improvements in this interview which the interviewer maybe hasn't considered?

- How do you like this questionnaire? (Improvements?)

- Was every question clear for you? If not, which question was not clear?

Comments:

REMARKS TO THIS INTERVIEW – WILL BE FILLED OUT BY THE INTERVIEWER AFTER THIS INTERVIEW:

- Atmoshere?

Appendix 36: Questionnaire of the expert interview (Process 3)

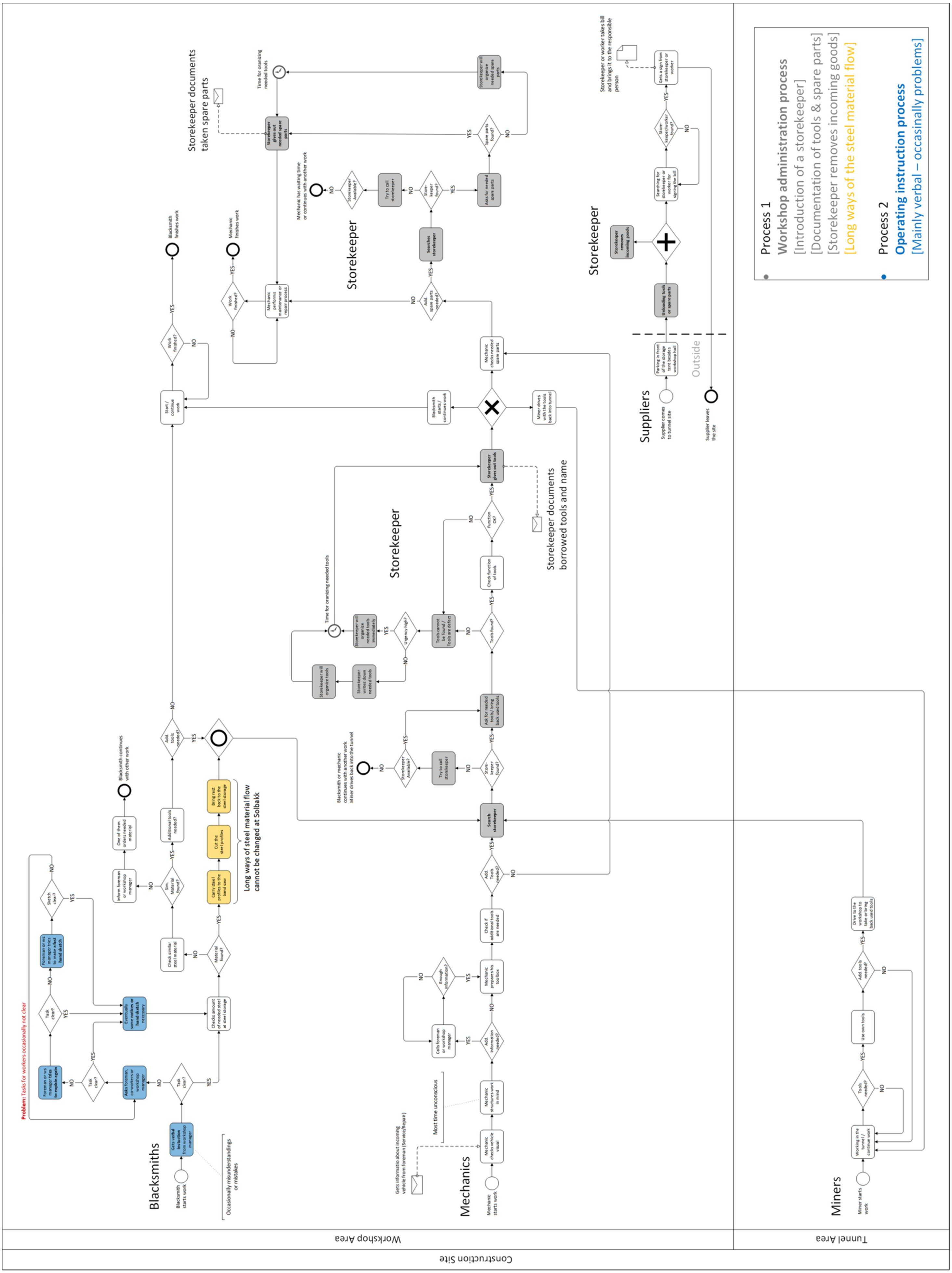
- Willingness of the expert to tell? (Does expert accept the expert role?)

- Mood / Body language (e.g. tired, excited, motivated,...)?

- Something strange during the interview? (Problems?)

- Room for improvement of the questions?

Appendix 37: BPMN (A) of the target state including process 1 and 2



Appendix 38: BPMN (B) of the target state of process 3