# Simulating production risk at Volvo Powertrain

## - Developing a simulation tool for decision making

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## Preface

This master thesis was performed at Volvo Powertrain in Köping in collaboration with the department of Packaging Logistics at the Faculty of Engineering (LTH) – Lund University.

Many people have had a significant role in making this master possible, both in terms of support and knowledge, and I would like to thank all of you.

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# Abstract

How can a small fire at a subcontractor in the USA lead to a multimillion dollar loss at a Swedish telephone company, and how can a single machine breakdown lead to a complete production stop at a production company? With today logistics and production trends, where terms such as Lean Production, Six Sigma, 5S, and World Class Manufacturing are used every day, production companies are introducing streamline production facilities and supply chain where goods and raw material are delivered just in time, where buffer zones are reduced, and where suppliers are reduced to a single source. These are trends that strengthen companies' competitiveness, but it also makes companies more vulnerable to risk events.

Volvo Powertrain in Köping is implementing World Class Manufacturing in Köping, and they are aware that there are risks that can harm the production and delay deliveries to their customers. They were looking for a tool that could visualize the consequences of such event to enable quick decision making.

From known historical events and from Volvo Powertrains request, a two folded purpose was developed. The first purpose was to perform a risk assessment on the production facilities at Volvo Powertrain in Köping and to find and analyze risks within the factory that has a high impact on the production. The second purpose of this master thesis was to develop a simulation model for a production industry that visualizing the consequences of a disruption and enables quick decision making. To make this possible, a single case study together with the empirical quantitative-based simulation methods was used whilst the theoretical foundation was based on the *AS/NZS 4360: 2004* standard.

A simulation model was developed using the probability safety assessment program RiskSpectrum. This required an accurate collection of information to reflect reality as good as possible. The information collected contained

historical risk events, different machine flows, different article numbers, fire cells etcetera, resulting in a simulation model containing almost 400 machines, 200 machine cells, 170 article numbers, and 600 different flows. The result were transferred to a Excel-file making it possible for the user to search on a machine or article number, and to see what machine are connected to which article numbers, and which machine that are critical and cannot be replaced by a different flow in the production line. The simulation also showed that many articles produced are critical connected to at least one or more machines that cannot be replaced today by another machine or by a 3$^{rd}$ party.

This master thesis does not intend to speak against new logistic and production trends, but rather to show how important it is to develop a strategy on how to handle risks when a risk event occurs. By having a well-developed action plan, a costly risk event can turn into a business opportunity.

## Sammanfattning

Hur kan en liten brand hos en underleverantör i USA leda till en miljardförlust för ett stort svenskt telekomföretag, och hur kan ett enskilt maskinhaveri leda till totalt produktionsstop hos ett tillverkningsföretag? Med dagens logistik- och produktionstrender, där termer som Lean Production, Six Sigma, 5s, och World Class Manufacturing används varje dag, har tillverkningsföretagen introducerat strömlinjeformade och optimerade produktionsanläggningar och logistikkedjor. Detta medför att varor och råmaterial levereras vid behov, där buffertzoner är reducerade, och det totala leverantörsantalet reducerat för att nå single source. Dessa trender stärker företagens konkurrenskraft, men det gör även så att företagen är känsligare mot risker.

Studien som står som grund för detta examensarbete utfördes på Volvo Powertrain som är världsledande inom produktion av tunga motorer, växellådor och axlar. Större delen av arbetet utfördes på plats i Köping på Volvo Powertrains produktionsanläggning där fokus ligger på produktion av växellådor. Volvo Powertrain i Köping använder sig idag av World Class Manufacturing, och de är medvetna om att det finns risker som kan skada produktionen och försena leveranser till deras kunder. De har därför framfört ett önskemål om att utveckla ett verktyg som visualiserar konsekvenserna av ett driftstopp i produktionen så att snabba beslut kan tas för att styra produktionen på bästa sätt.

Från historiska händelser och efter en förfrågan från Volvo Powertrain, formulerades ett tvådelat syfte fram. Det första syftet var att utföra en riskinventering på Volvo Powertrains produktionsanläggning i Köping för att hitta och analysera de risker inom fabriksområdet som har en stor påverkan på produktionen. Det andra syftet var att utveckla en simuleringsmodell för ett produktionsföretag som visualiserar konsekvenserna av ett avbrott i produktionen som möjliggör att snabba beslut kan tas.

För att få fram starka och säkra resultat valdes en kombinerad strategi där en fallstudie tillsammans med en simulering valdes som undersökningsmetod. Genom att använda en fallstudie tillsammans med en simulering kan resultatet stärkas jämfört med att använda de två forskningsmetoderna enskilt. Fallstudien omfattar historiska händelser där rådata tas fram, och simuleringsmetoden utgår från en uppbyggd modell som representerar verkligheten, där olika parametrar och förhållanden kan testas. Tillsammans genererar de resultat som är realistiska och precisa.

För att konstruera en simuleringsmodell var det viktigt att ha en djup förståelse för hur tillverkningen fungerade i Köping. Fallstudien användes för att bygga grunden som krävdes genom datainsamling. Genom fallstudien genererades kunskap om hur fabriken fungerade, vilka tänkbara problem som fanns, och vilka idéer som fanns för att förbättra tillverkningen. Informationen baserades framförallt på kvalitativ data som samlades in genom intervjuer, dokument, och observationer. Informationen för simuleringsmodellen baserad på kvalitativ data samlades in från företagspublikationer och från Volvos produktionssystem Volvo Production System. Den teoretiska grunden baserades på AS/NZS 4360: 2004 standarden.

Simuleringsmodellen i denna uppsats är baserad på ett antal nyckelobjekt. De tre huvudobjekten som behövdes för att bygga en simuleringsmodell för produktionsanläggningen i Köping var artikelnummer, de olika maskinerna på produktionslinan, samt möjliga flöden för varje artikel.

För att förstå hur produktionen fungerar och hur layouten på fabriken ser ut samlades data in på följande områden:

- Fabrikslayouten
- Produktionshastighet per artikelnummer
- Produktflöde
- Haverihistorik för varje maskin

- Kapacitetsförlust vid maskinhaveri
- Nyckelkomponenter

En preliminary hazard analysis (PHA) utfördes på företaget. Detta gjordes för att få en bild på hur verksamheten fungerade och att få fram vilka möjliga risker som fanns. Det första syftet med denna rapport var att identifiera och analysera möjliga risker som fanns på fabriksorådet i Köping. Resultatet från PHA:n var att modellen skulle ha möjligheten att handskas med tre typer av risker, den första där ett enskilt haveri slå ut en maskin, den andra ett större haveri som slår ut en maskincell, samt den tredje där en större olycka slår ut större delar av fabriken. Detta gör att simuleringsmodellen skall ha möjlighet att pröva olika scenarion där allt ifrån ett enskilt maskinhaveri till en större brand skall kunna simuleras.

Simuleringsmodellen som togs fram i denna rapport bygger strikt på felträdsprincipen. Volvo Powertrain i Köping har garderat sig för möjliga haverier eller olyckor och har därför upp till sju olika flöden för varje artikelnummer. Syftet med simuleringsmodellen är att på ett enkelt sätt visa konsekvenserna för en riskhändelse.

Idén till simuleringsmodellen kom från ett projekt som har utförts på de svenska kärnkraftverken som kallas för Common Cause Failure (CCF) där syftet var att se konsekvenserna av olika komponentfel med hänsyn på härdskador. Fördelen med att använda en felträdsmodell är att förutom varje maskin, kan man även lägga till andra beroenden som t.ex. transformatorer och inledande händelser som brand eller strömavbrott. Modellen bygger på att varje artikel har en toppgrind som representerar en färdig produkt. I nästa steg så ligger varje flöde representerat som en grind, upp till sju möjliga. Under varje grind som representerar ett möjligt flöde ligger sedan alla maskiner och beroenden inlagda i samma ordning som krävs för att tillverka artikeln.

För simuleringen gjordes två olika huvudfall, ett där man tittar på alla flöden, och ett där man endast tittar på normalflödet. Fallet där man tittar på alla flöden utfördes för att hitta kritiska maskiner i produktionsflödet, och fallet där man tittar på normalflöde är för att hitta kritiska artiklar. Totalt lades cirka 170 artikelnummer in i modellen med deras tillhörande flöden. Totalt blev det runt 600 möjliga flöden och några tusen artiklar som passerar de möjliga maskinerna.

För att få ett verktyg som är enkelt att arbeta i, lades alla resultat in i ett Excel dokument. I dokumentet finns sex olika rubriker man kan sorter efter. Dessa är följande:

- Maskincell
- Maskinnummer
- Artikelnummer
- Beskrivning av artikel
- Kapacitetsförlust vid haveri
- Artikelns tillstånd

Man kan här välja att söka på t.ex. ett maskinnummer eller artikelnumret. Vid sökning på ett artikelnummer fås de artiklar fram som utnyttjar maskinen, både på normal- och sekundärflöde. Det går då att se vilka artiklar som blir kritiska om en maskin går sönder, och vilka normalflöden som påverkas. På så vis går det t.ex. att få fram vilka artiklar som skall prioriteras vid kapacitetsförlust. Det går även att söka på artikelnummer som kan vara intressant att göra på nyckelartiklar för att få fram vilka maskiner som är kritiska och på så vis ta fram redundanta tillverkningsflöden.

Resultatet av studien visar att styrkan med denna simuleringsmodell är att den på ett visuellt och enkelt sätt åskådliggör konsekvenserna av en vald riskhändelse så att användaren lätt kan förstå situation och kan agera därefter. Simuleringsmodellen är även utbyggbar vilket gör det möjligt att lägga till nya

maskiner, artikelnummer, riskhändelser, så att den alltid är aktuell. I slutänden möjliggör simuleringsmodellen så att snabba beslut kan tas att för att begränsa effekterna av en riskhändelse och för att styra produktionen dit den behövs. Resultatet blir att Volvo Powertrain kan minska kapitalförlusterna som uppstår vid produktionsstop och höja kundnöjdheten då leveranssäkerheten till kund ökar.

I framtiden skulle det vara intressant att introducera alla företag som är kopplade till Volvo Powertrain i simuleringsmodellen, särskilt företag i logistikkedjan så som underleverantörer och transporter. Detta är intressant då det är möjligt att se konsekvenserna om en underleverantör inte kan leverera när det behövs, exempelvis på grund av en brand.

# Abbreviations

ABC – Activity Based Cost

CCF – Common Cause Failure

FMEA – Failure Mode Effect Analysis

FTA – Fault Tree Analysis

PHA – Preliminary Hazard Analysis

PSA – Probability Safety Analysis/Assessment

SCM - Supply Chain Management

SCRM - Supply Chain Risk Management

VPK – Volvo Powertrain in Köping

VPS – Volvo Production System

# Contents

# 1 Introduction

## 1.1 Background

Today all industrial activities are associated with risks in some ways. It's not uncommon with unexpected deviation from the daily work that can endanger the safety of personnel, cause the release of substances that can harm the environment and finally disruption of production leading to loss of income (Wennersten, 2003).

New trends in production and supply chain management, like Lean Production (Levy, 1997), has led to an increased risk of disruption due to for example increased complexity due to global sourcing, outsourcing, partnership that can lead to ripple effects in case of unexpected stops in production, company focus on reducing stocks and safety stocks and the introduction of single sourcing to reduce purchase and logistic prices (Hendricks & Singhal, 2005). An example of disruption is Ericsson and the fire at their subcontractor in Albuquerque, New Mexico (USA), which from a plant perspective was almost negligible, but for Ericsson it resulted in a major loss of about 400 million dollars primarily due to gaps in the supply of radio-frequency chips (Norrman & Jansson, 2004).

Tang (2005) classifies supply chain risk management into operational and disruption risk. The simplest way according to Christopher and Peck (2004) is to divide the risks into three categories, internal to the firm, external to the firm but internal to the supply chain, and external to the network. These risks can then be further subdivided into five categories. *Internal risks* to the firm involve process and control risks. It deals with disruptions caused by problems within the organizational boundaries such as machines breakdowns or IT/communication problems (Thun & Hoenig, 2011). These problems can be directly influenced by the company (Rice & Caniato, 2003). Supply chain

network (cross-company-based) risks involve demand and supply risks. Demand risks relates to potential or actual disturbances to the flow of the product to the customers, the goal is to have the right amount of products sought by the customer, neither less or more. Supply risks are the upstream equivalent of the demand risks (Christopher & Peck, 2004). Finally *external risks* to the network involve environmental risks and these can barely be influenced or controlled by the organization (Kleindorf & Saad, 2005).

## 1.2 Problem

For the production industries it's important to have a tool that can quickly identify the consequences of a disruption in the production chain to minimize the economic consequences for the industry and its customer.

For example, Volvo Powertrain in Köping (VPK), which is an essential supplier for the whole Volvo Group, must always be able to deliver its products to their customers. If the factory cannot produce the desired amount of products at the right time, the risk is that they won't be able to deliver in time, which can be costly for both VPK and their customers.

As many companies, Volvo Powertrain is using World Class Manufacturing (WCM) in their factory in Köping. WCM is a process-driven approach where different concepts, principles, policies and techniques are used to make improvements in areas such as quality, cost, lead time, flexibility, and customer service (Rockford Consulting Group, 1999). Philosophies and techniques usually associated with WCM are for example Lean Production, which purpose is to eliminate all non-value adding events (Liker, 2009, p. 28). This can be done by streamlining the production by reducing inventories, machines, space, staff, and even suppliers that don't add value to the customer. This often makes them more susceptible for risk, both in the production and in the supply chain (Norrman & Jansson, 2004).

A major problem today for the production at VPK is that some bottlenecks exists and when some of these machine breaks down they have an effect on the rest of the factory which has led to delays in production and failure to deliver parts to their customers. There are strategies today on how the production can switch flow but is hard to get an overview of the factory and which article numbers that are affected when a machine breaks down.

VPK has a need to handle disruptions in a quick way, to be able to adapt to new situation and to have the agility needed to do that. The management for Volvo Powertrain in Köping has expressed a desire to find a tool giving correct information when a disruption occurs that enables for quick decisions to steer the production to the most important articles in the production chain.

## 1.3 Purpose

This master thesis has a two folded purpose. The first purpose is to perform a risk assessment on the production facilities at Volvo Powertrain in Köping and to find and analyze risks within the factory that has a high impact on the production.

The second purpose of this master thesis is to develop a simulation model for a production industry that visualizing the consequences of a disruption and enables quick decision making.

## 1.4 Focus and delimitations

In this study the focus will be on internal risks which deals with disruptions caused by problems within the company boundaries as these problems can be manageable by Volvo Powertrain themselves (Thun & Hoenig, 2011).

Volvo Powertrain has operations in Sweden, France, Japan and North- and South America. In this master thesis the risk analysis and action will be performed only on the downstream material flow to the customer for the facilities in Köping, Sweden. Risk factors will neither be analyzed from Powertrains subcontractors.

## 1.5 Disposition

This master thesis is divided into three different parts. The first part contains chapter one to three and is an introduction to the research and how it will be carried out. The second part, chapter four will present the research and collected data in this report. Finally the third part, chapter five and six which combines part one and two, contains the results from the collected data and the discussion and conclusion.

# 2 Methodology

## 2.1 Research Approach

There are many different opinions about how and when too use different methods. Depending on a person's basic approach on knowledge, the purpose and goal of the research can be different (Björklund & Paulsson, 2003). Arbnor and Bjerke (1994) has identified three different method approaches, the analytical approach, the systems approach and the actor approach which are divided into explanatory- and understanding knowledge. The difference between the explanatory knowledge and understanding can be difficult to interpret thus both system- and actors approach affects them both (Arbnor & Bjerke, 1994).

### 2.1.1 The analytical approach

The analytical approach strives to explain the truth of a subject as completely and objective as possible. It doesn't matter if the researcher is objective or subjective to the research. The reason to this is that the researcher seeks to find the cause-effect relationships (Björklund & Paulsson, 2003). Conditions for using the analytical approach are that there is an existing theory and a number of techniques, that makes it possible to verify ore falsify given hypotheses. More proven hypotheses will give a clearer picture of the subject. No comparisons of relationship are made between proven hypotheses, in other words, all hypotheses should work on their own without needing part or further explanations from other hypotheses. From the hypotheses, theories are produced and the result is straightforward cause-effect relationships, logic models and representative cases. The result should be generalized so that further research can be done and the researcher should be positioned outside the object so that it's not influenced (Arbnor & Bjerke, 1994). The preferred method when using the analytical approach is the quantitative, however the qualitative methods are also used as a validation tool (Gammelgaard, 2004; Mentzer & Flint, 1997).

*2.1.2 The systems approach*

The systems approach also adopts an objective, available reality, however, assuming that this reality is built in a different way than the analytical approach (Arbnor & Bjerke, 1994). According to Gammelgaard (2004), it's meaningless to decomposing reality into parts from a systems perspective. A researcher with a systems approach always tries to explain the reality in an objective way. In contrast to the analytical approach, the researcher considers the whole concept can't be split into part where it's possible to explain all the different hypotheses by them self. Arbnor and Bjerke (1994) explains that in the systems approach $2 + 2 + 2 = 7$, this is because in reality the results will be made out of typical cases and some general classification mechanics, where unique cases can exist. The system relies on its parts and hypotheses and can therefore not be split up where each explanatory part explains the whole system.

The relationships between parts are as important as the parts themselves. That's why it's important to investigate the relations between systems parts to be able to understand the behavior of a system (Björklund & Paulsson, 2003). In a typical classical system approach the researcher is not directly involved in the object. With observation, the researcher gains information and can therefore propose improvements; reflect a view of reality that is objective, but susceptible to influence (Gammelgaard, 2004). The results are typical cases and some classification mechanisms, where partially unique cases may exist (Arbnor & Bjerke, 1994).

Churchman (1979) points out that the ideal method to use in system analysis is case studies. Both quantitative methods and qualitative methods can be used in the system approach (Gammelgaard, 2004).

*2.1.3 The actors approach*

The actors approach places emphasis on the fact that reality is a social construction that is affected by people and also effects people (Björklund &

Paulsson, 2003). It's the youngest of the three approaches and was accepted first in the late sixties. The actors approach has no interests in explaining different events or system parts, but is oriented into understanding the social connections between such. This means that it's oriented to map the significance and meanings of different actors, their actions and the surrounding environment of these (Arbnor & Bjerke, 1994). Gammelgaard (2004) states that the actors approach is highly contextual and that it is impossible to make predictions based on external cause-effect-relations of social reality due to the way humans are; intentional to different subjects. The results and descriptions thus given by the researcher is therefore highly dependent on his or hers experience and actions (Björklund & Paulsson, 2003). To gain deeper understanding of the reality, qualitative studies are primarily used (Gammelgaard, 2004).

### 2.1.4 Approach used in this master thesis

This study is based on two different approaches, the analytical- and the system approach. The main purpose of this study is to identify possibly risks within the factory in Köping, and to describe the consequences if a risk occurs. This is a typical analytical approach where the goal is to find the cause-effect relationships as mentioned by (Björklund & Paulsson, 2003). To be able to build a model of the factory in Köping, all parts of the system needs to be analyzed and understood. The result will be developed by using existing models and theories and then explain them according to the analytical approach. For the simulation model the relations between different parts in the system are as important as the parts themselves, all according to the systems approach (Arbnor & Bjerke, 1994).

## 2.2 Methodological approach

The size of the existing knowledge in a particular research area can have significant effects on which type of study that need to be done (Björklund & Paulsson, 2003). Arbnor and Bjerke (1994) states that a research doesn't need

to start with a hypothesis, and that a lot of studies aim to develop such. Those kinds of studies are called explorative. Explorative studies are used when there is little or no knowledge within a research area and the goal is to find basic knowledge. Descriptive studies are used when there is basic knowledge and understanding within the research area and the goal is to describe but not to explain relations (Björklund & Paulsson, 2003). Explanatory studies try to explain a phenomenon, like "how" or "why" did this happened. The goal is to get a deeper understanding and in the same time be able to describe it (Yin, 2003). The normative studies are used when there already is well-documented knowledge in a certain research area and the goal is to provide guidance and even solutions to a problem (Björklund & Paulsson, 2003).

This study is a combination of an explanative and a descriptive study. Even if risk management is a relatively new phenomenon in supply chain management and production there are many articles and information about the subject. The first part of this study is to identify risks and to describe them and therefore this meets the requirements for a descriptive study. The second part is to explain the consequences of a risk and to answer the questions around them, and this is a typical explanatory study according to (Yin, 2003).

## 2.3 Research strategy

In supply chain management it's becoming more common to use both the case study research method together with the empirical quantitative-based simulation methods (Hellström & Nilsson, 2006). In this section the theoretical explanation of case study- and simulation research will be performed, followed by an explanation of combining both strategies.

### 2.3.1 Case study research

A case study is intended to do an in-depth explanation of an subject, especially when questions such as "how" or "why" appears, when it's hard to control the events, and when focus is on a contemporary phenomenon within some real-life context (Yin, 2003). It's important to know which type of question that is

being asked and what control the researcher has over the events. It's also important to know what results that is desired and if it's possible to identify a defined system as focus for the research. In other words, a case study is a research about a specific phenomenon where the system is either important or represents any kind of hypothesis (Merriam, 1994). The case study describes a single case and the results are assumed not to be generalizing to other cases. Common used techniques for the case study are interviews, observation and content analysis (Höst, Regnell, & Runeson, 2006).

### 2.3.2 Simulation research

Bratley, Fox and Schrage (1987, ix) define simulation as "*Simulation means driving a model of a system with suitable inputs and observing the corresponding outputs"*. Simulations can be used for many different purposes, such as prediction, performance, training, entertainment, education, proof, and discovery. Simulations have the advantages that it allows analysis of both adaptive and rational agents. It also has the advantage that it's possible to add new data during the whole process, and the only thing that needs to be redone is the simulation (Axelrod, 1997). Simulation research can be divided into two different classifications, axiomatic or empirical model-based research where the axiomatic model-based research is relying on idealized problems and deterministic solutions, and the empirical model-based research which is based on empirical findings (J Will & M. Bertrand, 2002). To be able to get a correct model as possible when making an empirical simulation research, it's important to have great knowledge about the system that is being studied (Hellström & Nilsson, 2006).

### 2.3.3 Combined strategy

By combining simulation and case studies, there is a great potential of strengthen the result comparing to use each method alone. The case study method deals with events that are based on historical real-life events and where the data cannot be altered, while the simulation is an image of the real

world where the researcher can manipulate parameters and relations of interest. The case study can neither be replicated compared to the simulation which can be replicated as many time as the researcher wants. By using case study research, the objective is to capture realism, while the simulation provides the precision. Together they generate results that are realistic and precise (Hellström & Nilsson, 2006).

### 2.3.4 Research strategy in this master thesis

To be able to build the simulation model, great knowledge of the factory in Köping was needed. The case study method was used to build the foundation that was needed, and the collected data was inserted into a single case study. From this, knowledge was gathered on how the factory worked, what problems there were, and what ideas there were for improvements. The building stones for the case study were mostly based on qualitative data collected through interviews, documents, and observations. When the knowledge needed to understand the factory in Köping was achieved, it was possible to sketch the simulation model needed for this study. The data the simulation model was then based on was mainly quantitative and collected mainly from company publications and the Volvo Production System.

## 2.4 Data collection

There are many different methods on how to collect and process data for a project. Björklund and Paulsson (2003) mention a couple of scientific approaches and how these relate to each other. There is often a lot of information out there and the hardest part is often to find the relevant one.

According to Arbnor and Bjerke (1994) there are two main techniques for data collection: primary and secondary. Secondary data collection uses already collected material, while primary data is about collecting new. To gather new data there are three possibilities, through direct observations, interviews and by conducting experiments. When using secondary data it's important to see that it's not written in an angle and that the author has been objective (Arbnor

& Bjerke, 1994). In this section a theoretical explanation of the different data collection methods used in this study are explained followed by an explanation how the data was collected for.

### 2.4.1 Literature study

A literature study is often the first step in the beginning of a research, to see what has already been done, to get ideas in the research area and to build a frame of references. The literature study refers to all form of written material; books, brochures, journals and websites to name a few examples. The result from this study is typical secondary data. It's therefore important to be aware of that the information might be incorrect or not complete. The strength with literature studies is that it can be started in short time and it doesn't need any specific financial resources (Björklund & Paulsson, 2003).

### 2.4.2 Interviews

A common way to gather information for a research project is through interviews. These can be performed in different ways, through personnel interviews and by phone to mention a few. It's generally seen as an advantage to standardize the questions, so that it's easier to compare the answers to each other. Within the analytical approach it's often sought, if possible, to have closed questions so that it becomes easier to compile the results (Arbnor & Bjerke, 1994).

An advantage by using interviews is that it gives direct and new information about the research project. Interviews, however, are very time-consuming and can be costly as it may require a lot of travels. This can be eluded by doing the interviews by phone or other manner which doesn't require a personnel present. Obtained information from interviews is seen as primary data (Björklund & Paulsson, 2003).

## 2.4.3 Observations

Observations can be performed in many ways. There are two common forms; indirectly where the observation is performed retrospectively, or directly, where the observation is performed in real-time (Arbnor & Bjerke, 1994).

|  | | The observed knowledge that they are observed are: | |
|---|---|---|---|
|  | | **High** | **Low** |
| The observers interaction with the observed are: | **High** | Participant observation | Fully participant observation |
|  | **Low** | Trivial participant observation | Full observation |

**Figure 2.1**      Four types of observation in the present (Arbnor & Bjerke, 1994)

When performing a direct observation, four different sets of observations are possible as shown in figure 2.1. The researcher that performs the observation tries to be as integrated as possible in the group where the observed participants are fully aware about the observer. Data collection is done by doing notes or journal entries. Another way to do observation is by fully participate in the observed group, this is called observational research. The difference here is that the participants are not aware of that they are being observed. Also here the data is collected by notes and journal entries. The third kind of observation, participation observations, and the observer is integrated in the project without being a real part of it. The groups knows that there is an observer and data is collected through interviews and other open methods such as the "think out loud" method where the participant is asked to explain what he or she is thinking about when performing a task. The fourth observational method is the full observation, where the observer does not participate in the operation and is fully invisible for the subject that's being observed. Data collection is normally performed by using hidden technology as with a camera or voice recordings (Höst, Regnell, & Runeson, 2006). Observation are often

said to be a time- and resource-consuming data collection method, but that the result often are more objective than other ones (Björklund & Paulsson, 2003).

### 2.4.4 Data collection methods in this study

The data collection took place at Volvo Powertrains facilities in Köping – Sweden during the summer of 2012. In total two full weeks, about 80-100h were spent on-site performing data collection. During this time several interviews, group meetings, observations, and documents were collected. In total thousands of documents, several hours of recorded interviews, and dozens of sketches and notes were manufactured and collected. This resulting into the simulation model and its results presented in this master thesis.

The project started with a thorough literature study to see and confirm what has been done in this research area. The literature study also works as a foundation for the work that would be done in this study. Most of the data has been collected through secondary sources such as information from Volvo Powertrains databases, all according to the analytical approach. To validate the work and to find improvements that do not exist in the secondary data, interviews were performed with key personnel at Volvo Powertrain, both white- and blue collar personnel. In some extent observation was performed, but due to time needed to get reliable data it was mostly used when analyzing the flow of the factory and to find possible risks. In this section a thorough explanation on what data was needed and how it was collected will be performed.

### Data sources

To be able to gather the information needed the data was collected through many different sources. The data was then screened and only the key data was kept. From the raw data, tables, production rate for key articles, and average numbers that was needed for the model was developed. This was done by performing interviews, studying documents, holding group meetings, and

scanning databases. In table 2.1 six data collection activities are shown, and these are further described in this section.

**Table 2.1**     Sources for data collection

| Activity | How many (estimated) | How long (average) | Focus of data collection |
|---|---|---|---|
| Main interviews (startup of the thesis) | 3* | 1-2h | Establish context, information about risks and breakdowns |
| Documents | 10 | - | Establish knowledge about the production at the factory |
| Company website and publications | 2 | - | History and information about the company |
| Group meetings | 10 | 30-60min | Discussion about known problems and possible solutions |
| Volvo Production system (no database pages) | 1000 | - | Breakdown history, production rate, material flow |
| Interviews/follow up meetings | Multiple | 0,5 – 2h | Confirmation about results, questions about data |
| Observations | Multiple | - | Establish context, information about risks and breakdowns |

*One interview was performed multiple times during the process.*

*Interviews*

Three main interviews were performed during the data collection, one with personnel from management, one responsible for safety within the factory boundaries, and one with knowledge about breakdown history and critical machines. The questionnaires for the performed interviews can be found in Appendix A1, A2, and A3.

The interview with the person from management sat the basis for the work. From this information it was possible to find what problem was known within the factory today, what tools that were needed for making faster and easier decisions, and information on how the organization worked. The interview was done with two main questions (Appendix A1), and the main purpose was

to have a discussion on what Volvo wanted out of this thesis. The first idea that was developed, which main purpose was to perform an risk inventory of the factory was later changed to making a visualization tool for easier decision making when a risk occurs. The first question that was discussed was what problems the management at VPK thought was a problem and possible disruption risk at the production facilities in Köping. The result was that there were a couple of known problems that needed attention, and from that the first idea was to perform a risk inventory of the production facilities. Later discussion with the risk manager it was discovered that a full risk inventory had already been performed within the facilities in Köping. The second task was to discuss what results VPK wanted, and what kind a tool that they thought could improve the production and ensuring deliveries to their customers. From the discussion it was decided that the main purpose of the thesis would be to develop a tool that in an easy way could visualize the consequences of a disruption within the production facilities so that faster decisions could be made to ensure production of key articles even if a disruption occurs. This interview was done more than once due to new information that surfaced during the data collection, and in total around four to five hours was spend on discussing the bases of the thesis.

The second interview was with safety and risk manager at VPK. The questionnaires contained four main questions (Appendix A2) with the main purpose to find the most critical risks for the production line. This, however, developed into a two hour long discussion about risks and risk management at VPK. At this moment it was quickly noticed that Volvo had already researched and examined the risks and possible disruptions at the production site in Köping. There was already a lot of information about known risks, and history about disruption that had occurred in recent years. At this moment it was decided that, as described above, the main purpose of the study would be to develop a tool that would show and describe the consequences of a disruption within the production site. The information collected from this

interview laid the foundation on the layout of the simulation model. The result was that to be able to make lifelike simulation, not only single machines should be able to shut down, but also whole machine cells and areas.

The third interview was with personnel with knowledge about the machines, breakdown history of those, how reparations are performed in case of a machine breakdown, how long a normal breakdown usually is, and what percentage that is caused by human error (Appendix A3). The main information collected from this interview contained breakdown history and the ratio between machine breakdown caused by wear and human error.

*Documents*

To get a better understanding on what work had been done previously, and projects that would be done in the upcoming future at the production site in Köping, documents and reports were analyzed. The information from these documents had no importance for the simulation model per say, but had an important role on explaining the production facilities, future upcoming update of the factory that in the future will require an updated model.

*Company website and publications*

The be able to describe Volvo Powertrain in Köping, what products they produce, how many and how large the facilities are, the number of employees , and the history of the company, the company website and information folder was used. This is important to give the reader an understanding on what kind of business the simulation model and visualization tool is based on.

*Group meetings*

During the progress of the study, new data was collected and analyzed, and to be able to know which information that was critical and needed, most of the data collected were discussed in small groups, often containing two-three persons, both blue and white collar personnel, and was normally around 30-60 minutes long. The main purpose of the group meetings was to weed out all the

unnecessary data from all the thousands of pages of information that was collected, and to evaluate what data that was critical for the simulation model. The group meetings also had the purpose of discussing possible risks, known problems, and solutions with personnel in different departments with different tasks within the company.

*Volvo Production System (VPS)*

The be able to produce an accurate simulation model, to represent the production facilities in the most accurate way possible, information regarding article numbers such as production rate for each article number, production flow, breakdown history, gearbox variations and its contents, machine numbers, and the layout of the factory needed to be establish. Volvo is using a system called Volvo Production System (VPS) which is an offshoot of World Class Manufacturing (Verkstäderna, 2011). All the information needed to build the simulation model was in databases found in the VPS. Most of the information found was raw data, and from thousands of reviewed database pages, summaries, tables, and flowcharts were either elected instantly or refined to suit the needs.

*Shorter interviews and follow up meetings*

Shorter interviews and follow up meetings had the same purpose as the group meetings, to verify collected data, to find known risks or possible disruptions, and to find possible improvements from the staffs, both blue and white collar personnel. These interviews and follow up meeting were mostly performed with one or two premade questions, and mostly culminated into longer discussion. The main purpose was to clarify and verify collected data, mostly from the Volvo Production System, but also to find known problems in the production line and to get ideas and recommendations.

*Observation*

Observation was used to analyzing the flow of the factory and to find possible risks. It was also used to understand the production line and how the flow

could be redirected during a breakdown. Observations were also used to get ideas for the simulation model, and when something was unclear. During the data collection at Volvo Powertrain in 2012 several observations were performed.

## 2.5 Validity, reliability and objectivity

*"Using either established or more novel approaches to assessing the reliability and validity of research is one way of producing useful and trustworthy research findings"* (Roberts, Priest, & Traynor, 2006, p. 45). According to Björklund & Paulsson, 2003 there are three dimensions on studies credibility that should always be considered in a scientific context; validity, reliability and objectivity.

Validity means that the model doesn't have any systematical errors Wallén (1993), in other words, to what extent it really measures what it intends to measure (Björklund & Paulsson, 2003). The validity technique differs a lot for the different system approaches and should therefore be performed in different ways. For the analytical approach it's important to know that the used measuring techniques actually measures what they should and that the results are adequate. For the system approach it's not as important to link theory, definitions and reality to each other as when using the analytical approach. An important way to control the validity for the system approach is to see the effects when applying the results indicatively. Within the actors approach there are no specific validation criteria. But researchers that uses the actors approach often say that the only validation that may occur is on which degree the actors accepts the results and interpretations (Arbnor & Bjerke, 1994). Ways to improve validity is to use multiple perspectives and to ask direct questions as objective as possible (Björklund & Paulsson, 2003).

Reliability is about the possibility to get the same results regardless of how many times measurements are taken (Merriam, 1994). Reliability can be

increased by using control question where the interviewees are tested again. Triangulation can be used to increase reliability (Björklund & Paulsson, 2003).

As shown in figure 2.2, the goal is to have both high validity and reliability.



| Low validity<br>Low reliability | Low validity<br>High reliability | High validity<br>High reliability |
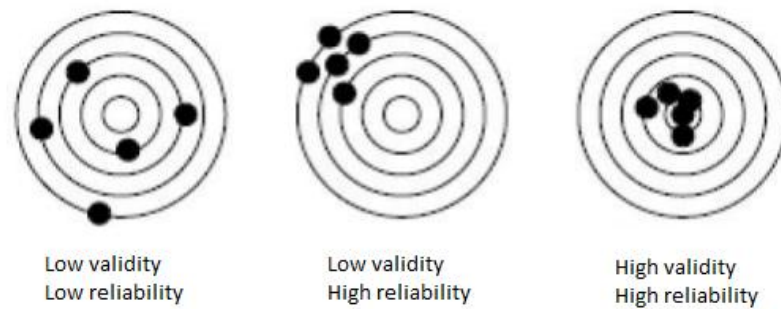
**Figure 2.2**   Illustration of validity and reliability (Björklund & Paulsson, 2003)

Objectivity is about how the researcher relates to the investigation, how his or her values might affect the result in a negative or positive way. To increase objectivity it's important to clarify and justify the different choices that are made so that the reader can evaluate the results of the study (Björklund & Paulsson, 2003).

## 2.6 Scientific reasoning

It's often difficult to capture social relations by using simple theories. But there is an urgent need to systematically address the social relationship in a theoretical way (Holme & Solvang, 1997). Arbnor & Bjerke (1994) shows in figure 2.3 the relationship between the empiric world which are full of facts, and the theoretical world, which are mostly quantitative build. In the models also three steps are described, Induction, deduction and abduction.

With induction the researcher summarizes the regularity from observations to theories without having made a previous scan of known theories. In other words with induction a subject can be studied without the knowledge about existing theories or models. And from these studies new theories are

formulated (Björklund & Paulsson, 2003). It's often underlined that when data is collected it should be done unconditionally. Because of this, induction has been criticized within the academic world thus the theory don't contain anything that's not in the empirical material (Wallén, 1993).

Deduction is on the other side a scientific method which by using general laws and theories makes predictions about the empirical data which is then compared and verified to the collected data. Conclusions are then drawn on separate phenomena from the existing theory (Björklund & Paulsson, 2003).

Abduction is when the researcher changes levels of abstraction between induction and deduction (Björklund & Paulsson, 2003).
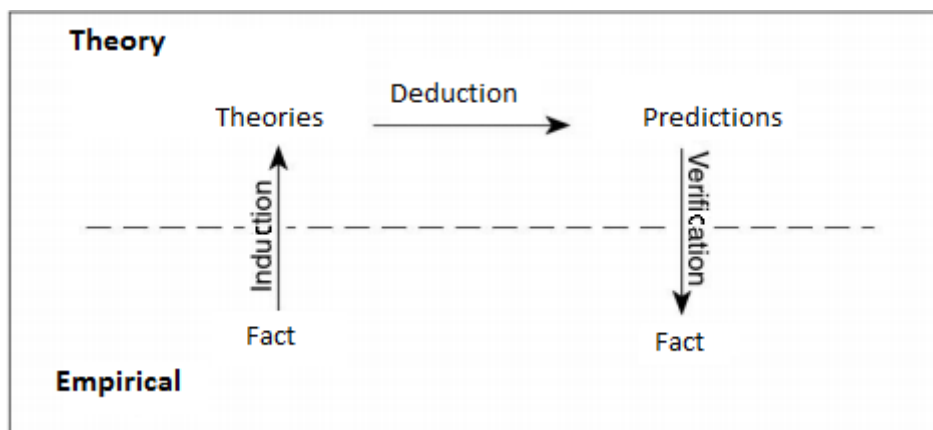


**Figure 2.3**, illustration of inductive and deductive approach (Arbnor & Bjerke, 1994)

# 3 Literature review

## 3.1 Different types of risks

*"Risk pervades every dimensions of our lives; both personnel and professional"* (Rao & Goldsby, 2009, p. 97). Often when we talk about risks the first thoughts for many are risks with flying or the risk concerning nuclear power plant. In these branches risk management is an everyday event and nothing that is unknown for the workers. If we're looking only 10 years back, earthquakes, economic crisis, SARS, strikes, terrorist attacks has disrupted production and supply chains around the world (Tang, 2005). Today with large international companies working in many different countries around the world it's common to streamline the supply chain according to Lean Production, World Class Manufacturing etc. to lower the cost and stabilize the supply chain (Levy, 1997). For many companies these trends has had a good impact on the supply chain due to less subcontractors, less products in circulation, smaller warehouses and so on. These effects and trends are often very effective in a stable environment, but they also get more vulnerable to disruption caused by uncertainties (Tang, 2005), like the fire at Ericsson's subcontractor in Albuquerque, New Mexico (USA) or the rapidly weakening demand for Cisco in 2001 due to locked-in supply agreements that resulted in a $2,5 billion inventory write-off (Norrman & Jansson, 2004) and the toy manufacturer Mattel that recalled 19 million toys due to lead paint or loose magnets in 2007 (Sodhi, Son, & Tang, 2012).

There are many different types of risks and they can be described in different ways. Sodhi et al. (2012) writes about how different risks are explained in the literature but that there is absence of a standard on the definition for supply chain risks. Manuj & Mentzer (2008) has chosen to divide the risks into eight different categories, where the first four are specifically associated with supply chains and the last four is a combination of supply, demand, operational, and security risks, see table 3.1.

**Table 3.1**    Summary of risks (Manuj & Mentzer, 2008, p 138)

| Type of risk | Source |
|---|---|
| Supply Risks | Disruption of supply, inventory, schedules, and technology access; price escalation; quality issues; technology uncertainty; product complexity; frequency of material design changes |
| Operational Risks | Breakdown of operations; inadequate manufacturing or processing capability; high levels of process variations; changes in technology; changes in operating exposure |
| Demand Risks | New product introductions; variations in demand (fads, seasonality, and new product introductions by competitors); chaos in the system (the bullwhip Effect on demand distortion and amplification) |
| Security Risks | Information systems security; infrastructure security; freight breaches from terrorism, vandalism, crime, and sabotage. |
| Macro Risks | Economic shifts in wage rates, interest rates, exchange rates, and prices. |
| Policy Risks | Actions of national governments like quota restrictions or sanctions |
| Competitive Risks | Lack of history about competitor activities and moves |
| Resource Risks | Unanticipated requirements |

## 3.2 Risk and operational risk

Risk is for many people a subject that still is kind of diffuse. But to be able to work with risk and be able to explain it, a definition of it is needed (Franzetti, 2011). There are a lot of different standards and frameworks that can be used to identify, assess and manage risk. The definition for risk can also differ a lot between different persons and that there is a lack of a standard in the scientific work that has led to different approaches to risk management in different fields (Hubbard, 2009).

According to the AS/NZS 4360 Risk Management standard, risk is defined as *"the chance of something happening that will have an impact on objectives"* where the risk is measured in terms of likelihood and consequences (AS/NZS4360:2004, 2004).

According to the ISO/IEC Guide 73 risk is defined as the combination of the probability of an event and its consequences (ISO/IEC, 2009).

Both these standards are well used around the world but is lacking in some parts according to some. Aven (2011, p725) points out that in both these standards the precise definition of likelihood and probability are lacking. He suggests that the definition should be *"Uncertainty about and severity of the consequences of an activity or the two-dimensional combination of consequences and associated uncertainties"*.

Crockford (1986) provides a well-known and popular classification that characterizes the consequences into four different areas; trivial, small, medium and large. The first one, trivial consequences, is an event that occur with a very high frequency and have a very low severity but a very high predictability. The second one, small consequences, is an event that that have a high frequency with a low severity and a reasonable predictability, but with their occurrence being infrequent. The third one, medium consequences, are events that have a low frequency with medium severity and a reasonable predictability with its occurrence being frequent. The fourth and last one, large consequences, are events that has a very low frequency with a high severity and a minimal predictability (Tummala & Schoenherr, 2011).

## 3.3 Risk management

Risk management involves the work to identify and evaluate risk and how to handle these by introducing different routines and technical safety systems. There are different steps and models that can be used to simplify the work and making it easier to address the most critical risks for the company (Wennersten, 2003). The AS/NZS 4360 Risk Management standard defines risk managements as "the culture, processes and structures that are directed towards realizing potential opportunities whilst managing adverse effects" whilst the risk management process is defined as "the systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context, identifying, analyzing, evaluating, treating, monitoring an reviewing risk" (AS/NZS4360:2004, 2004).

### 3.3.1 Aspects to consider

When analyzing a factory, such as Volvo Powertrain in Köping or any other production industry, the risk management framework needs to be applied for all the aspects of the production flow such as the production and machine itself, the personnel working in the factory, outside hazards such as earthquakes and forest fires, up- and downstream flow outside the factory and the management of the company.

### 3.3.2 Models and framework

When performing a risk assessment the parameters are decided depending on the situation and the aim of the assessment. That means that a risk model is chosen or modified to fit the specific case.

*The ARM method*

One of the risk models that were used as a comparison for this master thesis was the Avesta Risk Management (ARM) method that was developed for the Avesta-Sheffield group by Ingemar Grahn and is now also used by a variety of companies (Överstyrelsen för civil beredskap, 1999). This method starts by collecting all information and knowledge about all the flows, both inside and outside the company. This can be done by finding hazards and other possible event that can make disruptions within the factory and to find other possible flows for the production. When all the information is collected the real analysis start, the data is thoroughly reviewed on spot and the results are assessed. With the information it's possible for the company to protect themselves against risks and knowing how to mitigate the disruptions if the risk occurs (Överstyrelsen för civil beredskap, 1999).

*The DRISC model*

The Disruption Risks in Supply Chain (DRISC) model developed by Ulf Paulsson, in similarity to the ARM - method, looks at the risks from the companies' perspective in the supply chain (Paulsson, 2007). Paulsson explains the model as "The DRISC model intend to be a holistic and generic

model for managing disruption risks in the product flow of the supply chain that helps to treat supply chain risk issues systematically"

All risk aspects are taken into account, such as disruptions risks caused all the way from natural resources to the final product. It makes it possible to divide the risks into a total of 15 different "risk exposure boxes", of which three include known impact and 12 that represent expected impact. What makes the DRISC model to a perfect tool is that it's possible to summarize the risks into one number to make it easy to calculate on the total impact for the company (Paulsson, 2007).

*The five risk management steps*

Risk Management is a continuous process that concludes the work to identify and evaluate risks, and to handle these in the everyday work by introducing different routines and technical safety systems. The work to identify and evaluate different risks within the operation is called risk analysis. Risk assessment includes both the analysis and the evaluation whether the risks are acceptable or if measures need to be done (Wennersten, 2003).

Manuj and Mentzer (2008) explain a five step model for companies with a global supply chain to follow, from risk identification to strategies to deal with these risks. This model is not only for companies with a global supply chain but is essentially used in all risk management (Överstyrelsen för civil beredskap, 1999). The five steps include risk identification, risk assessment, risk mitigation, risk performance and a continuous improvement process.

The first step, risk identification (similar to risk analysis), is also the critical step. When doing the risk identification the aim is to discover all relevant risks, a bit like doing a health survey, and then to evaluate if the risk is relevant for the whole system, and therefore need further assessment (Kern, Moser, Hartmann, & Moder, 2012). The second step, the risk assessment, is more focused on the in-depth analysis of each risk to be able to effectively avoid it, reduce its probability and impact and to accept its occurrence or in the

cases where the business impact is too big to prepare a contingency plan (Baird & Thomas, 1985). The third step, risk mitigation, uses the data from the first two steps to find countermeasures for each risk. When talking about mitigation, there is two different ways to do it, either before the risk event, or after it, also called contingency plans. For each risk that may cause interference in any way, an appropriate mitigation strategy needs to be developed and executed. The fourth step, continuous improvement process, is a process that is continuously ongoing and affects all the steps in this model. After the mitigation is done, even if it was successful, to control the risk it's important to continuous monitor it and to analyze the effectiveness of the chosen mitigation strategy and if needed to adjust these measures for future risk management (Kern, Moser, Hartmann, & Moder, 2012). The fifth and final step is the risk performance. Risk management is a continuously ongoing process. It's therefore important that chosen measures is carried out, and not only the analysis. Risk management can be costly, both in effort and in money, often new investments, new routines, and above all, a new way to look at things. This is often up to the company management to take those decisions (Överstyrelsen för civil beredskap, 1999).

## 3.4 Risk analysis

### 3.4.1 Probabilistic safety analysis/assessment (PSA)

A probabilistic safety analysis is an analysis of probabilities that may occur and is used to find common cause failures that can burst all the barriers if a breakdown or accident occurs. Watson (1994, p. 261) explained it as *"A Probabilistic Safety Analysis expresses uncertainty about the possible future damaging consequences of complex installations,…, PSA may be seen as a tool for argument, rather than an objective representation of truth"*. What makes the PSA into a powerful tool is that in one model the whole system, with all the barriers and safety system may be analyzed. The result is thus a complete picture over the whole system. The problem with PSA is that it treats

rare events and thus the statistical uncertainty can be big (Swedish Nuclear Power Inspectorate, 2001). In this master thesis the PSA will be used to calculate the frequency of events that can lead to disruption in the production, to find disturbances, component failures and malpractices that has the biggest effect on the production, and finally to find possible safety improvement measures and which of these to priority.

### 3.4.2 Fault tree analysis (FTA)

Fault tree analysis is together with event tree analysis the most common methods for detailed risk management (Holmgren & Thedéen, 2003). It's today used in many branches such as the nuclear industry, air and space industry and the chemical industry. It's widely accepted today due to the usage as part of the probabilistic safety analysis (PSA) for improving the safety of nuclear power plants and the safety of the space missions (Cepin, 2011). In a fault tree analysis the model is based on an assumed accident/breakdown as the top gate. From here the goal is to find underlying events and causes that can lead to the top gate. In the nuclear industry the top gate can be a meltdown of the core, and the goal is to find common cause failures that can lead to this meltdown (Swedish Nuclear Power Inspectorate, 2001). In figure 3.1 an example of a fault tree model is shown, this is just an example chosen due to its simplicity, but the same principals applies for the Volvo Powertrain model. The top gate is failure to deliver water to tank A for four hours. The top gate is an "AND" gate, which means that all of the underlying events, in this case GA and GB, needs to break down for the top gate to fail. GA and GB on the other hand are "OR" gates, which means that it's enough that one of the underlying event occurs/breaks down for the gate to fail. So for gate G to occur at least one of the following basic events A1 - A4 together with at least one of B1 - B4 need to occur/break down. If each basic event has a probability to occur it's also possible to calculate the possibility for the top gate to occur (Holmgren & Thedéen, 2003).
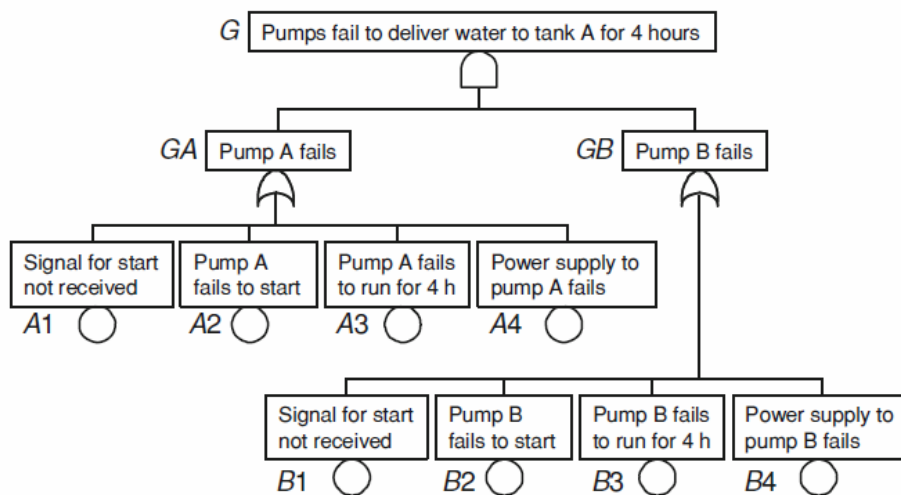
**Figure 3.1** fault tree analysis (Cepin, 2011)
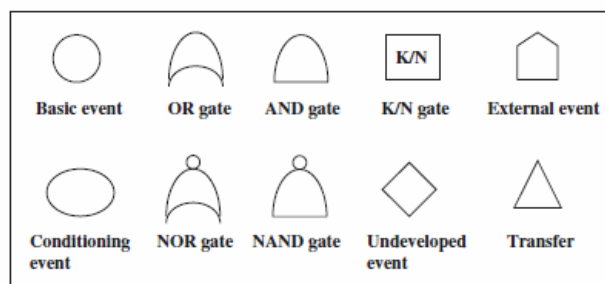


**Figure 3.2** fault tree symbols (Cepin, 2011)

### 3.4.3 The risk matrix

There are many risks out there for a production company and not to overflow
with data a first good step is to use the risk matrix to find which risks are most
critical for the company. The risk matrix is built by two axes, the first one
representing how often this risk may occur. The second one represents the
consequences if the risk occurs. In the first rough analysis different check list
can be used to identify known risks? The problem is often to calculate on risk
that is unknown for the company. To find these a "what if"-analysis can be
used (Holmgren & Thedéen, 2003). To know where to put the risks on the risk
matrix a definition can be used: Risk = probability (of the event) multiplied

with the Business Impact (or severity) of the event (Norrman & Jansson, 2004). The risk matrix has three different areas, the red one representing event that instantly needs a solution. The second step, the yellow, is risk that needs to be locked at as soon as possible but they don't represent any critical threats to the company. The third and last step is the white one, which are risk that doesn't have a real impact on the company, these risk should be noticed but they don't need any instant actions, see figure 3.3.
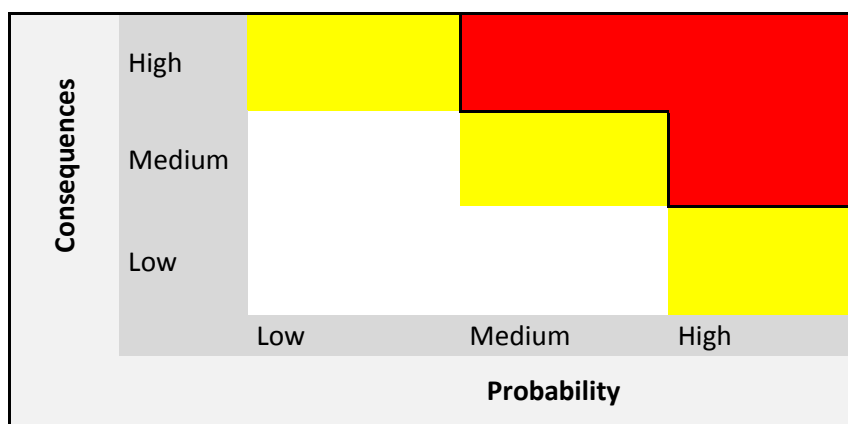


**Figure 3.3**    The risk matrix

### 3.4.4 Preliminary Hazard Analysis – PHA

A preliminary hazard analysis - PHA is used to find risk and harmful event in the beginning of a project (Johansson & Lundin, 1999). It's a semi-quantitative analysis that can be used to identify risks and harmful events and to rank this according to their severity and finally identify possible solutions on how to control these hazards and follow-up actions (Rausand, 2005; Department Of Defense, 1993).

### 3.4.5 Failure Mode Effect Analysis (FMEA)

Failure Mode Effect Analysis (FMEA) is commonly used to analyze potential failures, predicting their effects, and facilitating preventive action. Usually equipment is selected for analysis, the next step is to identify potential failures that could affect the system it belongs to, and to analyze whether the equipment is critical for the system or not. The failure modes are the possible

ways in which the equipment can fail. Effect analysis involves predicting the effects of each failure mode (Braaksma, Meesters, Klingenberg, & Hicks, 2012).

## 3.5 Risk mitigation, recovery and protection plans

### 3.5.1 Mitigation strategies

To reduce the impact on disruptions, environments and to people, risk mitigation measures are used. This can be done by several actions such as mapping of hazards, insurance and legislation and structural and non-structural measures.

Risk mitigation is a way to minimize the impact of a risk event and should be based on the risk assessment to be able to address known and unknown problems that may occur in the best way. Risk mitigation can be seen in two ways, long term and short term. Long term mitigation can for example be structural and non-structural defenses such as improvement of buildings and infrastructures or changing the relation of critical locations and areas and education of people, in other hand changes that is done before an accident. A short term risk mitigation measure is about improving the response and actions when a risk has occurred so that the impact can be reduced (Esteban, Delmonaco, & Ferrara, 2011). For each risk that is relevant for the company, an appropriate mitigation strategy needs to be done. (Kern, Moser, Hartmann, & Moder, 2012)

### 3.5.2 Recovery plans

If the risk should occur it's important to have a recovery plan so that facilities or operations are up and running as fast as possible so that critical services or product deliveries still can be performed. This can be done by following the examples on page 31.

- Have backup suppliers that can deliver the needed resources if the accident occurs at the sub-supplier
- Re-deploy personnel where it's needed
- Decide whether to repair or build a new facility or to relocate to another site if a structural incident occurs
- Find the resources necessary for restoring business operations
- Return to normal operations
- Resume the operation levels as they were before the disruption

(Minister of Public Works and Government Services, 2012)

### 3.5.3 Protection plans

There are many ways a company can protect themselves against risks. Manuj and Mentzer (2008) have identified seven strategies on how to protect a company from risks which are the following: avoidance, postponement, speculation, hedging, control, sharing/transferring, and security. For many of these strategies is often mandated the use of another strategy to make them work properly.

### Avoidance

Avoidance is just as the name explains, a way for the company to avoid risks. This is often bound to a certain product or geographical market. Avoidance can for example be to delay entry for a product or to only release a product in low uncertainty markets. (Miller, 1992)

### Postponement

Postponement is about delaying the usage of resources so that the company can be more flexible and less money bound in resources. Two different types of postponement are mentioned by Zinn and Bowersox (1988), Form postponement and time postponement. Form postponement includes manufacturing, assembly, packaging and labeling while time postponement

refs to the movement of the gods from the factory to customers only after the orders are received.

*Speculation*

Speculation is the opposite the postponement. In contrast to postponement, speculation decisions are made on anticipated customer demands. (Manuj & Mentzer, 2008)

*Hedging*

Hedging is a way of lowering the risk for event such as currency fluctuation or natural disasters. The idea is to have a number of suppliers, spread out in the world so if a risk occurs it will not affect all of the suppliers. Dual sourcing or multiple contracting is a good example on how a risk can be hedged. (Manuj & Mentzer, 2008)

*Control*

Miller (1992) explains controlling as ways companies may seek to control contingencies from the different risk sources instead of passively treat those risks. Control strategies are commonly used within organizations and can included vertical integration, increased stockpiling and to use buffers or maintaining overcapacity in the production, handling and transport, and finally storage. (Jüttner, Peck, & Christopher, 2003)

*Transferring/Sharing Risk*

To transfer or to share risks in a supply chain, achievement can be done by outsourcing, off-shoring and contracting to other firms. By outsourcing or off-shoring the risk is transferred from the company to the supplier. (Manuj & Mentzer, 2008)

*Security*

Security strategies is about finding and identifying nuclear, chemical, and/or biological element when shipping products. This is done today by hi-tech sensors that are capable of identifying such elements. The meaning is to sort

out what is moving and concentrate risk shipments so that the rest of the shipments can be dealt with.

## 3.6 Operational risk management

Operational risk management can be described as a decision-making process to systematically evaluate events that may occur so that actions can be taken to best determine the course of action for any given situation. (Phillips, 2000)

Operational risk has been around as long as businesses have been around. Every company is confronted with operational risks because the operation involves different type of processing, such as manufacturing or development. Operational risk is defined as the risk of loss resulting from inadequate or failed internal processes, people and systems, or from external events. (Franzetti, 2011)

### 3.6.1 Models and framework

There are many different definitions of the Operational Risk Framework. Some are simpler and some explains better on how to proceed. Franzetti (2011) has made a comparison of the models that is commonly used in operational risk management, the Basel Committee, the COSO, and finally the AS/NZS 4360: 2004 as shown in table 3.2. Since this study is based on the AS/NZS 4360: 2004, it will be described further in section 3.6.2.

**Table 3.2**     Comparison of risk standards (Franzetti, 2011)

| AS/NZS 4360: 2004 | COSO ERM | Basel 2 |
| --- | --- | --- |
| Establish the context | Internal environment, objective setting | (implicit) |
| Identify risks | Event identification | Identify |
| Analyze risks | Risk assessment | Assess |
| Evaluate risks | Risk assessment | (Measure) |
| Treat risks | Risk response and control activities | Control/mitigate |
| Monitor and review | Monitoring | Monitor |
| Communicate and consult | Information and communication | (implicit) |

### 3.6.2 The AS/NZS 4360: 2004 risk management process

The AS/NZS 4360: 2004 standard involves seven steps as shown in table XX2 and further described in picture 4.3.1. Three of the seven steps in the model are the risk assessment steps. Further down an explanation of the seven steps are performed in the order as the AS/NZS 4360: 2004 presents them.
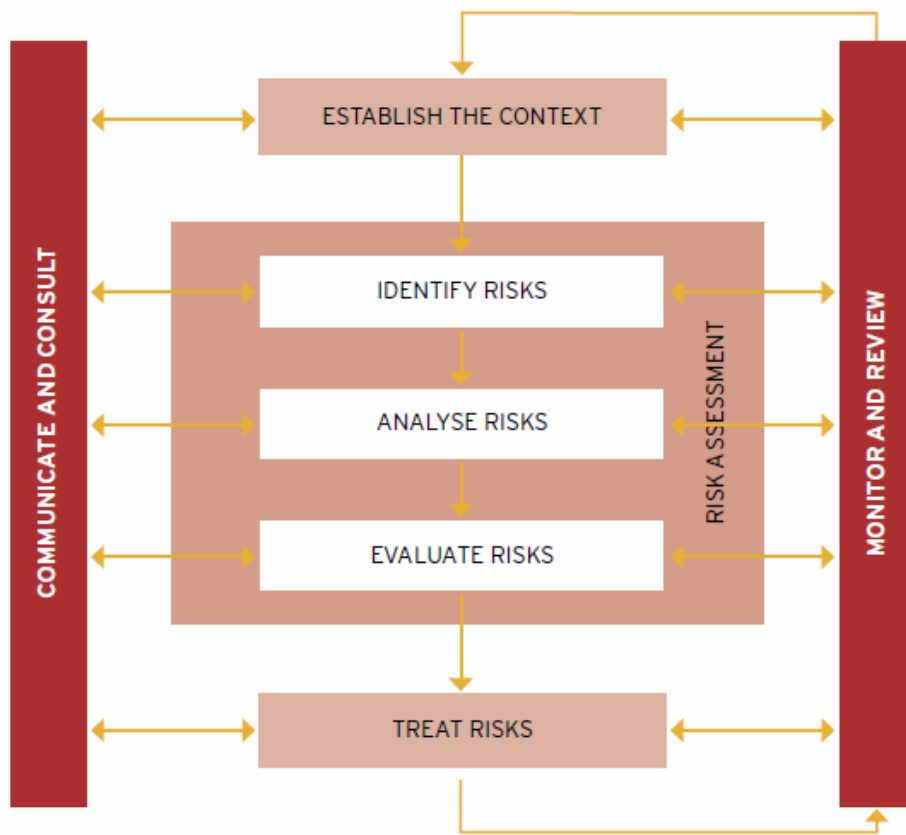
**Picture 3.4**   The AS/NZS 4360: 2004 steps

*Communicate and consult*

Communicate and consult are important through all the steps in the model.
Effective external and internal communication is important to a company so
that the right decision are made, both before and after a risk event occurs.
Stakeholders should be consulted all the way rather than a one way flow of
information from the decision makers to other stakeholders.
(AS/NZS4360:2004, 2004)

*Establish the context*

To be able to begin with the risk management process, the basic parameters
must be defined on which risk that must be managed. This also sets the scope
for the rest of the process. This step includes five sub steps which includes
establishing the following steps: the internal context, the external context, the

risk management context, to develop risk criteria's, and to define the structure for the rest of the process. (AS/NZS4360:2004, 2004)

*Identify risks*

As the name suggests, this step is about identifying the risks that need to be managed. This step is important and needs to be performed in a well-structured way, so that no risk misses to be identified and therefore not included in later analyses. Risk that is identified should both be those that are under control and those that are not. To be able to do a good risk identification the following sub steps should be used; what can happen, where and when?, why and how it can happen, and tools and techniques to use so that those risks can be found. (AS/NZS4360:2004, 2004)

*Analyze risks*

Risk analysis is the step where the goal is to understand the risks that may occur, whether it needs to be treated and what engagement to use. To be able to know how to engage the source of the risk need to be found together with its consequences regardless if they're positive or negative, the likelihood of these risks. Risk is the combination of consequences and likelihood. The risk analyzes starts with evaluating the existing control within the organization. When the risk is found its likelihood and consequences are calculated. The risk analyzes can use a variety of methods, depending on the needed detail, such as qualitative analyzes, semi-quantitative analyzes, and quantitative analyzes. To test the risk analyzes the potential controls a sensitivity analyzes are made. (AS/NZS4360:2004, 2004)

*Evaluate risks*

From the result of the risk analyzes, evaluations needs to be done so that a decision about which risks need to be treated and which ones to prioritize. Comparing the results from the risk analyzes with the risk criteria that was established when the context was considered, is the main part of risk evaluation. (AS/NZS4360:2004, 2004)

*Treat risks*

Risk treatment is the step where the possible options for treatment, assessing these options and the preparation and implementation of treatment plan. Included in risk treatment are identifying options for treatment of risks with both positive and negative outcome, assessing the risk treatment options and preparing and implementing treatment plans. (AS/NZS4360:2004, 2004)

*Monitor and review*

To be able to ensure that the management plan remains relevant throughout the work, an ongoing review is essential. Factors and other things may change during while the work is performed, and it's therefore necessary to repeat the risk management cycle regularly. Included in the monitor and review step is to learn lessons from the risk management process. (AS/NZS4360:2004, 2004)

## 3.7 Summary of Literature review

The Australian and New Zeeland standard AS/NZS 4360: 2004 has been the model which this master thesis is based on. One of the main parts of this study is to perform a risk assessment of the production facilities in Köping. The risk assessment according to the Australian and New Zeeland standard AS/NZS 4360: 2004 contains of three steps; identify risks, analyze risks, and finally to evaluate risks. To be able to perform the risk assessment and to produce an accurate simulation model, a preliminary hazard analysis (PRA) together with a risk matrix will be used to determine what risks that is important for this study.

To be able to evaluate risks within the factory in Köping, a fault tree analysis (FTA) simulation model will be built in the probability safety assessment (PSA) program RiskSpectrum. RiskSpectrum PSA is developed by Scandpower and is an advanced fault tree (FT) and event tree (ET) software that is used in half the nuclear power plants around the world (Scandpower, 2012).

# 4 Volvo Powertrain description

## 4.1 Volvo Group

Volvo Group is a world leading manufacturer of trucks, busses, construction equipment (CE), drivetrains for marine and industrial applications, and components for aircraft and aircraft engines. Volvo Powertrain Operations is a part of Volvo Groups Trucks Operation that has over 35 000 employees at 46 factories and 60 logistics centers around the world. Volvo is working hard on their core values to ensure a better future. This involves quality, safety, and environmental care. (VolvoGroup, 2012)

## 4.2 Volvo Powertrain Operations

Volvo Powertrain is responsible for the development and manufacturing of heavy engines, gearboxes and axles for the Volvo group. Volvo Powertrain is also a well-established manufacturer of large gearboxes, with manufacturing facilities in Köping – Sweden, and in Hagerstown - USA. A total of 9000 people are employed at Volvo Powertrain around the world.

Volvo Powertrain in Köping where this study was performed was founded in 1856. In the beginning it was called Köpings Mekaniska Verkstad but was bought by Volvo in 1942. The production facilities occupies 93 000 square meters and has around 1200 employees. The different products produced in Köping are divided into three main areas, Gearboxes SMT/AMT (Figure 4.1), Gearbox Powertronic (Figure 4.2), and Marine gears (Figure 4.3). (VolvoGroup, 2012)

| SMT/AMT Gearboxes |
| Produced for: |
| • **Volvo Trucks** |
| • **Renault Trucks** |
| • **Volvo Busses** |
| • **Volvo Parts** |
| • **UD trucks** |
| • **Mack trucks** |

**Figure 4.1** Gearboxes SMT/AMT



| Gearbox Powertronic |
| Produced for: |
| • **Volvo CE** |
| • **Renault Trucks** |
| • **Volvo Parts** |

**Figure 4.2** Gearbox Powertronic



| Marine Gears |
| Produced for: |
| • **Volvo Penta** |
| • **Volvo Parts** |

**Figure 4.3** Marine Gears

## 4.3 Volvo case description

The simulation model that is developed in this thesis is built on a number of key elements. There were three main elements that were needed to build a

simulation model of the production line. These elements were the different article numbers, the machines needed to produce those, and possible flows for each article number. To be able to understand the production and how the layout of the simulation model should be designed, the following information was needed:

- Layout of the factory
- Production rate per article number
- Production flows
- Breakdown reports for every machine
- Production capacity loss
- Parts of importance for producing gearboxes

All sections mentioned above will be further described in this chapter. Due to confidentiality all the numbers and tables in this chapter are fabricated examples whose purpose are to explain what material was needed to be able to develop the simulation model and visualization tool.

### 4.3.1 Layout of factory

To be able to produce an accurate simulation model and visualization tool of the factory, the layout of the factory had a key importance due to fire cells and other key objects within them that could change the outcome of a simulation. If only a single machine was modeled within the simulation model, larger events such as fires, power outage or other larger events that could knock out an entire fire cell or larger areas of the factory could not be simulated, and therefore not included in the visualization tool.

*Production lines at Volvo Powertrain in Köping*

The factory is divided into nine different production lines, where every line has its own breakdown reports, production rate etcetera. The nine areas include both production and assembly. Warehousing and contract production are included in the simulation model, but they lack representative data due to

the high amount of information needed to make an accurate model of those. Warehousing and contract production are also outside the production facilities and that was also a reason not to include those in an accurate way.

*Fire cells*

A fire cell is a delimited part of a building where a fire can developed during a prescribed minimum time without spreading to other parts of the building. A fire cell should be delimited from the building, either through walls and joist, or in other ways such a sprinkler system in an open building. The purpose of the fire cell is to protect adjacent fire cells or buildings during the prescribed minimum time. In a production line area within a factory, a fire cell normally contains a couple of machine cells. Therefore it's important to have the ability to simulate fires than can disrupt whole fire cells (Boverket, 2008).
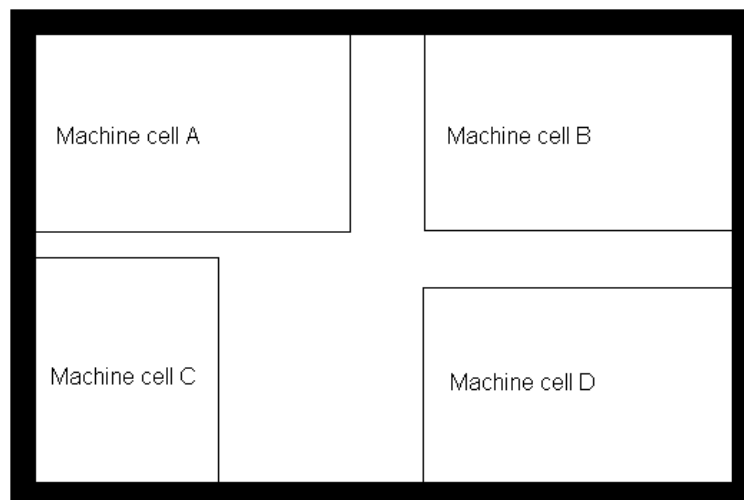


**Figure 4.1**    Fire cell containing four machine cells

*Machine cell*

An example of a machine cell is shown in figure 4.1. This one contains four different electric machines and is operated by a robot. Each machine is a part of a larger machine cell in each area. For the simulation model it's important to represent both the single machine, and linking it to its machine cell. This is important because it's possible that a lot of machine cells might not be able to

operate even if only a single machine breaks down. From the collected data there were almost 400 machines that were put into the simulation model, and in total almost 200 machine cells



**Figure 4.1**     Machine cell containing four machines (CIM, 2010)

## 4.3.2 Production rate

To illustrate the production line, only showing the article number in the visualization tool wouldn't make understanding of the production line better. To understand the consequences of a disruption each article number should also be represented in its yearly production rate, so it will be easier to see which components which are more important than others. This was the first data collected, and included production rate for the articles in the factory. All article numbers that had been produced in the factory at Volvo Powertrain in Köping since the beginning of the year was included. Each article number and its production rate was collected and inserted in a table, such as the example show in table 4.1. The two columns "days with receipts" and "number of parcel" is included in the model because it's included in the production rate database. Because those two columns are not important for the simulation model or the visualization tool, they can be excluded if a cleaner and easier understandable visualization tool is wanted.

**Table 4.1**     Production rate example (fabricated numbers)

| Article number | Days with receipts | Number of produced items between 110601 - 120601 | Number of parcel (pallets) between 110601 – 120601 |
|---|---|---|---|
| Article 1 | 213 | 321331 | 650 |
| Article 2 | 155 | 252175 | 516 |
| Article 3 | 231 | 222970 | 549 |
| Article 4 | 123 | 136811 | 523 |
| Article 5 | 122 | 121982 | 612 |
| Article 6 | 89 | 89388 | 445 |
| Article 7 | 221 | 87756 | 1162 |
| Article 8 | 167 | 86522 | 226 |
| … | … | … | … |
| Article 170 | 23 | 632 | 45 |

### 4.3.3 Production flow

One of the key data that was needed for the model was the main production flow, and possible flows, for each article number that is produced in the factory. Each article that is produced at Volvo Powertrain in Köping is dedicated a main flow. But to reduce the consequences of a breakdown, most articles that is produced also has one or more, up to seven different flows that can be chosen if needed. In total almost 600 flows for around 170 articles were modeled for the simulation model. The data needed for the flows were collected through databases in sheets, like the example shown in table 4.2 for article 91234. In this example, the article number has four different flows, with the normal flow being represented by flow A (N=normal). To make this article in the production it needs to go through eight different processes, including withdrawal raw material from the warehouse and assembly, before it's ready to ship to its customers. The table shows that if a machine breaks down, for example Facing tool B, the normal flow can't be used but by moving the process to Facing tool A or to an subcontractor, the article can still be produced.

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Table 4.2 Example production flow sheet

| Article 91234 Machine | Flow A (Normal flow) | Flow B | Flow C | Flow D |
|---|---|---|---|---|
| WITHDRAWEL WAREHOUSE | X | X | X | X |
| LATHE A | X | X | | |
| LATHE B | | | X | X |
| DRILL A | X | X | X | |
| DRILL B | | | | X |
| CUTTER A | X | | X | |
| CUTTER B | | X | | |
| CUTTER C | | | | X |
| OVEN A | | | X | X |
| OVEN B | X | X | | |
| FACING TOOL A | | X | X | |
| FACING TOOL B | X | | | |
| SUBCONTRACTING | | | | X |
| ASSEMBLY | X | X | X | X |

## 4.3.4 Breakdown reports

To be able to produce a model that can calculate the probability of a machine failure, every breakdown that has occurred in the factory needs to be logged and saved in databases. Both machine breakdowns caused by wear and human error, and larger events needs to be included. The more information there is about breakdowns such as how often they occur and why, the better the accuracy of the probability will be.

The data contained errors from a number of different areas in the factory. The data was divided into number of errors, number of the total errors that was caused by human error, and the downtime per machine. All the breakdowns that were collected were divided into groups, and an average breakdown report was performed for each area within the factory, such as the example in table 4.3. For model produced for VPK, the table contains two different sections; all reported errors and errors that were longer than 0.01 hours but less than 48

hours. This was done because all repots were not accurate, and those that had an abnormal downtime, both very short and very long, are only included in the total breakdown and should be compared to the one excluding events shorter than 0,01 or longer than 48 hours. The problem with this is that real disturbances that were longer than 48 hours are excluded, and for better accuracy a better screening of the breakdown reports can be done.

**Table 4.3**     Example of breakdown per factory machine cell (using fabricated numbers)

| Department | Area A | Area B | Area C | Area D | Area E | Area F | Area G | Area H | Total | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| *All reported errors:* | | | | | | | | | | |
| Number of errors | 152 | 211 | 75 | 87 | 173 | 351 | 298 | 311 | 1658 | 226 |
| Human errors | 12 | 29 | undef | 26 | undef | 115 | undef | undef | 191 | 38 |
| Average downtime (h) | 2,12 | 6,14 | 5,98 | 9,30 | 12,51 | 7,33 | 6,65 | 18,65 | | 8,76 |
| *Errors over 0.01h and under 48h* | | | | | | | | | | |
| Number of error | 144 | 253 | 53 | 177 | 136 | 334 | 244 | 298 | 1639 | 204 |
| Average downtime (h) | 8,15 | 5,84 | 2,73 | 8,08 | 1,7 | 5,98 | 1,6 | 6,19 | | 5,26 |

## 4.3.5 Production capacity loss

Volvo Powertrain has performed an activity base cost analysis (ABC) of the factory. In the ABC analysis it's possible to see the loss of capacity if a machine breaks down. This information was not possible to get for all machines, but for those that the data was collected it's then imported to the model. For those machines that did not have capacity loss numbers, the row is left empty.

*4.3.6 Parts of importance for producing gearboxes*

To make it easier for the management of Volvo Powertrain to take decision on how to control the flow after a disruption, each article number was interconnected with every different gearbox model it is used in.

A large amount of different gearboxes are produced in Köping for a number of different manufactures. An approximation of the different variation of gearboxes are shown table 4.4.

**Table 4.4**     Gearbox variations

| Gearbox product class | Approximated variations | Manufacturer |
|---|---|---|
| 04-TLV | 80 | Volvo Trucks |
| 24-HDV | 80 | Volvo Trucks (new platform) |
| 25-RT | 80 | Renault Trucks |
| 23-HDV | 76 | Renault Trucks (new platform) |
| 05-HDV | 10 | Nissan |
| 11, 12, 13-BUSS | 64 | Brazil busses, Prevost and Borås (Volvo) |
| 28-HDV | 13 | MACK |

In every product class there is a number of different gearbox families such as AT2412D, AT2612D, and ATO2612D and so on. Each gearbox normally contains around 300 article numbers and is presented in a list as the example shown in table 4.5. For each gearbox an assembly sheet containing all the needed articles for each gearbox variation were collected. With a total of around 400 different gearbox variations, containing around 300 article numbers, the total number of connections that would have to be done, would be around 120 000. Because of the large number of gearbox variations and its article numbers that they contain, only the top 20 gearboxes were chosen for the simulation model in this study. This can easily be extended in the future so all the variations would be represented in the simulation model and visualization tool.

**Table 4.5**    Example of gearbox components sheet (using fabricated

numbers)

| Gearbox: | AT26XXD | |
|---|---|---|
| **Number** | **Article number** | **Description** |
| 1 | 946212 | Flange screw |
| 2 | 946551 | Sprocket split M AX,S |
| 3 | 986530 | Circlip T=3.2 |
| 4 | 975532 | Roller bearing |
| 5 | 981002 | DISTANCE RING T = 9:54 |
| 6 | 982310 | PIPE OIL FILTER |
| 7 | 914556 | SPROCKET HP-MX |
| 8 | 912544 | SPROCKET BACK-BX |
| 9 | 965440 | OIL DISTRIBUTOR Main Shaft |
| … | … | … |
| 296 | 995440 | Bracket |

# 5 Results and discussion

## 5.1 Risk Assessment at Volvo Powertrain in Köping

The first step in identifying risks was made with a preliminary hazard analysis (PHA) of the company. The reason for this was to review the activities within the organizations and to map possible risks and harmful events in the beginning of this study. Every event is calculated based on consequences and frequencies, where the results are presented in a table and then put into the risk matrix. In this study the PHA was used to find and evaluate the most common risks within a production line, so that the model could be used for both smaller and larger event.

A PHA example divided into four different parts is presented in table 5.1. The *Scenario* is describing the reason for the risk. The *Initiating event is* describing how the event occurs. The *Probability* is qualitative, and is divided into three levels; low, medium and high. Low means that the risk barely or never occurs, medium that sometimes happens and high that means that the risk event often occurs. The *Consequence* describes what happens if the risk occurs, this section is also divided into three levels. Low means that smaller disruptions within in production may occur. Medium means that the stop time is longer but concerning a smaller part of the factory. High means that the stop time is really long or that the event affects a larger part of the factory and production.

**Table 5.1**     Example of PHA table (using fabricated numbers)

| SCENARIO | Initiating event | Probability | Consequence |
|---|---|---|---|
| **A. Machine stop** | **1.** Fire taking out single machine | **Medium** | **Medium** Planned maintenance and similar on the machine will not have high consequences in the production except for the downtime. Breakdowns and similar events can have a big impact on the production due to uncertainties of the downtime. Human error can either lead to requirement of repairs or shorter stops. |
| | **2.** Power outage | **Medium** | |
| | **3.** Breakdown by wear or similar | **High** | |
| | **4.** Human error | **High** | |
| | **5.** Planned | **High** | |
| **B. Breakdown of machine cell** | **1.** Breakdown of one or more of the total eight main transformers | **Low** | **High** Fire often has a high consequence on the production. Installed fire protection lowers the probability but if the risk occurs in can have a large impact. |
| | **2.** Fire taking out the entire machine cell | **Medium** | |
| | **3.** Water damage caused by sprinklers | **Medium** | |
| **C. Long downtime because of large accident** | **1.** Longer Power outage | **Low/medium** | **High** Longer power outage and similar large events will have a massive impact on the production and can be difficult to protect against. |
| | **2.** Large fire that takes out large parts of the factory | **Low** | |
| | **3.** Natural disasters | **Low** | |

## 5.1.1 Scenarios in the PHA

Through the PHA many other risks were established and analyzed. Because
the focus of this master thesis is about production disruptions, risks that were
found outside the production facilities that did not have an impact on the
production per say, were not included in the model. The risks that was found
when performing the PHA of the production facilities in Köping but that are
not shown in table 5.1, are not further described in this chapter due to
confidentiality. The three chosen risk scenarios chosen are described further
below.

*Machine stop*

The first and most important scenario for the model is machine stop due to
breakdowns or other events. Breakdown on single machine due to various

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reasons, are probably one of the most common disruption in production today, and therefor it's important to be able to simulate the effects of such event. The consequences are normally medium, but the probability is high and thus makes it important to know the fallout of a machine stop event. Typical events that disrupt a machine are breakdown caused by wear, human error, power outage, fires, and planned stops due to maintenance or preventive upgrades.

*Breakdown of machine cell*

The second scenario that is used in the model is breakdown of machine cell. Due to the fact that many of the machines within the production line are paired with other machine, resulting in machine cells, there is a possibility that a disruption occurs that could knock out the entire cell. The probability is minor comparing to single machine stop, but the consequences are higher, and therefore important to include in the analyses. Typical disruptions for a machine cell are similar to the ones for single machines; breakdown caused by wear, human error, power outage, fires, and planned stops due to maintenance or preventive upgrades.

*Long downtime due to larger accidents*

The third scenario, downtime caused by larger accident is the last scenario that is included in the analyses. Large accident can be describe as longer power outage, fire that takes out larger parts of the production line, and natural disasters such as flooding or extreme weather causing structural damage. Overall the probability is low, but the consequences are so severe that excluding them from the analysis should lower the reliability of the thesis event thus no larger events as those describe above have not yet taken place at the facilities. Unlike the first two scenarios, this one is not interesting to include in the simulation, thus the consequences for the short time production are already know to be severe, but are included in the PHA to highlight the risk.

## 5.1.2 The risk matrix

After establishing the preliminary hazard analyses, a risk matrix was used to establish which risk content that would be needed in the model. As seen in table 5.1; A3, A4, A5, B2, B3 and C1 were the risks that had the highest consequence/probability for this example. The conclusion of the data from Volvo Powertrain in Köping showed that it was important to be able to close down single machines, as well as a whole machine cell to be able to get the most correct data out of it.
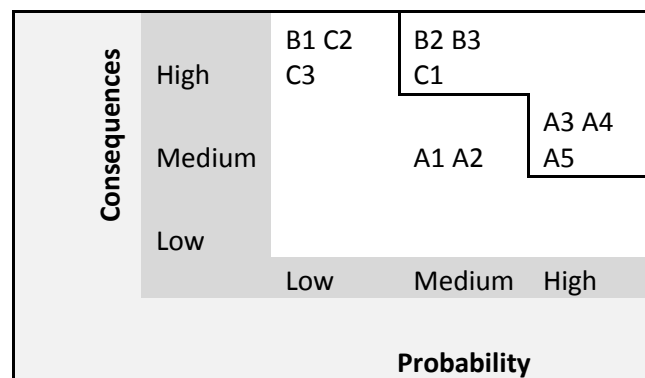


**Figure 5.1**   The risk matrix

## 5.1.3 Discussion risk assessment

The first purpose of this study was to identify and analyze possible risk elements within the factory boundaries that had a high impact on the production, all according to the Australian and New Zeeland standard AS/NZS4360:2004. This is called *internal risks* and involves processes and control risks and Thun and Hoenig (2011) explained it as disruptions caused within the organization boundaries such as machines breakdowns or IT/communication problems. Rice & Caniato (2003) explained it as problems that can be directly influenced by the company. The first step was therefore to identify all risks at Volvo Powertrains facilitys in Köping. This followed the first risk assessment step in the Australian and New Zeeland AS/NZS4360:2004; *Risk Identification*. Information about risks were collected from both databases containing historical events, and by performing interviews with key personnel. The results showed that Volvo Powertrain had

recently performed a precise risk identification and a thorough analysis on these risks and their impact on the factory. It can be concluded that further investigations couldn't find any new risks that were thought to have a possible high impact on the factory. On the other hand, while the risks were known, there was a desire from Volvo Powertrain in Köping to find a way to visualize the consequences of a risk event, so that quick decision could be made to limit the impact and to steer the production to where it was needed. The knowledge was already there, but spread out in different departments, which resulted in longer lead time for information.

The second step was to evaluate which risk that were thought to have a high impact on the production at the facilities in Köping, all according to the second step, *Analyze Risks*, in the risk assessment in the Australian and New Zeeland standard AS/NZS4360:2004. Most risks that were found in the risk identification performed by Volvo Powertrain, were risks that didn't directly threaten the production, and were therefore not intresting to include in the simulation model.

By perfoming interviews with people working on the production floor and people from the maintenance department, together with breakdown reports, the possible risks that were thought to have an impact on the production were selected, all according to the third step, *Evaluate Risks*, in the Risk Assessment in the Australian and New Zeeland standard AS/NZS4360:2004.The possible risks that was found important for the production was the result of the risk assessment and were added in the simulation model.

## 5.2 Simulating disruptions

The model developed for this master thesis is strictly a fault tree model. Volvo Powertrain Köping has already thought of possible breakdowns and failures in the production and most article numbers has possible routes, up to seven different, if a machine breaks down or other events occurs. This simulation models main purpose is to highlight the consequences of possible risk event.

In this section a description how the model, called the Volvo Powertrain Disruption Visualization Tool (VPK-DVT) were developed, from the planning stage, how the model was build, and how it works.

### 5.2.1 Planning of the model

The idea for the model came from projects performed at the Swedish nuclear power plants, called Common Cause Failure (CCF). The idea in the nuclear power plant project was to build up the whole reactor, with all the components included in the safety system, and then to simulate and find components that can lead to loss of cooling, and in the end a core meltdown. The first step was to discuss if it was even possible to use a nuclear probability safety assessment program for a production line. From this discussion it was clear that it hadn't been done before and therefore the purpose of the thesis changed to try the possibilities by using such model for the production industry. The possibilities of using such accurate program are that it's possible to get answers on consequences in a quick and easy way when the model is done. It is also possible to calculate accurate probability numbers, and in the future to expand the model so it can include more departments, external operations, and more products etcetera.

To be able to build the production line, knowledge from the nuclear power plant project showed that the main components needed to do such model was the machines in the factory, the different flows, and to link article numbers to these parameters.

### 5.2.2 Developing the model

The simulation model inputs are based on the different article numbers that are produced within the facilities at Volvo Powertrain in Köping. Each article number are presented in the model as a top gate, either an OR gate for simulating consequences on the normal flow, or an AND gate so simulate the overall consequences of all the flows within the factory for each article number, see Figure 5.2. It's enough if one basic event in any transfer gate to

fail to get the whole top gate to fail if it's an OR-gate. With an AND-gate, all the transfer gates or the basic events need to fail for the top gate to fail For example, if the normal flow in figure 5.3 breaks down, there are still two different flows that may be used if the broken machine is not in the other possible flows.

In Figure 5.3 en example on how the top gate for an article number can be seen. The top gate is described with the article number and a name for it, in this case a main shaft with the article number 1234567. This top gate is an AND-gate and is used for simulating the consequences for all the flows as described above. It has three transfer gates that represent three possible flows (Operations) than can be used. In this case the normal flow is dedicated to operation two. For the top gate to stop functioning (not possible to produce that article number), all three flows (operations) must be true (broken down). Each transfer gate contains the machines (basic event) in the right order needed to produce the top gates article number. The second keystone needed for the simulation model is the machines needed to produce each article number. Each machine is dedicated a unique basic event, describing both what kind of machine it is, and the machine dedicated number and machine cell, see Figure 5.4. The first number, LM44 describes which machine cell the machine belongs to, and the other number is the machine number and is unique for each machine.
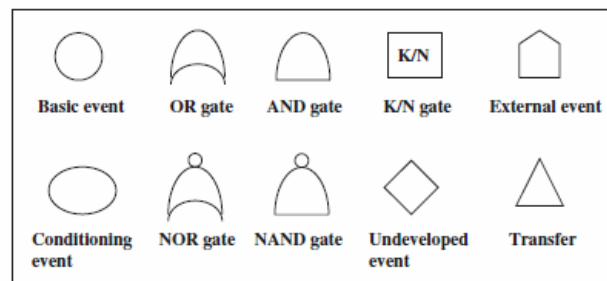


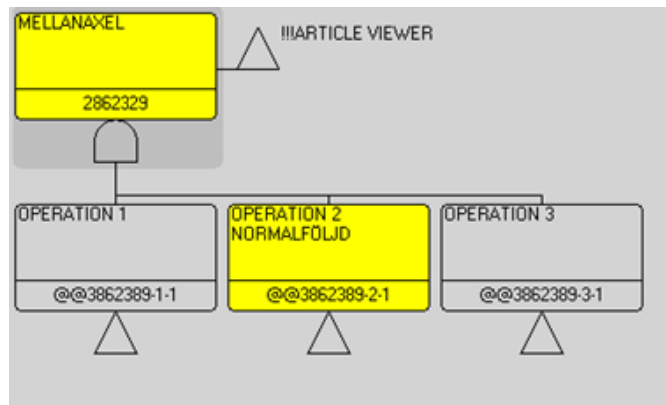**Figure 5.2**     Fault tree symbols (Cepin, 2011)

**Figure 5.3** Top gate for an article number. In the model over 160 such as this exist



**Figure 5.4** Basic event dedicated to a machine

Each transfer gate has the same layout as shown in figure 5.5 and represents the machines that are included for that flow. As can be seen the transfer gate is now the top gate, in this case an OR-gate which means that if one basic event fails, the top gate fails. In the model the machine is put into the right order in the production chain, starting with bringing the raw material from the warehouse, to the last operation sending the article to assembly or straight to their customers. As can be seen in the picture, the machine (basic events) is put horizontally order connected by empty gates and each gate under the main operation (transfer gate) is an "OR"-gate which means that if one machine breaks down, the whole operation breaks down. In total there are almost 400 different machines in the model divided into almost 200 different machine cells.

The advantage of using a fault tree model is that in addition to each machine, it's also possible to include the machine cell, transformers, and other initiating events. All these additional events are represented with a basic event that is placed in the same horizontal level as the machine it connected to. This makes it possible to see the consequences of events that are not just related to specific machines, but also events that are related to larger areas of the factory. An example of using basic events for initiating event can be seen in figure 5.5, where the extra basic events represent fire/breakdown of a machine cell, and failure of the main transformer.
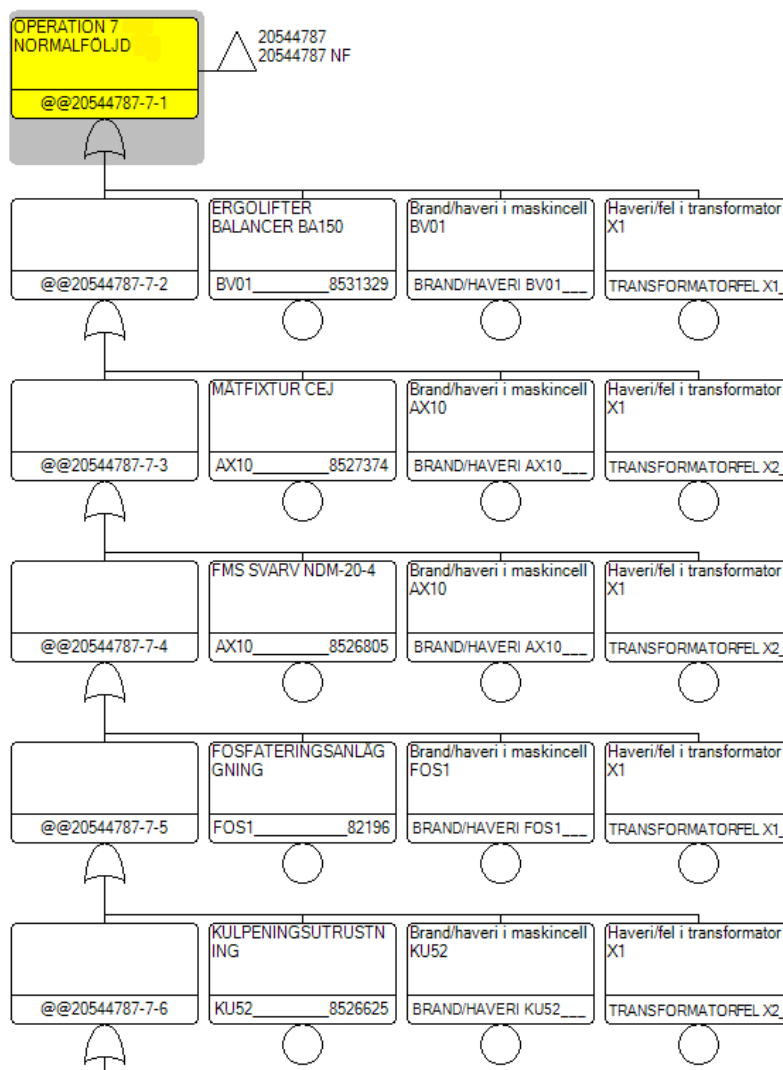


**Figure 5.5** Operation flows and basic event

The reason why two different simulation are done, the on concerning all flows for the specific article number, and the one only concerning the main flow, is that if the normal flow is disrupted most of the time a production decline will occur. In total around 170 article numbers were added to the model, and each article number has its own fault tree, where each transfer gate represents a different flow, resulting in almost 600 different flows and a couple of thousand article numbers passing through different machines.

### 5.2.3 Scope of the model

Volvo Powertrain in Köping has over 300 articles that are produced within the factory, though many are produced in quantities less than a couple of hundred each year. Because of this only around half, the ones thought to be the most important and most produced articles, are chosen in this model.

The risks that will be analyzed in this master thesis are those that effect the production within the factory. Therefore demand and competitive risks will not be included.

### 5.2.4 Verification and validation

Verification can be defined as whether a simulation model is a correct representation of the conceptual model. Validation can be defined as a determination of whether the simulation model represents the real system and thus can be a substitute for experimentation (Banks, 2000).

It must be emphasized that that the simulation model is not scientifically validated. However in simulation terms a face validation has been performed with key personal at Volvo Powertrain in Köping, all according to (Banks, 2000). The simulation model and its assumptions were discussed through several meetings with different people, and the results were also comparable to historical event that had occurred.

## 5.2.5 Simulation results

To represent possible outcomes of possible risks, two different types of simulations were done. The first simulation represents a bigger breakdown, fire or similar event that knocks out the entire machine cell. For this the whole machine cell is included, which for example can be all the machines starting with AV03 (see figure 5.6). In total 194 simulations were done, three more than the amount of machine cells due to the lack of names for three of the machines. The second simulation represents a smaller breakdown, fire or similar event that knocks out a single machine. For this a simulation was done for each machine, in total 381 simulations.

The simulation is performed by turning the state of a basic event from normal to true, see figure 5.7. When the state is turn to true, it represents that the machine or machine cell in question is out of order by breakdown or other similar events. In the Basic Event properties box shown in figure 5.7, different attributes can be chosen, such as the probability of a breakdown.

When a machines or machine cells state is turned to true, the simulation result will be all the article number that is effected by that machine or machine cell. For example, if a breakdown simulation of machine cell AV03 is wanted, the state is turn to true, and the simulation is then run. The output data will result in a list of article number that is affected, as can be seen in Table 5.2. There are three different outcomes, Critical, Normal Flow, and Not Critical. Critical means that all the different flows are affected, and therefore the article cannot be produced in any way. Normal flow means that the normal flow is affected, but that the secondary flows are still intact. That means that there will probably be a production decline, but the article can still be produced. Not critical means that the machine is part of a secondary flow and doesn't affect any normal flows. Normally that machine only becomes critical together with the breakdown of another machine. The capacity loss states how much capacity is lost if the machine breaks down. In some areas in the production

there can be redundant system, which means that a machine cell can have a number of similar machines performing the same task. In case of one of the machine breaks down the capacity loss might only be 50% for example. Therefore the machine is not critical as long as both the similar machines don't breaks down at the same time.

To make it easier and faster to find the simulation result, all the data was exported to an excel document with the same layout as in Table 5.2.

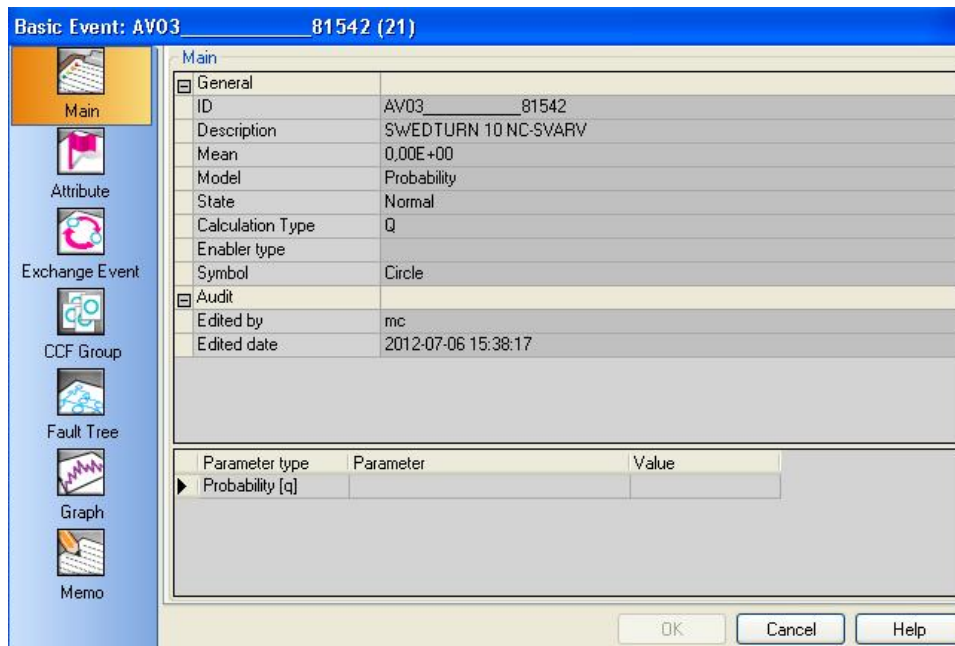| ID    Char # | Description |
|---|---|
| AV03_____80525 | SWEDTURN 10 NC-SVARV |
| AV03_____81542 | SWEDTURN 10 NC-SVARV |
| AV04_____82030 | MONFORTS NC-SVARV |
| AV05_____84295 | SMT 500 FLOP-SVARV |
| AV06_____8529161 | SMT 500 NC-SVARV |
| AV07_____8504749 | SMT 500 NC-SVARV |
| AV08_____8526573 | SMT 600 |
| AV09_____86684 | SWEDTURN 500 FLOP-SVARV |
| AV10_____8531029 | MAZAK SNC |
| AV11_____8533005 | MAZAK SNC |
| AV12_____8532697 | MAZAK INTEGREX |
| AV14_____80379 | SWEDTURN 10 NC-SVARV |
| AV15_____81757 | TORSHÄLLA TMC-84V FLOP- |
| AV17_____8515730 | SCHMID SE231 |
| AV18_____86806 | HELLER MCS-H 250 FLOP-M |
| AV20_____37030 | MONTERING SATURNUS |
| AV32_____83043 | LORENZ SN5 KUGGHYVEL |
| AV35_____19705 | 12 THL 1000 PELARBORRMASKIN |
| AV36_____42005 | GRATOMAT KUGGRADN. MASKIN |
| AV37_____80973 | PFAUTER P750NC KUGGFRÄS |
| AV42_____40007 | PFAUTER RA300 KUGGFRÄSMASKIN |
| AV43_____80977 | LORENZ LS420 |
| AV44_____8532122 | FELLOWS 10-4 |
| AV60_____37026 | GRADNING |
| AV61_____80748 | SAJO VF350 FRÄSMASKIN |
| AV62_____40545 | LORENZ SN4 KUGGHYVEL |
| AV62_____40584 | LORENZ SN4 KUGGHYVEL |
| AV63_____84122 | HURTH ZK-200 TAKFASMASKIN |
| AV65_____81432 | K KLINK DRIFTMASKIN |
| AV66_____83914 | PFAUTER KUGGFRÄSMASKIN |
| AV67_____83917 | HURTH ZS-350 SKAVMASKIN |
| AV68_____80526 | ZF TRYCKMASKIN |

**Figure 5.6**    Basic Event list

**Figure 5.7**　　Basic event properties

**Table 5.2**　　Simulation results from breakdown of machine cell AV03
(fabricated)

| Cell | Machine number | Article number | Description | Capacity loss at breakdown | State |
|------|----------------|----------------|-------------|---------------------------|-------|
| AV03 | AV03_____80525 | Article A | DRIVHJUL | 100% | Critical |
| AV03 | AV03_____80525 | Article B | TRYCKPLATTA | 100% | Critical |
| AV03 | AV03_____80525 | Article C | TANDHJUL, MEDBRINGARE | 100% | Critical |
| AV03 | AV03_____80525 | Article D | KOPPL.RING 3-4:AN | 100% | Normal flow |
| AV03 | AV03_____80525 | Article E | KOPPL. RING 3-4:AN | 50% | Normal flow |
| AV03 | AV03_____81542 | NOT CRITICAL | ... | 100% | Not Critical |

### *5.2.6 Result list from the simulation*

After all the simulations were performed for both single machines and
machine cells, including Critical, Normal Flow, and Not Critical events, a list
was generated including all the machines. In total about 70 % of the machines
became critical for one or more article numbers. The result is that there are
some bottlenecks in the production that are of such importance and that there

are no redundant systems that can coop with a breakdown or similar event that knocks out a machine or machine cell. The result list, with a similar layout as Table 5.2, included over 2000 events connecting machines to different article numbers. Because of confidentiality no detailed explanation or description of the result list will be performed.

### 5.2.7 Failure Mode Effect Analysis (FMEA)

The simulation model doesn't take into account whether a machine really is critical for the system or not. In the simulation model all machine within the factory boundaries are modeled. That means for example that a lift that feeds a machine with materials might turn out to be critical in the simulation results, but in reality it can be replaced by a forklift if needed. A Failure Mode Effect Analysis could be used to determine whether a machine really is critical or not. This will not be performed in this thesis thus it's not part of the purpose. This however is something that could be interesting to perform in the future.

### 5.2.8 Discussion simulation model

The second purpose was to develop and test a simulation model for a production industry (Volvo Powertrain in Köping) that could visualize the consequences of a disruption so that quick decision making could be possible. By using the Probability Safety Assessment (PSA) program RiskSpectrum (Scandpower, 2012) it was possible to investigate if there were any strength and advantages by using a tool developed for the nuclear industry, where risk management for obvious reason have a big impact on the organization and have more stringent requirements comparing to other industries such as production. To make the simulation model for Volvo Powertrain in Köping (VPK) as accurate as possible, a case study was performed to deal with events that had happened in real-life, gathering data from historical events. It was also a key to understand how the production performed and what flaws it had. With this information the simulation model for Volvo Powertrain in Köping was developed. The case study combined with the simulation resulted in a

study that was realistic and precise that represented the production facilities well, just as described by (Hellström & Nilsson, 2006).

The simulation model in this master thesis is modeled in the same way as it's done on the CCF project on the Swedish nuclear power plant. The idea of developing a simulation tool in RiskSpectrum came from an ongoing project at the Ringhals nuclear power plant outside Varberg in Sweden. The project was about finding critical Common Cause Component Groups (CCCG) in the various safety systems. For this all the safety systems were modeled in a Fault Tree (FT) model, including main components such as pumps, valves, diesel generator, and all the way down to smaller sub components such as pump motors, relays, and breakers. Included in the model was also signals and power supply. The purpose was to find components in the different safety systems that could knock out all the safety system and result in a core meltdown.

The results in this study demonstrated an advantage by using an accurate PSA tool used by the nuclear industry as it enables the user to analyze a system in depth, including both main components, subcomponents, and other systems such as the power grid. This is a great advantage comparing to other simulation programs such as Simul8 (SIMUL8, 2013) where only the machine or machine cell can be represented. This means that with the PSA tool it's possible to find common cause failures (CCF) and other events that can turn of a specific object, such as a motor breaker in a machine. This is exactly what happened at Forsmark Nuclear Power plant in 2006, where a short circuit in the 400kV switchyard outside the power plant, resulted in a severe voltage fluctuation which spread into several of the electrical systems in the plant, resulting in a reactor scram and most of the safety systems being knocked out on reactor 1. This was partly due to common cause failures (CCF) (KSU, 2007).

Another advantage is that the simulation model can develop over time, adding new machines, article numbers, and even new functions such as the probability

of a breakdown for each machine. This is one of the key strength of simulation studies according to (Axelrod, 1997). For Volvo Powertrain in Köping this means that by simulating events and adding the probability based on historical events, it's possible to calculate the needed spare-parts inventory, to seek out bottlenecks and other areas that might need improvement, or at least make specific action plans on what to do if a risk event occurs.

The strength with the FT model is that all the connection and flows are represented in the model, connecting machines to different article numbers, different areas within the factory, and possible risks and the probability of those. This makes it possible to see how all the machine and article numbers are connected, and how they depend on each other. This means that the overall strength with the simulation model in this study is that the results shows the consequences in a fast and in a comprehensible way when a machine, machine cell, or a fire cell gets unavailable because of breakdowns, fire, and other events. The user can choose to turn off certain machines and see what consequences it will have on the production. To make the simulation model easier to use, the results from the different simulations performed, were transferred to an Excel document as a visualization tool. This was performed so that it would be easier to use, and enable more users to use the results from the simulation without having access to RiskSpectrum. With the Excel document the user can choose a machine or machine cell, turn it off, and then see what article numbers that are affected. The result is color coded on green, yellow, and red, where green represents machine that are not critical, yellow where the normal flow of an article is affected, and red which represents that the machine is critical for that article number. The color codes make it easier for the user to visualize how critical the effects are. With one touch of a button the user receives what article numbers are affected and how serious it is.

The weakness with using a Fault Tree model in the Probability safety assessment program RiskSpectrum is the lack of visualizing of the flow and

the production like other programs as for example the logistic and production simulation program Simul8 (SIMUL8, 2013). Programs such as Simul8 has the advantage that it shows the flows within the factory as a picture on the screen, and when a machine breaks down it shows where the flows move if there is a secondary flow, or if it stops. RiskSpectrum only shows the consequences as numbers. RiskSpectrum also has the disadvantage that time automatically cannot be represented in the simulation model. This means that the simulation model itself cannot generate production losses in numbers. This can instead be achieved by using an excel-document where production data is connected to the machines and article number from the simulation model. In this study this was done by adding the connections and consequences from the simulation model to the production history sheet, resulting in the visualization tool produced for Volvo Powertrain in Köping as shown in Table 5.2. However, the purpose of the simulation model in this study was to show the consequences of possible risk events, and to show how all the machine and article numbers interact with each other, allowing for a better and faster decision making to steer the production to where it's needed. For example it can be discussed if the consequences of the fire at Ericsson subcontractor in Albuquerque, New Mexico (USA), which resulted in a major loss of about $400 million dollars because of gaps in the supply of radio-frequency chips, could be prevented or at least be alleviated if Ericsson knew the consequences before the accident. With the simulation model developed in this study, Ericsson could have had the knowledge needed to prevent such disaster, and maybe even taking advantage of the situation. By knowing the consequences and to have an action plan, a risk event can turn from being a major loss to a market possibility for a production company (Norrman & Jansson, 2004).

# 6 Concluding remarks

## 6.1 Conclusion

Today with large international companies working in many different countries around the world it's common to streamline the supply chain according to Lean Production, World Class Manufacturing etc. to lower the cost and stabilize the supply chain (Levy, 1997). For many companies these trends have had a good impact on the supply chain due to fewer subcontractors, less products in circulation, smaller warehouses and so on. These effects and trends are often very effective in a stable environment, but they also get more vulnerable to disruption caused by uncertainties (Tang, 2005). This makes it very interesting to find out the consequences on different events and how vulnerable a company is to possible disruptions.

The simulation model developed in this master thesis and tested on Volvo Powertrains production facilities in Köping, shows that it's important not only to know what possibly risks that exist, but also what the consequences are of those risks. The strength of the simulation model is that it visualizes the consequences of chosen event so that the user can easily understand. The simulation model is also extendable which makes it possible to add machines, articles, and risk events, so that it's always up to date. In the end it enables so that quick decision could be made to limit the impact and to steer the production to where it's needed.

## 6.2 Contribution

The contribution of this master thesis is mainly to Volvo Powertrain where the developed and validated simulation model enables production and operational managers to easily and quickly run the model in order to take critical decisions. Those critical decisions can be which article that shall be given priority when a machine breakdown occurs in the production and there is limited capacity, but also to find out which articles that is affected by the breakdown.

The result from the simulation model also highlights critical machines in the production line and where bottle necks might occur in a breakdown situation. All this information was known before but had never been demonstrated.

This simulation model also shows the strengths by using fault tree models. Building a correct model takes time and needs a lot of background information and data. But with a verified and validated model the results are accurate and easy to understand, and the result doesn't require long simulation hours. For other practitioners in supply chain or production management, the fault tree model is a good way of highlighting the consequences and results of a breakdown or crisis situation. That is the reason why it's a well-known tool for risk managers.

## 6.3 Future possibilities

In the future it would be interesting to add all companies connected to Volvo powertrain, especially companies in the supply chain, such as subcontractors. This is interesting because it makes it possible to see the consequences on the Volvo Powertrains production if a supplier can't deliver parts when it's needed.

Other future possibilities are to perform a Failure mode effect analysis (FMEA) on all the machines added to the simulation model. As described in section 3.4.5, machines that are found critical in the simulation might not be critical in real life. The simulation model doesn't take into account if a machine is critical for its task. For example, a lift that is feeding a lathe might in real life be replaced with a forklift for a short time to perform its task, and on the other hand an oven might not have any replacement that can perform its tasks. With a failure mode effect analysis (FMEA) the importance of each machine and its task can be found, and thus the focus on solutions can be on the machine that are really critical for the production.

The probability of a machine failure is known thanks to breakdown reports performed during a long period. This makes it possible to perform a deeper analysis of each machine and to calculate the inaccessibility, called an availability analysis. This is performed by using the following formula: $Q = \lambda * \beta$, where $Q$ = inaccessibility, $\lambda$ = failure rate (failures/hour) and $\beta$ = reparation time (hours). From here it's possible to perform a cost analysis to calculate the costs of a machine breakdown with all possible flows included. This is calculated with the formula $Y = Q * Z$, where $Y$ = total cost, $Q$ = inaccessibility (see above) and $Z$ = the total value of produced items for a specific machine. With this information it's possible calculate what each machine breakdown cost, and to rank what machines cost the most in production loss per year, and to link this to possible future investments for redundancy or to use 3rd party companies as backup. But the most important information given by the availability analysis and cost analysis is the possibility to prioritize repair work where it's needed the most at the given time.

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# Appendix

## A.1 Interview questions with management

Question 1: What known problems are there today?

Question 2: What problems have existed with the production within the organization?

Question 3: Which articles are the most important ones?

Question 4: What results are Volvo looking for in this master thesis

Question 5: Open discussion

**A.2 Interview questions with risk department**

Question 1: What kind of risk management is carried out on Volvo Powertrain today?

Question 2: What kind of accident has occurred in the past?

Question 3: What known risk is there at Volvo Powertrain today?

Question 4: Open discussion

**A.3 Interview questions with maintenance department**

Question 1: What known problems are there in the production at Volvo
Powertrain today?

Question 2: Which machines are considered to be the most critical?

Question 3: Are strategies for maintenance and repairs being developed?

Question 4: How are spare parts and other material being stocked?

Question 5: Open discussion