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MASTER THESIS

Behavioural, Management and Social sciences

Business Administration

Development of a Raw Material Supply Risk Monitoring Tool at Company X

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LIST OF ABBREVIATIONS

ERP	Enterprise Resource Planning
BPS	Business problem solving
BW	Business (data) Warehouse
NPR	Non-product related
OTIF	On time in full
PR	Product related
RD&I	Research, Development and Innovation
RM	Raw material

Contents

1. Managing inbound supply risk has become a critical aspect in firm performance

1.1 Recent global business trends call for proactive supply risk management

In today's globalised economy firms are increasingly reliant on their relation with other companies in order to create value for their customers. However, crises and catastrophes, globalization and more dynamic market places are causing these links to be more complex and more vulnerable.[1] The complexity of modern supply chains and the increased reliance on the competitive advantage of these supply chains leads to an increased exposure to supply risk for buying firms.[2] Increased supplier dependency and more vulnerable supply chains result in a higher likelihood of supply risks materializing.[3] Materialization of risks related to inbound supply can be costly and have significant negative impact on costs and/or customer satisfaction, especially when these risks remain undetected.[4] Boeing experienced the impact of risk materialization first hand. In 2002 a supplier failed to deliver a few critical parts necessary for production which resulted in a financial loss of $2.6 Billion.[5] Ericsson's experience with supply risk materialization was even worse. Due to a fire at a manufacturing site of one of its critical microchip suppliers they had to take in such a loss in its market positions that they were forced to leave the handset telecommunication market entirely.[6] Traditionally safety stock and time buffers were used as reactive risk mitigation strategies. However, increased outsourcing, reduction of inventories and just-in-time concepts call for proactive supply risk management that extends beyond the walls of the company.[7] As a result managing risk related to the inbound supply of materials has become a crucial component of supply management. By understanding the variety and interconnectedness of supply-chain risks, managers can tailor effective risk-reduction strategies for their companies.[8] Academics stress the importance that buying firms should not start by applying risk mitigation strategies based on gut feelings but should instead follow a structured supply risk management approach which is the main goal in this study.[9]

[1] (Hoffmann, Schiele, & Krabbendam, 2013, p. 200)
[2] (Hoffmann, Schiele, & Krabbendam, 2013, p. 199)
[3] (Zsidisin & Ritchie, 2009, p. 4)
[4] (Kern, Moser, Hartmann, & Moder, 2012, p. 61)
[5] (Radjou, 2002, p. 3)
[6] (Normann & Jansson, 2004, p. 441)
[7] (Blackhurst, Scheibe, & Johnson, 2008, p. 144)
[8] (Chopra & Sodhi, 2004, p. 55)
[9] (Zsidisin & Ritchie, 2009, p. 86)

1.2 Problem statement & Research Objective

1.2.1 Problem statement: No system in place to manage raw materials supply risk

The focus of this study is on the procurement function of Company X as this department is responsible for managing its inbound supply. Securing the inbound supply is one of the key challenges the procurement department is faced with.[10] For a large manufacturing company that yearly procures over thousands of different materials from over thousand suppliers securing supply can become a heavy task. The procurement director who is directly responsible for securing supply for a global business unit within Company X recognizes that recent business trends such as increased complexity of his supply base and the entire supply chain are causing a rise in exposure to raw material supply risk for his company. Furthermore, he is challenged with external pressures from key customers that require a structured supply risk management system from its suppliers to ensure that Company X delivers the needed products. The procurement director describes that he is currently having low visibility on supply risk exposure as the knowledge on supply risk and risk indicator data is decentralised and no structured supply risk management system is in place. This situation prevents him from proactively monitoring risks related to the inbound supply of raw materials that are needed for production. As a result he is looking for means to proactively manage risk related to inbound supply of raw materials which is the main driver of this thesis

The report starts with describing different aspects of supply risks from a theoretical perspective. Then, a company tailored weighted factor scoring methodology is proposed as a solution based on empirical findings from semi-structured interviews and business documentation.

[10] (Quayle, 1998, p. 205)

1.2.2 Research objective: Development of a management tool that identifies, measures and prioritizes raw materials in terms of supply risk.

Following up on the business problem a research objective was formulated. The objective was the outcome of a group discussion in which the procurement director and two procurement specialists participated.

Main research objective:

'Development of a management tool that can be used for monitoring inbound raw materials supply risk'

Several requirements were put into place so that optimal support is provided for the procurement function of Company X

- The tool should be based on a theoretical framework.
- The tool should ideally use readily available and factual data (if available)
- The tool should be able to prioritize raw materials in terms of supply risk.
- The tool should be self-explanatory and easy to use.

To achieve the research goal the thesis has been roughly divided into two parts. The first part aims at identifying which raw material supply risk are specifically relevant for Company X and at identifying which indicators can be found for measurement (Part I: Content of the management system). However, merely identifying risks does not increase successful supply risk management and therefore the second part of the thesis is focussed at developing a supply risk monitoring tool (Part II: Construction of the tool itself).[11] The focus of this study is at identifying, assessing and prioritizing supply risk at raw material level and does not aim at determining the best suitable risk mitigation strategies.

[11] (Hoffmann, Schiele, & Krabbendam, 2013)

1.3 Translation of business problem and research objective into a set of research questions

The business problem Company X is facing has been translated into a set of research questions that will be answered during the course of this thesis. The main objective is to develop a tool that reveals risks related to the inbound supply of raw materials and which subsequently can be used for periodic risk monitoring. Therefore, the following main research question has been put into place.

Main research question:

'How can Company X identify, assess, prioritize and monitor raw materials in terms of supply risk?'

The first part focuses on identifying what supply risks are relevant for Company X and should therefore be part of the monitoring system. In order to develop a supply risk monitoring system it is critical to understand that managerial perception on supply risk is not one-dimensional.[12] Empirical findings from Zsidisin show that the managerial perception on supply risk exists at three levels: (1) The purchased item, (2) each of the individual supply sources and (3) the entire supply market. A variety of risks can be perceived at each level. Due to constraints of time and resources it is important for the buying firm to focus on the risks that are specifically relevant for the focal firm and should therefore be part of the periodical risk monitoring system. The importance of this step is illustrated by the following example. When a supply base of a company is merely located within the boundaries of a political stable country it might not be worthwhile to allocate significant amounts resources in tracking political violence within surrounding countries for this company whilst a company that purchases globally it might be important to keep track of these political developments. A variety of factors can play a role in what managers perceive as supply risk. This can depend on the country in which the buying firm operates the company size or the complexity of the market.[13] Therefore, as a first step the study aims at identifying what types of supply risks are specifically relevant for Company X by answering the first sub-question:

[12] (Zsidisin, Managerial Perceptions of Supply Risk, 2003, p. 20)
[13] (Zsidisin, 2003, p. 15)

Sub-question 1.1:

'What situations are considered a risk to raw material supply for Company X?'

In order to truly reap the benefits of supply risk management the identified supply risk should be assessed by the use of indicators.[14] This resulted in the following sub-question:

Sub-question 1.2:

'Which supply risk indicators can be identified for assessing raw material supply risks?'

The supply risk environment in a global economy can be seen as highly dynamic.[15] Therefore, it is necessary to periodical monitor the risk related to inbound supply and continuously update the process.[16] Statistical evidence shows that supply risk management process maturity positively influences supply risk management performance.[17] Literature stresses the importance that periodical supply risk monitoring should rely on a formal structured system.[18] Therefore the following sub-question has been put into place:

Sub-question 2:

'How can Company X monitor the risks related to the inbound supply of raw materials?'

[14] (Hoffmann, Schiele, & Krabbendam, 2013)
[15] (Foerstl, Reuter, Hartmann, & Constantin, 2009, p. 118)
[16] (Blackhurst, Scheibe, & Johnson, 2008),
[17] (Hoffmann, Schiele, & Krabbendam, 2013)
[18] (Blackhurst, Scheibe, & Johnson, 2008) (Hallikas & Lintukangas, 2016)

1.4 Introduction to Company X

No public information

1.5 Introduction to Company X business unit

No public information

1.6 Procurement process of raw materials for Company X

No public information

Figure 1. **Company X external Raw Material spend 2017**

Source: Company X 2017 spend data

No public information

1.7 Set up of the procurement function

No public information

2. Literature review: Raw material Supply Risk management

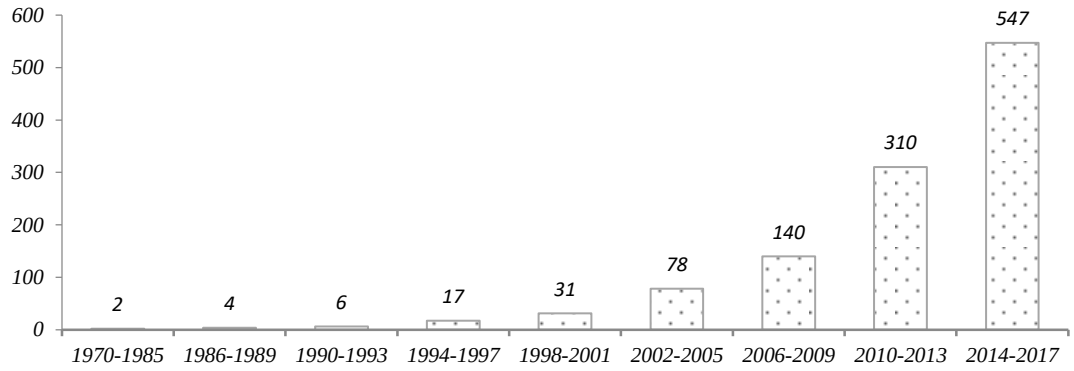
2.1 Introduction to the literature review

2.1.1 Increased academic interest and Search method

Companies face increased exposure to supply risk due to business trends like globalisation and increased supply chain complexity.[19] These trends lead to an increased interest from both the scientific world as from practitioner's side. Analysis of the academic research field of supply risk management shows exponential growth of publications in scientific journals. Figure 2 shows the number of articles relating to supply risk management that were published between 1970 and 2017. The analysis was performed using Scopus by searching in five scientific journals for a combination of the words consisting of: Supply, chain, risk and management. The subject area was limited to: Supply Chain Risk, Management, Business Management and Accounting, Social Sciences, Economics, Econometrics and Finance.

Figure 2. **Publications on supply chain risk management 1974-2017 (N 1137)**

Source: Scopus



The Literature review was conducted by the use of scientific journals, professional journals and management books. Three databases were used (Scopus, web of science and Google scholar) with the following word combinations:

Supply risk, Supply risk Management, Supply Chain Risk management, Inbound supply risk, Supply disruption, Supplier risk, Supply risk mitigation, Supply risk assessment, Supply chain resilience, supplier selection.

[19] (Juttner & Peck, Supply Chain Risk Management: Outlining an Agenda for Future Research, 2005), (Christopher & Holweg, 2011), (Wieland & Wallenburg, 2012)

2.1.2 General outlay of literature review

The literature review in this study serves multiple purposes and is divided into four sections which jointly contribute in answering the research questions.

- To answer the first research question it is vital to have a thorough understanding of the definition of supply risk. Therefore, a section is devoted to defining the main concept of this thesis.
- Another prerequisite in answering the first question is to structure the different aspects of supply which is done by categorizing the variety of supply risks. Literature revealed that there is not one right way of risk categorization and therefore the second section elaborates on the risk categorization applied in literature review and the further course of this thesis.
- Then a section is devoted to create understanding of the different phases in supply risk management. This was used to give structure to the general outlay of the thesis.
- The review then continues with a detailed elaboration on the different supply risks that were identified in prior research which was used to create the main research instrument. This instrument incorporates the latest literature on supply risk management.
- The final section of this chapter discusses two relevant studies focussing on a similar business problem. Several aspects from these studies were used in answering the final research question that aims at providing a practical solution for the business problem.

2.2 Defining the concept of Supply risk: Probability, Uncertainty and Impact

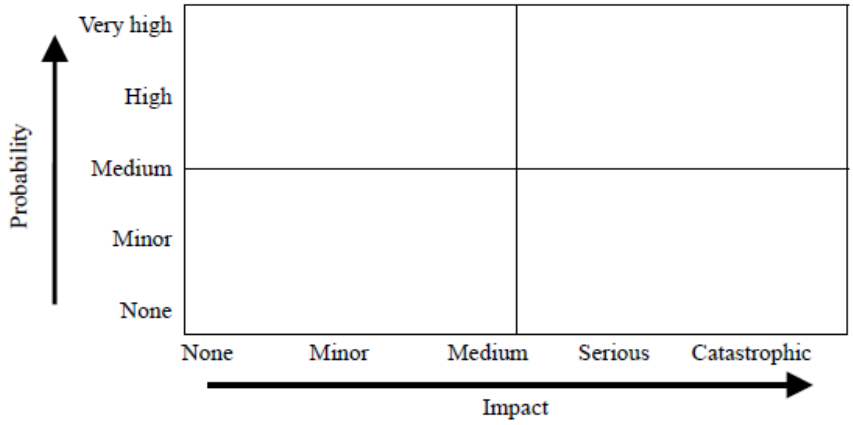
Understanding the term 'risk' can be confusing as the concept can be interpreted differently and no explicit agreed definition is currently present.[20] Therefore, a section is dedicated to understand the different aspects of the construct and to narrow it down for the purpose of this research.

In daily terms risk is explained by the Oxford English Dictionary as: "(exposure to) the possibility of loss, damage, injury, or other adverse or unwelcome circumstance; a chance or situation involving such a possibility"[21]. This explanation consists of multiple elements that can't be applied directly without further explanation. Risk is used in a wide variety of contexts in the academic discourse. When risk is used in a scientific context the authors usually start with an explanation of what they understand as risk. After a careful analysis on scientific literature related to risk Yates & Stone suggest that there seems to be an implicit agreement on the fundamental concepts of risk.[22] They conclude that in most studies the core conception of risk contains three elements: (1) Losses, (2) The significance of those losses and (3) Uncertainty associated with those losses. However, in some studies a simplified version is used where risk is explained as having only two components: probability and impact. In this conceptualization the amount of risk can be expressed mathematically by multiplying the probability of an undesired event with the impact of this event materializing.[23] The figure beneath can be helpful in understanding this way of thinking where focus should primarily lie on the upper right quadrant in terms of risk management.

[20] (Aven, 2011, p. 33)
[21] (Aven, 2011, p. 34)
[22] (Yates & Stone, 1992, p. 25)
[23] (Harland, Brenchley, & Walker, 2003, p. 52), (Yates & Stone, 1992)

Figure 3. **Risk diagram**

Source: Based on (Hallikas, Karvonen, Pulkkinen, Veli-Matti, & Tuominen, 2004, p. 53)



Although there seems to be some agreement on the general conceptualization of risk, this agreement seems to be lacking when risk is specifically conceptualized in the context of supply management. Some, for example discuss risk in terms of supply market complexity while others discuss risk based on types of loss.[24] A possible explanation for these differing perspectives might come from the fact that interpretation on supply risk depends on the managerial perception.[25] For the purpose of this thesis a definition developed by Zsidisin will be used in which supply risk is defined as: *'The probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety*[26]*.'* This definition provided is complete as it incorporates probability, loss and focuses on inbound supply.

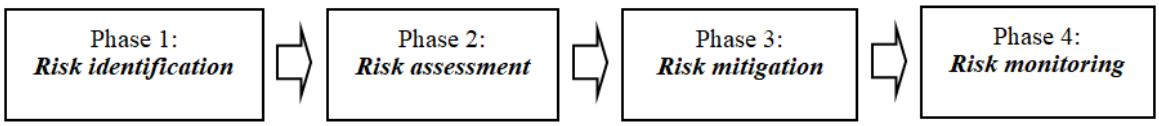
[24] (Kraljic, 1983), (Harland, Brenchley, & Walker, 2003)
[25] (Zsidisin, 2003, p. 222)
[26] (Zsidisin, A grounded definition of supply risk, 2003, p. 222)

2.3 The four components of supply risk management: Identification, assessment, mitigation and monitoring

Review of academic literature show that supply risk management systems typically consist of four phases (see figure) that will be discussed separately in this section.

Figure 4. **Phases in supply risk management**

Source: Invented by author



Phase 1: Risk identification

Despite the exponential growth in scientific articles most studies remain exploratory of nature and primarily focus on the risk identification phase. [27] The goal of this phase is creating awareness on the potential supply risks to which companies are exposed. Risk identification helps management to become conscious about the events that cause the uncertainty.[28]

Phase 2: Risk assessment

Subsequently, the buying firm should assess the risks that have been identified in the previous step. Risk assessment is needed before selecting suitable actions. [29] A Variety of methods can be applied for assessing supply risk. These techniques can be quantitative, qualitative of or a combination of both. The final section of this chapter elaborates on a selection of assessment methods applied in prior business cases to illustrate some of the applied methods.

Phase 3: Risk mitigation

When the risks are identified and assessed, suitable mitigation actions should follow. [30] In general these can be described as risk transferring, risk taking, risk elimination, risk reduction or further analysis of individual risks.[31] It is important note here that

[27] (Blackhurst, Scheibe, & Johnson, 2008)
[28] (Hallikas, Karvonen, Pulkkinen, Veli-Matti, & Tuominen, 2004, p. 52)
[29] (Choprah & Sodhi, 2004, p. 55), (Hallikas, Karvonen, Pulkkinen, Veli-Matti, & Tuominen, 2004, p. 52)
[30] (Choprah & Sodhi, 2004, p. 55)
[31] (Hallikas, Karvonen, Pulkkinen, Veli-Matti, & Tuominen, 2004, p. 54)

management should be aware of the fact that risk mitigation actions might lead to a risk increase in another risk category. For example, if a buying firm chooses to increase inventory as mitigation strategy the firm increases the risks of holding higher inventory (Increase of product obsolescence, inventory holding costs or demand and supply uncertainty.)[32] Therefore, companies should strive for a balance between risk mitigation strategies.

Phase 4: Risk monitoring

Ideally, the buying firm should then monitor the selected risks by the use of indicators. However, the risk monitoring-phase is often neglected even though studies show that proactive risk monitoring positively influences supply risk management performance.[33]

To conclude, supply risk management literature reveals that firms with structured supply risk management capabilities applying a comprehensive approach by taking into account all phases of supply risk management are more likely in successfully managing supply risk and improving firm performance. [34]

[32] (Chopra & Sodhi, 2004, p. 55)
[33] (Hoffmann, Schiele, & Krabbendam, 2013, p. 202), (Kern, Moser, Hartmann, & Moder, 2012), (Revilla & Saenz, 2017, p. 570)
[34] (Hoffmann, Schiele, & Krabbendam, 2013)

2.4 Risk categorization to structure the complexity of supply risk

Due to the complexity of the topic nearly all studies start by categorizing supply risk for which a variety of methods can be found in literature. It should be noted that there does not seem to be one way of categorizing supply risk. It seems that the applicability of the categorization scheme is dependent on the industry, company and/or management purposes.[35] For the purpose of this paper a combination of two categorization schemes is used. On the highest level the categorization scheme developed by Zsidisin is applied in which a distinction is made between risk related to the supplier, the purchased item and the supply market.[36] Risks related to the specific supplier were found to be from such a complexity that a subdivision was needed. To structure the individual supplier risks Hofmann developed a system that distinguishes four dimensions. The study describes that risks related to the individual supplier can be operational, financial, strategic, and environmental of nature.[37] This classification scheme was seemed to be the most comprehensive and is therefore used to subdivide the individual supplier risks. The classification scheme developed by the authors addresses different types of risks but also separates risk sources, indicators and mitigation strategies. However, the distinction between risk sources and risk indicators can be subject to different interpretation. Finally, the risk category 'environmental' as identified by Hofmann showed such a degree over overlap with the 'supply market'-category as identified in the classification of Zsidisin that decision was made to merge these into one category. As these risks are not specifically related to one supplier only the category on the highest level was applied as shown in figure 5.

Figure 5. **Supply risk categorization**

Source: Invented by author

[35] (Blackhurst, Scheibe, & Johnson, 2008, p. 147), (Zsidisin, 2003, p. 20)
[36] (Zsidisin, Managerial Perceptions of Supply Risk, 2003, pp. 15-20)
[37] (Hofmann, 2011)

2.5 Identification of supply risk situations in prior literature

2.5.1 Supply risks related to the individual supplier

2.5.1.1 Operational Supply Risk

The most frequently mentioned supply risks in literature can be characterised as being operational of nature. These risks are caused by the disability of the supplier to achieve a particular desired performance (despite all efforts made by supplier)[38]. Operational performance risk often receives most attention from the buying firm as these risks are most likely to be detected.[39] These are typically frequent recurring low-impact risks.[40] Companies develop plans (often holding reserves) to protect against recurrent risks that are operational of nature.[41] Literature addresses a wide variety of different operational risks from which the most frequently mentioned risks are described in this section. A full overview with authors discussing the different type of risk is provided in appendix I.

- **Quality Performance** is one of the most frequently mentioned risks to supply.[42] In case a supplier does not meet the desired quality standard of the buying firm this can cause severe problems in production lines or customer reputation.[43] This can have several causes like misinterpreting quality requirements or can be due to limitations in production competence.
- **Delivery performance** is acknowledged as a key metric for supporting supply chain operations.[44] The buyer and supplier usually agree a time window in which the delivery should take place. Lacking delivery performance has become increasingly important, especially when inventory levels decrease because of trends like just-in-time production. Therefore, many firms monitor the delivery performance of their suppliers and use variety methods to improve performance when the desired level is not met.[45]
- **Failure of communication** is another type of risk relating to supplier performance which was identified as a risk to supply in multiple studies.[46] Lacking buyer-supplier communication can have several negative consequences like supply delay or

[38] (Hofmann, 2011, p. 37)
[39] (Chopra & Sodhi, 2004, p. 54)
[40] (Chopra & Sodhi, 2004, p. 54)
[41] (Chopra & Sodhi, 2004, p. 54)
[42] (Carter, 2010), (Chopra & Sodhi, 2004), (Hofmann, 2011), (Blackhurst, Scheibe, & Johnson, 2008)
[43] (Tang, 2006, p. 457),
[44] (Bushuev, 2018, p. 66)
[45] (Bushuev, 2018), (Tang, Perspectives in supply chain risk management, 2006)
[46] (Zsidisin, 2003, p. 16), (Finch, 2004, p. 187), (Hofmann, 2011, p. 52)

disruption. Failure of communication can come from incompatible IT systems but can also originate from cultural differences.[47]

- **Fluctuating demand from customers** can become a risk when suppliers are not able to meet the quantity demand.[48] This 'forecast risk' becomes increasingly relevant in just-in-time warehouse management. This type of risk becomes virulent in longer supply chains in which each company orders from its immediate upstream supplier. In this context an inbound order from a downstream member serves as information for upstream members in terms of production and inventory quantities. This upstream information tends to be distorted and can misguide upstream companies in the supply chain in terms of production and inventory quantities.[49] This effect tends to increase upwards in the supply chain and is commonly described as the 'bullwhip effect'.
- **Sustainability performance** is a type of risk that seems particularly relevant in the chemical industry. This type of risk has been receiving increased attention in the past decade. The chemical industry is facing external pressures from customers and competitors that are leading towards more sustainable principles.[50] Therefore, suppliers that do not meet the required sustainability standards can have negative impact on the buying firm causing corporate reputational damage.[51] Supplier reputation is becoming increasingly important as the reputation of a firm's suppliers reflects on the buying firm and can even have negative impact on the firm's performance.[52] In addition, evidence is found for the fact that supply chain risk mitigation strategies are likely to be more effective when they are used in conjunction with sustainability efforts.[53]

[47] (Kraude, Narayanan, Talluri, Singh, & Kajiwara, 2018, p. 106)
[48] (Zsidisin, Ellram, R, & L, 2004), (Hofmann, 2011), (Tang, Teo, & Wei, Supply Chain Analysis, 2008)
[49] (Lee, Padmanabhan, & Whang, 2004, p. 1875)
[50] (Hall & Howe, 2010, p. 106), (Kolotzek, Helbig, Thorenz, Reller, & Tuma, 2018, p. 567)
[51] (Foerstl, Reuter, Hartmann, & Constantin, 2009)
[52] (Gatzert, 2015)
[53] (Gouda & Saranga, 2018, p. 12)

2.5.1.2 Financial supply risk

Financial supply risks come into play when supplier is facing issues related to liquidity and/or bankruptcy. Financial risk only affects the individual supplier and usually does not impact the entire supply market. The risk of supplier going bankrupt was discussed by multiple scholars as being an important aspect of supply risk. A variety of studies touched upon the fact that liquidity issues of a supplier can result into a supply disruption[54]. Supplier liquidity issues can have several causes like deterioration of orders from customers or the supplier being victim of a takeover.[55]

As financial risk is widely acknowledged as an important risk to supply, literature and practitioners provide solutions for managing this type of risk. To assess and monitor financial risk related to supply, the buying firm can use several methods. A proactive indicator of financial distress at the supplier is the payment behaviour of the supplier.[56] When suppliers are facing liquidity issues they might have trouble in paying their invoices. Information on payment behaviour can be bought from a third party specialised in financial assessment of companies. The payment behaviour of firms was proven to be a reliable predictor of financial distress of a company.[57] As a second source of information the buying firm can make projections based on ratio analysis on financial statements.[58] However, thorough financial statement analysis is a specialised and time consuming task.

2.5.1.3 Strategic supply risk

Most firms focus attention on identifying and assessing operational risk and a crucial aspect of supply risk is often neglected. This type of risk is described by Hofmann as strategic supply risk[59]. This type of risk is concerned with the strategic orientation of the supplier which occurs when the buying firm is not attractive enough for the supplier (anymore).[60] In this scenario the supplier would be technically capable to address issues but is not eager to do so due to other priorities. This type of risk is being described as the chance of not being treated as preferred customer.[61] This risk is customer specific as it only

[54] (Zsidisin, 2003) , (Chopra & Sodhi, 2004), (Wagner & Bode, 2008), (Tang, Teo, & Wei, 2008), (Zsidisin, 2003) (Schoenherr, Tummala, & Harrison, 2008), (Hofmann, 2011)
[55] (Hofmann, 2011), (Carter, 2010)
[56] (Hoffmann, Schiele, & Krabbendam, 2013, p. 208)
[57] (Hofmann, 2011)
[58] (Hofmann, 2011), (Kannan & Tan, 2006, p. 16)
[59] (Hofmann, 2011, p. 51)
[60] (Hofmann, 2011, p. 52)
[61] (Hofmann, 2011, p. 52)

affects some customers of the supplier (the non-preferred customers). In the scenario where there is limited production capacity in the industry non-preferred customers are the first ones to be neglected. Hofmann identified several reasons for this type of risk occurring: shift in priorities to other customers, dependency on suppliers, or supplier production capacity constraints.

2.5.2 Supply market risk

The second risk category relates to the supply market. This type of risk cannot be attributed to the individual supplier are risks a firm can't directly influence. This type of risk is covered widely in scientific papers as being a direct source supply risk. This type of risk becomes increasingly relevant when a company sources globally. Hofmann describes this type of risk as: Possible events in the environment of the buyer-supplier relationship that have detrimental effect on the purchasing firm.[62] Some examples of environmental risk are: Strikes[63], Natural disaster risk[64], Political instability risk, currency fluctuations or terrorist attacks.

Another aspect relating to the supply market was first addressed by Peter Kraljic in 1983.[65] He underlines the fact that risk is determined by the availability of supply. A Higher risk situation is present when availability of supply is limited. Limited availability of supply can have several causes: A market can be constrained due to scarcity, geographical concentration of suppliers or entry barriers. [66] Furthermore pace of technological advantage can be another cause of limited supply availability. Other scenario's that contribute to supply market risk is when the market is accompanied by trade restrictions or governments spending shifts.[67] A full overview of the risks related to the supply market can be found in appendix I.

[62] (Hofmann, 2011, p. 51)
[63] (Zsidisin, 2003)
[64] (Juttner & Peck, Supply Chain Risk Management: Outlining an Agenda for Future Research, 2005), (Finch, 2004), (Zsidisin, 2003), (Tang, Teo, & Wei, 2008)
[65] (Kraljic, 1983)
[66] (Zsidisin, 2003), (Kraljic, 1983), (Keilhacker & Minnder, 2017, p. 350)
[67] (Stecke & Kumar, 2009), (Min, 1994)

2.5.3 Item specific supply risk

Previous sections discussed a variety of risk sources. However, some risks that are being experienced by buying firms are specifically related to the purchased item. A multiple case study from Zsidisin shows that there are two item-related characteristics which supply management professionals perceive as a risk to their firms: The financial impact of the item and the nature of product application.[68]

- **Impact risk.** A commonly applied way to assess supply risk is by multiplying the probability of an undesired event materializing with the impact this materialization might have.[69] The actual materialization of such an event can impact a business in multiple ways. From a commercial business perspective supply risk should ideally be assessed based on profit impact as the core purpose of a commercial business is generating profit.[70] However, undesired events related to supply of materials can impact company objectives on a lower level as well. Scientific literature provides a selection of factors which can be impacted when an undesired event related to the inbound of supply materializes. The manner in which companies assess the impact of risk depends on managerial perception.[71] The impact assessments that were found in supply risk literature are: Sales value, customer reputation, or market share.[72]
- **Nature of product application** is the second aspect relating to the specific item that influenced managerial supply risk perception. Empirical findings at multiple case companies show that supply risk was perceived greater when products are used in new product application rather than in existing products.[73]

[68] (Kraljic, 1983), (Zsidisin, 2003, p. 17), (Wagner & Bode, 2008)
[69] (Harland, Brenchley, & Walker, 2003, p. 52)
[70] (Simon, 1964)
[71] (Zsidisin, 2003, p. 222)
[72] (Chopra & Sodhi, 2004), (Tate, Ellram, & Kirchoff, 2010), (Foerstl, Reuter, Hartmann, & Constantin, 2009), (Harland, Brenchley, & Walker, 2003), (Christopher & Lee, 2004)
[73] (Zsidisin, 2003, p. 18)

2.6 Buying firms apply a variety of methods and tools to cope with situation of increased supply risk

2.6.1 Telecommunication industry case

During the year 2000 a Philips-microchips manufacturing plant in New-Mexico temporarily shut down due to a ten minute fire caused by an electric power issue[74]. This plant was supplying both Sony Ericsson and Nokia with microchips operating in the telecom industry. Directly after the fire in the Philips plant Nokia immediately acted by starting to search for other suppliers. They even re-engineered some models of their phones so that they could also use microchips from suppliers that were not suitable before. Meanwhile, Ericsson had accepted the assurance of Phillips that the minor fire in the plant would not lead to any severe supply issues. However, when push came to shove, it turned out that Philips was unable to provide the chips. During the time leading up to this supply disruption Nokia already seized all substitute suppliers which caused a major production stop for Ericsson. This stop resulted in a $400 million loss and an increased position of Nokia in the supply market.[75]

After the incident Ericsson developed a new supply risk management approach from which different parts are applied in the solution design in this study. The method consists of six processes with feedback loops between processes: Risk identification, risk assessment, risk treatment, risk monitoring, incident handling and contingency planning (see figure 6). Risk identification starts with mapping the supply chain upstream for a specific product or product family. Each product is then classified based amount of sources and availability of alternative source. Then the impact is assessed based on business recovery time. The products that were found most critical based on these steps then undergo further investigation.

[74] (Blackhurst, S, & Christopher, 2011, p. 374)
[75] (Blackhurst, S, & Christopher, 2011, p. 374)

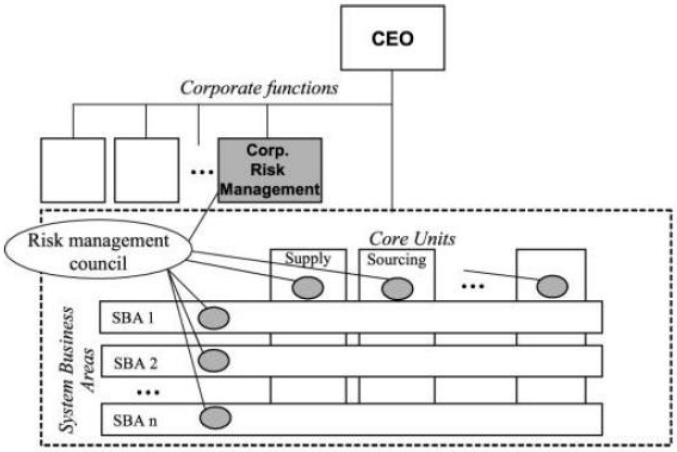
Figure 6. **Ericsson's basic approach to supply risk management**

Source: (Normann & Jansson, 2004, p. 442)

The further investigation is executed by the use of a tool that has been developed based on company requirements. This is a company tailored tool that covers a wide variety of risks and requires input from multiple persons. To make sure that information related to risk in the material supply they established they designed a matrix approach. This means that many different players are involved in sharing in information in multiple stages of supply risk management (see figure 7).

Figure 7. **Organization of risk management at Ericsson**

Source: (Normann & Jansson, 2004, p. 443)



2.6.2 Automotive industry case

Blackhurst et al. similarly recognized the need for proactively monitoring supply risk and the lack of tools to do so. In response to an urgent request from a major American automotive manufacturer they proposed a somewhat different practical approach. They developed a monitoring tool that is tailored to company and industry specifics. The supplier risk assessment and monitoring method they have constructed is a multi-criteria scoring model. They argue that this a suitable approach when multiple types of risk should be taken into account. Within this method the first step is to design an industry tailored categorization system. In the context of their study they distinguish two categories: Quality related risks, and Disruption/Disaster risks. Each category consists of several indicators like defects/million or chance of earthquake. In addition they suggest that weights are allocated to different risk categories based on their importance. These weights can be determined based on the relative impact that each category of disruption has on supply, or any other factor considered important to the firm.[76] Then, a calculation follows that multiplies the weights and the scores on each risk type to calculate the total risk. Benefits of this tool are the way of reporting. The tool gives insights in total material risk and the user can drill down to see what risk categories are causing the score.

Figure 8. **Supply risk assessment tool for the automotive industry**

Source: (Blackhurst, Scheibe, & Johnson, 2008, p. 152)

	Quality						Disturption / Disasters									
Critical / High Risk / Medium Risk / Low Risk	Defects/Million	Ease of Problem Resolution	Product Complexity	Timeliness of Corrective Action	Value of Product	Quality Mean	Earthquake	Fire	Flooding	Labor Availability	Labor Dispute	Political Issues	Supplier Bankruptcy	War and Terrorism	Distribution/Disasters Mean	Overall Rating
Category Weighting	60%						40%									
Sub-Category Weighting	30%	25%	15%	25%	5%	100%	5%	30%	5%	15%	10%	10%	15%	10%	100%	
Caliper Assembly	60.0	45.0	20.0	55.0	30.0	47.5	25.0	47.5	20.0	42.5	52.5	40.0	7.5	42.5	37.5	43.5
Hub Assembly	64.5	77.5	30.0	78.0	35.0	64.5	32.0	79.0	33.5	65.0	80.0	55.5	12.5	56.5	57.8	61.8
Rotot	30.0	39.0	15.0	37.0	25.0	31.5	53.0	50.0	38.0	49.0	49.0	48.0	25.0	42.0	44.6	36.7

[76] (Blackhurst, Scheibe, & Johnson, 2008) p.148

2.6.3 Summarized findings and limited applications of current models

Review of the supply risk literature showed that on a high level nearly all studies agree on the fact that supply risk management should follow four stages: (1) Identify risk, (2) Assess risk, (3) Apply balanced mitigation strategies (4) Monitor risk.[77] However, within each phase decisions are made in terms of scoping, prioritization and usage of methods and tools. The approach firms should take in managing supply risk seems to depend on industry, company size and company strategy. Findings indicate that there is no one size fits all approach and supply risk management should involve multiple business functions and be tailored to industry and company specifics.

Despite the fact that supply risk management has become a research field of increased interest most of supply risk management literature has focused merely on risk identification and risk categorization. Practical management tools for mitigation and monitoring are limited. The models that do go into detail in the risk assessment phase either seem mathematically too complex[78] or too subjective.[79] Secondly, prior studies are primarily supplier focused or product focused and methodologies addressing both aspects are limited. However, two scientific articles were found in the academic discourse that provided methods for practical implication. Within these studies the requirements were in line with the needs of the business problem that is leading in this project. The first model that was constructed and implemented in the telephone industry consists of multiple processes and tools for that aim at supply chain risk management.[80] The second study, in which a tool was developed for the automotive industry, factual company data was applied in a way that did not seem to be too complex.[81] However, both models do not capture sustainability risk which has become increasingly important and seems particularly relevant in the chemical industry.[82] Secondly, both models do not incorporate the impact that unavailability of a material can have on the company from a sales perspective which is a second important aspect within context of this study.

The tool that will be constructed in this thesis will provide management with insights in company specific risks on a material and supplier level. The results can be used in taking proactive measures to mitigate risks related to inbound supply of raw materials.

[77] (Zsidisin & Ritchie, Supply Chain Risk, 2009)
[78] (Santoso, Ahmed, Goetschalkcx, & Shapiro, 2005), (Gupta & Maranas, 2000)
[79] (Manuj, 2008)
[80] (Normann & Jansson, 2004)
[81] (Blackhurst, Scheibe, & Johnson, 2008)
[82] (Fahimnia, Tang, Davarzani, & Sarkis, 2015)

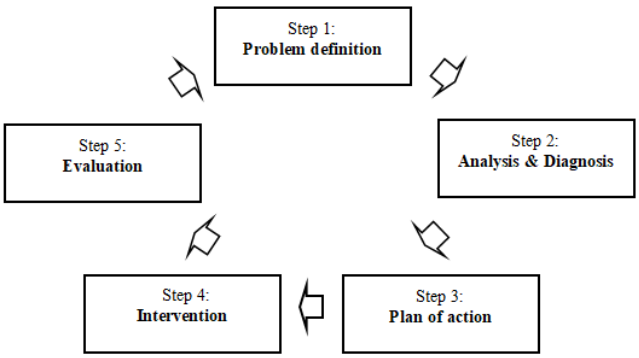
3. Methodology: Theory based- & Design focused business problem solving

3.1 Van Aken's business problem solving methodology explained

This chapter explains the methodology that was applied to answer the research questions as set up in chapter two. Van Aken developed a methodology that specifically aims at supporting students (in a consultant role) that are challenged with solving real life business problems.[83] This methodology is characterised as theory-based and design focused. 'Design focused' means that the project deals primarily with solving a business problem and not with increasing pure knowledge of the problem.[84] 'Theory-based' means that within the process of solving the business problem the student does not merely rely on its own specialised knowledge but applies state of the art literature is designing a solution.[85] This chapter describes how literature is used in conjunction with scientific data gathering methods to provide a tailored solution for the business problem. The basic steps that can be identified in setting up a problem-solving project can be seen in figure 3. A description is provided for each step as these were addressed subsequently during the course of the research project. The headers of the steps reveal in which chapters the individual steps are covered.

Figure 9. **The basic steps in a business problem solving project**

Source: Adjusted by author. Based on (Van Aken, Berends, & Van der Beij, 2007, p. 13)



[83] (Van Aken, Berends, & Van der Beij, 2007)
[84] (Van Aken, Berends, & Van der Beij, 2007, p. 17)
[85] (Van Aken, Berends, & Van der Beij, 2007, p. 4)

Step 1: Problem definition (Chapter 1)

The first step of the project is about clearly defining the business problem. The problem definition is based on an agreement between the procurement director, the student and the University supervisors. At this stage of the research the scope of the project is clearly defined. Defining the problem was done by the use of multiple separate discussions between the researcher (project owner), the principal of the project (Procurement director) and the University supervisors. The problem definition and scope as agreed between the three parties can be found in the introduction of this thesis.

Step 2: Analysis and Diagnosis (Chapter 2, 3 and 4)

During the second step traditional research methods are used to deepen the knowledge on the topic in which the researcher aimed at producing specific knowledge on the context and nature of the problem.[86] This study can be classified as a design study in which scientific literature is used in conjunction with semi-structured interviews as methods of data gathering. It should be noted that the literature review in this study does not aim at searching for relevant theories and constructing hypotheses but aims at identifying different characteristics of supply risk. The findings on different characteristics of supply risk in the literature review are used to develop a risk identification instrument. A detailed description of the construction and analysis of the interviews is provided in the second section of this chapter. The empirical findings from the interviews are then used as input for the plan of action.

[86] (Van Aken, Berends, & Van der Beij, 2007, p. 14)

Step 3: Plan of action (Chapter 4)

Step three is about designing the solution for the problem in its context based on the findings from the previous step. This solution aims at solving the business problem based on inputs from interviewees. A detailed description on how the supply risk monitoring tool was constructed can be found in chapter four of this study.

Step 4: Intervention (Chapter 4)

The intervention step is challenged with changing work processes on the basis of the solution design that has been developed.[87] For this step the student will merely provide advice as the actual change needs to be realized by management. This advice was provided by the means of a final presentation to the procurement director and group of procurement specialists that support his function. The key points can be found in final section of chapter four.

Step 5: Evaluation (Out of scope)

Successful implementation of the solution design requires a formal evaluation process in time.[88] This evaluation step aims at identifying if the desired result has been achieved. This is step is particularly relevant to see if the developed supply risk model was able to support management in decisions making. As the researcher has already left the company by then then he will not be involved in the evaluation.

[87] (Van Aken, Berends, & Van der Beij, 2007, p. 14)
[88] (Van Aken, Berends, & Van der Beij, 2007, p. 14)

3.2 Proposed methodology for risk identification, assessment and monitoring

3.2.1 Supply Risk identification based on extensive supply risk questionnaire (RQ 1)

The academic literature identified a wide variety of situations that can be a risk to supply. Due to limitations of time and resources companies should not try to monitor all existing risks related to supply.[89] Therefore answering the first research question aims at identifying what risks are specifically relevant for Company X.

Subquestion 1.1:

'What situations are considered a risk to raw material supply for Company X?'

In order to obtain reliable and valid answer on this question the researcher should strive for data triangulation in which the researcher relies on multiple sources of evidence. Using multiple sources of evidence can remedy each shortcoming by correcting each other.[90] The Ericsson case showed that knowledge related to inbound supply risk comes from different business functions. The researcher should therefore incorporate employees that work in different positions at different hierarchy levels.[91] To identify the relevant supply risks for Company X with a high degree of reliability the researcher proposed to construct a questionnaire that was based on an extensive literature review in which the respondents were asked to use their expert knowledge to score risk situations based on its rate of occurrence and likelihood of timely detection and its potential impact on production. The results of these risk questionnaires would then be used together with validation interviews with category managers to identify Company X specific supply risks.
Unfortunately, the principal and the sponsor of the project did not want to take this amount of time from employees across multiple business functions by requesting them to fill in a risk identification questionnaire.

[89] (Hoffmann, Schiele, & Krabbendam, 2013, p. 207)
[90] (Van Aken, Berends, & Van der Beij, 2007, p. 116), (Yin, 2003, p. 54)
[91] (Normann & Jansson, 2004, p. 443)

Thereafter the decision was made to use a smaller sample that consists of three procurement specialists (see sampling procedure) to identify Company X relevant supply risk using the risk questionnaire. Subsequently, the findings were presented to an audience of sourcing analysts, category managers and spend area main buyers. They were asked to comment on the selected risk and questioned if in their perception important supply risks were missing. This resulted in a selection of Company X relevant supply risk situations and provided an answer to the first sub-question.

3.2.2.1 Set up of risk interview

The risk interview contains three sections. Each section relates to the risk categories that were used in the literature review: (1) Supplier related risks, (2) Supply market related risk and (3) Risk relating to the purchased item. Each category contains a set of supply risk situations which have been identified in literature. Each risk situation contains an explanation for which the interviewee is asked for input on relevance for Company X. Finally the questionnaire leaves room for input from the respondent. This way, the risks that have not been identified in literature but are found to be relevant for Company X will still be addressed.

3.2.2.2 Risk identification Interviewee selection based on theoretical sampling

To cope with the fact that only a small sample of interviewees could be used, the decision was made to apply a purposive theoretical sampling technique. This specific sampling method is useful in getting information from a population by the use of a sample of that is believed to know most about a subject.[92] The subjects were selected based on their function within the procurement department and working years within the company. As the sample is from such a small size it is important to selects respondents that have an overview of the supply risk within the company. In case there are reoccurring problems with the suppliers the procurement director and his team with supporting procurement specialist are responsible. Therefore, respondents that are characterized by having the combination of multiple years of experience and fulfilling their role within procurement are likely to provide most valid input in terms of inbound supply risk. An overview of the selected respondents for the risk identification interviews is provided in table 1.

[92] (Walliman, 2016, p. 79), (Creswell, 2007, p. 125)

Table 1. **Interview participants risk identification interview**

Function	Date	Number of years employed
SMU Procurement Director	16.02.2018	4
SMU Procurement specialist I	15.02.2018	5
SMU Procurement specialist II	14.02.2018	7

3.2.2 Indicator selection for assessment (RQ 2)

3.2.2.1 Participant selection for follow-up interviews

The second phase of supply risk management aims at measuring the identified risks by the means of indicators.

Subquestion 1.2

'Which supply risk indicators can be identified that can be used for supply risk assessment?'

For the identified risks situations follow-up interviews were held to increase the researchers' knowledge on measurement. The respondents for the follow-up interviews were selected based on their specialised expertise. The list of persons that were interviewed and their accompanying topics is provided in table 2.

Table 2. **Participants for follow-up interviews on selected risk indicators**

Function interviewee	Topic	Date
Quality controller	Material quality assessment	19.02.2018
ERP system specialist	Bill of materials	08.03.2018
Procurement specialist	Contract management	12.03.2018
Procurement process specialist	OTIF assessment	13.03.2018
Supplier sustainability specialist	Sustainability assessment	20.03.2018
D&B financial assessment specialist	Financial Risk	03.04.2018
Procurement specialist slates list	Alternative materials Slates	11.04.2018

3.2.2.2 Data analysis

During the interviews and group discussions with the subject matter experts' input was captured by taking notes. The interviews and discussions with the experts were not recorded as these consist in many cases of smaller discussions in different settings and recordings would not be likely to contribute to the validity of the research. Therefore, the researcher decided to capture all input by means of notes which were then used for further analysis. All notes that have been collected by the researcher were written down and analysed using the framework analysis methodology. This type of analysis is a variant of content analysis by applying a matrix and was developed by Ritch & Spencer in 1994. The framework analysis is typically suitable to research that has specific questions, a limited time frame, a pre-designed sample (professional participants) and a priori issues that need to be dealt with.[93] This method seems most suitable as the full sample of interviewees consists of specialists that all have in-depth knowledge in the interview topic, the questions are derived from specific supply risk situations that have been identified in the scientific literature and the study aims at solving a pre-determined goal.

Framework analysis does not primarily aim at generating theory but is specifically useful in identifying what is happening in a particular setting which is the aim of this business problem solving project.[94]

The framework analysis approach consists of 5 steps[95]:

1. Familiarisation
2. Identifying a thematic framework
3. Indexing
4. Charting
5. Interpretation

During the first step the researcher becomes familiarised with the interview notes that were collected during the semi-structured interviews. The researcher dives into all the collected data to become aware of the key aspects and recurrent themes that were found in the notes. The second step aims at identifying a thematic framework. These themes can emerge but can also be a priori. Within the context of this study a priori themes were used. The themes

[93] (Srivastava & Thomson, 2009, p. 73)
[94] (Srivastava & Thomson, 2009, p. 73)
[95] (Ward, Furber, Tierney, & Swallow, 2013, p. 2426)

that were applied were derived from scientific literature and can be found in Appendix IV. Each of the risk situations was seen as a specific theme in which sub-themes were applied when going into detail on measurement possibilities.

During the indexing phase the researcher identifies sections of the data that correspond to a particular theme.[96] This process has been executed for all the notes that have been gathered.

After the indexing phase the data is now arranged in charts of the themes. The pieces of data are lifted from their original context and placed in the charts of the themes which can be found in the results chapter.

Finally, the interpretation phase aims at analysis of the key characteristics that were found in the charts. The researcher can now draw conclusions and provides explanations based on the findings after following the pervious steps. These can be found in the final part of each section in chapter four.

[96] (Srivastava & Thomson, 2009, p. 76)

3.3.3 Risk monitoring tool development (RQ 3)

Merely knowing what risks are relevant does not contribute to supply risk management performance. [97] Once the relevant supply risks and indicators have been identified these should be used for periodical risk monitoring. Therefore, once the risk indicators have been selected these are combined and used for which the final research question was put into place.

Subquestion 2:

How can Company X periodically monitor risk related to inbound supply of raw materials?

For sound business problem solving academic literature can provide solid ideas for designing solutions.[98] Therefore, relevant literature in the field of supply risk management is reviewed for practical solution concepts with a specific aims at articles. These ideas were used in conjunction with the risk identification interviews, desk research and feedback discussions. The proposed monitoring tool represents itself in a weighted factor scoring model in which each material receives a score on selected risk indicators. A detailed analysis of how the was constructed and should be used can be found in chapter 5.

[97] (Hoffmann, Schiele, & Krabbendam, 2013)
[98] (Van Aken, Berends, & Van der Beij, 2007, p. 88)

3.3 Quality Criteria of the BPS project: Controllability, reliability, validity and results recognition

Solving the real-life business problem is the main driver of this thesis. In order to provide a solution for the business a specific research methodology was designed. The methodology aims at achieving the goal that was set up by agreement between the principal of the project, the researcher and the University supervisors. This section addresses the controllability, validity, reliability and results recognition of the research design.

The first quality criteria that is addressed relates to the controllability of the research. To establish a certain degree of controllability the researcher should reveal how the study was executed, which is a perquisite for further evaluation of the study.[99] To establish high controllability the study provides detailed information on data collection methods, respondent selection, the questions that were asked, how the questions were developed, and on methods of data analysis. Each of the mentioned steps is described in detail which established high degree of controllability.

Results of a study can be classified as reliable when they are independent of the particular characteristics of that study and can thus be replicated in other studies.[100] Reliability bias can originate from the researcher, the instrument, the respondents and the situation. Reliability is high when a different researcher uses different respondents and applies different methods but yields similar results. In order to achieve a high level of reliability the researcher should strive for data triangulation. Therefore, the interviewees that were selected came from different hierarchy levels and business documentation and group discussions were used for verification. Secondly, the instrument that was developed was based on a thorough literature review applying a structured search method. To check the reliability of the instrument that has been developed the respondents were asked to comment on the relevance of the different supply risk separately. This way the researcher was able to check inconsistencies which are discussed in the results section.

In the field of social research methodology a research is commonly classified as valid when the empirical measurement adequately reflects the real meaning of the concept that the researcher intents to measure.[101] Translating this definition into a BPS-project van Aken describes that research can be seen as valid when the study provides good reason to believe that the result are true and adequate. From this perspective validity refers to the

[99] (Van Aken, Berends, & Van der Beij, 2007, p. 157)
[100] (Van Aken, Berends, & Van der Beij, 2007, p. 158)
[101] (Babbie, 2008, p. 160)

relationship between a research result or conclusion and the way it has been generated.[102] The most relevant types of validity in a BPS-project are construct validity and internal validity and will be discussed separately. [103]

Construct validity can be described as the extent to which a measuring instrument measures what it is intended to measure.[104] Construct validity is high if the way a concept is measured corresponds to the meaning of the concept.[105] Van Aken describes two components of construct validity that should be specifically taken into account for a BPS-project: (1) The concept should be covered completely and (2) the measurement should have no components that do not fit the meaning of the concept. It is important to note here that the meaning of the main concept in this study (supply risk) is dependent on personal perception.[106] Therefore a strategy has been developed that tries to cover the whole concept by combining the latest literature with the perception of the Company X procurement management. In order to cover the whole concept of supply risk the interview questions were constructed based on thorough analysis of supply risk literature in conjunction with procurement experts input.

Results of a study are internally valid when conclusions about relationships are justified and complete.[107] A complete overview of the business problem was achieved by theoretical triangulation. As the concept of supply risk is multidimensional different theoretical perspectives in conjunction with discussions with company experts helped in the diagnostic phase which increases internal validity by applying multiple theoretical perspectives and reviewing these with company experts.

External validity refers to the generalizability of the research results. The external validity of a business problem solving project is often limited as the aim of this type of research is to provide a solution for a specific situation. Even though the project was focused on a specific situation the tool that has been developed can still be useful different contexts if the limitations are properly taken into account. The generalizability is further discussed in chapter 8.

[102] (Van Aken, Berends, & Van der Beij, 2007, p. 163)
[103] (Van Aken, Berends, & Van der Beij, 2007, p. 163)
[104] (Van Aken, Berends, & Van der Beij, 2007, p. 163), (Saldana, 2011, p. 194), (Babbie, 2008, p. 162)
[105] (Van Aken, Berends, & Van der Beij, 2007, p. 163)
[106] (Zsidisin, Managerial Perceptions of Supply Risk, 2003)
[107] (Van Aken, Berends, & Van der Beij, 2007, p. 164)

The final quality criteria, which is typically relevant in business problem solving projects, relates to the recognition of results. Results recognition refers to the degree to which the principal client, the problem owner and other members of the organization recognize the research results in a BPS project.[108] This recognition is crucial for later successful implementation of organizational changes. The researcher presented its progress in form of two feedback sessions to procurement specialists. A final presentation to an audience that was selected based on their specialised knowledge provided final feedback on the design. This input was captured by the researcher and incorporated in the solution to establish high degree of result recognition.

[108] (Van Aken, Berends, & Van der Beij, 2007, p. 166)

4. Empirical findings: Interviews results on identification & measurement for individual supplier risks, supply market risk and item specific risk

4.1 Empirical findings

This chapter presents the empirical findings from the risk identification questionnaire and the semi-structured follow up interviews that aim at risk indicator selection. The chapter consists of three sections: The first section relates to the findings on risk emerging from individual suppliers, the second section relates to risk emerging from the supply market and the final section discusses risks that are specific to the purchased item.

Each section starts with a table in which the first column shows the supply risk as identified in the scientific literature. The second column shows if the described risk was found relevant to periodically assess in terms of supply risk by the procurement specialists. A represents procurement director, B represents procurement specialist I and C represents procurement specialist II. In case none of the respondents found the selected supply risk situation as identified in literature relevant it is left out of the table as these situations will not be used for periodical risk measurement. Risks that were not identified as being important by all three specialists were addressed during a group discussion. This way the respondent could defend their statement on why the selected risk is relevant for Company X. This followed by an agreed decision from all three specialists on in- or exclusion. The final column provides a summary on input from the follow up interviews that aimed at identifying risk indicators for the selected supply risks. This column elaborates on current methods of assessment and explains how to collect the data (if available). This information was used to construct supply risk monitoring tool which is described in chapter five.

4.2 Findings on risk related to the individual supplier

To identify what risks are relevant for Company X different situations as identified in literature are discussed with company specialists. The first category elaborates on supply risk characteristics that relate to a specific supplier. Findings are presented in table 3.

Table 3. **Results from specialists on supply risk relating to individual suppliers**

Supply Risk identified in literature with motivation	Relevant Y/N?	Summarized findings from interviewees on risk situation and follow up interview on indicators for measurement
Quality performance (operational) *Insufficient quality of materials causes risk to production process and customer satisfaction.*	A,B,C	All interviewees agreed on the importance of raw material quality risks. Further elaboration with quality control staff shows that all materials delivered at the production sites are checked based on predetermined quality requirements. These requirements are set up by RD&I in so called 'inspection-lots'. The materials arriving at production site are checked against the inspection lots and are then accepted or rejected for manufacturing. Performance on quality scores of suppliers at material level can be retrieved from the local ERP systems.
Delivery performance (operational) *Consistent early and/or late deliveries can cause issues in manufacturing- and supply chain process*	A,B,C	All experts agree on the fact that the supply risk model should incorporate the delivery score as this is being perceived as an important risk to RM supply. Further insight on measurement was provided through discussion with a procurement specialist and analysis of business process documentation. These information sources show that delivery performance is assessed based on percentage of products that have been delivered on-time-in-full at the production site. This score is based on a predetermined agreement between buyer and supplier. If the delivery is before or after the agreed time window the delivery is classified as early or late. Suppliers are scored on delivery performance on material level. Thus, suppliers that provide multiple materials are assessed separately for each material. Data on delivery performance is filed in the local ERP system and can be retrieved from the BW OTIF-reports.
Communication responsiveness (Operational) *Late or non-response in communication can result in delay or disruption in supply.*	A,B,C	All interviewees agreed on the fact that communication failure in the buyer-supplier relation is a risk to supply. Follow up interviews reveal that spend area main buyers categorize suppliers according to definition: Preferred, Approved, Phase-in, Phase-out and Unavoidable. The procurement specialists explain that this status partly represents the communicative responsiveness. The supplier status can be found in supplier status report in business data warehouse.
Sustainability performance (operational) *Suppliers that not meet requirements in terms of sustainability are a risk to meeting sustainable development goals and can cause corporate reputational damage*	A,B,C	Consensus was found on the importance of assessing RM supply risk in terms of sustainability. One procurement specialists explains that Company X monitors all of its vendors in terms of sustainability and refers to a sustainability expert. The follow-up interview with the sustainability expert shows that all vendors receive a sustainability maturity score. Several aspects of sustainability were incorporated in this maturity score. Based on the availability of a signed code of conduct form and a supplier self-assessment score on sustainability a decision is made if an on- site sustainability assessment is necessary. A combination of the availability of a signed code of conduct form with the scores from the assessments leads to an overall sustainability maturity score. These scores are updated quarterly and the most up-to-date version of the maturity score is available at sharepoint.
Financial risk *Financial supply risk appears when supplier faces liquidity issues or*	A,B,C	All respondents agree on relevance of financial supply risk. However, the risk of a supplier going bankrupt is currently not assessed. A common way of assessment is using third parties that specialize in

bankruptcy. In case supplier goes bankrupt this can cause a disruption in supply of materials.		financial supplier risk. The researcher got in touch with a representative of a third party to enquire information their methodology and the costs. The D&B representative explained that to financially assess firms they use four indicators: (1) Trade experiences, public detrimental information, demographics, corporate linkage and financial ratios. This information was taken into account in the follow up interview with the procurement specialists on periodical financial assessment of suppliers. Two specialists elaborate on several problems relating to financial risk assessment of the suppliers. First, many suppliers are subsidiaries of parent vendors which are likely to provide financial support in case of financial distress at their daughter companies. For this reason it does not seems to make sense to assess the subsidiaries that provide materials to Company X in terms financial risk. Another issue comes from the fact that the supply base is of extensive size and benefits of assessing all suppliers in terms of financial risk are not likely to outweigh the costs.
Production capacity (strategic) *In case of insufficient production capacity in the entire industry, non-preferred customers are forgotten.*	A,B,C	Limited production capacity was perceived as situation to supply risk by all specialists. However, data on production capacity of suppliers is currently not readily available. Data is requested for new suppliers but not stored centrally and not present for current suppliers. Furthermore, one of the procurement specialists noted that the production capacity can change rapidly which makes monitoring difficult and unreliable.
Supplier obligations to other customers (strategic) *When supplier has obligations to other customers non-preferred customers are forgotten.*	A,B	A supplier's obligation to other customers was found a risk to supply by two procurement specialists. Both address the fact that there is no data readily available which can be easily linked to individual raw materials. One of the specialists explains that on (sub) spend area level this strategic aspect is touched upon. Spend area managers address this type of risk when they assess the importance of Company X as a customer to the supplier (or entire supply market) However, this information is restricted and not stored centrally. Another specialist explains that the supplier status as discussed in communication responsiveness also partly covers strategic alignment between Company X and its suppliers.
Compliance *(Respondents own input)*	A,B,C	All three specialists stress the importance of supplier non-compliance risk. Suppliers that not meet compliancy standards are a risk to supply continuity and corporate reputation. This point shows overlap with supplier sustainability standards but is extended with integrity and safety and corporate social responsibility which is covered in the code of conduct. Suppliers that have not signed the code of conduct are a risk to supply. A business partner screening tool provides a risk assessment by screening suppliers in terms of sanction, embargo, government watch list database, politically exposed persons, litigation and adverse media articles on web. Suppliers receive a score based on compliance risk which is used for assessment.

Table 3 elaborates on supply risk that relate to the individual supplier. Seventeen different supply risk situations have been identified in literature and were discussed with the responsible procurement director and two procurement specialists.

Findings show consistency between the three interviewees on relevance of assessing the different risks related to the individual supplier. All respondents acknowledge the importance of operational aspects and on the financial risks. The strategic aspect of supplier risk was subject to debate. Two specialists recognized the risk of not being a preferred customer is a risk to supply. Further discussion on the strategic aspect resulted in inclusion of this aspect as being relevant to periodically assess. In addition to the risks which were identified in academic literature supplier compliancy was introduced. All three procurement specialists addressed supplier non-compliance as an important risk characteristic.

Even though a high degree of consistency seems to be present between the procurement specialists on the selection of supply risks not for all risk situations data was readily available which could be used for assessment. These risk indicators are financial assessment, natural disaster risk, political risk and risk coming from production capacity constraints. Based on a group discussion with the project team decision was made to construct a theoretical overview and an actual assessment model. The theoretical overview will show all the risks that have been identified as important accompanied by a description. The risks that have been identified but for which no measurement was possible due to limitations in data availability will be addressed in the advice to management in chapter five. The actual assessment model assesses the raw materials in terms of supply risk based on the available indicator data.

4.3 Findings on risk related to the supply market

The second category elaborates on supply risk characteristics relating to the supply market in which the buying firm operates. Findings on perceived relevance and measurement indicators are presented in table 4.

Table 4. **Results from specialists on supply risk relating to supply market**

Supply Risk identified in literature with motivation	Relevant Y/N?	Summarized findings from interviewees on risk situation and follow up interview on indicators for measurement
Number of qualified suppliers in market *As the number of qualified suppliers increases the extent of supply risk decreases as multiple supply sources are available.*	A,B,C	All specialists agreed on the fact that limited number of qualified suppliers in the market is a risk to supply of raw materials. Follow-up interview with one of the procurement specialists reveal that there does not seem to be a central location in which information can be found that elaborates on the number of qualified suppliers. Further discussion however shows that spend category managers deliver (sub) spend area strategies in which they scrutinize market characteristics. One important aspect is characterizing the supply market based on number of suppliers. However, due to sensitivity of this data and local storage these strategies are not readily available and knowledge remains local.
Constrained markets/Market shortages *Market risk is defined as balance between supply and demand. In case of a tight market there is a higher supply risk when demand exceeds supply.*	A,B,C	Market shortages were found to be an important risk by all three specialists. Spend category managers deliver (sub)spend area strategies in which they elaborate on market characteristics. Within the strategy the category managers are required to assess the balance between supply and demand of the materials. However, due to sensitivity of data and local storage these strategies are not readily available and therefore no overview can be provided for each (sub) spend area.
Grip on raw materials *Supplier has strong market position and can therefore dictate prices.*	C	In the opinion of one of the specialists the grip on raw material was found to be a relevant risk for monitoring. The market position of suppliers is covered and updated in the (sub) spend area strategy. This information in not stored centrally and accessible due to sensitivity of data. Therefore, no data relating to the market position of the supplier is readily available for periodical risk monitoring.
Regulatory risk *Risk relating to regulations in supply market.*	A,B	Two of the procurement specialists agree on the fact that regulatory risk is important to monitor periodically. Follow-up interview with the procurement director explains that suppliers are assessed in terms of compliance. Company X does not do business with suppliers that are non-compliant to regulations. Assessment on compliance of suppliers can be found in a compliance monitoring tool which has been developed to assess suppliers in terms of regulatory risk.
Natural disaster (environmental) *Natural disasters like earthquakes or floodings can cause a disruption in supply when supplier is impacted.*	A,B,C	The risk of natural disasters was acknowledges by all interviewees. To use data on areas in which natural disaster are more likely to happen the location of the manufacturing site or the supplier site should be known. This data is not readily available and natural disaster risk is currently not assessed.
Political instability risk (environmental) *Rapid change in political environment and/or political violence can cause a risk to supply.*	A,B,C	Political instability and/or political violence in certain countries are acknowledged as a risk to supply by all interviewees. Nation reports can provide valuable information. However due to lacking data on supplier location of production sites there is no system in place that tracks political risk on a material level.

Table 4 elaborated on risk relating to the supply market of the purchased materials. Six characteristics relating the supply market have been identified in literature and were discussed with the selected interviewees. From the risks that were identified in literature three were found to be relevant for Company X by all three respondents. Importance of 'Grip on raw materials' was addressed by only one interviewee.

The input from respondents in combination with business documentation show that supply market risk information is present in the sourcing strategies for the (sub) spend areas which is developed by category management. The strategy document contains different aspect of supply market risk like the balance between supply and demand, government policy risks, price drivers and number of suppliers in the entire market. This documentation is sensitive as it also includes aspects of future strategy of Company X and is therefore restricted.

One of the procurement specialists recognizes the criticality of having the supply market aspect in a periodical risk monitoring tool. During discussion the specialist requested for a solution in collecting specific parts of the strategy documentation that is relevant for supply market risk assessment. However, due to time constraints it was not possible to collect the necessary supply market risk data from category management. The supply market risk aspect will be solely taken into account in the final advice to management and will be added in the theoretical part of the supply risk model.

4.4 Findings on risk related to the purchased item

The final category that was addressed during the risk identification phase specifically relates to the purchased item. The findings of the input of the interviewees on relevance for Company X are presented in the second column and the summarized findings on measurement possibilities are shown in the third column.

Table 5. **Results from specialists on supply risk relating to purchased item**

Supply Risk identified in literature with motivation	Respondent input	Summarized findings from interviewees on risk situation and follow up interview on indicators for measurement
Impact on sales *The criticality of raw materials increases when the materials are used in products with high sales value.*	A,B,C	Consensus was found on the importance of assessing the sales impact of the purchased materials. During follow-up interviews a procurement specialist explains that the sales impact can be calculated by connecting sales data to raw materials used in end products. This is done by creating a Bill of material report in the ERP system. For each raw material it should then be identified in which end-products these are used. The annual sales value of the end-products is then accumulated to provide the total sales value at stake in case the material is not available. The specialists explain that it is currently not possible to automatically extract the sales impact on raw materials level from the ERP system.
Number of manufacturers (Respondents own input)	A,B,C	All three specialist address the number of raw material manufacturers is a risk to supply Follow-up interview show that Company X harmonizes its vendor master data and distinguishes between manufacturers, parent vendors and local vendors. The specialist explains that there are situations in which Company X purchases the same material from multiple suppliers that rely on the same manufacturer. If this manufacturer has trouble supplying the material both local suppliers and subsequently Company X will suffer the consequences. Therefore, the number of harmonized manufacturers that are present in the system was found to be an important risk indicator. The number of harmonized manufacturers that are approved can be populated by applying a pivot table on spend data. The spend data is available in the business warehouse spend report.
Availability of contract (Respondents own input)	A,B,C	All respondents stress the importance of having a contract with suppliers. The specialists explain that the risk of not having a contract is materials specific as Company X might purchase variety of materials from the same supplier. A contract might be present for one material while lacking for another. If Company X orders materials by the use of a contract the supply risk is less because of contractual requirements. During a follow up interview it becomes clear that due to multiple ERP systems and complexity of the overall company structure it is not possible to connect a specific raw material to the availability of a contract as contracts can be stored locally or in different databases. Another specialist explains that in the business unit a manual exercise was started in which the buyers are asked to identify for which raw materials they know a contract is available.
Alternative material approved by RD&I (Respondents own input)	A,B,C	All three specialists address the fact that for some materials alternatives are approved by RD&I The specialists explain that in some cases multiple materials can be

		used for the same production process. The approval process can be time consuming as RD&I have to thoroughly test the alternative. Respondents explain that supply risk decreases when an alternative is available as Company X can fall back on the alternative. When a material has been formally approved as an alternative this is updated in so called 'slates-lists' on sharepoint. The slates lists contain sensitive information relating to the composition of products and are therefore restricted. Access can be granted by slates team after consideration of necessity.

Table 5 shows supply risk situations relating to the purchased item. Four different item specific risks were identified in scientific literature and were discussed with the subject matter experts. From the risk identified in literature only sales impact was found relevant for assessing and monitoring periodically. Furthermore, three different aspects were introduced by the procurement specialists that were found to influence supply risk and needed to be taken into account. These aspects are: Number of manufacturers, availability of contract and the availability of an approved alternative. For all of the selected indicators data is available which can be used in constructing the risk assessment tool in the following chapter.

The risk identification interviewees show high consistency on what the selected specialists identified as being a situation of supply risk for Company X. Only in four cases there was initially no consensus on the perceived importance of the described situation. Based on a group discussion, decision was made whether to include or exclude these risk for periodical assessment. This exercise identified eighteen different situations of supply risk are specifically relevant for Company X. These risks will be used in constructing a risk assessment tool in chapter five. The tool assesses and prioritizes raw materials based on the selected risk indicators for which data was available. The risks for which no data was readily available will be covered in a theoretical model and will be subject in the final advice to management.

5. Construction of a Raw Material supply risk model based on scientific literature and empirical findings

5.1 Construction of raw materials supply risk monitoring tool

The main goal of this thesis was to construct a practical supply risk monitoring tool that management of Company X can use to identify, assess and prioritize raw materials based on supply risks exposure. Several requirements were formulated during discussions with the procurement specialists:

- The tool should be able to assess risks on a material specific level.
- The tool is based on factual and readily available data.
- The tool should be self-explanatory and easy to understand.

Based on findings from scientific literature, interviews and multiple feedback sessions with procurement specialist the researcher constructed a weighted factor scoring model (WFS) in which weights are determined by the Analytical Hierarchy Process (AHP).
This chapter starts with explaining how a weighted factor scoring model is applied in combination with the AHP methodology to assess raw materials in terms of supply risk. Then a section is allocated on why and how raw material sales impact was incorporated in the tool. The chapter then elaborates on how the tool should be used, the results it provides and the accompanying limitations and assumptions.

5.2 The application of a weighed factor scoring model to generate a risk profile for raw materials

The outcome of the supply risk identification interview lead to a selection of Company X relevant supply risk indicators for which factual data is readily available. In the context of this thesis a solution is designed in which these indicators are used to assess supply risk for raw materials by means of a weighted factor scoring model. The weighted factor scoring model consists of the following component:

1. Set of risk indicators
2. Each materials receives a score on each indicator
3. Each indicator has a weight
4. The scores are then multiplied by the indicator weights
5. The scores are added to generate a total score.

Each of the five components is described in this section.

5.2.1 Scoring raw materials based on selected risk indicators

Based on discussions with procurement specialists the decision was made to score each indicator on a range from 1 to 5 in which a higher score refers to a higher degree of risk. The 1-5 range was applied as three of the operational risk indicators already apply a scale consisting of five intervals. For each of the indicators a description is provided on how the 1-5 scores were allocated. A full overview on the scales can be found in appendix II.

Number of Raw Material manufacturers in current supply base

The first indicator relates to the number of raw material manufactures that are present in the current supply base. Analysis of the spend data shows that for very few materials more than two manufacturers are available. Furthermore, procurement specialist explains that the incremental risk of having three instead of two manufacturers is far less than having one instead of two. Therefore, the decision was made to allocate a risk score of 5 to a situation of having one manufacturer and 1 to the situation of having more than one manufacturer.

Alternative material approved by RD&I

The research & development function can determine if different raw materials can be used for the same purpose. When there is an alternative the risk of production stop is less as Company X can fall back on the potential alternative. Therefore a risk is score of 5 is allocated when no alternative material can be used and 1 if there is an alternative available.

Availability of contract

When Company X has a contract with the supplier of a raw material the supply risk is less due to contractual requirements. For the risk assessment in the tool a situation in which no contract is available receives the highest risk score which is a 5. In case a contract is present the supplier receives the lowest score which is 1.

Delivery Performance

Consistent early and/or late deliveries can cause issues in manufacturing- and supply chain process. For scoring materials in terms of supply risk the present scale that Company X applies for supplier rating purposes was applied. The scale consists of five intervals which each receives a higher risk score when performance decreases. For some materials no score on delivery performance was available. Based on input from company specialists decision was made to give a score of 3 when no score was available.

Quality performance

Insufficient quality of materials causes risk to customer satisfaction. Quality performance is assessed based on quality delivery data retrieved from local ERP system. Assessment is made based on percentage of materials delivered within specified quality criteria. Discussions with company specialist lead to the decision to apply the same performance scale that was used for delivery performance.

Sustainability performance

Suppliers that not meet the requirements in terms of sustainability are a risk to meeting UN sustainable development goals and can cause corporate reputational damage.
Company X monitors the sustainability of its suppliers based on supplier sustainability scorecard. The maturity score present in the scorecard is used to assess supply risk. The suppliers are filed in a five maturity phases. Higher maturity in terms of sustainability corresponds with lower degrees of risk. Therefore a maturity score of 5 receives a risk score of 0, a maturity score of 4 receives a risk score of 2 and so on.

Communication & Strategic alignment

Low communication responsiveness increases risk to supply as ability to timely solve supply issues decreases. In case Company X has differing strategy this can cause a strategic supply risk on long term as supplier has diverging focus. Bad communication and strategic alignment are currently measured by the same indicator.
Category managers and spend area main buyers categorizes suppliers according to definition: Preferred, Approved, Phase-in, Phase-out and Unavoidable. The supplier status

represents the communicative responsiveness and strategic alignment. Based on specialists input a score of 1 was given to preferred suppliers, approved and phase-in receive a 2, phase-out and no-status were perceived as the highest risk and therefore receive a 5

5.2.2 Applying Analytical Hierarchy Process (AHP) to determine indicator weights

It is highly unlikely that all selected risk indicators are equally important in terms of supply risks. Determining the appropriate weights for the risk indicators can be a difficult task, especially when the number of indicators increases. The AHP-method is provided as a solution in reducing the complexity of allocating weights to indicators by using one to one comparisons.[109] AHP applies a verbal scale that enables the supply risk expert to incorporate experience and knowledge in an intuitive and natural way.[110]

However, it is important to note that due to limitations of resources it was not possible to determine weights based on input from multiple respondents. Therefore, decision was made to let the procurement director execute the pairwise comparison questionnaire as he needs to have the most comprehensive view of supply risks based on his role. The limitation that comes from this small sample is discussed in chapter seven.

[109] (Saaty, 2008, p. 84), (Wu, Blackhurst, & Chidambaram, 2006, p. 355)
[110] (Wu, Blackhurst, & Chidambaram, 2006, p. 354)

5.2.3 Explanation and application of AHP based on a three indicator example

Within the AHP process each indicator is compared pairwise to all the other indicators based on the input from the expert. In case the expert believes having more than 1 manufacturer is strongly more important to decrease supply risk than having the possibility of using another material for production he rates a 5 on the scale (see figure 11 first item). When he thinks that having a contract is more important than having more than one manufacturer the reciprocal is filled in 1/5 (see figure 11 second item). For each pair a comparison score is provided which is then filled in the pairwise comparisons matrix.

Figure 10. **AHP pairwise comparison questionnaire**

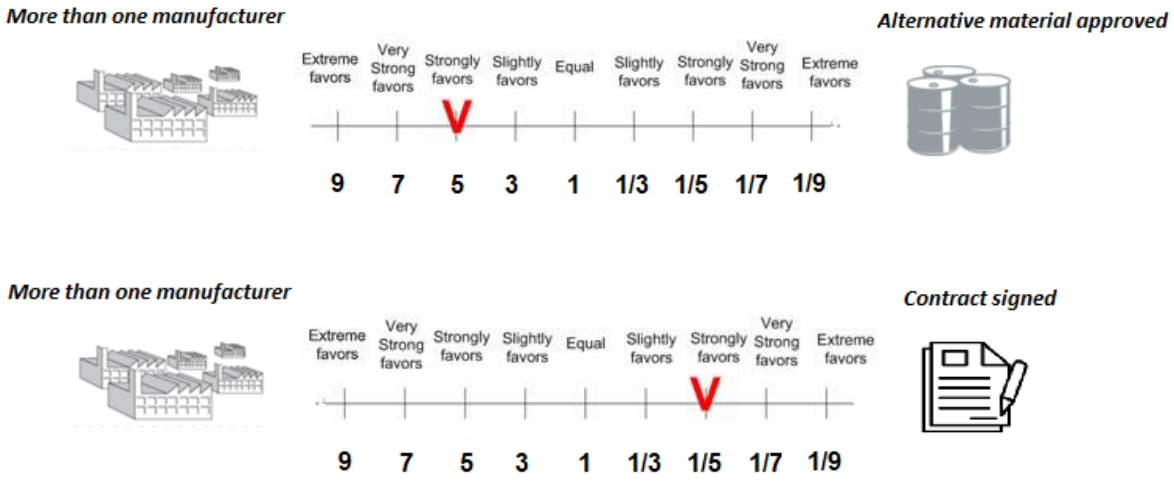


Table 6. **Pairwise comparisons**

Source: Made up figures for explanation purposes, actual figures in Appendix III

Risk indicator	>1 Manufacturer	Alternative material	Availability of contract
>1 Manufacturer	1.00	5.00	0.20
Alternative material	0.20	1.00	3.00
Availability of contract	5.00	0.33	1.00
Sum	6.20	6.33	4.20

To construct the weights for the indicators the columns in the pairwise comparison matrix are summed (see final row table 6). Then each number in the table is divided by the sum of the column to provide the normalized weight which is filled in the standardized matrix (Table 7). The individual weights for the indicators can now be calculated by averaging the rows.

Table 7. **Standardized Matrix**

Risk indicator	>1 Manufacturer	Alternative material	Availability of contract	**Weight**
>1 Manufacturer	0.16	0.79	0.05	**33.3%**
Alternative material	0.03	0.16	0.71	**30.1%**
Availability of contract	6.20	0.05	0.24	**36.6%**

This process was applied for the selected risk indicators that were selected in the risk identification phase. The complete pairwise comparison table, standardized matrix table and the weights that have been calculated by applying the AHP-methodology can be found in Appendix II.

5.3 Application of sales impact in the supply risk management tool

Literature identified the sales impact as an item specific risk.[111] Results from interviews show that the procurement specialists acknowledge the importance of taking the sales impact into account for supply risk management. Therefore, the researcher investigated the sales impact to see if and how this aspect should be incorporated in designing the solution.

The sales impact can be described as the sales value at stake when a material is not available for production. This can be caused by a variety of unwanted events (see literature review). The drawing below shows the increased impact the unavailability a material has based on its usage (red arrows). A specific raw material can end up in a wide variety of intermediate products which are subsequently used in a wide variety of end products. These intermediate products are sometimes even transferred to different locations for further usage which increases the impact even more.

Figure 11. **Raw material sales impact**

Source: Invented by author, made up figures

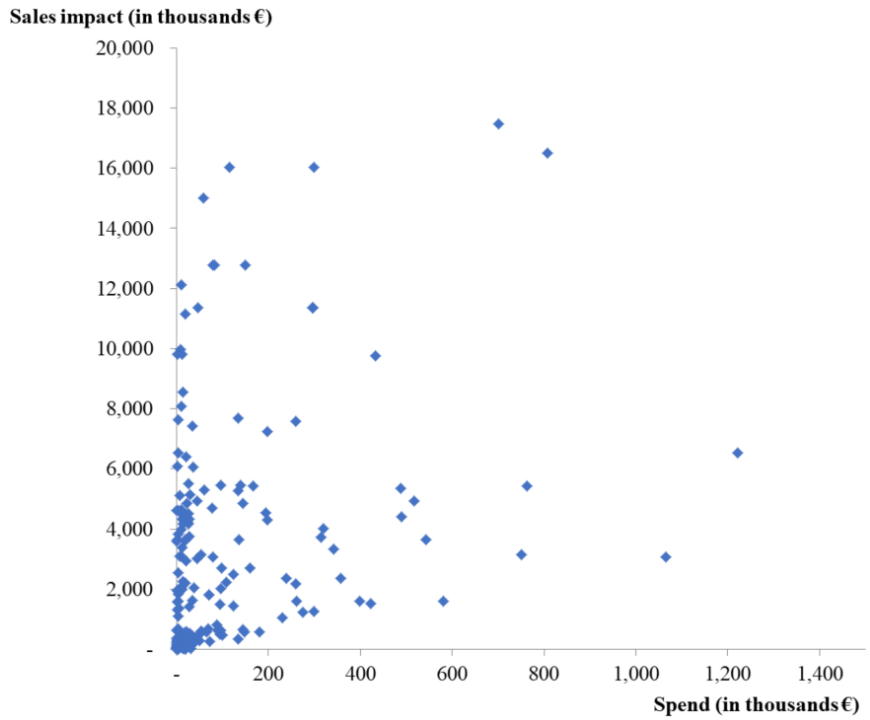
No public information

[111] (Kraljic, 1983), (Zsidisin, 2003, p. 17), (Wagner & Bode, 2008)

To calculate the sales impact for the individual purchased raw materials the materials need to be connected to the sales values of the products in which they are used. The ERP system contains the bill of material for each SKU. The previous year's sales data is then connected to the raw materials to calculate the sales impact. The importance of the material specific sales impact is revealed when material spend is plotted against the sales impact (see figure 10). Each of the dots represents a specific material and its accompanying spend and sales contribution in euros. The figure shows that the spend value is not an indication of the sales impact of materials. This can be concluded as the dots would then be situated around a trend line. Furthermore, the figure shows that there are a variety of materials that have a relatively high sales impact and low spend value. These materials are situated along the upper part of the vertical axis. The acquired knowledge in the literature review on the concept of supply risk and the figure suggests that in terms of supply risk management it is recommended to focus on sales impact rather than on high material spend value.

Figure 9. **Sales impact vs spend**

Source: Constructed by author



The importance of material sales impact then needs to be translated into a practical application for the risk monitoring tool. The literature explains that the concept of risk in its simplest form can be calculated as probability*impact.[112] This perception of risk is used in the context of this thesis to incorporate the sales impact into the tool. This incorporation was done by multiplying the total materials score of the selected indicators with the materials sales impact to provide an overall risk score which can be used for prioritization. Now that the construction of the different components of the tool is discussed, the next section will elaborate on how the tool looks, how it should be used, the results provides and its assumptions and limitations.

5.4 Explanation and application of the RM supply risk tool based on indicators for which data was available.

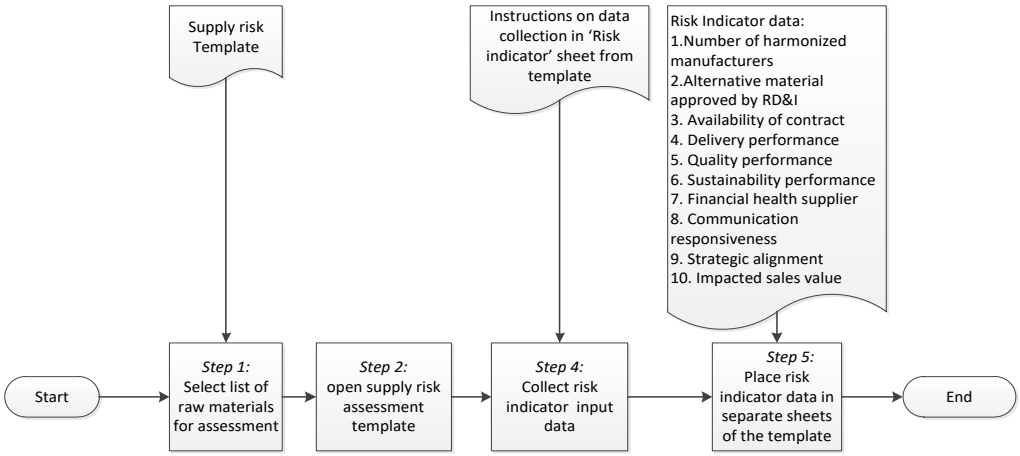
One of the formulated requirements was that the tool should be self-explanatory, easy to use and should have the possibility to be rolled out over multiple business units. To make sure that the tool is understandable for employees a user manual and a flowchart was developed (see Appendix VIII). This section briefly explains the different steps in the flowchart (see figure 12).

Depending on the function and/or business unit within the company the user should select the list of raw materials that he or she would like to assess in terms of supply risk. The user should then open the template in excel that has been developed by the author and fill in the previous years' spend data. Subsequently, the risk indicator data needs to be collected by following the instructions which can be found in the 'Risk indicator' sheet of the template. For each indicator a description is provided on how the material is assessed and where to find the required data. Finally, the collected data should be placed in the designated sheets of the template. When the risk indicator data is placed in the right sheets and the right columns, the template automatically assesses the supply risk by connecting the risk indicator data to the scales and weights in the 'scales & weights'-sheet of the template. The next section will elaborate on how to interpret the results of the tool.

[112] (Harland, Brenchley, & Walker, 2003, p. 52),

Figure 12. **RM supply risk tool user guidance flowchart**

Source: Invented by author



5.5 Application of the scores provided by the tool

The RM supply risk model has been tested on a little over 150 materials that were procured for the business unit. Once each material received a score based on the selected indicators the scores are added up to a total score. This score is then multiplied by the sales to provide the final risk score which can be used for prioritization.

Figure 13. **Raw material supply risk scoring model**

Source: Created by author

	Current supply base			Supplier performance			Supplier relation	Risk Prioritization Score	
	0.11	0.09	0.08	0.12	0.20	0.14	0.26		
Acoat	Number of harmonized manufacturers	Alternative material approved by RD&I	Availability of contrac	Delivery performanc	Quality performance	Sustainability performance	Communication responsiveness &Strategic alignment	Total risk score	(KPI) RISK * SALES IMPACT
[redacted]	5	5	1	5	1	1	5	66	12,056,013.90
	5	5	1	5	1	1	5	66	9,538,684.12
	5	5	1	4	1	1	5	64	8,562,941.20
	5	5	5	5	3	1	5	81	7,273,358.99
	5	5	5	5	4	1	5	85	6,510,371.72
	5	5	5	5	1	1	5	72	6,488,832.98

The model shows the risk score for the indicators that were found important by the procurement specialists. As the type of risk is shown by the model the user can use this information for tailoring its risk mitigation strategy accordingly. For example, if no contract is available logical risk mitigation should be discussing contract possibilities with category managers. If no alternative material is available a suitable mitigation strategy might be contacting R&D to request investigation for alternatives.

Another useful application for the user is that he can drill down into several aspects like spend area, subspend area, specific vendors or production plants. Figure 15 shows a selection of materials and is filtered down on the spend area resins and precursors. The model shows the total risk score for the selected materials. Furthermore, the user can directly identify the parent vendor, the local vendor, the plant using the material and the purchasing value of the materials in the previous year. This detailed information can be of support to make factually informed decisions.

Figure 14. **Materials filtered on spend area**

Source: Invented by author

No public information

Another aspect in which the model can be of support is by revealing how the scores are set up. The user can directly see the data input for each indicator. Figure 16 for example shows the supplier operational indicator data input that result in the scores for a selection of raw materials.

Figure 15. **Supplier performance indicator data**

Source: Created by author

No public information

Now that most of the key functionalities of the tool are described the next section will elaborate on the limitations and assumptions of the tool.

5.6 Limitations and Assumptions of the RM supply risk tool

As a pilot the model assessed materials for the business unit. However, due to limitations in data availability and differing ERP systems the tool contains several limitations and assumptions which can be found in table 9.

Table 8. **Limitations and assumption of raw materials supply risk tool**

Limitation/ Assumption	Description
Limitation	One of the biggest limitations of the tool is that not for all the situations that have been identified as a risk to supply risk data was available. These situations were therefore captured in a theoretical model accompanied with advice to collect this data but not included in current material prioritization based on factual data.
Limitation	Weights are currently determined based on AHP assessment from the procurement director. For more valid results larger sample size is required.
Limitation	The sales impact per material was not readily available in the ERP system and required an extensive manual exercise. Therefore the appendix provides a detailed description on how to extract the sales impact of raw materials from the system manually. Currently, the bill of material report does not automatically show if a material present in an end product is purchased at a different production site. Therefore, the current risk assessment does not take into account raw materials procured at different production sites.
Assumption	The sales impact risk assessment is based on previous years' data. Significant changes in sales of product during the following year can therefore give slightly distorted impact information.
Assumption	As the lowest possible score on each indicator is 1 instead of 0 the materials with the highest sales impact will never end up as having lowest priority. This was done intentionally as it cannot be stated with certainty that all risk situations are covered by the model and therefore ensure 0 probabilities of issues with supply.

5.7 Key points in the advice to Company X for managing RM supply risk

Taking into account the academic supply risk literature, the empirical findings, and the researchers' judgement this chapter aims at providing advice to management.

The tool provides an assessment on material level based on scores received from risk indicators. These scores can change due to intervention from management or external influences. As the model applies real time data the tool should ideally be applied periodically (e.g. quarterly) to monitor changes in material risk scores in relation to the previous period. It should be noted here that currently data for delivery performance and quality performance from the entire prior year was used as this was the first time the model was introduced and these scores are therefore more reliable. Finally the researcher established a list with specific recommendations for management:

- Suitable mitigation strategies should be applied based on the identified supply risks.
- Use bigger sample to determine the appropriate weights for the selected indicators with the AHP methodology.
- Track and store the data of the tool in combination with disruption data to perform statistical analysis to assess predictive power of selected indicators.
- Due to sensitivity of data (especially sales impact) make sure access is controlled and according to compliance rules.
- Strive for continuous improvement as changes in risk environment and availability of risk indicator data the risk indicators should be reviewed (cross-functionally) and updated periodically (e.g. yearly).
- Collect missing indicator data based on advice that is provided in the theoretical model.

6. Conclusion

The complexity of today's supply chains and the increased reliance on the competitive advantage of these supply chains leads to an increased risk exposure for buying firms.[113] Procurement organizations are challenged with managing inbound supply and the accompanying risks. The extent to which companies can cope with risk materialization depends on the degree of preparedness.[114] Companies that take proactive measures were found to be more likely in successfully managing inbound supply risk then firms that rely primarily on reactive measures.[115] The procurement director of Company X recognizes the increased risks related to inbound supply of raw materials. He therefore searched for means to proactively cope with this situation which resulted in the main goal of this project: Development of a management tool for Company X that can identify, assess and prioritizes raw materials in terms of supply risk. This goal was translated into a set of research questions that have been answered during the course of this thesis.

Sub-question 1.1:

'What situations are considered a risk to raw material supply for Company X?'

The solution design was based on a problem solving methodology developed by van Aken.[116] The first phase of the research aimed at identifying supply risk situations that are specifically relevant for Company X and the industry in which it operates. Based on supply risk literature a risk identification questionnaire was constructed. Experienced procurement specialists were then asked to provide input on the relevance of the described risk situation based on their expertise. Within the selected categories the following situations have been identified as a risk to raw material supply:

[113] (Hoffmann, Schiele, & Krabbendam, 2013, p. 199)
[114] (Chopra & Sodhi, 2004, p. 53)
[115] (Hoffmann, Schiele, & Krabbendam, 2013, p. 207)
[116] (Van Aken, Berends, & Van der Beij, 2007)

Table 9. **Identified supply risks**

Individual Supplier Risk	Supply market risk	Item specific risk
Operational ▪ Quality performance ▪ Delivery performance ▪ Sustainability performance ▪ Compliancy ▪ Production capacity *Financial risk* ▪ Liquidity issues *Strategic risk* ▪ Supplier obligation to other customer	▪ Number of qualified suppliers in the market ▪ Constrained market ▪ Grip on raw material price ▪ Regulatory risk ▪ Natural disaster risk ▪ Political instability risk	▪ Sales impact ▪ Number of manufacturers ▪ Availability of contract ▪ Alternative material internally approved

However, merely knowing what supply risks exist does not contribute to successful supply risk management.[117] Therefore, the next step aims at identifying risk indicators that can be used for measurement by answering the next sub-question.

Sub-question 1.2:

'Which supply risk indicators can be identified for assessing raw material supply risks?'

For the selected risk situations in the previous step further investigation by means of follow-up interviews with company specialists and desk research was executed to identify measurement possibilities. This exercise provided detailed insights in the availability of data in the selected risk field that could be used for assessment. The outcome revealed that not for all identified risk situations data was readily available. Therefore, the decision was made to provide Company X management with advice on how to collect the missing data and proceed with the risk assessment by using the indicators for which data was available. The risk indicators that are used for assessment can be seen in table 11.

[117] (Hoffmann, Schiele, & Krabbendam, 2013)

Sub-question 2:

'How can Company X monitor the risks related to the inbound supply of raw materials?'

Based on the findings from scientific literature, interviews, discussions with procurement specialists and business documentation a management tool was constructed that applies readily available data to assess and prioritize raw materials in terms of supply risk. This tool is self-explanatory and is accompanied by a detailed user guide so that application of the tool is not dependent on the researcher (see appendix IV).

The tool represents itself in a weighted factor scoring model in which the weights of the risk indicators are determined by applying the Analytical Hierarchy Process.

The extent of supply risk was expressed by multiplying the probability with impact.[118] In the context of this thesis the impact is defined as the sales value at stake in case a material is not delivered. The probability is defined by combining the scores materials receive from risk indicators. In order to prioritize raw materials, the extent of risk per material is calculated by multiplying the accumulated indicator score with the calculated sales impact in euros.

Table 10. **Selected indicators with accompanying scale, score and weight**

Indicator	Scale	score	Weight
Number of manufacturers	>1 Manufacturer	0	0.07
	1 Manufacturer	5	
Alternative material approved	Yes	0	0.11
	No	5	
Availability of contract	Yes	0	0.08
	No	5	
Delivery performance	%>95	1	0.11
	% 90-95	2	
	% 85-90	3	
	%80-85	4	
	%<80	5	
	No Value	3	
Quality performance	%>99	1	0.21
	% 95-99	2	
	% 90-95	3	
	%80-90	4	
	%<80	5	
	No value	3	
Sustainability performance	Maturity level 5	0	0.14
	Maturity level 4	0	
	Maturity level 3	2	
	Maturity level 2	3	
	Maturity level 1	4	
	Maturity level 0	5	
	No data available	5	
Supplier relationship & Strategic alignment	Preferred supplier	0	0.27
	Approved supplier	2	
	Phase-in supplier	2	
	Phase-out supplier	5	

[118] (Harland, Brenchley, & Walker, 2003, p. 52), (Yates & Stone, 1992)

Main:

How can Company X identify, assess, prioritize and monitor raw materials in terms of supply risk?'

Answering the main research question is done by integrating the answers to the sub-questions. This starts with identifying what risks are relevant and what indicators can be identified for assessment. This assessment should then be done periodically as the literature revealed that the supply risk environment is highly dynamic.

To conclude, advice to Company X management is to proceed with applying tailored mitigation strategies based on results provided by the tool.

7. Limitations

The research that has been conducted contains multiple limitations which are discussed separately in this chapter.

- One of the main limitations in this study comes from the selected sample in the risk identification phase. Everyone in an organization is responsible for its own risk and therefore, the perception on the criticality of a risk can differ depending on the role.[119] Results from empirical findings shows that some of the risks which have been identified as a risk to supply in the academic discourse were not found to be relevant for Company X by the selected respondents. In case a wider audience was targeted the risk identification phase might have provided different results. The research does not contain further elaboration on why specific risks were not found to be important to take into account for periodical assessment.
- Another limitation is coming from the methodology that was applied relates to the strategic aspect of supply risks. Literature showed that primarily the operational risks like delivery performance and quality performance are likely to be detected as these directly influence production process.[120] It seems therefore most logical that the respondents who are asked on what they perceive as a risk place emphasis on the operational aspects and strategic aspects might be underexposed.
- Finally, the researcher executed a thorough literature review to identify all characteristics of supply risk. Because of the increased importance of supply risk management a vast amount of literature was available. The researcher can therefore not state with full certainty that all relevant literature was scrutinized.

[119] (Zsidisin, 2003), (Blackhurst, Scheibe, & Johnson, 2008, p. 145)
[120] (Choprah & Sodhi, 2004, p. 55), (Hofmann, 2011, p. 7)

8. Generalizability & Future research

The generalizability of the conclusions and results of the research to other situations in business problem solving projects is often limited because these typically focus primarily on a specific problem.[121] However, this research involves a pilot study from which certain aspects are directly applicable in other business units within the same company. However, few things should be taken in consideration before applying the tool in a different setting. First, it is still advisable to review the selected risk situations on applicability and relevance before directly proceeding with applying the tool as different business units do not have an identical supply base. Secondly, other business units might procure the same raw materials but have a different sales impact as the materials are used in other end products. Taking these things into considerations, nearly all indicator data is extracted from companywide systems and therefore the user manual for collecting data can be applied directly in other business units.

The study is finalised by discussing potential future research. First, the risk identification questionnaire was focussed merely on procurement professionals that came from within the case company. To gather more insights it is recommended take into account the perspective of the supplier as well. Secondly, when identifying risks to supply it is important to know the predictive power of the tool. Therefore, a future longitudinal study in which data provided by the tool is stored and statistically analysed in relation to disruptions can provide insights. This way the predictive power of the selected indicators can be identified. Finally, the research conducted in this study is focussing primarily on internal data relating to tier-one suppliers. Future research should aim on identifying possibilities in the application of big data in supply chain risk management. This external data can be utilised to improve the predictive power of the tool and help management in providing more detailed insights in raw materials supply risks.

[121] (Van Aken, Berends, & Van der Beij, 2007, p. 166)

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Appendix I: Overview of supply risk situations identified in literature

Table 11. **Overview of supply risk situations as identified in literature**

Supply Risk Category	Summarized description of supply risk situation	Touched upon by
Operational supplier risk *Operational supplier risks are caused by the disability of the supplier to achieve a particular desired performance (despite all efforts made by supplier).*[122]	Quality performance *Insufficient quality of materials causes risk to production process and customer satisfaction.*	- (Noordewier, John, & Nevin, 1990) - (Min, 1994) - (Quayle, 1998) - (Zsidisin, 2003) - (Chopra & Sodhi, 2004) - (Christopher & Lee, 2004) - (Kleindorfer & Saad, 2005) - (Blackhurst, Scheibe, & Johnson, 2008) - (Handfiel & McCromack, 2008) - (Wagner & Bode, 2008) - (Tang, Teo, & Wei, 2008) - (Hoffmann, Schiele, & Krabbendam, 2013)
	Delivery Performance *Consistent early and/or late deliveries can cause issues in manufacturing- and supply chain process.*	- (Noordewier, John, & Nevin, 1990) - (Min, 1994) - (Zsidisin, 2003) - (Sinha, Whitman, & Malzahn, 2004) - (Chopra & Sodhi, 2004) - (Christopher & Lee, 2004) - (Kleindorfer & Saad, 2005) - (Wagner & Bode, 2008) - (Blackhurst, Scheibe, & Johnson, 2008) - (Hoffmann, Schiele, & Krabbendam, 2013)
	Communication failure *A failure in communication can result in delay or disruption in supply.*	- (Noordewier, John, & Nevin, 1990) - (Zsidisin, 2003) - (Finch, 2004) - (Juttner & Peck, 2005) - (Sinha, Whitman, & Malzahn, 2004) - (Hofmann, 2011)

[122] (Hofmann, 2011)

	Incompatible IT-systems *Supply risk emerges when supplier is not capable to timely transfer relevant information to the buying firm*	- (Zsidisin, 2003) - (Finch, 2004) - (Hofmann, 2011)
	Fluctuating demand from customers *Strong fluctuations in demand from customers causing distortion in upward order information in supply chain resulting in issues in RM supply.*	- (Lee, Padmanabhan, & Whang, 2004)
	Inability to reduce costs *When the supplier can't reduce costs this can become a risk in competitive markets.*	- (Zsidisin, 2003) - (Hofmann, 2011)
	Purchasing logistics *Issues related to the logistics of the procurement of the items*	- (Zsidisin, 2003) - (Chopra & Sodhi, 2004) - - (Stecke & Kumar, 2009) - (Hofmann, 2011)
	Sustainability performance *Suppliers that not meet requirements in terms of sustainability are a risk to meeting sustainable development goals and can cause corporate reputational damage*	- (Foerstl, Reuter, Hartmann, & Constantin, 2009) - (Gatzert, 2015) - (Gold & Schleper, 2017) - (Gouda & Saranga, 2018)
Financial supplier risk *Financial supply risks appear when supplier is facing liquidity issues and/or bankruptcy.*[123]	Supplier liquidity issues *Mismanagement or economic downturn can cause suppliers to face liquidity issues.*	- (Zsidisin, 2003) - (Tang, Teo, & Wei, Supply Chain Analysis, 2008) - (Hofmann, 2011)

[123] (Hofmann, 2011)

Strategic supply risk *Strategic risks occur if the buying firm is not attractive enough for the supplier anymore.*[124]	Supplier obligations to other customers *When supplier has obligations to other customers non-preferred customers are forgotten.*	- (Zsidisin, 2003) - (Hofmann, 2011)
	Production capacity *In case of insufficient production capacity in the entire industry, non-preferred customers are forgotten.*	- (Zsidisin, 2003) - (Lee, Padmanabhan, & Whang, 2004) - (Normann & Jansson, 2004) - (Chopra & Sodhi, 2004) - (Hofmann, 2011)
	Employee turnover *Multiple turnover of employees is an indicator of supply risk because ending personnel connections might cause a shift in the suppliers strategy*	- (Hofmann, 2011)
	Dependency *Situation in which the buyer relies on the actions of the supplier to achieve it's goals. When the supplier is dependent on the buyer, the buyer is less likely to walk out on the relationship.*	- (Zsidisin, 2003) - (Tang, Teo, & Wei, 2008) - (Hofmann, 2011)
Political and Environmental supply risk *Political and environmental risks are exogenous causes that cannot be directly influenced by a company and are equal for all market players.*[125]	Economic downturn Complete economic downturn can impact risk to supply.	- (Juttner & Peck, 2005) - (Zsidisin & Ritchie, 2009) - - (Hofmann, 2011)
	Natural disaster *Natural disasters like earthquakes or flooding can cause a disruption in supply when supplier is impacted.*	- (Chopra & Sodhi, 2004) - (Normann & Jansson, 2004) - (Juttner & Peck, 2005) - (Zsidisin, 2003) - (Tang, Teo, & Wei, 2008) - (Stecke & Kumar, 2009)

[124] (Hofmann, 2011)
[125] (Hofmann, 2011)

	Political ins(Zsidisin, 2003)tability *Rapid change in political environment can cause a risk to supply.*	- (Min, 1994) - (Juttner & Peck, 2005) - (Zsidisin & Ritchie, 2009) - (Hofmann, 2011)
	Currency fluctuations *Change in foreign exchange rates can be a risk to supply*	- (Juttner & Peck, 2005) - (Zsidisin & Ritchie, 2009) - (Hofmann, 2011)
Supply Market risk *Market risks, are risks related to market conditions in which the buying firm operates*[126].	Number of qualified suppliers *Situations of few qualified suppliers limits the buying firm possibilities to switch suppliers and is therefore more likely to be a risk to supply*	- (Zsidisin, 2003) - (Blackhurst, Scheibe, & Johnson, 2008) - (Gualandris & Kalchschmidt, 2015) - (Brindley, 2017)
	Constrained markets/Market shortages *When only one or few sources of item/material are present this can become a risk when demand exceeds supply.*	- (Zsidisin, 2003) - (Brindley, 2017)
	Grip on Raw materials *Supplier has strong market position and can therefore dictate prices*	- (Kraljic, 1983) - (Steele & Court, 1996) - (Hofmann, 2011)
	Market volatility *The market in which the supplier is active is characterized as volatile*	- (Noordewier, John, & Nevin, 1990) - (Zsidisin, 2003) - (Chopra & Sodhi, 2004) - (Hofmann, 2011)
	Trade restrictions *Trade restriction can limit access to markets and are therefore barriers to the flow of goods and can have negative impact on supply of goods.*	- (Tang, Teo, & Wei, 2008) - (Stecke & Kumar, 2009) - (Zsidisin & Ritchie, 2009) - (Brindley, 2017)

[126] (Zsidisin, Managerial Perceptions of Supply Risk, 2003)

Item specific risk *Item specific risks are risks related to the purchased item/material.*[127]	Impact on profitability *The criticality of raw materials increases when the materials are used in products with high sales value.*	- (Kraljic, 1983) - (Zsidisin, 2003)
	Impact on sales *The criticality of raw materials increases when the materials are used in products with high sales value.*	- (Chopra & Sodhi, 2004)
	Nature of product application *The use of an item for a new product application is a higher risk than application in existing product*	- (Zsidisin, 2003) - (Wynstra, Van Weele, & Weggemann, 2001)
	Product complexity *The supplier is not able to cope with the complexity of the item.*	- (Zsidisin, 2003) - (Chopra & Sodhi, 2004)

[127] (Zsidisin, Managerial Perceptions of Supply Risk, 2003)

Appendix II: AHP tables

Pairwise comparisons

Item Number	Item Number	1	2	3	4	5	6	7
	Item Description	>1 Manufacturers	Alternative material approved by R&D	Availability of contract	Delivery performance	Quality performance	Sustainability performance	Communication & alignment
1	>1 Manufacturers	1.00	0.33	3.00	0.33	0.20	1.00	0.20
2	Alternative material approved by R&D	3.00	1.00	0.20	3.00	0.20	1.00	0.20
3	Availability of contract	0.33	5.00	1.00	1.00	0.33	0.33	0.14
4	Delivery performance	3.00	0.33	1.00	1.00	1.00	1.00	0.33
5	Quality performance	5.00	5.00	3.00	1.00	1.00	1.00	1.00
6	Sustainability performance	1.00	1.00	3.00	1.00	1.00	1.00	1.00
7	Communication & alignment	5.00	5.00	7.00	3.00	1.00	1.00	1.00
	Sum	18.33	17.67	18.20	10.33	4.73	6.33	3.88

STANDARDIZED MATRIX

		>1 Manufacturers	Alternative material approved by R&D	Availability of contract	Delivery performance	Quality performance	Sustainability performance	Communication & alignment	**Weight**
1	>1 Manufacturers	0.05	0.02	0.16	0.03	0.04	0.16	0.05	7.5%
2	Alternative material approved by R&D	0.16	0.06	0.01	0.29	0.04	0.16	0.05	11.0%
3	Availability of contract	0.02	0.28	0.05	0.10	0.07	0.05	0.04	8.8%
4	Delivery performance	0.16	0.02	0.05	0.10	0.21	0.16	0.09	11.3%
5	Quality performance	0.27	0.28	0.16	0.10	0.21	0.16	0.26	20.6%
6	Sustainability performance	0.05	0.06	0.16	0.10	0.21	0.16	0.26	14.3%
7	Communication & alignment	0.27	0.28	0.38	0.29	0.21	0.16	0.26	26.5%

Appendix III: Interview protocol

General Info interviewee:

Name:	
Date:	
Function:	
Years employed:	

Section I: Questions related to the individual supplier

1. What situations related to the individual supplier do you consider a risk to the inbound supply of product related materials and could you comment on means to assess?

	Supply risk situation	***Considered as risk to supply Y/N?***	***Comment on assessment***
<u>Operational supplier risk</u> *Operational supplier risks are caused by the disability of the supplier to achieve a particular desired performance (despite all efforts made by supplier).*	<u>1.1 Quality performance</u> *Insufficient quality of materials that causes a risk to production process and customer satisfaction.*		
	<u>1.2 Delivery Performance</u> *Consistent early and/or late deliveries can causing issues in manufacturing- and supply chain process.*		
	<u>1.3 Communication failure</u> *A failure in communication can resulting in delay or disruption in supply.*		
	<u>1.4 Incompatible IT-systems</u> *Supply risk emerges when supplier is not capable to timely transfer relevant information to the buying firm*		
	<u>1.5 Fluctuating demand from customers</u> *Strong fluctuations in demand from customers causing distortion in upward order information in supply chain resulting in issues in RM supply.*		
	<u>1.6 Purchasing logistics</u> *Issues related to the logistics of the procurement of the items*		
	<u>1.7 Sustainability performance</u> *Suppliers that not meet requirements in terms of sustainability are a risk to meeting sustainable development*		

	goals and can cause corporate reputational damage		
Financial supplier risk *Financial supply risks appear when supplier is facing liquidity issues and/or bankruptcy.*	1.9 Supplier liquidity issues *Mismanagement or economic downturn can cause suppliers to face liquidity issues.*		
Strategic supply risk *Strategic risks occur if the buying firm is not attractive enough for the supplier anymore.*	1.10 Supplier obligations to other customers *When supplier has obligations to other customers non-preferred customers are forgotten.*		
	1.11 Employee turnover *Multiple turnover of employees is an indicator of supply risk because ending personnel connections might cause a shift in the suppliers strategy*		
	1.12 Dependency *Situation in which the buyer relies on the actions of the supplier to achieve its goals. When the supplier is dependent on the buyer, the buyer is less likely to walk out on the relationship.*		
	1.4 Production capacity *In case of insufficient production capacity in the entire industry, non-preferred customers are forgotten.*		
Political and Environmental supply risk *Political and environmental risks are exogenous causes that cannot be directly influenced by a company and are equal for all market players.*	1.13 Economic downturn *Complete economic downturn can impact risk to supply.*		
	1.14 Natural disaster *Natural disasters like earthquakes or floodings can cause a disruption in supply when supplier is impacted.*		
	1.15 Political instability *Rapid change in political environment can cause a risk to supply.*		
	1.16 Currency fluctuations *Change in foreign exchange rates can be a risk to supply*		
Other	…		

Section II: Questions related to the supply market

2. What situations related to the supply market of product related materials do you consider a risk to the inbound supply of raw materials and could you comment on means to assess?

Supply risk situation	*Considered as risk to supply Y/N??*	*Considered as risk to supply Y/N?*	*Comment on assessment*
<u>Supply Market risk</u> *Market risks, are risks related to market conditions in which the buying firm operates.*	<u>2.1 Number of qualified suppliers</u> *Situations of few qualified suppliers limits the buying firm possibilities to switch suppliers and is therefore more likely to be a risk to supply*		
	<u>2.2 Constrained markets/Market shortages</u> *When only one or few sources of item/material are present this can become a risk when demand exceeds supply.*		
	<u>2.3 Grip on Raw materials</u> *Supplier has strong market position and can therefore dictate prices*		
	<u>2.4 Market volatility</u> *The market in which the supplier is active is characterized as volatile*		
	<u>2.5 Trade restrictions</u> *Trade restriction can limit access to markets and are therefore barriers to the flow of goods and can have negative impact on supply of goods.*		
Other	…		

Section III: Questions related to the purchased item

3. What situations related to the purchased item do you consider a risk to the inbound supply of raw materials and could you comment on means to assess?

	Supply risk situation	*Considered as risk to supply Y/N??*	*Comment on assessment*
<u>Item specific risk</u> *Item specific risks are related to the purchased item/material.*	<u>3.1 Impact on profitability</u> *Unavailability of an item can have negative impact on profit.*		
	<u>3.1 Impact on sales</u> *Unavailability of an item can have negative impact on sales.*		
	<u>3.2 Nature of product application</u> *The use of an item for a new product application is a higher risk than application in existing product.*		
	<u>3.3 Product complexity</u> *The supplier is not able to cope with the complexity of the item.*		
Other	...		

Appendix IV: Thematic framework

Table 12. **Thematic framework**

Theme	Sub-Themes	Description of subtheme	Subsub-themes
Individual suppliers risks	Quality performance	Insufficient quality of materials leading to negative effect in production process and/or customer satisfaction.	-why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Delivery Performance	Early and/or late deliveries that cause issues in manufacturing- and supply chain process	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Inability to reduce costs	The inability to reduce cost resulting in negative impact on supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Incompatible IT-systems	The the inability of timely transfer of relevant information to the buying firm resulting in supply issues	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Production capacity	Insufficient production capacity of suppliers resulting in issues to supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Communication responsiveness	Late or non-response in communication resulting in delay or disruption in supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Purchasing logistics	Issues related to the logistics of the procurement of materials resulting in late delivery.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Issues related to NPD	Increased responsibility of	-Why risk? -Currently

		suppliers in the NPD process that resulting into higher costs, lead times or decreased quality or product performance.	measured? -How measured? -Data availability? -Data location?
	Sustainability performance	The inability of suppliers meeting requirements in terms of sustainability that negatively influence the buying firm.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Supplier liquidity issues	Mismanagement or economic downturn causing liquidity issues for suppliers which impacts supply of materials.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Supplier obligations to other customers	Prioritization of suppliers obligation to other customers leading to issues with supply of materials.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Employee turnover	Ending personnel connections causing a shift in the supplier's strategy leading to issues in supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Dependency	Supplier dependency on the buyer resulting in the buyer to walk out on the relationship causing issues in supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Economic downturn	Complete economic downturn impacting supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Natural disaster	Natural disasters like earthquakes or flooding causing a disruption in supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Political instability	Rapid change in	-Why risk?

		political environment causing issues to supply.	-Currently measured? -How measured? -Data availability? -Data location?
Supply market risk	Number of qualified suppliers	Situation of limited qualified suppliers causing to have fewer possibilities to switch suppliers and therefore resulting in supply issues.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Constrained markets/Market shortages	Situation in which only one or few sources of item/material are present causing issues in supply when demand exceeds supply.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Grip on Raw materials	Strong market position of supplier which dictates prices that can't be passed on to customers.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Market volatility	The market in which the supplier is active is characterized as volatile leading to supply issues.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Trade restrictions	Trade restriction in market which serve as barriers to the flow of goods resulting in a disruption or delay in supply	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
Item specific risks	Impact on profitability	The unavailability of an high sales item that has negative impact on profit.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?
	Nature of product application	The use of an item for a new product application as higher	-Why risk? -Currently measured?

		risk than application in existing product.	-How measured? -Data availability? -Data location?
	Product complexity	Supplier's ability to cope with the complexity of the item.	-Why risk? -Currently measured? -How measured? -Data availability? -Data location?

Appendix V: Shortlist interview notes sheet

Shortlist interview notes sheet

Candidate name: Job function: Date:

Individual supplier risks	**Risk Y/N**	**Notes**
Delivery Performance		
Quality performance		
Financial Risk		
Issues related to NPD		
Production capacity constraints		
Incompatible IT-systems		
Communication responsiveness		
Possibility of technical assistance		
Cultural difference		
Not being preferred customer		
Dependence on supplier		
Diverging strategies		
Other		
Other		

Supply Market risk	**Risk Y/N**	**Notes**
Number of qualified suppliers		
Geographical density of suppliers		
Constrained markets/Market shortages		
Grip on raw materials		
Trade restrictions		
Other		
Other		

Item specific risk	**Risk Y/N**	**Notes**
Impact on profitability		
Product complexity		
Nature of product application		
Other		

Appendix VI: Interview Notes

Interview 1

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Global Procurement Director

No public information

Interview 2

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Procurement Specialist

No public information

Interview 3

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Procurement specialist \

No public information

Interview 4

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Quality controller

No public information

Interview 5

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Sales analyst

No public information

Interview 6

Interviewer: Researcher (Lennart van Roeden)

Interviewee: ERP system specialist

No public information

Interview 7

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Procurement specialist Contracts

No public information

Interview 8

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Procurement process specialist

No public information

Interview 9

Interviewer: Researcher (Lennart van Roeden)

Interviewee: Supplier sustainability specialist

No public information

Appendix VII: (AHP) Pairwise comparison questionnaire

AHP Pairwise comparison questionnaire												
To decrease situations of supply risk which of the following risk factors is in your perception more important?												
		Only enter score in yellow field										
#	Risk factor	Extremely more important	Very strongly more important	strongly more important	slightly more important	Equally important	Slightly more important	strongly more important	Very strongly more important	Extremely more important	Risk factor	*Fill in score here!*
1	Having more than one manufacturer for the same material	9	7	5	3	1	1/3	1/5	1/7	1/9	Having an alternative material formally approved by RD&I	1
2	Having more than one manufacturer for the same material	9	7	5	3	1	1/3	1/5	1/7	1/9	Having a contract signed with the supplier for the material	1
3	Having more than one manufacturer for the same material	9	7	5	3	1	1/3	1/5	1/7	1/9	Consistent on time delivery	1
4	Having more than one manufacturer for the same material	9	7	5	3	1	1/3	1/5	1/7	1/9	Quality capability of the supplier	1
5	Having more than one manufacturer for the same material	9	7	5	3	1	1/3	1/5	1/7	1/9	Sustainabilty performance of the supplier	1
6	Having more than one manufacturer for the same material	9	7	5	3	1	1/3	1/5	1/7	1/9	Strategic alignment & Timely communication	1
7	Having an alternative material formally approved by RD&I	9	7	5	3	1	1/3	1/5	1/7	1/9	Having a contract signed for with the supplier for the material	1
8	Having an alternative material formally approved by RD&I	9	7	5	3	1	1/3	1/5	1/7	1/9	Consistent on time delivery	1
9	Having an alternative material formally approved by RD&I	9	7	5	3	1	1/3	1/5	1/7	1/9	Quality capability of the supplier	1
10	Having an alternative material formally approved by RD&I	9	7	5	3	1	1/3	1/5	1/7	1/9	Sustainabilty performance of the supplier	1
11	Having an alternative material formally approved by RD&I	9	7	5	3	1	1/3	1/5	1/7	1/9	Strategic alignment & Timely communication	1
12	Having a contract signed with the supplier for the material	9	7	5	3	1	1/3	1/5	1/7	1/9	Consistent on time delivery	1
13	Having a contract signed with the supplier for the material	9	7	5	3	1	1/3	1/5	1/7	1/9	Quality capability of the supplier	1
14	Having a contract signed with the supplier for the material	9	7	5	3	1	1/3	1/5	1/7	1/9	Sustainabilty performance of the supplier	1
15	Having a contract signed with the supplier for the material	9	7	5	3	1	1/3	1/5	1/7	1/9	Strategic alignment & Timely communication	1
16	Consistent on time delivery	9	7	5	3	1	1/3	1/5	1/7	1/9	Quality capability of the supplier	1
17	Consistent on time delivery	9	7	5	3	1	1/3	1/5	1/7	1/9	Sustainabilty performance of the supplier	1
18	Consistent on time delivery	9	7	5	3	1	1/3	1/5	1/7	1/9	Strategic alignment & Timely communication	1
19	Quality capability of the supplier	9	7	5	3	1	1/3	1/5	1/7	1/9	Sustainabilty performance of the supplier	1
20	Quality capability of the supplier	9	7	5	3	1	1/3	1/5	1/7	1/9	Strategic alignment & Timely communication	1
21	Sustainabilty performance of the supplier	9	7	5	3	1	1/3	1/5	1/7	1/9	Strategic alignment & Timely communication	1

Appendix VIII: Process description of tool usage

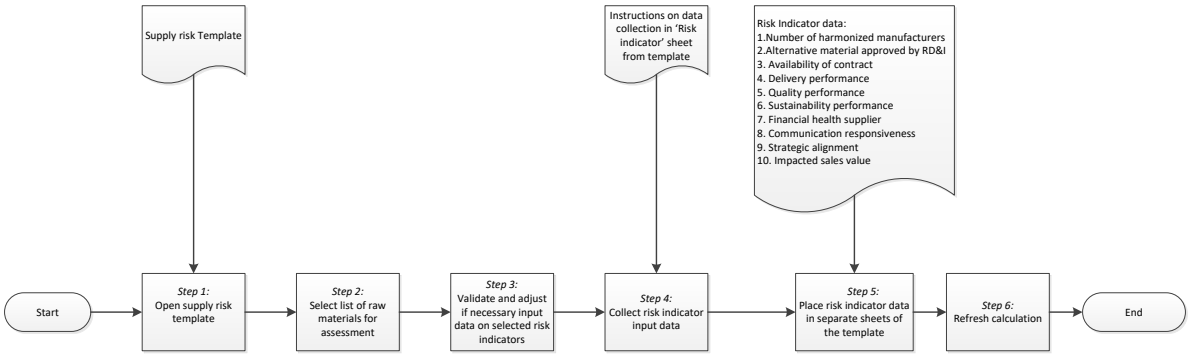
This section contains a description on how to use the raw material supply risk monitoring tool. The tool represents itself in an excel file. The first sheet of the file provides a description on how the different risk indicators are measured and where to find the required data. The risk indicator data is then placed in the designated sheets of the template. The template automatically assesses the supply risk by connecting the risk indicator data to the scales and weights in the 'scales & weights'-sheet of the template.

The table and flowchart below explain the structured process that should be followed in order to assess the risk related to the inbound supply of raw materials. Table 1 explains the scope of the tool, requirements, activities, input and the output. Flowchart 1 shows the individual steps followed by a written description of the activities.

Table 1. **Description of process for tool usage**

Name of tool:	**Supply risk monitoring tool**		
Created By:	Lennart van Roeden	**Last Updated By:**	
Date Created:	20/05/2018	**Last Revision Date:**	
Purpose:	The purpose of this process is to provide guidance on how to use the raw material supply risk monitoring tool that has been developed to increase visibility of risks related to the inbound supply of raw materials through proactively monitoring supply risk indicators.		
Scope:	The process is applicable to raw materials purchased from external vendors.		
Requirements:	General knowledge BW. Access to one SAP. Access to slates lists. Access to Securimate business partner compliance screening tool.		
Input:	Supply risk template Supply risk indicator data.		
Activities:	(Start) 1. Open the supply risk monitoring template. 2. Select list of raw materials for assessment. 3. Validate and adjust if necessary input data on selected risk indicators. 4. Collect risk indicator input data. 5. Place risk indicator data in separate sheets of the template. 6. Refresh calculations. (End)		
Output:	The output of the process is a prioritization of raw materials based on scores received on the selected supply risk indicators.		

Flowchart 1. **Activities for filling in supply risk tool**



Description of steps

Step 1: Open Raw Material supply risk template

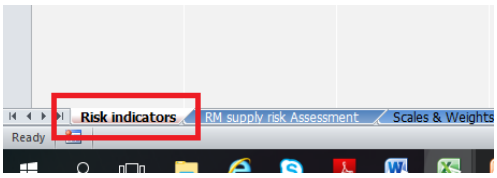
Open the excel template.

Step2: Select list of raw materials for assessment

Select the raw materials that need assessment in terms of inbound supply risk.

Step 3: Validate and adjust if necessary input data on selected risk indicators

Due to changes in overall supply risk environment and availability of data, the risk indicators should be validated and adjusted if necessary. The user of the tool should perform this step for the individual indicators in the 'Risk indicator' sheet of the template.



Step 4: Collect risk indicator input data

The risk indicator data is collected by following the instructions which can be found in the 'Risk indicator' sheet in the template. For each indicator a description is provided on how the indicator is assessed and where to find the required data.

Step 5: Place the risk indicator data in the designated sheets of the template

The collected data should then be placed in the designated sheets of the template.

Step 6: Refresh calculation

As a final step the calculations should be refreshed to ensure that the formulas and link