Improving the Risk Identification Process for a Global Supply Chain

by

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B.S. Operations Research, Columbia University, 2005

Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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ABSTRACT

This thesis describes a proposed risk identification process that is intended to systematically identify potential risks that could materialize within a company's supply chain that would affect component supply. The process is based on a specific situation at Nokia though is intended to extend to other companies that rely extensively on outsourced component manufacturing. An analysis of the current risk identification process at Nokia revealed three areas of potential improvement: the lack of full upstream visibility, the supplier-centric nature of the process and risk reports not fully conveying desired information. Based on a review of existing literature on supply chain risk management and other risk prediction techniques, as well an analysis of the specific situation at Nokia, which has a complex and rapidly-changing supply chain, a new risk identification process was developed. This process consists of two steps: first, mapping out the network structure of the company's supply chain; second, identifying and tracking certain data that could be used as factors to identify potential supply risks. The process proposes a model based on fuzzy logic to aggregate and map the data to highlight potential risks. The thesis also contains a discussion of implementation of the proposed approach, including software requirements as well as organizational roles and responsibilities.

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1 Introduction and Problem Statement

1.1 Thesis Motivation

This thesis is based on a project that took place at Nokia's headquarters in Espoo, Finland, from June 2011 through December 2011. The goal for the project was to improve the company's material supply risk identification process. The problem as stated was to develop an approach that would allow Nokia to more systematically identify potential risks that could materialize within its supply chain that would affect component supply by monitoring certain data.

1.2 Project scope and context

The current supply chain risk management strategy at Nokia is divided into three distinct steps: supply risk identification, risk assessment, and risk mitigation (as shown in Figure 1 below). This thesis focuses on the development of a better approach for the first step of risk identification for a given supply chain, and suggests how this approach can be used to help with risk assessment and mitigation processes.

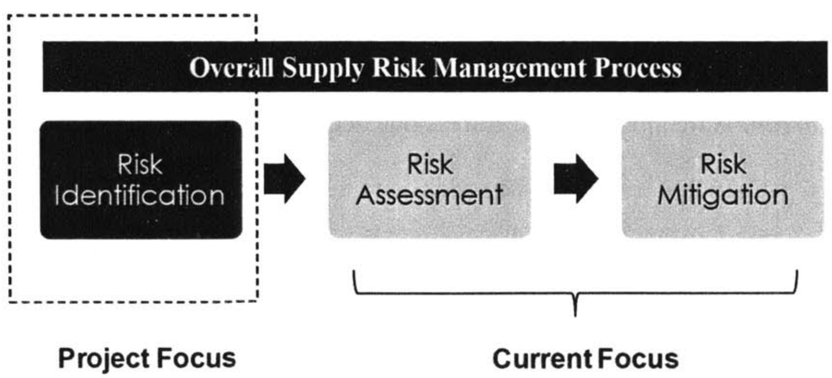

Figure 1: Project Scope

This thesis is directed towards those involved in supply chain risk management, both within Nokia and at other companies with similar supply chain structures. In addition to proposing a new and practical approach towards risk identification, the thesis also discusses the organizational responsibilities and reporting procedures that would be necessary to implement such an approach. The thesis examines a specific situation that can hopefully serve as a useful example for others in organizations that face a comparable problem.

1.3 Research Approach

The research project described in this thesis occurred during June-December 2011 at Nokia's headquarters in Espoo, Finland. The approach consisted of the following steps:

(1) **Introduction to problem statement:** The problem that this thesis attempts to address is how to better anticipate material supply risks for a given supply chain in which component manufacturing is outsourced to many different suppliers. In order to do this, a specific situation of supply risk identification at Nokia was examined. The goal for the project is to devise an approach that can be used by companies with similar supply chain characteristics.

(2) **Current state analysis**: The current practice of overall risk management specifically supply risk identification at Nokia was analyzed, including organizational structure of relevant teams, individual responsibilities and reporting procedures. Based on interviews and historical data analysis, potential areas of improvement within the current process were identified.

(3) **Literature review:** Current risk identification practices that are often used in industry and have been proposed in literature were reviewed. The review identified key aspects of each practice and situations in which each may be applicable, and where they are likely not. The

relevant literature that was identified was referenced throughout the project as the proposed approach was constructed and as it evolved.

(4) **Proposing a new approach:** An approach that potentially addresses the key areas of improvement identified in the current risk identification process was developed. The approach consists of two main steps: first, understanding the network structure of the supply chain, including tiers of the network beyond just the first tier component supplier; second, using data to identify risks within this network.

The second step of the approach involves tracking external and internal data and expert opinions, which have been identified as potential signals to identify risks. This data is aggregated using a combination of crisp and fuzzy logic, which, along with the network structure of the supply chain, should address the key deficiencies and improve the group's ability to identify potential supply risks.

(5) **Implementation of approach:** Implementation of the proposed approach was also considered. This includes a suggestion of how potential data factors can be systematically tracked. The tracking systems will be based on downloads of external data, linking to internal Nokia data or periodically collecting data through surveys of members of the Materials Planning team and component sourcing teams. In addition, the individual roles and responsibilities necessary to implement the proposed approach were also considered. The suggestions for implementation take into account the current organizational structure to ensure that the proposed approach can realistically be implemented within the current organization.

1.4 Thesis Structure

The thesis is organized into seven chapters. Chapter 2 provides an overview of the literature that was reviewed, including both academic literature and examples of real-world applications of supply chain risk identification approaches. This literature is divided into three categories: supply chain risk management, social science research and fuzzy logic modeling and risk prediction techniques.

Chapter 3 contains background information related to Nokia as well as the current supply risk identification process, including organizational roles and responsibilities. The chapter also contains a discussion of the three potential deficiencies that were found with the current process.

Chapter 4 provides an overview of the approach used to develop an improved risk identification process, including the discussion of alternatives that were considered, why they were deemed insufficient and how this helped devise the proposed approach.

Chapter 5 contains a discussion of the fuzzy logic model that was developed for the proposed risk identification approach. It begins with an overview of fuzzy logic modeling, including some key advantages and disadvantages of its use in this situation. It then describes the specific characteristics of the model that was developed in this case.

Chapter 6 contains a discussion of implementation of the proposed risk identification approach, including issues to consider in terms of both software and organizational requirements. It provides an overview of the Microsoft Excel model that was constructed for this project, as well as suggestions for organizational responsibilities.

Chapter 7 provides a conclusion and summarizes the key aspects of the proposed risk identification process.

2 Literature Review

2.1 Summary

The issue addressed in this thesis is narrower and unique in scope as compared to existing literature on supply chain risk management, in that the intent is to develop a risk identification system for a given supply chain for a particular product. In addition, the risk being considered is limited to the risk of insufficient availability of a particular component needed for Nokia to meet its production plans, as opposed to the broader categories of supply chain risk covered by the vast majority of existing literature. While the thesis builds on ideas found in existing literature, it proposes a new approach that combines concepts of how to think about different categories of risk, how to model a supply chain as a network, risk identification techniques that incorporate fuzzy and crisp logic modeling along with traditional supplier assessment using surveys of sourcing managers and other experts. The thesis also discusses how the approach can be realistically implemented within Nokia, considering the current organizational structure and reporting processes.

The literature review covered literature related to overall supply chain risk management, as well as that related to general risk prediction techniques. Academic articles on proposed methodologies as well as papers highlighting practices that have actually been implemented were both reviewed. Literature pertaining to specific techniques used for this project—in particular conducting social science research and soliciting and analyzing expert opinions, as well as fuzzy logic modeling—was also reviewed. The articles and books that were significantly drawn upon in the thesis are discussed below, divided into three categories: supply chain risk management, social science research, and fuzzy logic modeling and risk prediction.

2.2 Supply Chain Risk Management

The study of supply chain risk management is a relatively new research area within the broader field of supply chain management. As a result, the amount of related literature that exists is limited, in particular that which specifically addresses the initial step of risk identification within the broader risk management process. Further, there is limited publicly available information on real-world applications of supply risk management techniques.

In *The Resilient Enterprise* (2005), Yossi Sheffi claims that many companies have supply chains that are ill-prepared for large-scale disruptions. The author provides examples of many such companies throughout the book, as well as those who have successfully navigated potentially disastrous situations. Sheffi intends to provide a high-level framework for companies to use in thinking about resilient supply chain design. According to the author, a robust supply chain should incorporate not only traditional supply chain design elements such as redundancy and standardization when appropriate, but should also be based on collaboration with suppliers and reflect a corporate culture in which responsiveness is given high priority. The book is directed towards high-level executives involved in supply chain risk management for corporations.

While *The Resilient Enterprise* provides helpful high-level insight into company thoughts and practices, there is little publicly available literature on specific processes used for supply chain risk management in the real world. One exception is "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident" (2005), in which Andreas Norrman and Ulf Jansson highlight the practices employed by Ericsson, the Swedish technology company, to manage supply chain risk more proactively following a fire at a manufacturing site of one of the company's suppliers. The authors provide a comprehensive overview of the risk management approach that Ericsson began to use, which included mapping out the supply chain network to gain upstream visibility as well as more clearly delineating roles and responsibilities within the company's supply chain group. The authors intend to provide an example of an innovative approach taken by a particular company to use as an example for those involved in supply chain risk management given the limited available public information on actual company practices. This thesis incorporates certain elements of Erisson's approach, including mapping the company's upstream supply chain as well as specific categorizations of supplier sourcing options described in Chapter 4.

In "Harnessing Uncertainty: The Future of Risk Analytics" (2008), Bonnie Ray, Chid Apte, Kevin McAuliffe, and Lea Deleris claim that companies should take a more holistic approach to risk management given their increased complexity as a result of globalization and outsourcing. The authors highlight the efforts of IBM Research to develop practical tools which allow companies to view supply chains as networks and precisely quantify risk probabilities and impacts. In addition, the authors provide a categorization framework to use in thinking about different types of risks that could impact the supply chain of an organization, as shown in Figure 2.

High Level Risk Category	Definition	Examples
Market Risk	Losses due to fluctuations in demand and supply, competitors, and other exogenous economic forces	market fluctuations, interest rates, currency fluctuations
Credit Risk	Losses due to the inability of counterparties to deliver on a contract	loan defaults, customer concentration
Operations Risk	Losses due to failed or inadequate internal processes, systems, resources	information technology availability, data integrity, employee fraud, regulatory compliance, sourcing, project
Environment Risk	Losses due to external events	competitor actions, geopolitical issues, natural disasters
Strategic Risk	Losses due to strategic business	business model, business

Figure 2: Example of supply chain risk categories

Source: Adapted from Ray et al. (2008)

In "Supply Chain Risk Management: A Delicate Balancing Act. A Multi-faceted view on managing risk in a globally integrated enterprise" (2008), Basu et al. further build on the practical approach suggested by IBM researchers for an organization to manage supply chain risk. The authors introduce the concept of a Bayesian network which maps the causes of risks and resulting impact on specific performance measures. By constructing such a network map, the authors were able identify the data needed to build an influence diagram which maps root causes to specific risks. The parameters of the model could then be updated based on actual data that materializes within the supply chain. The article concluded with some key lessons learned in building out such a system for IBM's System X Server supply chain, including the need to collect and maintain databases with geographical information of suppliers.

While the categorizations of risk provided in these two papers served as a helpful starting point to think about the various supply risks that Nokia faces, the use of an influence diagram in the form of a Bayesian network has limited applicability to Nokia, given that Nokia's products involve hundreds of individual components whose supply networks can be extremely complex. Therefore, mapping out an influence diagram as described that captures each business process in the supply chain network would be very difficult. In addition, maintaining such a diagram for a supply chain in a rapidly-changing industry such as mobile technology would be challenging.

In "Managing Risk to Avoid Supply Chain Breakdown" (2004), Sunil Chopra and ManMohan S. Sodhi provide a strategy for managers to think about supply chain risk management. The authors first introduce a categorization of risks and common root causes, as shown in Figure 3. The authors claim that in order for managers to be capable of assessing and mitigating a particular risk, they must first understand the nature of risk itself as well as its root cause. Chopra and Sodhi then describe how managers can mitigate these specific risks by using certain strategies depending on the category of risk. These risk mitigation techniques are shown in Figure 4.

Category of Risk	Drivers of Risk
Disruptions	- Natural disaster - Labor dispute - Supplier bankruptcy - War and terrorism - Dependency on a single source of supply as well as the capacity and responsiveness of alternative suppliers
Delays	- High capacity utilization at supply source - Inflexibility of supply source - Poor quality or yield at supply source - Excessive handling due to border crossings or to change in transportation models
Systems	- Information infrastructure breakdown - System integration or extensive systems networking - E-commerce
Forecast	- Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base - "Bullwhip effect" or information distortion due to sales promotions, incentives, lack of supply chain visibility and exaggeration in demand in times of product shortage
Intellectual Property	- Vertical integration of supply chain - Global outsourcing and markets
Procurement	- Exchange rate risk - Percentage of a key component or raw material procured from a single source - Industrywide capacity utilization - Long-term versus short-term contracts
Receivables	- Number of customers - Financial strength of customers
Inventory	- Rate of product obsolescense - Inventory holding cost - Product value - Demand and supply uncertainty
Capacity	- Cost of capacity - Capacity flexibility

Figure 3: Risk categories and potential causes

Source: Adapted from Chopra and Sodhi (2004)

Mitigation Approach	Tailored Strategies
Increase capacity	- Focus on low-cost, decentralized capacity for predictable demand - Build centralized capacity for unpredictable demand. Increase decentralization as cost of capacity drops.
Acquire Redundant Suppliers	- Favor more redundant supply for high-volume products, less redundancy for low-volume products. - Centralize redundancy for low-volume products in a few flexible suppliers.
Increase Responsiveness	- Favor cost over responsiveness for commodity products. - Favor responsiveness over cost for short life-cycle products.
Increase Inventory	- Decentralize inventory of predictable, lower-value products. - Centralize inventory of less predictable, higher-value products.
Increase Flexibility	- Favor cost over flexibility for predictable, high-volume products. - Favor flexibility for low-volume unpredictable products. - Centralize flexibility in a few locations if it is expensive.
Pool or Aggregate Demand	- Increase aggregation as unpredictability grows.
Increase Capability	- Prefer capability over cost for high-value, high-risk products. - Favor cost over capability for low-value commodity products. - Centralize high capability in flexible source if possible.

Figure 4: Risk mitigation approaches

Source: Adapted from Chopra and Sodhi (2004)

An important contribution of Chopra and Sodhi's paper is the recognition of sources of supply risk that are generated internally within a company, and specifically due to forecasts that turn out to be inaccurate, which has increasingly occurred at Nokia over the past couple of years. The categorization of risks used in the proposed approach for this project was adapted primarily from Chopra and Sodhi's paper.

In "Supply chain risk in turbulent environments—A conceptual model for managing supply chain network risk" (2009), Peter Trkman and Kevin McCormack claim that current literature on supply chain risk management fails to recognize risks that are the result of continuous changes in a company's surrounding environment as opposed to discrete events. The risk identification approach proposed in this thesis attempts to capture the former type of risks, primarily by capturing internal and external data on an ongoing basis. The authors also introduce the important distinction between endogenous (i.e., the source of the risk is within the supply chain) and exogenous (the source is external to the supply chain) factors, and claim that the distinction is important because risk mitigation approaches can differ significantly between the two. According to the authors, in the former case, risks can generally be mitigated by proactive risk management approaches, while in the latter case risks generally cannot be lessened. The authors also describe a framework to evaluate the risk that a supplier fails, as shown in Figure 5. The framework is based on four types of factors: the characteristics of the supply chain, the attributes of the supplier, endogenous (i.e., the source of the risk is within the supply chain), and exogenous (the source of the risk is external to the supply chain) factors.

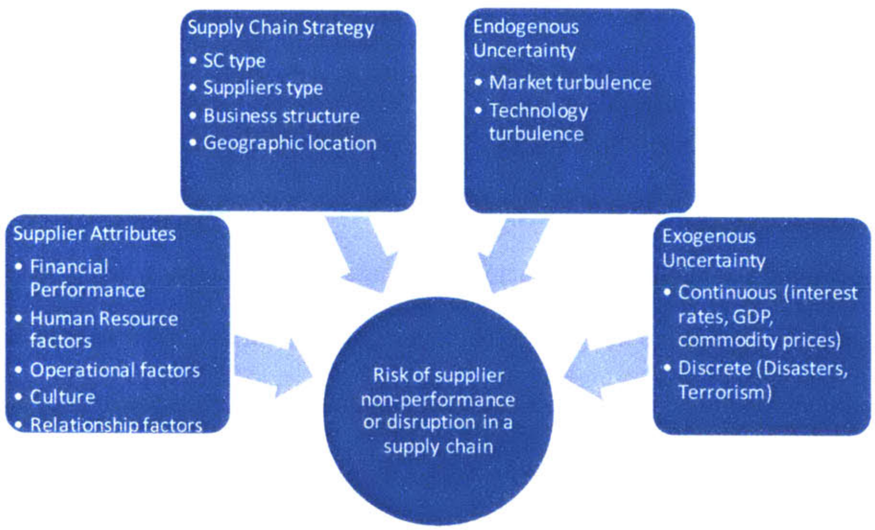

Figure 5: Conceptual model to predict supply risks

Source: Adapted from Trkman and McCormack (2009)

As opposed to many approaches discussed in literature that focus only on specific categories of risk and their potential causes, Trkman and McCormack point out that supply disruptions can be by the interaction between factors within these four categories. While the approach proposed in this thesis does not explicitly categorize supply chain risk factors into these four categories, it attempts to recognize this potential interaction between factors within each of the categories in attempting to identify overall supply risk.

2.3 Social Science Research

Given that the project involved the elicitation of opinions of employees of Nokia, both to identify current deficiencies in the risk identification approach as well as to provide ongoing data points for the new proposed approach, it was important to consider different aspects of conducting social science research. Two textbooks served as helpful references throughout the project.

In *The Practice of Social Research* (2010), Earl Babbie provides a comprehensive introduction to the field of social science research. In Chapter 9 of the book, the author discusses effective techniques for written and oral survey research in order to produce data that is unbiased and answers desired questions adequately, taking into account both the structure and content of the questions being asked. The techniques are mostly intended to mitigate psychological factors that can bias respondents' answers. These considerations should be taken into account in the initial interview process to identify key deficiencies in the current risk identification process.

Specifically, attempting to identify deficiencies of the current process required people to critique their own performance, to some extent. While the focus of the project was on the process of risk identification as opposed to how individuals executed the process, the distinction between the two is not always clear. Therefore, it is important to avoid inherent biases that may come about when asking people about historical events that occurred in which they were directly involved. Some basic concepts that were incorporated and should be in conducting such interviews include carefully avoiding leading questions. To do this, it was important that questions were open-ended (i.e., that respondents were free to answer as they wished as opposed to being given choices), and that the questions were concise.

Certain considerations were also taken into account in constructing the questionnaires that were developed for the proposed risk identification approach. Once again, the questions are not leading and therefore should avoid biased responses. In addition, Babbie recommends that questionnaires should not include "double-barreled" questions, in which a question has multiple parts that may make it difficult to analyze. The surveys that were developed follow this idea and ask separate questions for each desired data point as opposed to grouping questions together.

Bilal M. Ayyub's textbook, *Elicitation of Expert Opinion for Uncertainty and Risks* (2001), was also a helpful resource. The book introduces many techniques that can be used to effectively elicit, aggregate and analyze opinions to assess uncertainty and risks. The author's intent is to provide guidelines for social science research tailored specifically at "experts" in a field (while the definition of an expert is not explicit, it is implied to mean someone with significant education or practical experience in a particular subject area). In Chapter 3 the author covers methods used to effectively design questionnaires. Similar to Babbie, Ayyub stresses clarity and brevity in designing questions to elicit expert opinions. Ayyub also raises the point that questions should be kept factual as opposed to abstract in order to generate concrete answers such as the numerical data points needed for the approach proposed for this project. Ayyub also provides some procedural steps to consider in implementing questionnaires that perhaps should be taken into account. He proposes that respondents be given a cover letter or introductory statement of some sort to help them understand the purpose of the questionnaire, as well as how responses will be used. Such steps are particular important in a situation such as this in which some answers may not be known by respondents. To encourage people to answer as best as possible in these situations, it is helpful that they understand how the responses will fit into the overall risk identification approach.

In Chapters 4 and 5 Ayyub presents different techniques—including the use of fuzzy set theory, Bayesian methods, rough sets and probability theory—to analyze the resulting data, and also highlights the potential advantages and disadvantages of each. Ayyub asserts that fuzzy sets are helpful for applications in which experts wish to express themselves in vague terms such as "likely," or "poor quality" as opposed to precise definitions. This was the primary reason for choosing fuzzy logic modeling for the approach proposed in this thesis. Chapter 5 contains an introduction to fuzzy logic, a justification of its use in this situation and discusses some of its advantages and disadvantages.

Another important aspect of the project was determining the potential supply risks that Nokia faces. In "Managing risks in the supply chain using the AHP method" (2006), Barbara Gaudenzi and Antonio Borghesi introduce a method based on the analytic hierarchy process (AHP) to identify and assess supply chain risks. The intent of the authors is to provide a quantitative method that could potentially reveal risk factors and priorities that contradict what people's inherent biases that develop over time lead them to believe. This method consists of four phases:

- Phase 1: Identifying and prioritizing supply chain objectives and risk factors that could impact these objectives by polling managers and using AHP
- Phase 2: Narrowing down the list of risk factors to those which specifically impact delivery of an order to a customer
- Phase 3: Collaborating with managers to understand specific measureable data points and their impact on the risk factors chosen during the prior phase
- Phase 4: Visualizing the data and its impact on risk factors appropriately by understanding the different aspects of the supply chain and their respective objectives

The authors present a case study in which their method is applied to a European medical device company to identify the most important risk areas and potential causal factors. The authors conclude that the model may be helpful in raising awareness of risk factors, and that it is critical that managers from different areas within the company be involved throughout the process to fully understand interdependencies between risks and causal factors.

2.4 Fuzzy Logic Modeling and Risk Prediction

The proposed approach described in this thesis is based on fuzzy logic modeling, a concept first introduced by Lotfi Zadeh of the University of California at Berkeley in the 1960s (Zadeh 1965). The premise behind fuzzy logic is that it provides a way to translate human language into numbers, recognizing that human language characterizations are often subjective and not precise. Fuzzy logic is based on fuzzy set theory, which asserts that there are two types of sets of numbers: traditional, or "crisp" sets, in which elements either belong or do not belong to a set; and fuzzy sets, in which elements can have partial membership in more than one set. Chapter 5 contains a more detailed introduction to fuzzy logic modeling. While the approach proposed in this thesis is new in that it combines fuzzy logic modeling with the idea of mapping out a supply chain network, there is extensive literature on the use of fuzzy logic in risk analysis.

In "A Rule-Based System Embedded with Fuzzy Logic for Risk Estimation" (2011), Cassandra Tang and H.C.W. Lau present a method based on fuzzy logic to assess the risk level for a corporation's supply chain. The authors outline a four-part process to ascribe risk levels to the supply chain within three different categories of risk: operational, political and technological. The process includes establishing a set of rules to translate human language characterization of the risks into fuzzy numbers, as well as aggregating these numbers into an overall risk score. This process is then applied to a specific case of an express delivery company.

The process described by Tang and Lau serves as the basis for the fuzzy logic modeling approach proposed in this thesis. However, the risk categories used are insufficient to capture many supply issues that Nokia has encountered. In addition, the scope of the problem that Tang and Lau address is a single supplier for a single product, whereas Nokia's supply chain consists of many products and hundreds of individual suppliers.

In "Multicriteria Security System Performance Assessment Using Fuzzy Logic" (2007), William McGill and Bilal M. Ayyub introduce a simple model that uses fuzzy logic to assess the probability of threat from external factors for a security system. The methodology used for this project is similar to that used by McGill and Ayyub; the authors first construct a fuzzy logic system that is based on linguistic variables that have traditionally been used to describe the security system though never quantified. Similarly, the model developed for this project contains certain linguistic characterizations of factors within Nokia's supply chain that may not have been previously quantified. The authors also include a discussion of the trade-off between precision and complexity in fuzzy logic models, which is a key consideration in using fuzzy logic modeling for the purpose described in this thesis. The authors also discuss how implementation of the model could work, including the use of a three-phase process as shown in Figure 7 below.

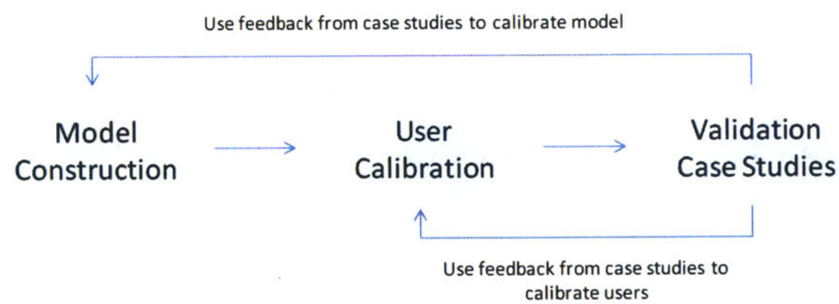

Figure 6: Proposed process to implement security evaluation model based on fuzzy logic

Source: Adapted from McGill and Bilal M. Ayyub (2007)

The consideration of implementation of the proposed approach is based on this process described by McGill and Ayyub. The need to validate and calibrate the model based on individual cases will be critical to the success of the approach if implemented.

Another important aspect of the proposed risk identification approach is the selection of key data signals to anticipate potential supply risks. While the signals chosen for the initial model are based on a small subset of risks that Nokia encountered for a specific component, there are potentially more robust methods to use once the data set is extended. In "Global supplier development considering risk factors using a fuzzy extended AHP-based approach" (2007), Felix T.S. Chan and Niraj Kumar introduce a methodology based on fuzzy extended analytic hierarchy process (FEAHP) to address the problem of supplier selection. The intent of the paper is to build upon the traditional analytic hierarchy process (AHP) to account for imprecision involved when data is of the form of people's opinions. The authors develop a set of criteria to use for global supplier selection, which consists of five elements: cost, quality, service performance, supplier profile and risk factors. The authors then apply FEAHP to evaluate each supplier along each of the five elements, with the goals of both assigning priorities to the different criteria as well as selecting the optimal supplier. This approach described by Chan and Kumar could be applied to the problem of prioritizing data signals to use in the risk identification process as opposed to selecting a particular supplier.

In "A Combined Fuzzy Decision Making Approach to Supply Chain Risk Assessment" (2010), Pooria Moenizadeh and Abbas Hajfathaliha claim that a limitation of current supply chain risk management methods that incorporate fuzzy AHP is that these methods fail to account for interdependencies between identified causal factors. To address this supposed deficiency, the authors propose a method that uses fuzzy analytic network process (fuzzy ANP or F-ANP) to evaluate risk. The primary difference between ANP and AHP is that the former allows for the evaluation of interdependencies between factors when making pair-wise comparisons, whereas the latter does not. The authors also introduce a six-step framework to think about supply risk management, which is shown in Figure 7.

Figure 7: Supply chain risk management system

Source: Adapted from Moenizadeh and Hajfathaliha (2010)

3 Background

3.1 Company background and recent trends

3.1.1 Company background

Nokia is one of the world's largest mobile technology companies, with revenue in 2010 of US$56 billion operating profit of US$2.7 billion, sales in over 160 countries and over 132,000 employees as of the end of that year. Nokia is based in Espoo, Finland and was founded 147 years ago as a pulp and paper manufacturer. The company entered the telecommunications market in 1960 and made a strategic decision to make telecommunications its core business in the early 1990s (Nokia 2010 Annual Report).

As of 2012, Nokia is divided into three business segments:

- **Devices and Services**: the segment responsible for the company's mobile phone portfolio. Devices and Services accounted for approximately 70% of the company's revenue in 2010 and greater than 100% of its operating profit (operating profit contribution from each of the other two segments was negative). The segment is divided into two business units: Smart Devices and Mobile Phones, which are individually responsible for Nokia's portfolio of smartphones and mass-market mobile phones. The project described in this thesis focused solely on the Devices and Services segment.

- **Nokia Siemens Networks:** a subsidiary jointly owned by Nokia and Siemens Corp. that focuses on network infrastructure for the mobile phone industry. It comprised the vast majority of the remaining 30% of Nokia's revenue in 2010.

- **NAVTEQ**: a provider of digital location information used in mobile navigation devices. It accounted for less than 1% of Nokia's revenue in 2010.

3.1.2 Project motivation

This project attempts to address the problem of risk identification within the broader field of supply chain risk management. As highlighted in the Literature Review in Chapter 2, while supply chain risk management practices have been scrutinized and improved considerably as companies have increasingly become global and outsourced component manufacturing, the initial step of risk identification is often overlooked. This project examines a particular situation at Nokia to propose an approach that could potentially be extended to other companies and industries that face a comparable problem.

As is the case in many high technology industries, the mobile phone industry relies heavily on the outsourcing of component manufacturing, including many suppliers who specialize in making particular components. Nokia now relies on hundreds of individual component suppliers located throughout the world. According to the company's 2010 Annual Report, "[Nokia's] dependence on third-party suppliers has increased as a result of strategic decisions to outsource certain activities, for example parts of [their] own chipset as well as wireless modems R&D, and to expand the use of commercially available chipsets and wireless modems."

While outsourcing of component manufacturing has many benefits for companies such as Nokia – including the opportunity to incur lower component costs, outlay less capital investment and leverage individual companies' technology specialization – one disadvantage is that supply chain risk management can be challenging (Berggren and Bengtsson, 2004). This increased difficulty is driven by a number of factors, including less control over suppliers and less visibility into the company's supply chain beyond first tier component suppliers.

One important characteristic of Nokia's supply chain in particular that has made supply risk management difficult is very high demand uncertainty. As Figure 8 shows, quarterly units sold for the Devices and Services segment has been very volatile since 2004. This has been driven by several factors: from 2004 until 2006, unit growth increased steadily as Nokia aggressively expanded its product portfolio, software program offerings and geographic footprint (Upbin 2007).

In 2007, however, unit growth slowed when smartphone penetration began to increase rapidly throughout the industry, and Nokia lost market share in developed markets, such as the United States, as its smartphone products were unable to compete effectively with others in the industry. According to an article in article in Forbes magazine from November 2007, "Nokia's refusal to tailor its phones for U.S. carriers was the biggest reason its market share in the U.S. dropped from 33% in 2002 to 10% [as of November 2007] (Upbin 2007).

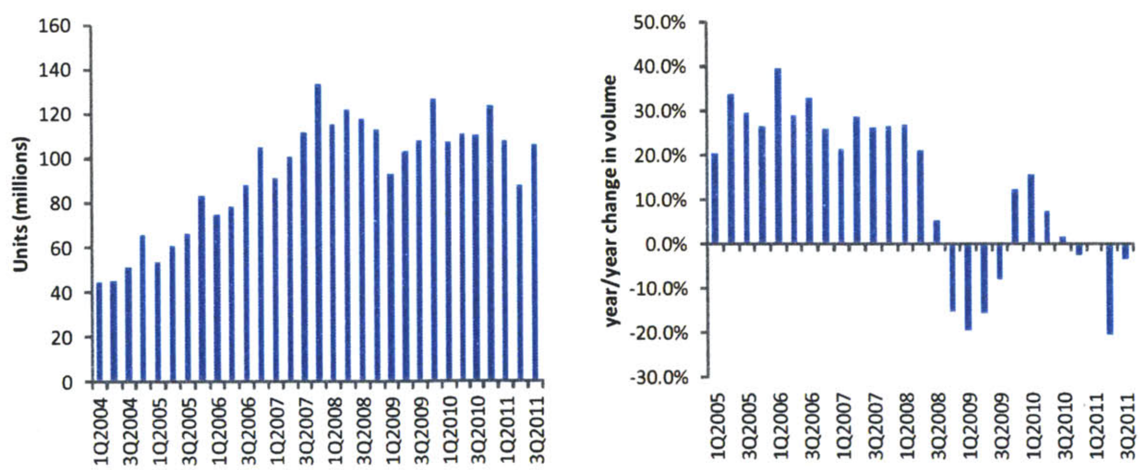

Figure 8: Nokia mobile phones volumes sold by quarter and year-over-year growth

Source: Nokia Quarterly Earnings Reports (from company website).

In late 2008 and in early 2009, unit growth declined rapidly due to both internal issues related to product competitiveness as Nokia seemingly shifted its focus away from hardware manufacturing towards software services, as well as a challenging global economic environment (The Economist, 2008). Unit growth began to stabilize in 2010, though in 2011 the company announced a major strategic transformation in which it signed an agreement with Microsoft to provide the software for each product in its smartphone portfolio. Nokia has seen a decline in demand for its smartphone products as it has transitioned its portfolio to these new products based on the Microsoft software platform (Nokia 2010 Annual Reports). Given this high demand uncertainty, actual volumes of phones sold may often differ significantly from the company's internal projections.

The combination of increased outsourcing and very high demand uncertainty has made it more difficult to anticipate material supply shortages. For the purposes of this project, a material supply shortage refers to insufficient availability of particular components at Nokia's production facilities to meet the company's production plans.

3.2 Current supply risk identification process

3.2.1 Collaboration with suppliers

Nokia has a unique model of collaboration with its component suppliers in that the suppliers own the majority of the component inventory, even after delivery to Nokia's production facilities, until the components are used for product assembly. Nokia first generates demand forecasts for individual mobile phone products and, based on the product's bill of materials, the separate components of these products. These forecasts are revised and communicated with the company's first-tier component suppliers on a weekly basis (or sometimes less frequently depending on the forecast horizon). Suppliers then confirm or deny availability of production capacity to support Nokia's production plans.

Nokia's forecasts as given to suppliers consist of weekly production plans for the following 13 weeks (including the week the forecast is provided), as well as on a monthly basis for the following 12 months. As a result, the first-tier suppliers essentially have a 9-15 month view of Nokia's intended production plans so that they can plan production capacity allocation accordingly. Nokia is also able to receive feedback of any potential material shortage issues so that the company can react appropriately, either by finding alternate suppliers or modifying its production plans.

3.2.2 Current organizational structure

The part of the organization relevant to the supply risk identification process is the Supply Chain division, and in particular the individual component (e.g. display, battery, camera, etc.) sourcing teams, the Materials Planning team, and Mobile Phones and Smart Devices business units. The primary responsibilities of the individual component sourcing teams include developing and maintaining supplier relationships throughout the lifecycle of a component for a particular product. The Materials Planning team works with the component sourcing teams to compile a comprehensive overview of supply risk, which it then shares with the business units. The business units are ultimately responsible for the financial results of each product line, and therefore must ensure that production plans are met for the mobile phone products that fall under their respective unit. The organizational structure is shown in Figure 9.

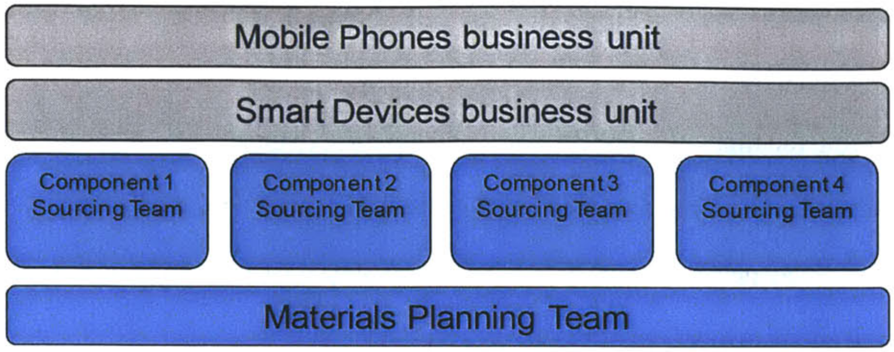

Figure 9: Structure of Supply Chain organization within Nokia that is relevant to the supply risk identification process

3.2.3 Supply risk identification processes

Since the beginning of 2009, the practice of risk identification at Nokia has been divided into two distinct processes:

(1) **Medium-term risk reports:** One method of risk identification relies on individual component sourcing teams working mostly independently to identify potential risks, and then communicating these risks to the Materials Planning team. The Materials Planning team aggregates these risks on a regular basis and produces risk reports, in the form of slide presentations that highlight potential material supply shortages that could occur within the planning horizon of a particular product. These presentations are shared with members of the business units to plan appropriate responses if necessary. In many cases, these shortages would occur within the lead time of the components, at which point mitigation (as opposed to preventative) measures must be taken. The specific parts of each slide are:

- **Overall status:** This section contains a subjective view of the overall risk level for the particular component. The risk level is indicated by color, where red corresponds to "high risk," yellow to "medium risk" and green to "low risk."

- **Executive summary:** This area contains a high-level view of upcoming risks, as well as details as to which programs, suppliers and products may be affected. It is not necessarily an exhaustive list of each of these elements.

- **Material shortages:** This section highlights specific potential first-tier component shortages by supplier.

- **Sole sources:** This section highlights those components which are sole-sourced and for which the component sourcing team has identified a potential risk of shortage.

- **Supplier-specific highlights:** This section contains information about certain suppliers, including the status of product ramp-ups, financial health, Nokia's relationship with the supplier, and any potential issues that could impact material supply availability. There is no specific format for this section that is used consistently for each supplier.

(2) Short-term risk reports: The second method of risk identification relies on short-term risk reports, which are generated on a weekly basis. These reports highlight the upcoming material shortages within the next three months based on the weekly component confirmation data provided by suppliers. The reports provide information about the specific component, which particular products are affected, and the apparent root causes for the shortage. While these reports are more comprehensive than the medium-term risk reports, they are intended to summarize supply availability issues that will occur with a very high probability as opposed to those for which preventative actions can be taken.

3.3 Analysis of current state

3.3.1 Methodology to identify potential areas of improvement

The process to identify and understand potential areas of improvement within the current risk identification process consisted of both a review of historical material supply issues that have occurred as well as interviews with key stakeholders in the process.

For the project, medium-term risk reports and short-term risk reports described in the prior section were collected since January 2009, which was the earliest these reports began to be generated on a regular basis. Given time constraints, the analysis focused on a particular component area which has seen significantly availability issues in recent years as opposed to a more comprehensive analysis of all components. Overall, the analysis covered approximately 25 separate incidences when Nokia encountered material supply availability issues.

The interviews were conducted with members of the Materials Planning team, the sourcing team for the component area for which the risk reports were studied as well as business units. The interviews were conducted throughout the project, from June-December 2011, at first to determine potential causes of the material availability issues that have occurred and then to generate feedback on proposed ideas for a new system and process.

3.3.2 Potential areas of improvement within the current risk identification process

The analysis revealed three potential areas of improvement within the risk identification process. As mentioned previously, the approach to the project assumed that the risk identification process had aspects that could be improved, and therefore sought to identify these areas and suggest a process that addresses them. However, it may have been the case that other aspects of the broader supply risk management process separate from the risk identification process did not function as intended, which may have caused the material supply availability issues that the project analyzed. As examples, these other aspects could include people not appropriately responding to certain data signals or following up with suppliers as signals warranted. Given that the project did not consider these, it is possible that these factors appeared to be deficiencies in the risk identification process itself. A more comprehensive study of the entire supply risk management process would be needed to determine whether this was the case.

The new proposed approach discussed in Chapter can potentially improve on the current risk identification process in the following ways.

(1) An improved risk identification process could potentially help identify risks further in advance. In examining the timing of when a risk was first highlighted in the medium-term risk report and when the same risk first appeared in the short-term risk report, it appears that there may be a way to identify risks earlier. Figure 10 shows the frequency of this time difference for each of the cases analyzed. On several occasions, this difference in time was one month or less. Given that once a risk is highlighted in the short-term risk report, it has been determined that there will very likely will be a shortage in supply at some point during the next thirteen weeks, this time period could be insufficient to plan mitigation actions.

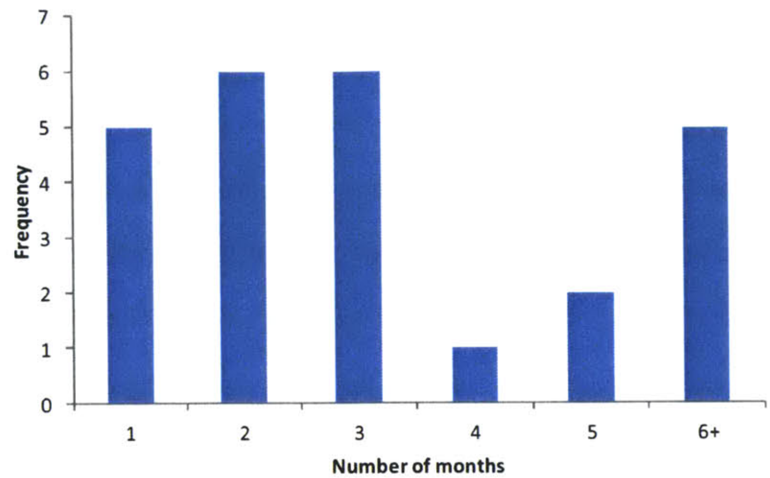

Figure 10: Frequency of difference in time between when a risk was highlighted in the medium-term report and short-term report

Source: Nokia Materials Planning team.

The lack of visibility into the company's supply chain beyond first-tier component suppliers may be contributing to the issue of insufficient advanced notice. While the medium-term risk report covers the next four quarters, supply chain problems could originate in tiers of the supply chain into which Nokia lacks visibility. While Nokia has strong collaborative relationships with its first-tier suppliers, the company does not have complete information about suppliers further upstream. For many of the material supply issues that were encountered, it seemed that additional information about suppliers beyond those in the first tier could have helped Nokia better anticipate first-tier supply availability issues. The proposed approach will focus on how additional visibility into the supply chain could help identify supply risks, though in reality this could perhaps be addressed by better managing first-tier suppliers.

(2) An improved risk identification process could potentially help companies like Nokia account for supply issues that result from the interaction between internal factors and those that are outside of its

control. As discussed in the literature review in section 2.1, this interaction could be particularly important for an organization with an outsourced supply chain such as Nokia. One important finding in examining Nokia's historical supply availability issues is that it is often difficult to determine a single root cause for a particular supply issue. Instead, many are the result of a number of factors, including some that are within Nokia's control and others that are not.

(3) A more systematic risk identification process could potentially help generate additional reports which help with the subsequent processes of risk assessment and mitigation. Currently the data contained in the current risk reports being generated does not fully align with the desires of key stakeholders. The medium-term risk reports, which are the key "early warning" system for material supply availability issues, highlight potential supply risks for a particular technology, industry, geography or supplier. Discussions with members of the material planning team and business units throughout the project revealed two additional desired dimensions of visibility for these reports.

First, the reports generated from a systematic risk identification process could aggregate risk information into a comprehensive overview of how a material shortage would impact a particular product or financial metric such as revenue. This would allow for easier formulation of risk assessment and mitigation plans, as important products or those which may have the greatest financial impact on the company can be given priority. Second, the reports could also aggregate all of the risks for a particular product and supplier, as opposed to by first-tier component as is currently the case. This would both allow members of the business units to identify products which are more at risk of failing to meet production targets, as well as members of the component sourcing teams to better identify and work with particular suppliers who are encountering component availability issues.

4 Developing an improved risk identification approach

4.1 Summary

A new supply risk identification approach was developed during the project to address the three key deficiencies of the current process highlighted in Chapter 3. The approach is intended to allow the Supply Chain group to better identify material supply risks. This chapter contains a discussion of the process used to develop the approach, an overview of the approach as well as a description of the initial model that was constructed based on the approach.

4.2 Process to develop the proposed approach

The new risk identification approach attempts to overcome the deficiencies highlighted in Chapter 3. Existing literature on supply chain risk management (discussed in Chapter 2) provided a starting point to devise a potential improved solution. The approach developed and changed throughout the course of the project based on feedback from individuals on the Materials Planning team, component sourcing teams and business units. Sections 4.2.1-4.2.2 discusses alternative approaches that were considered and why each was insufficient.

4.2.1 Supplier scorecards

One approach which has been discussed in literature and is used extensively in practice is based on a scorecard that measures different attributes of suppliers. As examples, these measures could include financial stability, supplier quality or geopolitical risk. In such a system, each supplier would be given a numerical score for each of these attributes. This score would be based on either questionnaires given to sourcing managers or actual historical data. The individual scores would then be aggregated in some way to determine an overall score for each supplier. Such a system is currently in place at Nokia to screen new potential first-tier suppliers.

One idea to improve the risk identification process was to apply this idea of a scorecard to risk identification in addition to the screening of potential suppliers. To do this, the scorecards would have to be updated on a regular basis. While such a system could potentially help highlight supplier issues earlier on, it is insufficient for two reasons: first, the use of a scorecard fails to recognize risks whose root causes are internal. For example, it may be the case that a supplier is fully capable of meeting a manufacturer's initial intended production plans. However, if demand forecasts change, the supplier may not have the capability to expand production based on revised forecasts. An approach that uses a scorecard could fail to account for this interaction between internal and external factors, or what Peter Trkman and Kevin McCormack describe as supply chain strategy and exogenous factors (Trkman and McCormack 2009).

The second reason that using the scorecard approach was deemed to be insufficient for the purposes of this project was that it would still fail to capture risks further upstream, as the scorecards are currently in use only for screening first-tier suppliers. While the scorecards could be extended to suppliers further upstream, the amount of data currently captured would be too difficult to gather and regularly update for many smaller suppliers. Thus, any proposed approach would have to keep in mind the balance between capturing a sufficient amount of data to be able to highlight potential supply risks, while at the same time not impose unrealistic or overly burdensome requirements of people's time to keep the data current.

4.2.2 Regression analyses

A second approach that was considered was utilizing some type of regression analysis to help identify potential supply risks. In this case, the hypothesis was that there may be some factors (for example, the supplier itself, the region in which the supplier is located, the product supplied, historical demand confirmation data) which could serve as independent variables in a regression, with the likelihood of a material supply availability issue as the dependent variable.

Such an approach would hopefully produce the desired outcome in a robust way: knowing and keeping track of specific data elements could theoretically produce a probability of a supply risk. However, upon examination of the historical risks that were encountered and supply confirmation data, it became apparent that such a regression analysis would not be possible in this case. In addition to the problem of the lack of upstream supplier visibility, the supply risks were all very different and generally the result of a chain of events, and there were few common factors that could be identified across the various risks. One approach that was not considered but potentially could be explored is estimating parameters based on expert opinions; a historical analysis of supply risks could potentially reveal commonalities that are not necessarily captured in numerical data. Also, attempting to base a risk identification system on current data being tracked suggested that additional data would be necessary.

As an example, one proposed idea was to determine whether a supplier's historical pattern of weekly supply confirmation (as discussed in section 3.2.1) could potentially be used as an indication of whether that particular supplier would encounter availability issues if forecasts changed. In confirming Nokia's forecasts, a supplier would respond with a production number. This number could be less than, equal to or greater than Nokia's production plan. In the case that the number was less than Nokia's plan, it was clear that supply would likely be constrained. However, in all three cases the number actually conveys little information about a supplier's capability. If the number was equal to Nokia's plan, it may be that the supplier is only capable of producing that quantity, or that the supplier intended to confirm that amount but actually has the capability to produce a larger quantity if desired. If the number was larger than Nokia's plan, it indicated that the supplier has excess capacity to produce that component, though it was unclear whether the difference between the confirmed amount and Nokia's plan represented the amount of excess capacity. Understanding the capability of a supplier was necessary to help identify supply risks but could not be captured using this historical data.

The attempt to produce a regression analysis highlighted another important aspect of any proposed approach: as opposed to the initial idea that perhaps data could be systematically tracked to forecast risks with a specific probability or timing, the initial step of risk identification would have to be limited to highlighting potential risk areas. Based on this, a person could then determine whether the risk exists, the severity of it and what mitigation actions should be taken.

4.3 The proposed approach

Examining the alternative approaches described above and the reasons for which each was insufficient ultimately led to the following approach, which consists of three distinct steps:

1) Mapping out the network structure of the supply chain, including tiers of the network beyond the first-tier component suppliers;
2) Identifying potential risks and data signals that could help anticipate these risks by analyzing historical data and through interviews; and
3) Determining appropriate linkages between the chosen data and risks. For the initial proposed system, the data was aggregated using a combination of crisp and fuzzy logic.

The added visibility provided by mapping out the supply chain network, combined with a systematic and centralized approach to data collection and appropriate data linkages, should address the key deficiencies and improve the group's ability to identify potential supply risks.

4.4 Desired goal

In addition to identifying the potential key weaknesses of the current process, it was also necessary to understand the desired end goal of the important stakeholders who would be involved in the risk identification process. Interviews were conducted upfront and throughout the project to understand stakeholder desires to ensure that the proposed process would address these.

One important characteristic of the proposed risk identification approach is that it is difficult to measure its potential effectiveness in a precise way because the types of risks that could impact material availability, as well as their causes, are very different and have historically occurred infrequently. In addition, given the large number of factors that could potentially lead to component shortages, including many unpredictable elements such as human errors and exogenous events, a historical analysis of how the approach could have been applied to prior actual supply shortages is also difficult.

Ultimately, the success of this new approach will most likely be measured by the extent to which it is actually used in practice, given the need to continuously update and refine the parameters of the model. Therefore, the feasibility of incorporating the approach into current practices at the company, as well as the usability of risk reports that could be produced, were important considerations throughout the project.

4.5 Understanding the supply chain as a network

The first step for the proposed approach to improve the risk identification process is to better understand Nokia's supply chain network. Currently, component sourcing teams communicate regularly with first-tier component suppliers. The sourcing teams work closely with the first-tier suppliers to maintain relationships, as well as understand the suppliers' technology capabilities and potential capacity, among other things. However, this visibility generally does not extend beyond the first tier suppliers. As a result, Nokia does not have a complete understanding of its risk exposure to different supply availability issues that may arise.

One simple example to illustrate how this lack of visibility can mask potential risks is that of a manufacturing company that diversifies its first-tier supplier base for a particular component in an effort to reduce risk, as Figure 12 shows. However, the manufacturer fails to realize that each of its first-tier suppliers purchases a specific component from the same second-tier supplier. In this case, the manufacturer both underestimates its risk exposure to the particular first-tier suppliers and cannot effectively respond to an issue that arises with the second-tier supplier. In reality, supply chain networks can be much more complicated that this simple illustration, and there may be good reason to source material from a common supplier even if the manufacturer realizes that this is the case. However, a lack of visibility upstream could mask potential risks.

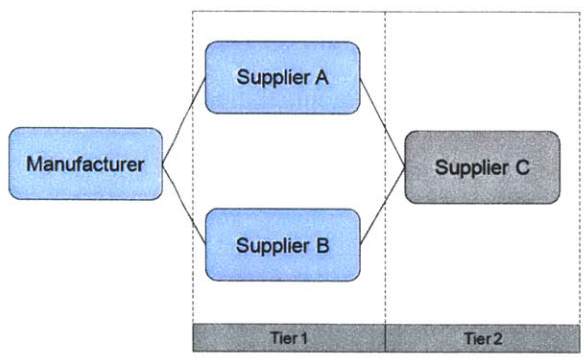

Figure 11: Simple example of how visibility into only first tier supply base can hide overall risk exposure for a manufacturer. In this case, the manufacturer does not know that both Supplier A and B purchase the same component from Supplier C

In addition to the visibility that an understanding of the supply network would provide, it would also allow Nokia to quickly estimate the impact of a material availability issue on a particular first-tier component or product, and therefore also the company's financial performance. Currently, if an issue arises with a particular supplier or within a certain geographic area, it is difficult to determine Nokia's overall exposure to that issue in terms of volume or revenue. A more complete understanding of the supply network would allow the company to easily determine how such a supply availability issue could impact production and sales.

4.5.1 The network view of the supply chain

The goal in constructing a structure for a network view of the supply chain for the initial risk identification model was to represent each component within the supply chain as a node. Each node captures certain data elements, some of which are mapped to other data tables, as Figure 13 below shows. The structure allows for an estimated risk level for each potential risk that has been identified at each individual node. By knowing the structure of the network, risks at particular nodes can then be aggregated into overall risk measures for the supply network for a particular component or product. Chapter 5 discusses how these risk levels are calculated in initial model.

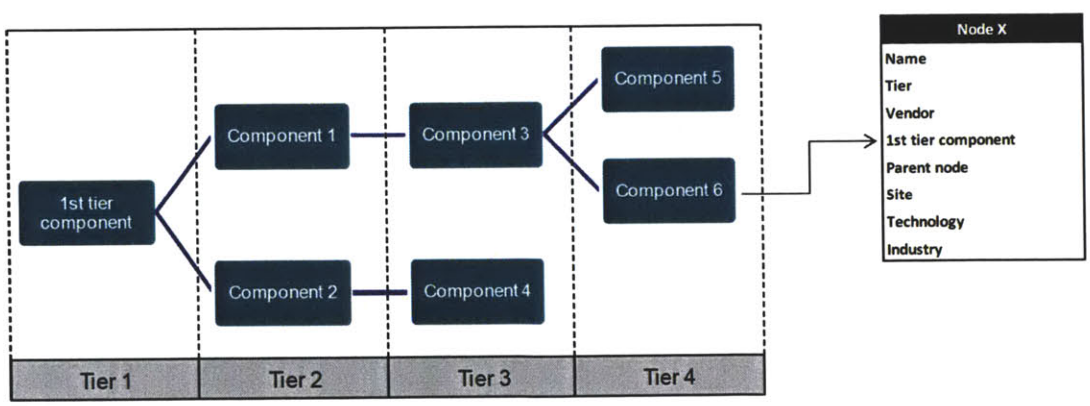

Figure 12: Example of the proposed supply chain network structure

For the initial model that was developed for the purposes of this project, each node contains the following data elements (bold indicates that the data element also represents a separate data table):

- Name: The name of the component; this also serves as the unique identifier for the node
- Tier: The tier of the supply chain in which the component sits
- **Vendor:** The supplier who manufacturers the component
- **1st tier component:** The first tier component of which the component is a part
- **Parent node:** The component at the next manufacturing step downstream
- **Site:** The site where the component is manufactured
- **Technology:** The relevant technology associated with the component (if applicable)
- **Industry:** The industry to which the component belongs

4.5.2 The data structure

In order to determine how to structure a network view of the company's supply base, the main considerations taken into account were:

1) **Desired visibility and reports:** The data structure should be designed to allow for easy generation of desired risk reports. Chapter 6, which discusses implementation of the approach, contains a discussion of how the proposed data structure would achieve this goal.

2) **Feasibility of data collection and maintenance:** The structure should contain data that is relatively easy to collect and maintain.

3) **Minimal redundancy:** To maintain data integrity, the data structure should minimize redundancy of data. To do this, each data element within each table should either be a link to another data table or a unique member of that table.

The proposed data structure that Figure 14 shows was designed with these considerations in mind. The six individual risks that were chosen for the initial model (discussed further in Section 4.7) are all elements of data tables within the data structure (highlighted in red in Figure 14). Each of the individual risks are also members of separate data tables, which each capture all of the potential data signals used to identify that particular risk. As structured, each individual node will be associated with each of the six individual risks that were chosen. In addition, each of the data elements is likely already being tracked internally at a manufacturing company like Nokia or is easy to obtain from an external source (discussed further in Chapter 5).

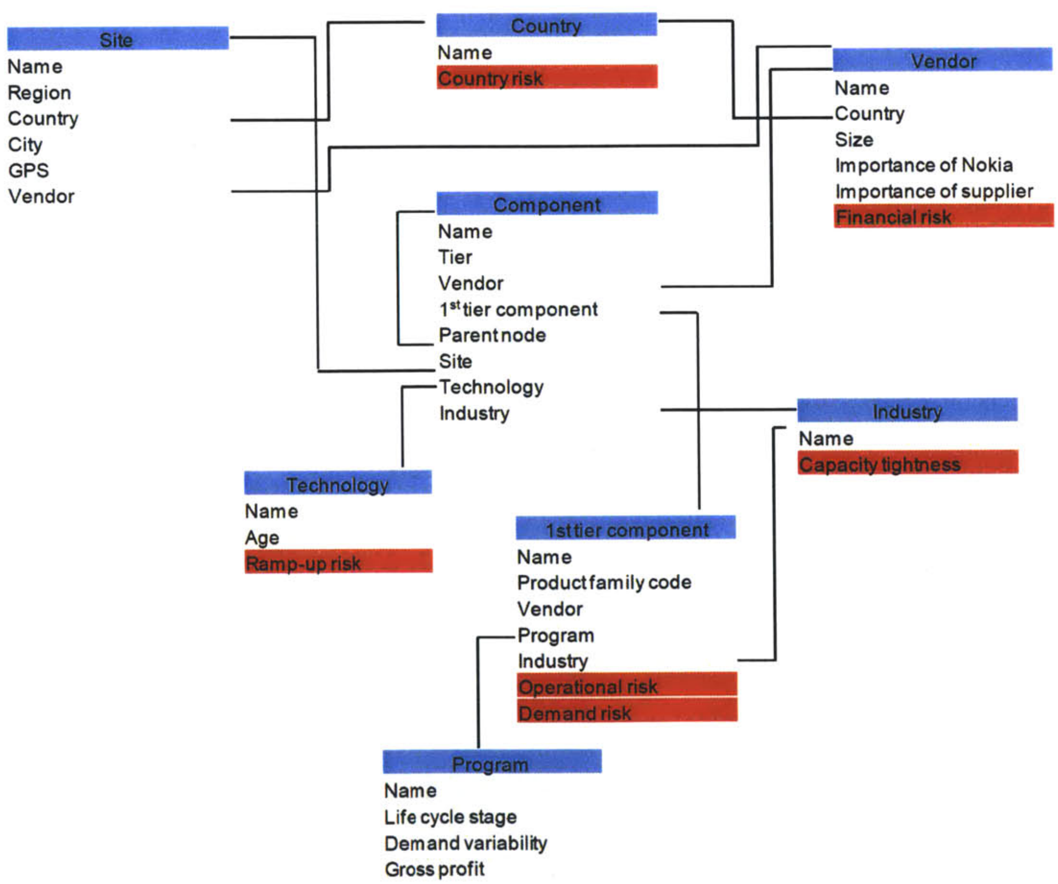

Figure 13: Proposed data structure to map supply chain network

4.6 Mapping data to risks

4.6.1 Identifying potential risks

The first step in identifying potential supply risks was to define and categorize the concept of "risk." For this project, a risk was defined as an increased likelihood that availability of a component would be insufficient to meet Nokia's production plans. Existing literature on supply chain risk management suggests many different categorizations of the types of supply risks that an organization may encounter. However, as discussed in the literature review chapter (Chapter 2), none of these categorizations would be appropriate for this project given its limited scope.

More specifically, an iterative process was used to determine the most significant component supply risks for Nokia and categorize them. Categorizations described in literature served as a starting point to describe risks faced by Nokia (in particular the categories described by Chopra and Sodhi and shown in Figure 3) and were modified over time to suit its particular supply chain structure. The categories and sub-categories of risk chosen for the initial proposed approach are not meant to be exhaustive nor final; rather, the categories and specific risks identified will vary by component area and likely change over time given the rapidly changing nature of the mobile technology industry.

As an example, environmental compliance and the sustainability of suppliers is an increasingly important issue for many companies including Nokia. While this issue had not impacted component availability historically in the data that was examined, it was cited during interviews as an increasingly important potential risk that perhaps should be included in any comprehensives supply risk identification system. Figure 15 shows the categories of risk and specific risks chosen for the initial model.

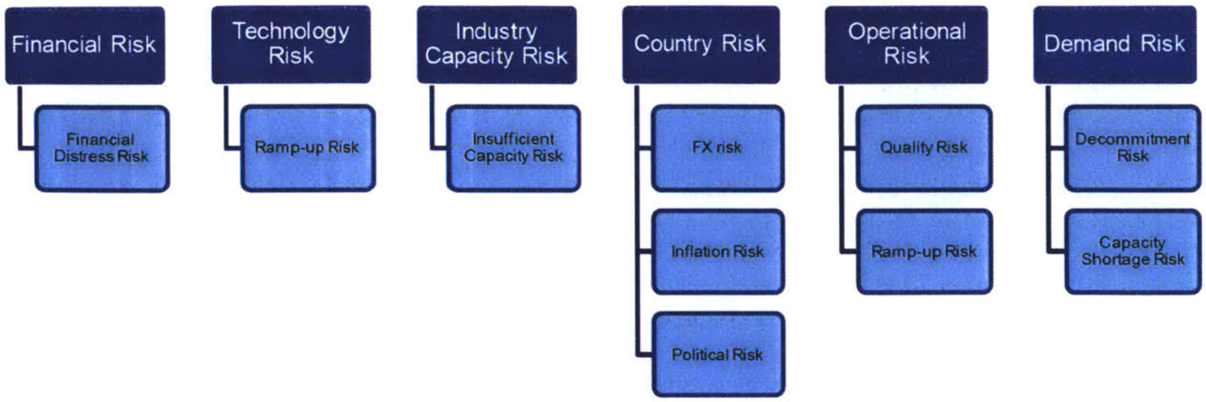

Figure 14: Categories of risk chosen for initial risk identification model

The categories of risk that were chosen for the initial model are:

1) **Financial Risk:** risk that a supplier encounters financial challenges that could impact its ability to produce and supply a particular component
2) **Technology Risk:** risk that the production ramp-up of a new technology does not occur as planned
3) **Industry Capacity Risk:** risk that there in insufficient industry-wide capacity for a particular component
4) **Country Risk:** risk that a particular country encounters a problem, such as inflation or political risk, that could impact supply availability
5) **Operational Risk:** risk of an operational issue at a supplier, such as deterioration of quality or inability to ramp up production of a new component

6) **Demand Risk:** risk that unexpected variations in demand cause either component shortages or excesses beyond acceptable levels

Together, these categories of risk covered 24 of the 25 cases of historical material supply shortages that were analyzed. Figure 16 below shows the breakdown of historical risk cases by category.

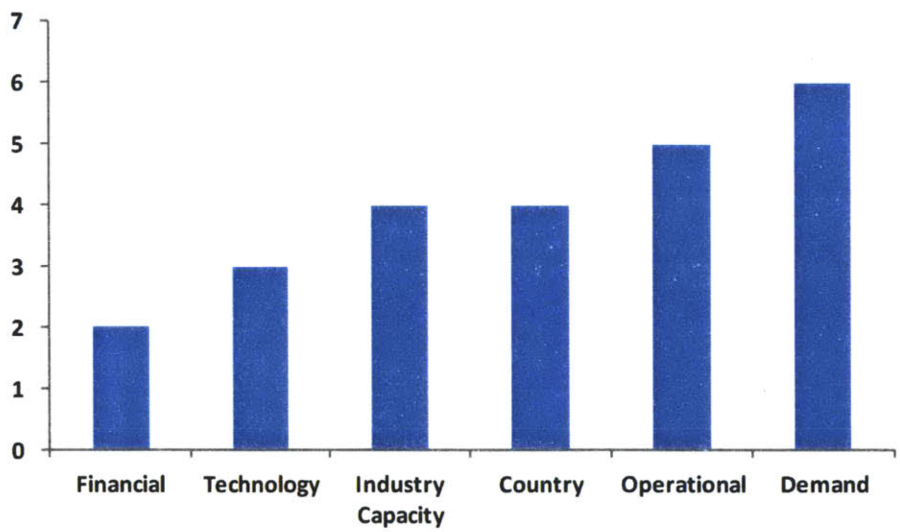

Figure 15: Breakdown of historical risks by category

Source: Nokia Materials Planning team.

4.7 Determining potential data signals to identify risks

The process used to determine potential data signals was also iterative. Given the nature of the risks being examined and the limited data set available because of the infrequency with which each risk has occurred historically, a more precise, quantitative approach (such as multivariate regression) could not be used. Instead, potential data signals were identified based on historical cases and then discussed and refined with members of the Materials Planning team and component sourcing teams.

Figure 16 illustrates the process to determine potential data signals.

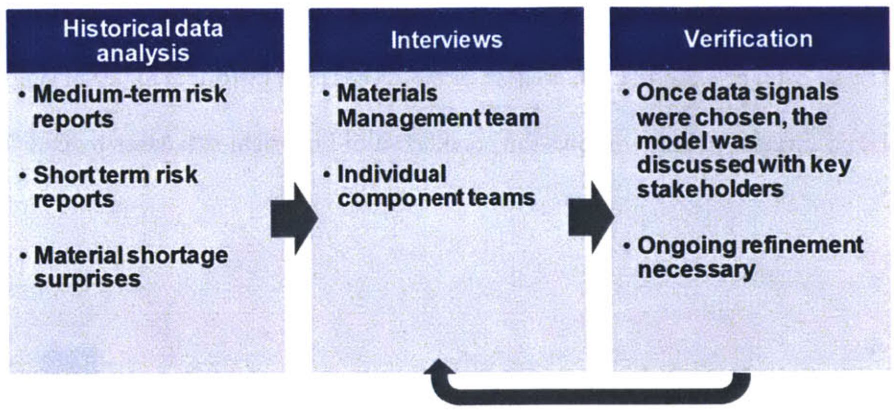

Figure 16: Process to determine potential data signals to identify risks

The analysis to determine data signals did not seek to identify exact factors that may have had precise causal relationships to specific risks. Rather, it sought to identify data that, if systematically monitored, may indicate an increased likelihood of a potential risk materializing. This was done in two ways:

1) Analysis of historical risks: Historical risk reports were analyzed to determine the most significant factors that have impacted component availability over the past two years. This was done for a subset of components within a particular component area, though this same analysis could be extended to other component areas as well. Specifically, the types of historical reports examined were the medium-term and short-term risk reports discussed in Chapter 3, as well as material shortage surprise reports. The material shortage surprise reports capture actual component shortages that occurred that were not highlighted in either the medium- or short-term reports.

In contrast to the analysis to determine the key deficiencies in the current risk identification process, the analysis to determine potential data signals to track focused more on the short-term risk reports, as these reports contain detailed explanations of the root causes of actual material supply shortages.

2) Expert discussions: Discussions were held with members of both the Materials Planning team as well as individual component sourcing teams in order to get their perspective on data that could be monitored to identify risks. In some cases, the data selected was already being collected and tracked by someone within the organization, though not always in a systematic way. After an initial list of potential data signals was gathered based on the analysis of historical risk reports, this list was discussed and modified based on these discussions.

This process resulted in potential data signals to track to anticipate the risks that had been previously identified. The data is of three distinct types:

1) External data: The external data to be tracked includes supplier financial information as well as economic indicators for individual countries.
2) Internal data: The internal data used in the process includes Nokia's demand forecast history and supplier historical performance.
3) Expert opinion: The process also includes data that is generated from periodic surveys given to personnel within Nokia. These surveys are intended to capture data points that are subjective assessments of people on the component sourcing teams. In some cases, these data signals are being monitored in the current risk identification process, though the information is not tracked systematically. In other cases, the surveys are intended to capture data that component sourcing teams may not currently be monitoring but that could help identify potential supply risks.

Sections 4.7.1 – 4.7.6 provide an overview on the potential data signals identified for the individual risks that were shown in Exhibit 4.4. Chapter 5 provides the definitions of the metrics chosen, as well as descriptions of the surveys that were devised.

4.7.1 Financial Risk

Financial risk represents the risk associated with a particular supplier encountering financial difficulties that could impact its ability to produce and supply components. The data selected to be monitored was chosen based on a paper by Carter and Giunipero (2010), which discusses important financial ratios that should be tracked to monitor supplier financial health, as well as Nokia's internal practice of monitoring the financial condition of its suppliers. The financial ratios (profitability, liquidity, efficiency and leverage) are calculated based on public financial information if it is available; otherwise they are based on ongoing monitoring of these metrics by either component sourcing teams or members of the business units.

The ratios are supplemented by a qualitative measure that is based on a survey given to component sourcing managers on a regular basis. The purpose of the qualitative measure is to capture an elevated risk level based on the component sourcing manager's knowledge for cases in which financial metrics, which are updated quarterly and therefore may not reflect the current status of the supplier, may not be accurate. In addition, the qualitative measure is needed when public information is not available, as is the case for many smaller suppliers further upstream.

Figure 17 illustrates how the potential data signals map to Financial Risk.

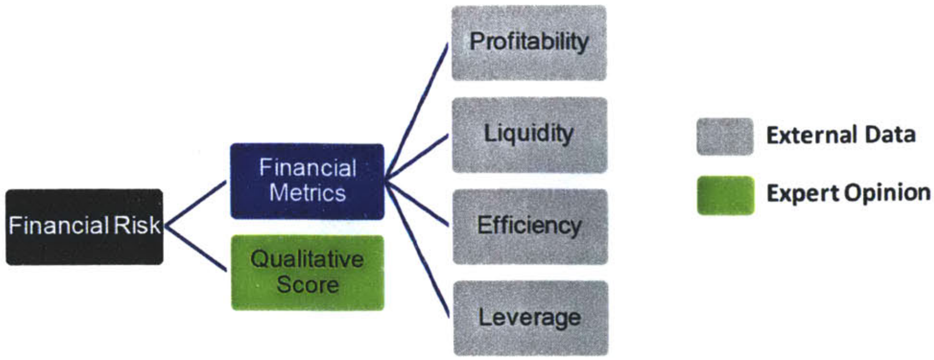

Figure 17: Financial risk categories and data signals

4.7.2 Technology Risk

Technology risk is meant to capture the risk associated with the ramp-up of a new technology. Currently, the initial production of components using a new technology represents a period during which component sourcing managers at Nokia are closely monitoring the status of the supplier. In many cases, the technology being used has not yet been produced successfully on a large scale by the particular supplier, so it is necessary to monitor the production status to ensure that the ramp-up proceeds as planned.

The three data signals identified (technology yield, sourcing alternatives and age of the technology) are all currently being tracked by component sourcing teams, though the data is not aggregated across components or by product. The metrics are once again supplemented by a qualitative measure, to capture the cases in which a component sourcing manager is aware of an elevated risk that has yet to materialize in the data that is being monitored.

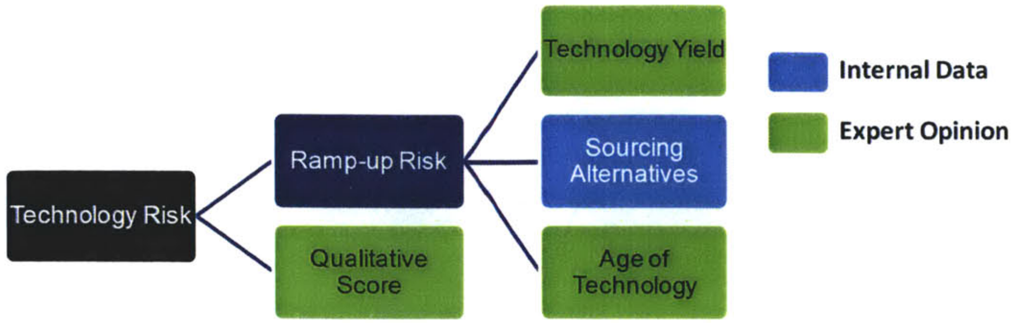

Figure 18: Technology risk categories and potential data signals

4.7.3 Industry Capacity Risk

Industry capacity risk represents the risk that there is insufficient capacity industry-wise (as opposed to the capacity at a particular supplier) for a particular component. Based on historical data and discussions with stakeholders, it became apparent that there is a need to distinguish situations in which a capacity shortage is limited to a particular supplier from those in which the capacity shortage exists across an industry because the risk mitigation approach to the two situations would be very different. For the case in which the shortage exists at a supplier, alternative suppliers could be used if available. If the shortage is industry-wide, it may instead be necessary to adjust production plans.

There were four data metrics chosen as potential indicators of an elevated risk of industry-wide capacity tightness: the level of inventories across the industry, the level of investment being made into expanding production capacity, the construction lead time for new investment in capacity, and expected industry-wide demand growth. The first three of these are based on external data as Figure 19 shows, if such data exists for the particular industry, while the fourth is based on a survey given to the component sourcing team. If reliable data does not exist for an industry, all four metrics would be based on survey results. The data is again supplemented by a qualitative score.

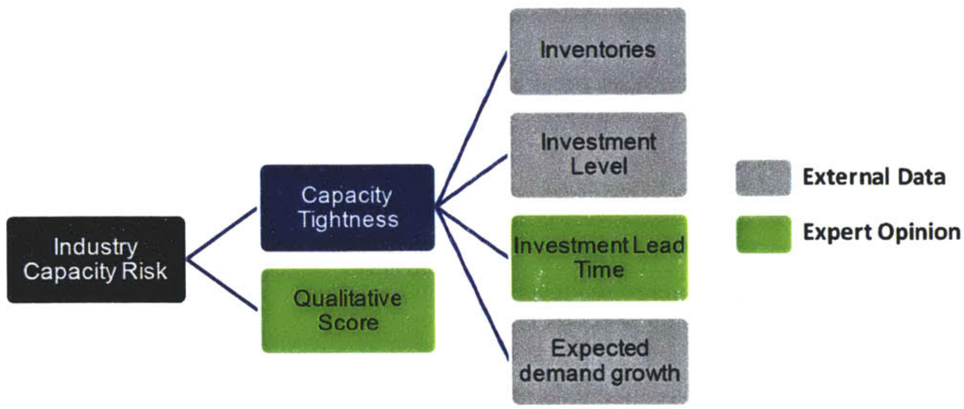

Figure 19: Industry capacity risk categories and potential data signals

4.7.4 Country Risk

Country risk represents the risk that a particular country encounters problems that could prevent a supplier based in that country from meeting its targeted production plans. The specific risks being examined include three that had materialized in the past: foreign exchange rate risk, inflation risk and labor risk. Each of the data signals chosen for these three risks is collected using publicly available information for individual countries. Political risk was also suggested as a risk that is increasingly important for Nokia to monitor. The data chosen to identify potential political risk is a comprehensive index-based score compiled by the company Euromoney. Chapter 5 provides additional information about the calculation methodology of the Euromoney index.

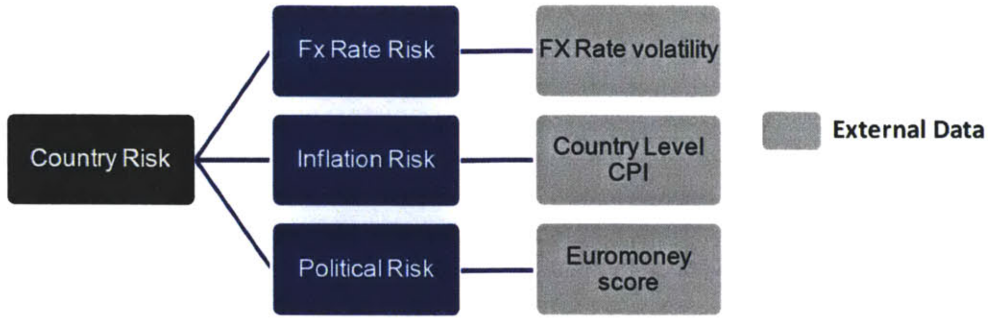

Figure 20: Country risk categories and potential data signals

4.7.5 Operational Risk

Operational risk represents two distinct types of risk that are related to a supplier encountering operational challenges that could prevent it from supplying a sufficient quantity components to meet Nokia's intended production plans. First, quality risk represents the risk associated with suppliers failing to meet certain quality standards that are set by Nokia for its parts. The data signals monitored to anticipate quality risk are historical quality data that is currently tracked by Nokia as well as a score based on a survey taken regularly by component sourcing teams.

The second risk is ramp-up risk for a particular component. This is similar to the ramp-up risk that was categorized under Technology Risk, though in this case it represents the risk for a new supplier of a particular component, not necessarily a new technology. The four data signals being used to identify ramp-up risk are program demand variability, which represents the expected variability for the particular program (i.e. product) of which the component is a part, as well as three other metrics that are based on regular surveys taken by the component sourcing teams.

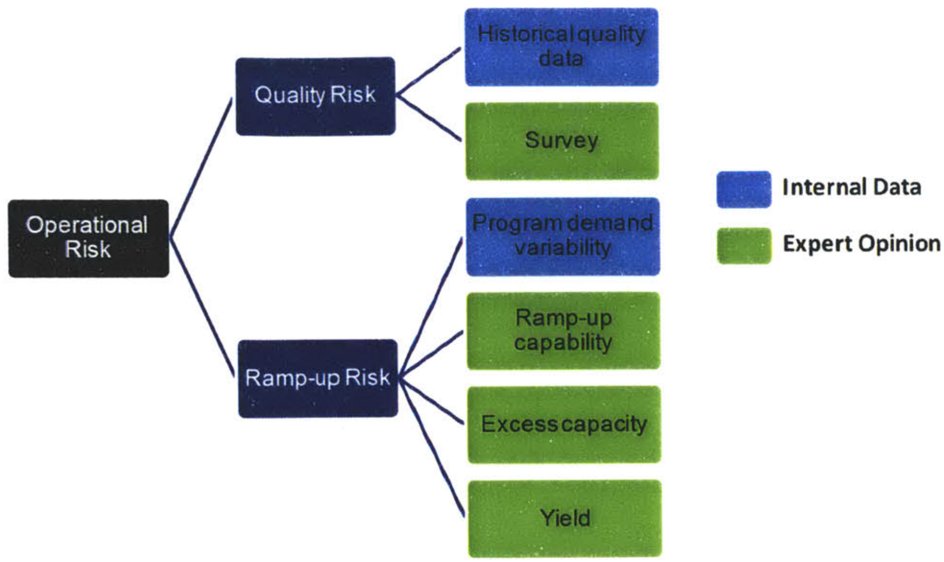

Figure 21: Operational risk categories and potential data signals

4.7.6 Demand Risk

Demand risk represents the increased probability that component availability will be insufficient if demand is significantly different than predicted by the company. There were two related component availability issues that have materialized in the data analyzed for this project when demand deviated significantly from internal forecasts. First, in cases where demand was significantly less than expected, Nokia encountered issues where certain suppliers who had previously reserved or set aside capacity for Nokia instead decided to use that capacity for either other customers or other products. The data signals to be tracked to potentially anticipate this risk include the demand variability of the program, as well as qualitative scores of certain metrics based on a periodic survey, including the amount of excess capacity the supplier has, the importance of Nokia as a customer to the particular supplier, and the profitability of the component for the supplier relative to its expectations.

Secondly, in cases where demand exceeded expectations, the company encountered capacity shortages. Once again, the expected demand variability of the program was identified as a data point to track. The other data points include the excess capacity of the supplier, sourcing alternatives for the component, as well as the availability of labor to the supplier to meet increased production targets.

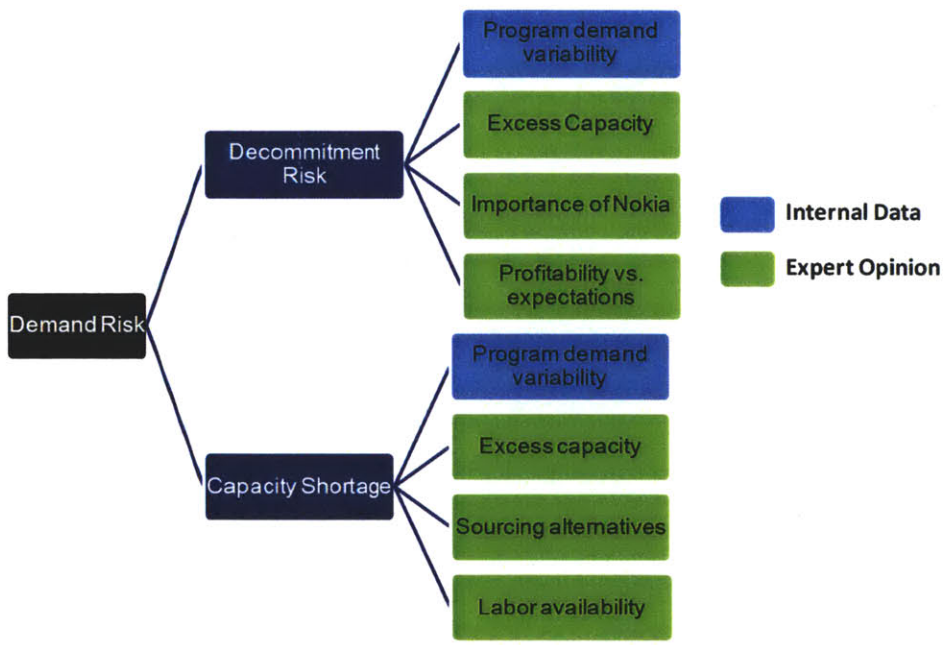

Figure 22: Demand risk categories and potential data signals

4.8 Potential data signals

Figure 23 shows a list of the individual data signals that were chosen for initial risk identification model that was developed based on the proposed approach. The table also shows the category and sub-category of risk for which the data has been chosen, as well as the scope of the data within the network structure of the supply chain and the data source.

Risk Category	Sub-category	Data Scope	Data	Source
Financial	Financial distress	Supplier	Profitability	Bloomberg
Financial	Financial distress	Supplier	Liquidity	Bloomberg
Financial	Financial distress	Supplier	Efficiency	Bloomberg
Financial	Financial distress	Supplier	Leverage	Bloomberg
Financial	Financial distress	Supplier	Survey	Survey
Technology	Ramp-up risk	Technology	Technology yield	Survey
Technology	Ramp-up risk	Technology	Sourcing Alternatives	Survey
Technology	Ramp-up risk	Technology	Age of technology	Survey
Technology	Ramp-up risk	Technology	Supplier	Survey
Industry Capacity	Capacity tightness	Industry	Inventories	External data/Survey
Industry Capacity	Capacity tightness	Industry	Investment level	External data/Survey
Industry Capacity	Capacity tightness	Industry	Investment lead time	External data/Survey
Industry Capacity	Capacity tightness	Industry	Expected demand growth	External data/Survey
Country	FX risk	Country	FX rate volatility	St. Louis Fed
Country	Inflation risk	Country	Country level CPI	St. Louis Fed
Country	Labor risk	Country	Unemployment	St. Louis Fed
Country	Political risk	Country	Euromoney score	Euromoney
Operational	Quality	Supplier	Historical quality data	Nokia historical data
Operational	Quality	Supplier	Qualitative score	Survey
Operational	Ramp-up risk	Supplier	Program demand var.	Nokia historical data
Operational	Ramp-up risk	Supplier-component	Ramp-up capability	Survey
Operational	Ramp-up risk	Supplier-component	Excess capacity	Survey
Operational	Ramp-up risk	Supplier-component	Yield	Survey
Demand	Decommitment	Supplier-component	Historical forecast accuracy	Nokia historical data
Demand	Decommitment	Supplier-component	Excess capacity	Survey
Demand	Decommitment	Supplier-component	Importance of Nokia	Survey
Demand	Decommitment	Supplier-component	Profit vs. Expectations	Survey
Demand	Capacity shortage	Supplier-component	Program demand var.	Nokia historical data
Demand	Capacity shortage	Supplier-component	Excess capacity	Survey
Demand	Capacity shortage	Supplier-component	Historical reliability	Nokia historical data
Demand	Capacity shortage	Supplier-component	Sourcing Alternatives	Survey
Demand	Capacity shortage	Supplier-component	Labor availability	Survey

Figure 23: Demand risk categories, potential data signals and data sources selected for the initial model

4.9 Determining data linkages

Once data signals to identify potential risks were chosen and mapped to particular risks, the data linkages needed to be determined. At this point in the process, the data signals are only hypothesized to correlate either positively or negatively with actual risks, though it is not known whether the factors are actually significant variables in terms of predicting potential risks. In addition, given that the purpose of the risk identification process is to identify potential risk areas as opposed to exact probabilities and timing of risks, the magnitude to which a particular data signal increases a risk level will not be known. Given this imprecision, as well as the fact that many of the data signals consist of people's opinions as opposed to precise quantifiable data, the goal for this final step for the initial model was to create a logic system as opposed to a precise quantitative model. Chapter 5 discusses the logic model in more detail.

5 The logic model

5.1 Summary

The decision system chosen for the initial model is based on fuzzy logic modeling. This type of risk identification model has been detailed in literature (as discussed in the literature review in Chapter 2) and used in practice in other fields, though apparently not in the area of supply risk identification. This chapter contains an introduction to and exploration of fuzzy logic, a discussion of its advantages and disadvantages versus other possible modeling techniques, as well as an overview of the initial model that was developed for this project.

5.2 Model goals

As discussed in Chapter 4, the purpose of the model that was developed is to calculate a particular risk score for each of the sub-categories of risk that were chosen. To maintain consistency with the current process of risk identification, this risk score will be a number between 0 and 3 and will then correspond to a particular color for that risk category in the output risk report. Therefore, the model should essentially be a decision system, for which the inputs are certain values of each data signal and the output is the risk score.

Currently, this "decision system" is manual and arbitrary. If a person generating the risk report believes that a certain potential material supply availability issue warrants immediate attention, the person will use the color red on the slide presentation described in section 3.2.3 to indicate a high level of risk. Similarly, if the person believes that there is no potential risk, he or she will use the color green. The purpose of the model is to systematize this decision-making process, so that particular values of the data signals will consistently generate the same risk score.

There are two main challenges in creating a model for this decision system. First, the logic model becomes exponentially more complex with each additional data signal chosen. If there are n particular data signals, each with x possible values, it would be necessary to create x^n logic rules, one for each possible case. The model should somehow aggregate similar values of the data signals to reduce the number of logic rules that need to be enumerated.

Second, many of the data signals that have been chosen are responses to survey questions as opposed to precise values that have been calculated. Given this, the decision system must account for the natural variability that will occur with different people answering the same survey questions. With answers based on a scale of 1 to 10, it is difficult, for example, to distinguish one person's answer of "3" with another person's answer of "4" if the question asks about the person's opinion. Therefore, the model should not simply take specific input values or ranges for the data signals and translate these into a particular risk score. Rather, the model should somehow capture this inherent uncertainty in how people respond to questions. In order to overcome these challenges, fuzzy logic modeling was used.

5.3 Introduction to Fuzzy Logic

5.3.1 Background

Fuzzy logic is based on fuzzy set theory, which was first introduced by Lotfi Zadeh of the University of California at Berkeley in the 1970s. The premise behind the theory is that sets of numbers can be divided into traditional or "crisp" sets and fuzzy sets. In the former case, each element within a particular set is assessed in binary terms; the element either does or not does belong to a particular set. In a fuzzy set, elements can have partial membership, such that a particular element can belong partially to more than one set.

Mathematically, in a classic set of numbers S, a particular number x either does or does not belong to S. This can be represented by the characteristic function of that number, namely $\mu_S(x)$. For each possible point, the function $\mu_S(x)$ will take a value in the binary set $\{0,1\}$. If $\mu_S(a) = 1$, then the point a belongs to S. If $\mu_S(a) = 0$, then the point a does not belong to S. In a fuzzy set, the domain of the characteristic function can be generalized to the interval $[0,1]$ as opposed to a binary set. Therefore, the characteristic function $\mu_S(x)$ can take on any value between 0 and 1 to indicate the point's degree of membership in the particular set S.

It is easiest to illustrate fuzzy set theory using a simple example of its application. Consider a case of temperature, which can be categorized as either "hot," "medium" or "cold." In the case of a classic set, differentiating between these three would involve precise thresholds. For example the set could be defined as follows, if T represents the temperature in degrees fahrenheit:

$$\text{if } T < 35 \text{ then HOT} = 0,\ \text{MEDIUM} = 0,\ \text{COLD} = 1$$

$$\text{if } 35 <= T <= 65 \text{ then HOT} = 0,\ \text{MEDIUM} = 1,\ \text{COLD} = 0$$

$$\text{if } T > 65 \text{ then HOT} = 1,\ \text{MEDIUM} = 0,\ \text{COLD} = 0$$

This set could be represented graphically as shown in Figure 24.

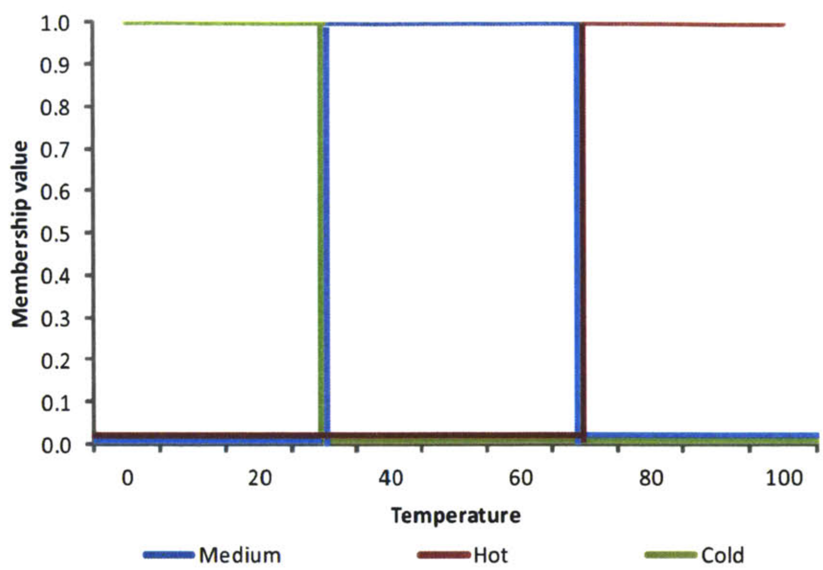

Figure 24: Example of a classic set. In this case, each point between 0 and 100 degrees has a membership value that is 0 or 1 for each of the three cases (medium, hot, cold)

Fuzzy set theory recognizes that in many cases, values such as these are not necessarily precise and depend on human language interpretation. In this example, defining the threshold values exactly may not make sense. While some may consider a temperature of 29 degrees to be cold, others may consider it to be medium. This can be particularly important if the interpretation for such a value is being used to make a decision (e.g. to turn on a heater).

In a fuzzy set, there exists some overlap between the different sub-sets, such that certain values can be partial members of more than one sub-set. Continuing with the temperature example, a fuzzy set might allow for a value between 20 and 50 degrees to be considered as partially cold and partially medium, and a value between 50 and 80 to be considered as partially medium and partially hot. In this case, a graphical representation of the set would be:

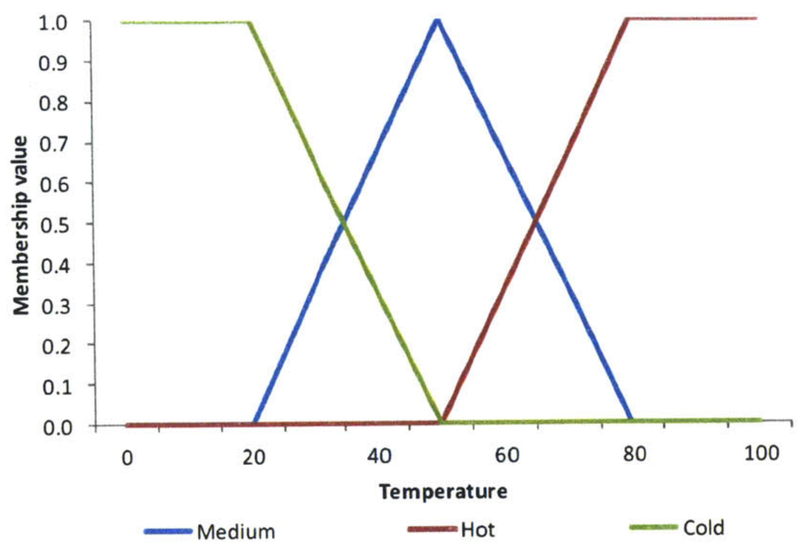

Figure 25: Example of fuzzy set. In this case, certain temperature values have partial membership in two different sets.

In this case, a specific temperature would map to its membership value of one of the sub-sets according to the following mathematical functions:

if T < 20 then HOT = 0, MEDIUM = 0, COLD = 1

if 20 < T < 50 then HOT = 0, MEDIUM = (T-20) / (50-20) , COLD = (50-T) / (50-20)

if 50 < T < 80 then HOT = (T-50) / (80-50), MEDIUM = (80 - T) / (80-50) , COLD = 0

if T > 80 then HOT = 1, MEDIUM = 0, COLD = 0

Examples of temperatures and corresponding membership values are shown in Figure 26.

Temperature - Fuzzy Membership Values			
Temp. (°F)	Hot	Medium	Cold
0	0.00	0.00	1.00
10	0.00	0.00	1.00
26	0.00	0.20	0.80
38	0.00	0.60	0.40
45	0.00	0.83	0.17
54	0.13	0.87	0.00
62	0.40	0.60	0.00
80	1.00	0.00	0.00

Figure 26: Examples of fuzzy logic membership values

In this way a particular temperature will not necessarily be a member of precisely one of the three categories. Instead, each temperature value will have a degree of membership for each of the three categories. While it is still necessary to define threshold values for each of the three categories (for example, 50 is the lower bound for a temperature to be considered hot), these threshold values are set in such a way that it is extremely unlikely that anyone would consider a value outside of the defined range of a particular set to be a member of that set. As discussed in section 4.4, the model was developed so that a user can define these threshold values.

5.3.2 Fuzzy Logic Mathematical Operations

Similar to a crisp logic system, fuzzy logic sets can be combined using mathematical operations. Given two fuzzy sets X and Y with membership functions $\mu(x)$ and $\mu(y)$, the following mathematical operations can be performed:

$$X \text{ OR } Y: \max(\mu(x), \mu(y))$$

$$X \text{ AND } Y: \min(\mu(x), \mu(y))$$

$$\text{NOT } X: 1 - \mu(x)$$

Continuing with the temperature example, suppose that the goal is to create a simple decision model to determine at what level (between 1 and 3) to turn on a heater based on both the temperature and whether or not the sun is shining. For this example, the "sun is shining" variable can be defined using a fuzzy set with a measure of 0 to 100, where 0 corresponds to darkness and 100 to bright sunlight.

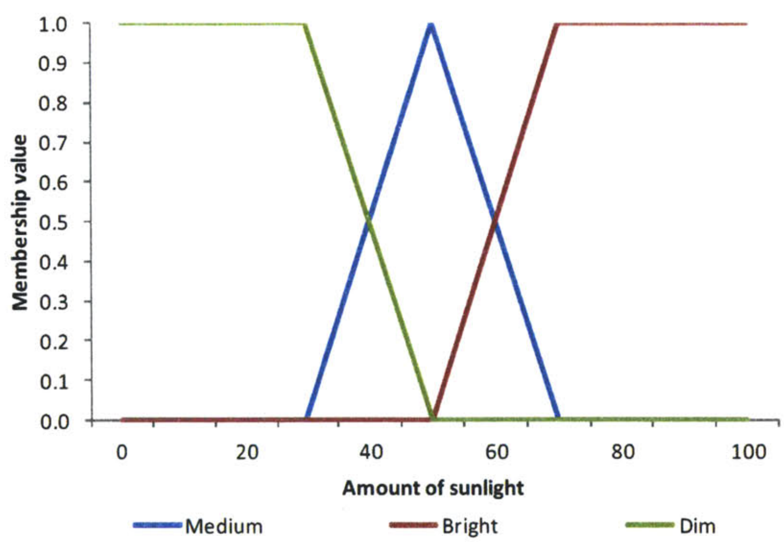

Figure 27: Example of fuzzy to measure sunlight

Specifically, the sets are defined as:

if S < 30 then Bright = 0, Medium = 0, Dim = 1

if 30 < S < 50 then Bright = 0, Medium = (S-30) / (50-30) , Dim = (50-S) / (50-30)

if 50 < S < 70 then Bright = (S-50) / (70-50), Medium = (70-S) / (70-50) , Dim = 0

if T > 70 then Bright = 1, Medium = 0, Dim = 0

The decision model will be based on the following logic table, which lists human language rules for a certain level of temperature and sunlight to determine the appropriate heater level.

Rule	Temperature	Sun	Heater Level
1	Hot	Bright	1
2	Hot	Medium	1
3	Hot	Dim	1
4	Medium	Bright	2
5	Medium	Medium	2
6	Medium	Dim	3
7	Cold	Bright	2
8	Cold	Medium	3
9	Cold	Dim	3

Figure 28: Logic rules to determine heater level based on linguistic variables for temperature and sunlight

For example, the table above specifies the following condition:

If Temperature = HOT and Sun = BRIGHT Then Heater = Level 1

Based on this logic table, any particular temperature and value of the "sun shining" variable will determine a value for what level the heater should be set to. The process to do this consists of four steps:

1) For each variable, determine corresponding membership value
2) Evaluate each logic rule individually
3) Calculate fuzzy inference values
4) Defuzzify into a crisp value

5.3.3 Defuzzification

The initial model uses the fuzzy centroid method to "defuzzify" the fuzzy set into a crisp number. Specifically, the formula for this method is:

$$Crisp\ value = \frac{\mathrm{Off}_{\mathrm{center}} * \mathrm{Off}_{\mathrm{strength}} + \mathrm{Low}_{\mathrm{center}} * \mathrm{Low}_{\mathrm{strength}} + \mathrm{High}_{\mathrm{center}} * \mathrm{High}_{\mathrm{strength}}}{\mathrm{Off}_{\mathrm{strength}} + \mathrm{Low}_{\mathrm{strength}} + \mathrm{High}_{\mathrm{strength}}}$$

$$\mathrm{Off}_{\mathrm{center}} = center\ of\ value\ corresponding\ to\ \mathrm{Off}$$

$$\mathrm{Off}_{\mathrm{strength}} = strength\ of\ output\ member\ function$$

In the temperature example, if consider a temperature of 45 degrees and a "sun shining" value of 42, then the calculation would proceed as follows:

1) Determine corresponding membership values

For temperature = 45 degrees, HOT = 0, MEDIUM = 0.83, COLD = 0.17

For sun shining = 42, BRIGHT = 0, MEDIUM = 0.75, DIM = 0.25

2) Evaluate each logic rule individually

Rule	Temperature	Sun	Heater Level	Evaluation
1	Hot	Bright	1	MIN (0,0) = 0
2	Hot	Medium	1	MIN (0,0.75) = 0
3	Hot	Dim	1	MIN (0,0.25) = 0
4	Medium	Bright	2	MIN (0.83,0) = 0
5	Medium	Medium	2	MIN (0.83,0.75) = 0.75
6	Medium	Dim	3	MIN (0.83,0.25) = 0.25
7	Cold	Bright	2	MIN (0.17,0) = 0
8	Cold	Medium	3	MIN (0.17,0.75) = 0.17
9	Cold	Dim	3	MIN (0.17,0.25) = 0.17

Figure 29: Evaluation of each logic rule using fuzzy logic mathematical operations

3) Calculate fuzzy inference values

There are several ways to calculate fuzzy inference values. The initial model uses the root sum square (RSS) method, which takes the square root of the sum of squares of the resulting value based on each individual rule.

The fuzzy inference values in this case are:

$$OFF = \sqrt{0^2 + 0^2 + 0^2} = 0$$
$$LOW = \sqrt{0^2 + 0.75^2 + 0^2} = 0.75$$
$$HIGH = \sqrt{0.25^2 + 0.17^2 + 0.17^2} = 0.34$$

4) Defuzzification

$$Crisp\ value = \frac{1 * 0 + 2 * 0.75 + 3 * 0.34}{0 + 0.75 + 0.34}$$

=2.3

The interpretation of this result is that the heater should be set to the value of 2.3 based on a temperature of 45 and a sun shining value of 42.

5.4 Fuzzy Logic Advantages and Disadvantages

5.4.1 Advantages of Fuzzy Logic

The key advantages of fuzzy logic modeling that justify its use for the initial model are:

1) It provides a way to combine expert opinions with quantitative data. As discussed in Section 5.2, fuzzy logic provides a way to translate human language into mathematical equivalents, which is necessary for a decision model in which many of the input variables are not precise quantities.

2) It allows for the aggregation of input values into ranges to reduce the number of logic rules that need to be specified. This is particularly important in this case given the likely need to continue to update and refine the parameters of the model. With several survey questions requesting sourcing managers to give answers based on a scale of 1 to 10, the number of logic rules that would have to be evaluated would likely be too large to maintain and update on a regular basis. Chapter 6

contains a discussion of implementation of the model that illustrates how the fuzzy logic model parameters can be updated.

3) It eliminates the need to specify arbitrary, precise thresholds for the ranges of the input values. Instead, with fuzzy logic, one can define ranges of sets in which the threshold values are extreme cases, beyond which it is extremely unlikely that a value would be considered part of the set.

5.4.2 Disadvantages of Fuzzy Logic

Two key disadvantages of a fuzzy logic model for this application are:

1) It requires the use of an obscure subject that does not necessarily accomplish something that traditional, or crisp logic, rules cannot. As discussed above, it is possible to establish crisp logic rules that will lead to the same conclusion as a fuzzy logic model. In the temperature example above, one could create logic rules for each value of the temperature and the sunlight measure in order to determine at what level the heater should be set. A traditional logic model would be easier to understand and eliminate the need for users of the model to learn about a subject with which they are most likely not familiar.

2) It still requires the enumeration of logic rules. While the number of rules will be fewer than in the case of a crisp set in which input values are not aggregated into ranges, there will still be many logic rules that need to be created and maintained, and the number of logic rules will still increase exponentially with the number of data input variables chosen. The implementation of the model should allow for easy updating of these logic rules, though the sheer number of logic rules that need to be created could represent a major obstacle in using a fuzzy logic-based model for this purpose.

5.5 The Initial Model

The risk model here was developed using a fuzzy logic system as described above. Specifically, each of the six categories of risk discussed in Chapter 3 was modeled as follows:

5.5.1 Financial Risk

As shown previously, the four quantitative metrics used to assess financial risk are liquidity, profitability, cash flow and leverage. These metrics are combined with a qualitative, survey-based assessment of a supplier's financial condition to come up with an overall financial risk score.

The four financial metrics are defined as follows:

Metric	Data	Calc
Leverage Risk	Net debt / EV	Total debt - Cash - Marketable Securities / (Market Cap + Net Debt)
Liquidity Risk	Quick ratio	(Cash + Market Securities + Short-Term Investments + Accounts Receivable) / Current Liabilities
Profitability Risk	Operating Margin	Operating Income / Total Revenue
Cash Flow Risk	Free cash Flow	Cash flow from operations - Capital expenditures

Figure 30: Definitions of financial metrics used for financial risk score

This financial risk assessment was taken from a process previously being done at Nokia on a regular basis, but no longer carried out given personnel changes. These same four metrics were used previously, though the threshold values being used to determine whether or not a particular ratio was at an acceptable level was arbitrary. In this system, these threshold values can also be easily defined by the user. The initial model sets the parameters as shown in Figure 31. The logic used to determine the financial metric risk level is shown in Figure 32.

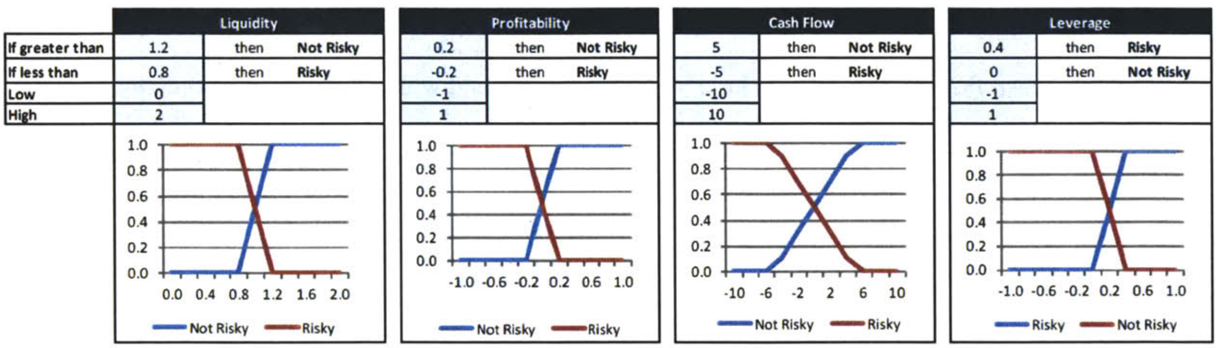

Figure 31: Graphs showing fuzzy rules for financial metrics

Risk Score	Definition
1	If none risky
2	If L risky If P risky If C risky If Le risky If L and P risky If P and C risky If C and Le risky If L and C risky If L and Le risky If P and Le risky
3	If L,P,C risky If L,P, Le risky If P,C,Le risky If L,C,Le risky If all risky

Figure 32: Logic table for financial metric risk score

L = Liquidity, P = Profitability, C = Cash Flow, and Le = Leverage

The overall Financial Risk is then determined using the following logic table:

Financial Metric Risk	Qualitiative Risk	Financial Risk
1.0	1.0	**1.0**
1.0	2.0	**2.0**
1.0	3.0	**2.0**
2.0	1.0	**2.0**
2.0	2.0	**2.0**
2.0	3.0	**3.0**
3.0	1.0	**2.0**
3.0	2.0	**3.0**
3.0	3.0	**3.0**

Figure 33: Logic table to determine overall financial risk score

5.5.2 Technology Risk

The model uses a combination of crisp and fuzzy values to attempt to determine an overall risk score to assess the likelihood that a particular technology will either encounter problems when ramping up or will become obsolete. The specific logic used for each of these cases is:

- **Technology Yield:** This is a fuzzy variable that is calculated based on the yield of a particular technology versus its expected yield. It is based on a survey response and given a value from 1 to 10, corresponding to low to high.

- **Age:** This is the age of the technology as measured in years. The age is then mapped to a particular value from 1 to 3, corresponding to old-new as shown in Figure 34.

Age	
1	< 1 year old
2	1 to 2 years old
3	> 2 years old

Figure 34: Table for technology age

- **Sourcing Alternatives:** There are four different options for sourcing alternatives for a particular technology. This methodology is taken from a paper titled "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident" (Normann & Jansson, 2004). These are:

Sourcing Alternatives	
1	Currently >1 supplier approved and available
2	Currently sole-sourced, but others are approved and ready to supply
3	Current sole-sourced, others are available but not yet ready
4	Currently sole-sourced and no alternatives available

Figure 35: Sourcing alternative options

These three parameters map to a ramp-up risk value based on the following logic table. In the table, the values 1, 2 and 3 correspond to low, medium, and high, respectively.

Technology Yield	Sourcing Alternatives	Age	Risk
1	1	1	3
1	1	2	2
1	1	3	2
1	2	1	3
1	2	2	2
1	2	3	2
1	3	1	3
1	3	2	2
1	3	3	2
1	4	1	3
1	4	2	3
1	4	3	3

Technology Yield	Sourcing Alternatives	Age	Risk
2	1	1	1
2	1	2	1
2	1	3	1
2	2	1	1
2	2	2	1
2	2	3	1
2	3	1	2
2	3	2	2
2	3	3	2
2	4	1	3
2	4	2	2
2	4	3	2

Technology Yield	Sourcing Alternatives	Age	Risk
3	1	1	1
3	1	2	1
3	1	3	1
3	2	1	1
3	2	2	1
3	2	3	1
3	3	1	2
3	3	2	2
3	3	3	2
3	4	1	3
3	4	2	2
3	4	3	2

Figure 36: Logic used for ramp-up risk

The logic used to determine the overall technology risk level is:

Ramp-up risk	Qualitataive Score	Risk
1	1	1
1	2	2
1	3	3
2	1	2
2	2	2
2	3	3
3	1	3
3	2	3
3	3	3

Figure 37: Logic for overall technology risk level

5.5.3 Industry Capacity Risk

The industry capacity risk in this model is based on a survey response of four specific factors. For certain industries, it is possible to be more precise for these factors if industry data is readily available (e.g., semiconductors). In that case, it may make sense to actually build a model to forecast these different factors. This model represents the more general case in which data is assumed to be difficult to obtain and thus is dependent on the knowledge of the industry expert. In each case, each factor is based on a survey response from 1 to 10, which is then mapped to a "low," "medium," or "high" linguistic variable as shown in Figure 38.

If greater than	7	then	**High**
If less than	3	then	**Low**
Low	0		
High	10		

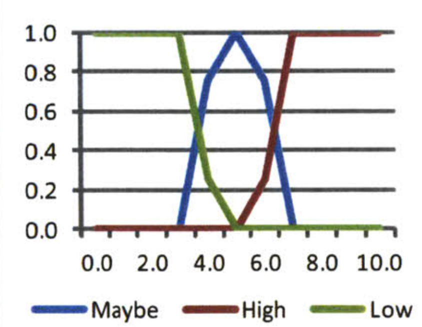

Figure 38: Fuzzy logic used for each of the four metrics for industry capacity risk

The four parameters are:

- **Inventories:** This represents the level of inventories versus the historical average level.
- **Investment level:** The current amount of investment being made in capacity growth.

- **Investment lead time:** The current lead time for capacity growth, as measured from the point at which investment into capacity expansion begins until first production.
- **Demand growth:** The expected demand growth over the lead time period.

The four parameters determine an overall industry capacity risk score based on the following decision table:

Inv.	Invest. Level	Lead Time	Demand Growth	Risk Level
1	1	1	1	2
1	1	1	2	2
1	1	1	3	3
1	1	2	1	2
1	1	2	2	2
1	1	2	3	3
1	1	3	1	3
1	1	3	2	3
1	1	3	3	3
1	2	1	1	2
1	2	1	2	2
1	2	1	3	3
1	2	2	1	2
1	2	2	2	2
1	2	2	3	3
1	2	3	1	3
1	2	3	2	3
1	2	3	3	3
1	3	1	1	2
1	3	1	2	2
1	3	1	3	3
1	3	2	1	2
1	3	2	2	2
1	3	2	3	3
1	3	3	1	3
1	3	3	2	3
1	3	3	3	3

Inv.	Invest. Level	Lead Time	Demand Growth	Risk Level
2	1	1	1	1
2	1	1	2	2
2	1	1	3	3
2	1	2	1	1
2	1	2	2	2
2	1	2	3	3
2	1	3	1	1
2	1	3	2	3
2	1	3	3	3
2	2	1	1	1
2	2	1	2	2
2	2	1	3	3
2	2	2	1	1
2	2	2	2	2
2	2	2	3	3
2	2	3	1	1
2	2	3	2	3
2	2	3	3	3
2	2	1	1	1
2	3	1	2	2
2	3	1	3	3
2	3	2	1	1
2	3	2	2	2
2	3	2	3	3
2	3	3	1	1
2	3	3	2	3
2	3	3	3	3

Inv.	Invest. Level	Lead Time	Demand Growth	Risk Level
3	1	1	1	1
3	1	1	2	1
3	1	1	3	2
3	1	2	1	1
3	1	2	2	1
3	1	2	3	2
3	1	3	1	1
3	1	3	2	1
3	1	3	3	2
3	2	1	1	1
3	2	1	2	1
3	2	1	3	2
3	2	2	1	1
3	2	2	2	1
3	2	2	3	2
3	2	3	1	1
3	2	3	2	1
3	2	3	3	2
3	2	1	1	1
3	3	1	2	1
3	3	1	3	2
3	3	2	1	1
3	3	2	2	1
3	3	2	3	2
3	3	3	1	1
3	3	3	2	1
3	3	3	3	2

Figure 39: Logic rules for industry capacity risk

This fuzzy variable is then combined with a qualitative assessment of industry capacity tightness. The logic used to determine the overall risk level is:

Industry Capacity	Qualitative Score	Industry Risk
1	1	1
1	2	1
1	3	3
2	1	1
2	2	2
2	3	3
3	1	2
3	2	3
3	3	3

Figure 40: Logic table to determine overall industry capacity risk score

5.5.4 Country Risk

The country risk score is based on four metrics which can be found easily for any country. The four metrics are defined as shown in Figure 41. The Euromoney country risk is a score calculated based on five different metrics: economic characteristics, political characteristics, structural (i.e., the quality of physical infrastructure) characteristics, ease of access to capital markets and credit ratings, and debt indicators for the country. The score can be downloaded from the website www.euromoney.com.

Metric	Data	Calc
FX risk	FX rate	std. dev. of 1-month trailing FX rate / historical avg. 1-month std. dev.
Inflation Risk	Consumer Price Index (CPI)	inflation rate (year/year change in CPI)
Overall Risk	Euromoney country Risk	Euromoney country risk index

Figure 41: Country risk data

Each of these is mapped to a risk level using fuzzy logic according to the following parameters:

	FX volatility			Inflation			Euromoney Risk		
If greater than	1.5	then	Risky	0.1	then	Risky	85	then	Risky
If less than	1	then	Not Risky	0.05	then	Not Risky	60	then	Not Risky
Low	0.5			0			40		
High	2			0.15			105		

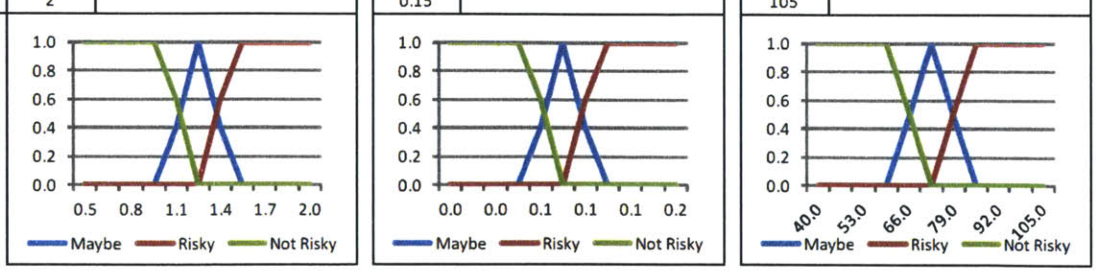

Figure 42: Fuzzy logic rules for country risk parameters

The logic used to determine the overall risk level is shown in Figure 43. Again, the numbers 1, 2 and 3 correspond to the fuzzy sets for low, medium and high, respectively, for each of the three factors.

FX volatility	Inflation	Euromoney index	Risk	FX volatility	Inflation	Euromoney index	Risk	FX volatility	Inflation	Euromoney index	Risk
1	1	1	1.0	2	1	1	2.0	3	1	1	3.0
1	1	2	2.0	2	1	2	2.0	3	1	2	3.0
1	1	3	3.0	2	1	3	3.0	3	1	3	3.0
1	2	1	2.0	2	2	1	2.0	3	2	1	3.0
1	2	2	2.0	2	2	2	2.0	3	2	2	3.0
1	2	3	3.0	2	2	3	3.0	3	2	3	3.0
1	3	1	3.0	2	3	1	3.0	3	3	1	3.0
1	3	2	3.0	2	3	2	3.0	3	3	2	3.0
1	3	3	3.0	2	3	3	3.0	3	3	3	3.0

Figure 43: Logic used to determine overall country risk score

5.5.5 Operational Risk

Operational risk consists of two separate risks: quality and ramp-up risk. For quality risk, the following parameters are used:

- **Historical quality data:** This is a measure of a supplier's historical quality based on an internal system which tracks historical quality rates.
- **Qualitative score:** This is based on a survey response.

These two scores are combined according to the logic table shown in Figure 44:

Historical Quality Data	Qualitative Score	Quality Risk
1	1	1
1	2	1
1	3	2
2	1	2
2	2	2
2	3	3
3	1	2
3	2	3
3	3	3

Figure 44: Logic used to determine quality risk score

Ramp-up risk involves the following parameters:

- **Program demand variability:** This represents the historical end product demand variability. It is either based on historical demand variability, measured as the coefficient of variation of weekly demand, for existing products, or based on expected demand variability for new products. It is measured as follows:

	Coeff. Of var.
1	< 0.1
2	0.1 to 0.25
3	> 0.25

Figure 45: Parameters for program demand variability

The remaining three factors are all based on survey responses for the particular component. In each case, each factor is based on a survey response from 1 to 10, which is then mapped to a "low," "medium," or "high" linguistic variable as shown in Figure 46.

If greater than	7	then	**High**
If less than	3	then	**Low**
Low	0		
High	10		

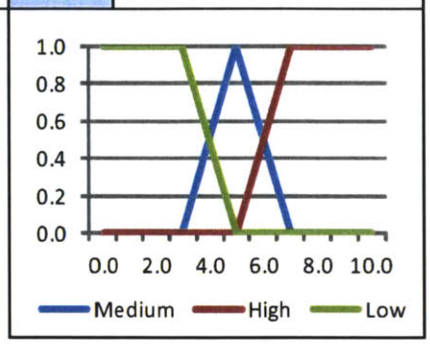

Figure 46: Fuzzy logic rules for ramp-up capability, excess capacity and yield

The parameters are:

- **Ramp-up capability:** The ability of the supplier to ramp-up production of the particular component.
- **Excess capacity:** This amount of excess capacity that the supplier has to product the particular component.
- **Yield:** The current production yield versus expected yield.

These four parameters are combined using the following decision table.

Ramp-up capability	Excess Capacity	Yield	Demand Var.	Risk
1	1	1	1	2
1	1	1	2	3
1	1	1	3	3
1	1	2	1	2
1	1	2	2	2
1	1	2	3	3
1	1	3	1	1
1	1	3	2	1
1	1	3	3	3
1	2	1	1	1
1	2	1	2	1
1	2	1	3	3
1	2	2	1	1
1	2	2	2	1
1	2	2	3	2
1	2	3	1	1
1	2	3	2	2
1	2	3	3	2
1	3	1	1	1
1	3	1	2	1
1	3	1	3	2
1	3	2	1	1
1	3	2	2	1
1	3	2	3	2
1	3	3	1	1
1	3	3	2	1
1	3	3	3	2

Ramp-up capability	Excess Capacity	Yield	Demand Var.	Risk
2	1	1	1	2
2	1	1	2	2
2	1	1	3	2
2	1	2	1	2
2	1	2	2	2
2	1	2	3	3
2	1	3	1	1
2	1	3	2	1
2	1	3	3	3
2	2	1	1	1
2	2	1	2	1
2	2	1	3	2
2	2	2	1	1
2	2	2	2	1
2	2	2	3	2
2	2	3	1	1
2	2	3	2	2
2	2	3	3	2
2	2	1	1	1
2	3	1	2	1
2	3	1	3	2
2	3	2	1	1
2	3	2	2	1
2	3	2	3	2
2	3	3	1	1
2	3	3	2	1
2	3	3	3	2

Ramp-up capability	Excess Capacity	Yield	Demand Var.	Risk
3	1	1	1	2
3	1	1	2	2
3	1	1	3	2
3	1	2	1	2
3	1	2	2	2
3	1	2	3	2
3	1	3	1	1
3	1	3	2	1
3	1	3	3	2
3	2	1	1	1
3	2	1	2	1
3	2	1	3	2
3	2	2	1	1
3	2	2	2	1
3	2	2	3	2
3	2	3	1	1
3	2	3	2	2
3	2	3	3	2
3	2	1	1	1
3	3	1	2	1
3	3	1	3	2
3	3	2	1	1
3	3	2	2	1
3	3	2	3	2
3	3	3	1	1
3	3	3	2	1
3	3	3	3	2

Figure 47: Logic used to determine ramp-up risk

The logic used to determine the overall risk level is:

Quality Risk	Ramp-up Risk	Operational Risk
1	1	1
1	2	2
1	3	3
2	1	2
2	2	2
2	3	3
3	1	3
3	2	3
3	3	3

Figure 48: Logic table to determine overall operational risk score

5.5.6 Demand Risk

Demand risk represents the risk that changes in end product demand will lead to insufficient component availability. Based on historical data, this risk manifests itself in one of two ways: either demand exceeds the plan, and there is insufficient capacity available to satisfy upwardly revised production forecasts, or demand falls short of plans, and suppliers choose to de-commit capacity as a result.

For the first case of insufficient capacity, there are four parameters that were chosen as potential data signals. These are:

- **Program demand variability:** As with the case with operational risk, this represents the historical end product demand variability. It is either based on historical demand variability, measured as the coefficient of variation of weekly demand, for existing products, or based on expected demand variability for new products. It is measured as follows:

	Coeff. Of var.
1	< 0.1
2	0.1 to 0.25
3	> 0.25

Figure 49: Parameters for program demand variability

- **Sourcing alternatives:** There are four different options for sourcing alternatives for a particular technology (as described in section 4.4.2 above). These are:

Sourcing Alternatives	
1	Currently >1 supplier approved and available
2	Currently sole-sourced, but others are approved and ready to supply
3	Current sole-sourced, others are available but not yet ready
4	Currently sole-sourced and no alternatives available

Figure 50: Sourcing alternative options

The remaining two factors are all based on survey responses for the particular component. In each case, each factor is based on a survey response from 1 to 10, which is then mapped to a "low," "medium," or "high" linguistic variable as follows:

If greater than	7	then **High**
If less than	3	then **Low**
Low	0	
High	10	

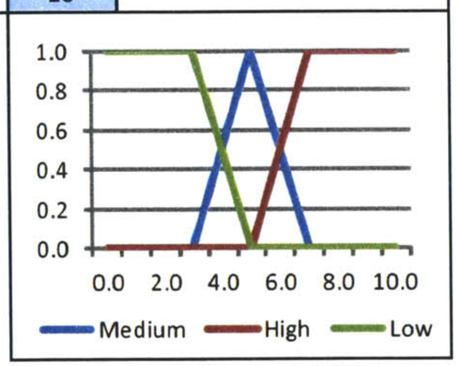

Figure 51: Fuzzy logic rules for excess capacity and labor availability

The parameters are:

- **Excess capacity:** This amount of excess capacity that the supplier has to product the particular component.
- **Labor availability:** This is a measure of the supplier's ability to increase its labor force to meet additional production.

These four parameters are combined as shown in Figure 52.

Demand Var.	Excess Capacity	Labor Avail.	Sourcing	Risk Level
1	1	1	1	1
1	1	1	2	2
1	1	1	3	2
1	1	1	4	2
1	1	2	1	2
1	1	2	2	2
1	1	2	3	2
1	1	2	4	2
1	1	3	1	2
1	1	3	2	1
1	1	3	3	2
1	1	3	4	2
1	2	1	1	1
1	2	1	2	1
1	2	1	3	1
1	2	1	4	2
1	2	2	1	1
1	2	2	2	1
1	2	2	3	1
1	2	2	4	1
1	2	3	1	1
1	2	3	2	1
1	2	3	3	1
1	2	3	4	1
1	3	1	1	1
1	3	1	2	1
1	3	1	3	1
1	3	1	4	1
1	3	2	1	2
1	3	2	2	3
1	3	2	3	1
1	3	2	4	2
1	3	3	1	3
1	3	3	2	1
1	3	3	3	2
1	3	3	4	3

Demand Var.	Excess Capacity	Labor Avail.	Sourcing	Risk Level
2	1	1	1	2
2	1	1	2	2
2	1	1	3	2
2	1	1	4	3
2	1	2	1	2
2	1	2	2	2
2	1	2	3	2
2	1	2	4	3
2	1	3	1	2
2	1	3	2	2
2	1	3	3	2
2	1	3	4	3
2	2	1	1	1
2	2	1	2	2
2	2	1	3	2
2	2	1	4	2
2	2	2	1	1
2	2	2	2	2
2	2	2	3	2
2	2	2	4	2
2	2	3	1	1
2	2	3	2	2
2	2	3	3	2
2	2	3	4	2
2	3	1	1	2
2	3	1	2	1
2	3	1	3	3
2	3	1	4	1
2	3	2	1	2
2	3	2	2	2
2	3	2	3	1
2	3	2	4	2
2	3	3	1	1
2	3	3	2	1
2	3	3	3	2
2	3	3	4	2

Demand Var.	Excess Capacity	Labor Avail.	Sourcing	Risk Level
3	1	1	1	3
3	1	1	2	3
3	1	1	3	3
3	1	1	4	3
3	1	2	1	2
3	1	2	2	3
3	1	2	3	3
3	1	2	4	3
3	1	3	1	3
3	1	3	2	3
3	1	3	3	3
3	1	3	4	3
3	2	1	1	3
3	2	1	2	3
3	2	1	3	3
3	2	1	4	3
3	2	2	1	2
3	2	2	2	2
3	2	2	3	3
3	2	2	4	3
3	2	3	1	2
3	2	3	2	2
3	2	3	3	3
3	2	3	4	3
3	3	1	1	3
3	3	1	2	3
3	3	1	3	3
3	3	1	4	3
3	3	2	1	2
3	3	2	2	2
3	3	2	3	2
3	3	2	4	3
3	3	3	1	2
3	3	3	2	2
3	3	3	3	2
3	3	3	4	2

Figure 52: Logic used to determine insufficient capacity risk

For the case of decommitment risk, there are four parameters chosen as causal factors. The first is again program demand variability, as in the case of insufficient capacity risk above.

The remaining three factors are all based on survey responses for the particular component. In each case, each factor is based on a survey response from 1 to 10, which is then mapped to a "low," "medium," or "high" linguistic variable as follows:

If greater than	7	then	High
If less than	3	then	Low
Low	0		
High	10		

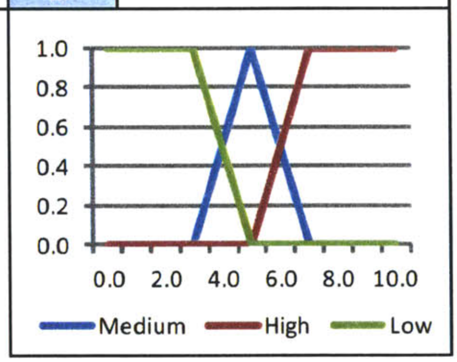

Figure 53: Fuzzy logic rules for excess capacity, importance of Nokia to the supplier and profitability of the component versus expectations

The parameters are:

- **Excess capacity:** This amount of excess capacity that the supplier has to product the particular component.
- **Importance of Nokia to supplier:** This is a measure of how important Nokia is to the supplier, measured as a percentage of the total revenue of the supplier.

- **Profitability of component vs. expectations:** This is a measure of how profitable this particular component is to the supplier versus the expected profitability of the component.

These four parameters are combined as follows:

Excess Capacity	Nokia import.	Profit	Demand Var.	Risk	Excess Capacity	Nokia import.	Profit	Demand Var.	Risk	Excess Capacity	Nokia import.	Profit	Demand Var.	Risk
1	1	1	1	1	2	1	1	1	1	3	1	1	1	1
1	1	1	2	2	2	1	1	2	2	3	1	1	2	2
1	1	1	3	3	2	1	1	3	3	3	1	1	3	3
1	1	2	1	1	2	1	2	1	1	3	1	2	1	1
1	1	2	2	2	2	1	2	2	2	3	1	2	2	2
1	1	2	3	3	2	1	2	3	3	3	1	2	3	3
1	1	3	1	1	2	1	3	1	1	3	1	3	1	1
1	1	3	2	2	2	1	3	2	2	3	1	3	2	2
1	1	3	3	3	2	1	3	3	3	3	1	3	3	3
1	2	1	1	1	2	2	1	1	1	3	2	1	1	1
1	2	1	2	2	2	2	1	2	2	3	2	1	2	2
1	2	1	3	3	2	2	1	3	3	3	2	1	3	3
1	2	2	1	1	2	2	2	1	1	3	2	2	1	1
1	2	2	2	2	2	2	2	2	2	3	2	2	2	2
1	2	2	3	3	2	2	2	3	3	3	2	2	3	3
1	2	3	1	1	2	2	3	1	1	3	2	3	1	1
1	2	3	2	2	2	2	3	2	2	3	2	3	2	2
1	2	3	3	3	2	2	3	3	3	3	2	3	3	3
1	3	1	1	1	2	2	1	1	1	3	2	1	1	1
1	3	1	2	2	2	3	1	2	2	3	3	1	2	2
1	3	1	3	3	2	3	1	3	3	3	3	1	3	3
1	3	2	1	1	2	3	2	1	1	3	3	2	1	1
1	3	2	2	2	2	3	2	2	2	3	3	2	2	2
1	3	2	3	3	2	3	2	3	3	3	3	2	3	3
1	3	3	1	1	2	3	3	1	1	3	3	3	1	1
1	3	3	2	2	2	3	3	2	2	3	3	3	2	2
1	3	3	3	3	2	3	3	3	3	3	3	3	3	3

Figure 54: Logic used to determine de-commitment risk score

The overall demand risk level is then determined using the following logic:

Capacity shortage	Decommit-ment	Demand
1	1	1
1	2	2
1	3	3
2	1	2
2	2	2
2	3	3
3	1	3
3	2	3
3	3	3

Figure 55: Logic used to determine overall demand risk

5.6 Determining overall risk score

Each of the categories of risk identified is grouped into a particular data table that has been constructed, with the goal that every node in the supply network will have an overall risk score for each of the six risk categories. In order for a person to easily see the risk level associated with a particular component, supplier or product, these individual risk scores would have to be aggregated. This can be done in a variety of ways.

The simplest way to aggregate the individual risk scores is to generate a single number that represents the overall risk score for each category of risk. To do this, an average of the risk scores of each node within the network can be taken. Specifically, the overall risk score would be calculated as follows:

$$\text{Overall category risk score} = \frac{\sum_{i=0}^{n} Xi}{n}$$

where Xi = the individual node score for a particular category;

n = the number of nodes in the network for that particular product, supplier or first-tier component

The downside to this method is that it does not necessarily capture the significance of a particular risk. Instead, the score that represents the overall risk of the network could be equal to that of the "weakest link" within the network. That is, the overall risk level for that particular supply network should be equivalent to the highest (most risky) score for any individual node.

Overall category risk score = $Max(Xi)$

where Xi = the individual node score for a particular category

n = the number of nodes in the network for that particular program, supplier or first-tier component

Once again, however, this single measure seems insufficient, given that it would essentially discard information for all nodes for a particular supply chain except for one.

The idea of calculating an overall risk score highlights an important trade-off in the risk identification approach: the upside in using a single number to represent the overall risk score is that a user can quickly identify which first-tier component, supplier or product requires attention and may require risk mitigation actions. In addition, a single measure could correspond to a color code, which would be familiar to users since it would be consistent with the current risk identification system.

The downside in using a single number to represent the overall score is that it cannot easily capture the distribution of risk levels across the supply chain. In using the prior method, a supply chain in which each node has a risk level of 2 may warrant more attention than one in which each node is 1 and a single node has a risk level of 3. In observing only the maximum, the latter supply chain would seem more at risk and the former could therefore be overlooked.

To deal with this trade-off between simplicity and robustness, the initial tool that was developed shows two different views: first, the model shows the distribution of risk levels for all nodes within a supply network. This distribution is represented by a scatter chart as shown in Figure 56 below. The second view shows a single numerical risk score, which is calculated as the maximum score of each node in the network (i.e., the second method described above).

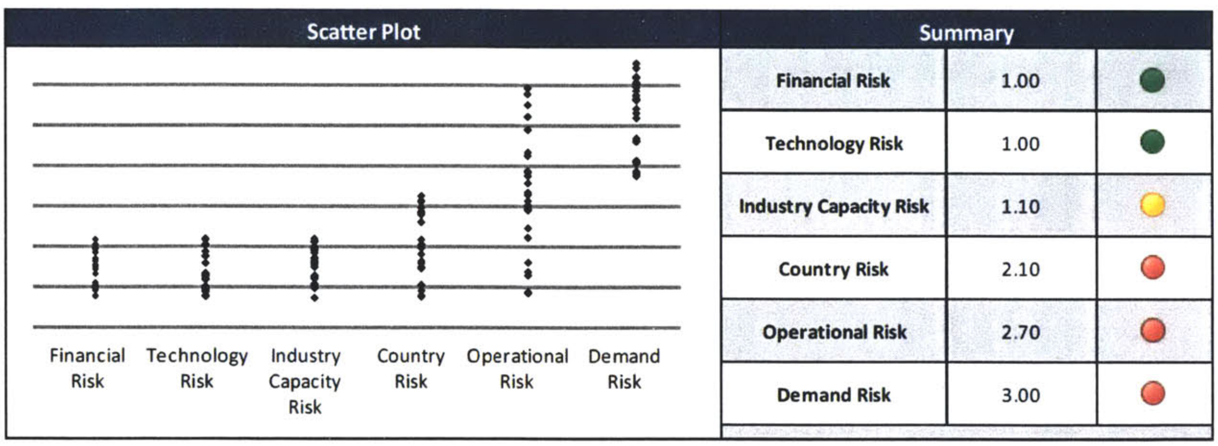

Figure 56: Example of two views of the overall risk score

The scatter plot on the left shows the distribution of the risk level of all nodes within the network. The table to the right shows a single numerical score along with a corresponding color.

Ultimately, this single overall risk score for a network will depend on many factors, including the amount of time and resources dedicated to the process of risk assessment and mitigation, the actual use of a process such as this, as well as the key stakeholders' desired reports. If this type of risk identification process is meant to serve as only a supplemental screen to the current process, it may be sufficient to calculate overall risk using an average score. While this may mask the most significant risks in the network, it will provide an indication for which products, suppliers or first-tier components may need follow-up actions to assess supply availability risk.

If, on the other hand, the intention is for this approach to replace the current process and identify as many potential risks as possible, the second, "weakest link" calculation should be used. While it will highlight more potential risks than would be the case using an average score, it will also be more encompassing in that any node with a high risk level will elevate the risk level of the entire network of which the node is a part. In this case, it would be necessary for Nokia to have sufficient resources available for subsequent steps of risk assessment and mitigation.

6 Implementation

This chapter discusses an implementation approach for the proposed risk identification process. The considerations taken into account fall into three categories: technical/software, data requirements and reporting responsibilities. This chapter describes the issues considered within each category and provides an overview of the Microsoft Excel model that was developed and suggestions for possible reporting responsibilities.

6.1 The software tool

6.1.1 Software requirements

Microsoft Excel was chosen for the initial model. Given that the usability of the process will play a large role in whether or not it is successful, software requirements were considered throughout the project. Specifically, the key considerations in terms of software requirements for the proposed approach are:

1. **Ability to organize data into tables:** Given the network design of the supply chain described in Chapter 3, the software should allow for easy organization of data, including allowing different tables and easy linkages between them.

2. **Familiarity**: As discussed in Chapter 4, the parameters of the logic model will require continuous updating and refining. In addition, given that the tool will be used by different people across the organization, it should be based on software that is familiar to most people.

3. **Visualization capability:** Since the model is intended to be highly interactive, both in terms of specifying and modifying input parameters of the logic model as well as for generating desired risk reports, it should allow for easy visualization and generation of desired graphics.

4. **Integration capability**: Given that the model requires the use of internal data, it should easily integrate with existing software that Nokia currently uses. This will allow the model to extract the necessary data automatically as opposed to manually.

6.1.2 The Microsoft Excel Model

With these considerations in mind, Microsoft Excel was chosen as the software on which to base in the initial tool. If the process is to be built out further for additional products and components, more robust data storage software (such as Microsoft Access) may need to be considered to store the data, while Microsoft Excel could perhaps be used as the user interface.

The initial tool was designed such that there is one unique Excel file for each of the six risks that have been identified and discussed in Chapters 3 and 4, as well as one file that aggregates these risks into a comprehensive risk overview for a particular supplier, first-tier component or product.

6.1.3 Individual risk spreadsheets

The individual risk spreadsheets each contain the four tabs described below. The consistency in terms of content and format across each of the risk spreadsheets should allow a user to more easily become familiar with these spreadsheets to allow him or her to easily maintain and update each of them.

1. **Risk Summary:** This tab highlights each data element for that particular risk category and the associated risk score. An example of the tab for the Financial Risk category is shown in Figure 57.

Financial Risk Summary

Supplier	Liquidity Risk	Profitability Risk	Cash Flow Risk	Leverage Risk	Financial Metric Risk	Qualitative Risk	Financial Risk	
Supplier 1	2	2	2	1	2.0	1.0	2.0	
Supplier 2	1	1	1	1	1.0	1.0	1.0	
Supplier 3	1	1	1	1	2.0	1.0	2.0	
Supplier 4	2	2	2	1	2.0	1.0	2.0	
Supplier 5	2	1	1	2	2.0	1.0	2.0	
Supplier 6	2	2	2	2	3.0	1.0	2.0	
Supplier 7	2	1	1	2	2.0	1.0	2.0	
Supplier 8	2	1	1	1	2.0	1.0	2.0	
Supplier 9	1	2	1	1	2.0	1.0	2.0	
Supplier 10	2	2	1	1	2.0	1.0	2.0	
Supplier 11	1	1	1	1	1.0	1.0	1.0	
Supplier 12	2	2	2	1	2.0	1.0	2.0	
Supplier 13	1	1	1	1	1.0	1.0	1.0	
Supplier 14	1	1	1	1	1.0	1.0	1.0	
Supplier 15	1	1	1	1	2.0	1.0	2.0	
Supplier 16	2	2	2	1	2.0	1.0	2.0	
Supplier 17	1	1	1	1	2.0	1.0	2.0	
Supplier 18	1	1	1	1	1.0	1.0	1.0	
Supplier 19	2	1	2	1	2.0	1.0	2.0	

Figure 57: Example of the Risk Summary tab

The components of the Risk Summary tab (highlighted numerically in Figure 57) are:

(1) Data List: This is a comprehensive list of the individual data elements depending on the scope of the risk. In the example in Exhibit 6.1, the scope of Financial Risk is supplier. The scope of each risk is the table to which it belongs as highlighted in Exhibit 3.3 in Chapter 3.

(2) **Fuzzy Logic Model:** These columns illustrates the risk level based on the fuzzy logic rules specified for each of the different potential data signals that were chosen. In the case of Financial Risk, the four data signals chosen are the individual financial metrics. These are then used to determine an overall Financial Metric Risk level as described in Chapter 4.

(3) **Qualitative Score:** This column contains the qualitative, survey-based risk score. The column is included in the spreadsheet for those risks which use such a qualitative score.

(4) **Overall Risk Level:** This column shows the overall risk level which is calculated based on the fuzzy logic model and qualitative score, once again based on the logic rules highlighted in Chapter 4.

(5) **Fuzzy Logic Macro Button:** This button allows the user to re-run the fuzzy logic algorithm (as described in Chapter 4) that calculates the risk score one data for each element is updated. It is a relatively simple Visual Basic macro that iterates through each data element, evaluates each rule in the fuzzy logic decision table, calculates the corresponding strength and then de-fuzzifies to generate a crisp value for the risk score.

(6) **Color code:** The color code shows a visual representation of the overall Financial Risk column. The intent is to allow a user to easily identify those data elements for which the risk level is elevated. The color green represents a risk level of 1, yellow corresponds to 2, and red to a risk level of 3.

2. **Fuzzy Rules tab:** This tab specifies the parameters that are used in the fuzzy logic model.

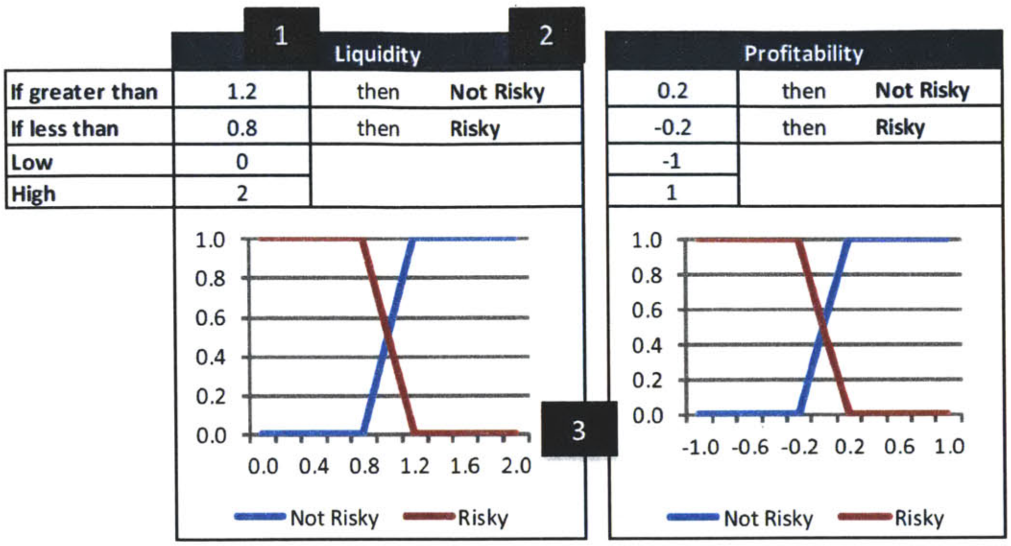

Figure 58: Fuzzy Rules tab screenshot

The components of the Fuzzy Rules tab (highlighted numerically in Figure 58) are:

(1) **Input threshold values:** This section allows a user to input specific values for the fuzzy logic thresholds, as well as the minimum and maximum values to use as limits for the X-axis in the graph below.

(2) **Characterization of values:** This section allows the user to characterize the range which he or she defined using the threshold values. In this case, the first entry corresponds to the rule that if the liquidity ratio (described in Chapter 5) is greater than 1.2, that should be considered as "Not Risky."

(3) **Graph:** This is a graph which illustrates the fuzzy rules that have been entered by the user.

3. **Data tab:** This tab contains the raw data for each data element. It links to either internal or external data sources or to the periodic surveys given to members of the component sourcing teams. In the case of Financial Risk, the data tab links directly to Bloomberg so that the user can easily download the desired financial metrics using a computer with Bloomberg software installed.

4. **Decision Table tab:** This tab contains the decision table for the overall risk score that is based on the sub-categories of risk. The example for Financial Risk is shown below.

Financial Metric Risk	Qualitiative Risk	Financial Risk
1.0	1.0	**1.0**
1.0	2.0	**2.0**
1.0	3.0	**2.0**
2.0	1.0	**2.0**
2.0	2.0	**2.0**
2.0	3.0	**3.0**
3.0	1.0	**2.0**
3.0	2.0	**3.0**
3.0	3.0	**3.0**

Figure 59: Decision Table tab contents

6.1.4 Surveys

The survey that was devised to capture data used in the logic models is shown in Figure 60 below.

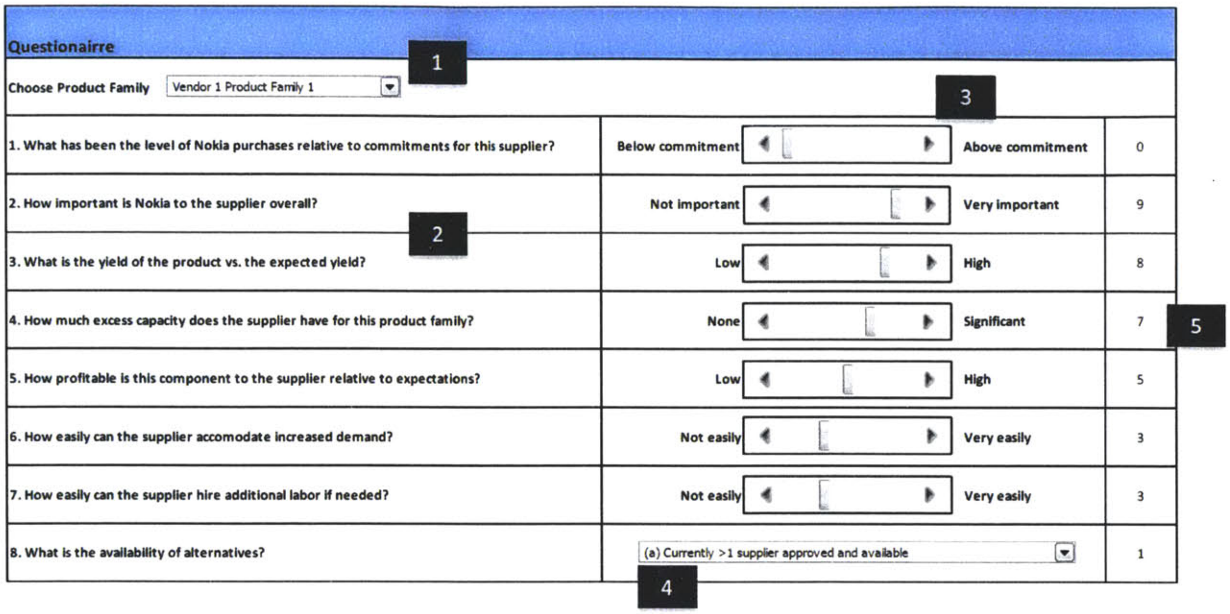

Figure 60: Survey given to component sourcing teams

The components of the survey are highlighted numerically in Figure 60 and described below.

(1) **Product Family menu:** The menu allows a user to select the particular product family for which the survey will be used. Once the user selects the desired product family, the survey data will automatically populate using a Visual Basic macro that is activated upon selection of an element in the drop-down menu.

(2) **Questions:** These are the eight questions that would be asked of the sourcing managers. Each of them is intended to provide a specific data point that will be used as a data signal in the logic model described in Chapter 4.

(3) **Answer scroll bars:** These scroll bars allow a user to select a number between 1 and 10 to answer each question. The corresponding descriptions are indicated on either side of each scroll bar.

(4) **Drop-down menu:** This menu allows the user to select one of the four distinct choices to characterize the availability of alternative sources for that particular component.

(5) **Numerical values:** This column displays the corresponding numerical values based on the scroll bar.

6.1.5 The Overall Risk file

The overall risk file aggregates the data from the six individual risk files into a comprehensive overview of risk. This file has 11 tabs: one for each of the 8 tables shown in Figure 14, as well as 3 additional tabs which aggregate the risk scores into three different reporting views discussed below. The aggregation of the risk score is calculated based on the methodology described in Section 4 of Chapter 5.

Based on discussions with individuals on the sourcing teams, there were three key desired reports for this type of risk identification tool:

1. **Detailed Risk by Category:** This report would show the risk score for each of the six categories, and then the components that make up the risk score based on the detailed supply chain network for that particular product. An example of the report is shown in Figure 61 below.

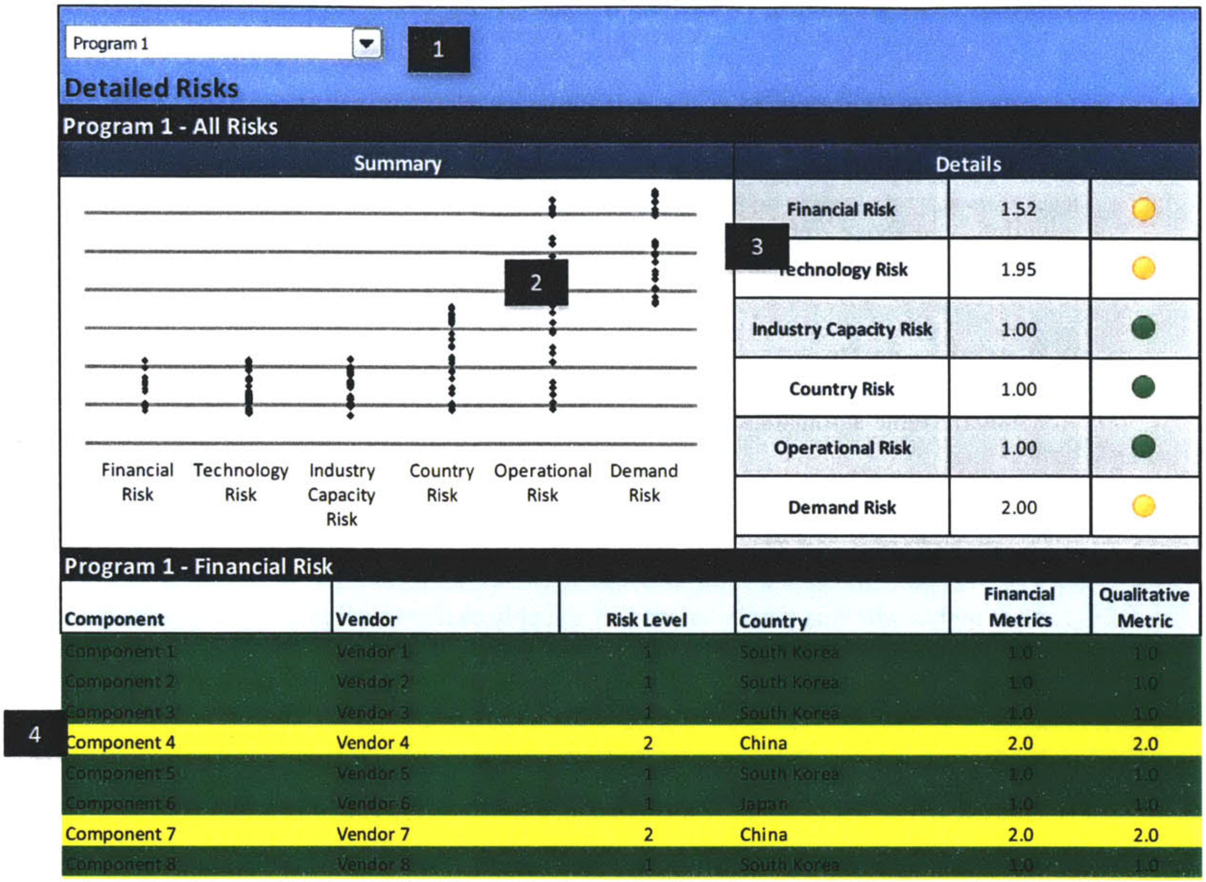

Figure 61: Example of Detailed Risk by Category report

The components of the report are highlighted numerically in Figure 61 and described below.

(1) **Drop-down menu to select product/first-tier component/supplier:** This drop-down menu allows the user to select a particular product, first-tier component or supplier. The overall risk scores will then be displayed for each category for that choice.

(2) **Illustration of risk level:** As discussed in Section 5.6, the illustration of the risk level shows two different charts: the scatter chart shows the distribution of risk for all nodes within the

network, while the numerical scores and corresponding colors collapse these individual risk scores into a single number. The colors provide a simple way to view the risk level, with a score less than or equal to 1 corresponding to green, between 1 and 2 corresponding to yellow, and above 2 corresponding to red.

(3) **Risk category:** The risk categories also function as buttons. When double-clicked, the rows below the table automatically populate with the individual nodes that constitute that particular product's supply chain, first-tier component supply chain, or those with which the chosen supplier is associated. This is accomplished using a Visual Basic macro that locates each node within with that particular product's supply chain as well as the relevant data for those nodes.

(4) **Node list:** The list of nodes that is populated based on the user's selection is color-coded so that a user can easily see which nodes have an elevated risk score. In addition, the columns display the individual data signals on which the risk score is based. In the example above, a user can easily see that for Component 4, the Financial Metric risk score is elevated. The user can then open the Financial Risk spreadsheet to determine why this is the case and whether follow-up actions are necessary.

2. **Risk map:** This view would show a color-coded risk map for each product, first-tier component or supplier across the six categories of risk. The risk level for each category would be indicated by a color, with red corresponding to high risk, yellow as medium and green as low risk. In this case, double-clicking on a particular box would take the user to the "Detailed Risk by Category" tab, which would then highlight the specific risk chosen and populate the node list below. An example of a risk map is shown in Figure 62.

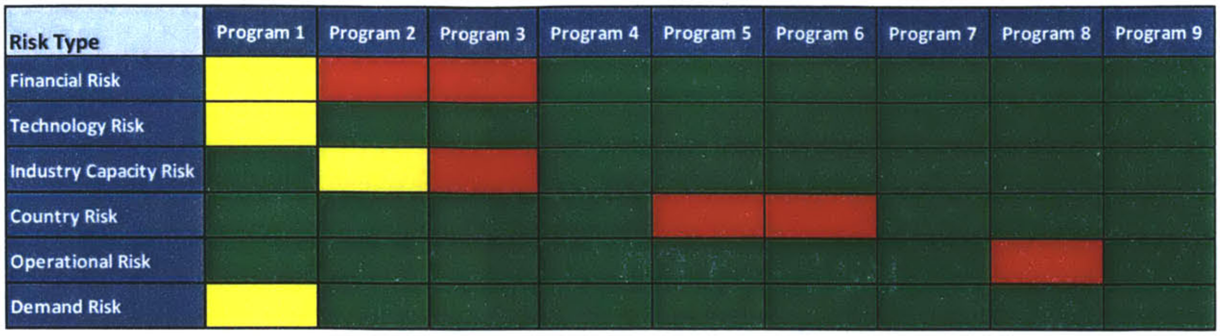

Figure 62: Risk map report view screenshot

3. **Risk charts:** This view would show individual risk levels for a product, first-tier component or supplier based on its revenue or profitability impact. For a first-tier component, the monetary impact would be based on the product to which it belongs. For a supplier, it would be based on the associated products for which it manufacturers components. The purpose of this view is to allow a user to quickly determine which potential risks have the greatest potential financial impact on the company. Figure 63 illustrates an example of this type of risk chart.

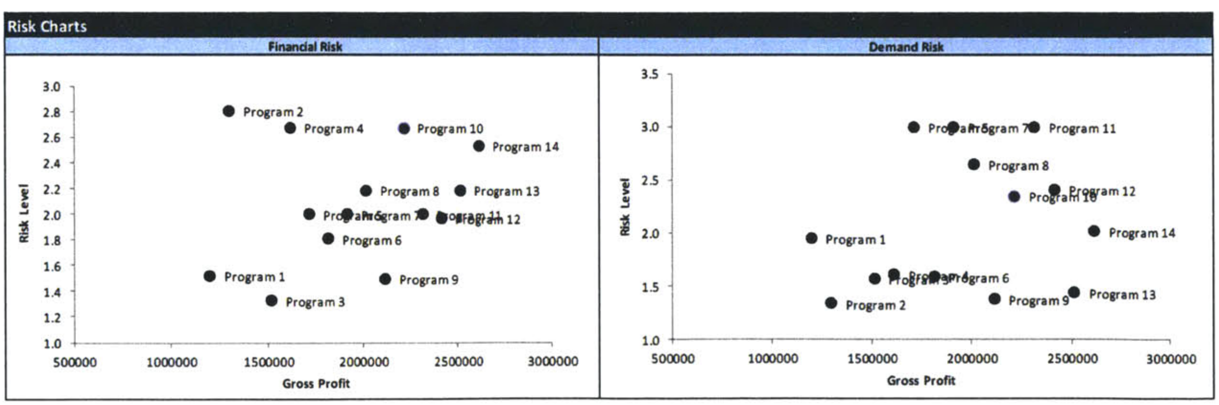

Figure 63: Risk charts that show risk level versus gross profit

6.2 Data considerations

The process as proposed has significant data requirements, which perhaps represents the largest obstacle to implement this risk identification process. As discussed in section 4.2.2, the ideal state for such a process would be one in which the full supply chain network for each major component and every product is known and visible. For each node within the network, the tool would require up to 30 data points. The data elements highlighted in Chapter 5 for the initial model were chosen because they are already being collected at the company or could be collected easily and automatically from external sources. However, for a product as complex as a mobile phone, gathering and maintaining a database this large simply may not be feasible given the complexity of the product and large number of components.

Given this, it may be necessary to prioritize products or components which are deemed to more significant. For products, it could be products which have greater strategic or financial value to the company, such as newer products or those that contribute the largest amount of revenue or profit. For components, it may be those which have historically had more frequent or significant supply shortages.

One other important consideration regarding data is whether or not certain data will actually be available at Nokia. The initial building out of the tool for a particular product requires the participation of first-tier suppliers, who may have information that Nokia does not about their own suppliers further upstream. These first-tier suppliers will have to share certain information that has thus far been confidential in order for Nokia to have full visibility into its supply chain. The willingness of suppliers to share this information will be important.

6.3 Organizational responsibilities

Given that usability of the tool was a high priority, it was important that responsibilities for using the tool are considered within the current organizational structure and do not s alter individuals' daily roles. As highlighted above, usage of the tool would involve the following personnel:

- **Materials Management Team:** The Materials Management team should have primary responsibility for maintaining the tool and updating its parameters. The team should ensure that external data is downloaded periodically as described, that internal data is current and accurate and that surveys are filled out by the component sourcing teams in a timely manner. The team should also work with the business units to ensure that their needs are being met in terms of desired reports in order to best highlight potential supply risks.

- **Component Sourcing Team:** The primary responsibility of the component sourcing teams would be to fill out the necessary survey questions as requested by the materials management team. In addition, it would be the responsibility of the component sourcing teams to work with first-tier suppliers to gather the necessary data for suppliers further upstream given that they have the closest supplier relationships. Component sourcing teams should also likely be involved in refining and updating the parameters of the model as well, given that they would likely have the most knowledge in terms of technological changes and supplier capabilities.

- **Business Units:** The responsibility of the business units should be to provide input to the Materials Management team as to what the desired reporting views should be. In addition, business units should have ultimate responsibility for any follow-up steps of risk assessment and mitigation that may be necessary. This step could involve working with the materials management team and component sourcing teams depending on the type of product involved, the type of risk identified and the supplier.

Figure 64 below illustrates how the process of risk identification may work with the proposed process, along with key roles and responsibilities of the three different groups involved.

	Step					
	Refining Model	Updating Model	Survey responses	Determining risk reports	Generating risk reports	Risk assessment/ mitigation
Primary Responsibility	Materials Management Team	Materials Management Team	Component Sourcing Teams	Component Sourcing Teams	Materials Management Team	Business Units
Working with	Component Sourcing Teams	Component Sourcing Teams Business Units Suppliers		Business Units		Materials Management Team Component Sourcing Teams Suppliers

Figure 64: Organizational responsibilities for proposed risk identification process

6.4 Implementation Approach

The implementation of the proposed approach would not only be a matter of devising an appropriate software tool and delegating responsibility of using the tool to different groups. There are several initial steps that would have to be taken in order to introduce the approach into the organization. These include:

(1) **Building out supply network database:** The first step would be to build out the database as discussed in Section 4.5. In order to do this, participation of first-tier suppliers and their willingness to share information about suppliers further upstream will be critical. To get first-tier supplier buy-in, it may be necessary to communicate benefits to them of an improved risk identification approach.

(2) **Define and categorize risks:** This project consisted of an initial attempt to categorize and define risks based on a small sample size of risks that were historically encountered by Nokia. In order to generalize the approach to other component areas, a more comprehensive analysis of the risks that have been encountered would have to be conducted. From these, it may be necessary to narrow down the scope into those risks that are deemed to be most important or most frequently impact the company.

(3) **Determine key data to track:** The next step would be to determine what data to track that could potentially help anticipate the risks that have been identified. This could be accomplished both by looking at historical data that have been tracked by the company and interviews with key stakeholders in the risk identification approach. This step should consider feasibility of tracking and maintaining updated data on a consistent basis in choosing appropriate data elements.

(4) **Define causal linkages:** Based on the chosen data, the linkages between data and risks would have to be determined. These could be based on a regression analysis if possible in certain cases, or a logic model similar to the one constructed for this project.

(5) **Understand reporting desires:** It is important to understand what risk identification reports to generate that would be most helpful to those who will actually use them. For this project, discussions with key stakeholders suggested a desire to view risks not only by supplier, but also by product or first-tier component, and how a particular risk could financially impact the company. Additional discussions with members of the business units could reveal further dimensions of desired reporting visibility. Understanding these needs will help determine how to build a model to best address them.

7 Conclusion

The project described in this thesis aims to improve on existing supply risk identification approaches for companies with complex supply chains in which component manufacturing is outsourced. After examining a specific situation at Nokia, as well as risk identification approaches that have been proposed in literature and used in practice, a new risk identification process was developed. This process consists of three main steps: mapping out the supply chain network, defining key risks and identifying data elements that could potentially help anticipate these risks.

This project contains suggestions and important considerations for how to proceed with each of these steps by using the risk identification process at Nokia as an example. In order to map out the supply chain network, certain data elements should be captured, but the amount of data should be limited to ensure that data is consistently available and easy to obtain. Categorization of key risks can be based on historical risks that have materialized, though the categories and risks may vary by component type and may change over time. In choosing appropriate data elements, one should consider internal data, external data as well as the opinions of experts that are elicited through questionnaires, as no single one of these data types is sufficient to anticipate risks. The model developed should consider how the interaction of these factors can anticipate supply risks.

There are certain drawbacks to consider in using the proposed approach. These include the potentially large data requirements which would depend on initial and ongoing participation of first-tier suppliers. Certain data may not be available or may be difficult to get for smaller suppliers in particular. Also, the use of a logic model would require the enumeration and maintenance of many logic rules, the number of which would increase exponentially with the number of explanatory data factors chosen. Finally, the model would have to be constantly updated and refined, particularly in an industry such as mobile phones in product life-cycles are relatively short and technological change is rapid.

Despite these drawbacks, an improved risk identification approach could improve on existing risk identification practices in three ways: first, additional visibility into upstream suppliers could help identify risks earlier on; second, the approach could help connect previously disparate factors whose interaction leads to supply availability issues; third, the approach could help generate certain reports that would help with subsequent steps of risk assessment and mitigation.

8 References

Alpert, B. (2004), "Nokia's Bold Expansion Plans," Barron's, November 8, 2004.

Anderson, J., and Jonsson, M. (2005), "Mobile Transitions," *Business Strategy Review,* London Business School.

Ayyub, B. (2001), *Elicitation of Expert Opinion for Uncertainty and Risks*, CRC Press LLC, Boca Raton, FL.

Babbie, E. (2010), *The Practice of Social Research*, Wadsworth, Belmont, CA.

Basu, G., Ben-Hamida, M., Butner, K., Cope, E., Dao, H., Deleris, L., Dong, J., Helander, M., Katircioglu, K., Ray, B., and Torpy, J. (2008), "*Supply Chain Risk Management: A Delicate Balancing Act. A Multi-faceted view on managing risk in a globally integrated enterprise*," IBM Global Business Services, Somers, NY.

Berggren, C. and Bengtsson, L. (2004), "Rethinking Outsourcing in Manufaturing: A Tale of Two Telecom Firms," European Management Journal, Volume 22, pp. 211-223.

Carter, P., and Guinipero, L. (2010) "Supplier Financial and Operational Risk Management," CAPS Research.

Chan, F., and Kumar, N. (2005), "Global supplier development considering risk factors using a fuzzy extended AHP-based approach," *Omega: The International Journal of Management Science*, Volume 35, pp. 417-431.

Chopra, S., and Sodhi, M. (2004), "Managing Risk to Avoid Supply Chain Breakdown," *MIT Sloan Management Review*, Volume 46, No. 1.

The Economist (2008), "Nokia: Ovi go again," December 6, 2008.

Gaudenzi, B., and Borghesi, A. (2006), "Managing risks in the supply chain using the AHP method," *International Journal of Logistics Management*, Volume 17, Issue 1, pp. 114-136.

McGill, W., and Ayyub, B. (2007), "Multicriteria Security System Performance Assessment Using Fuzzy Logic," *The Journal of Defense Modeling and Simulation: Application, Methodology, Technology*, Volume 4, Issue 4, pp. 356-376.

Moeinzadeh, P., and Hajfathaliha, A. (2010), "A Combined Fuzzy Decision Making Approach to Supply Chain Risk Assessment," *International Journal of Human and Social Sciences*, Volume 5, Issue 13, pp. 859-875.

Nokia, 2005-2010 Annual Reports, from company website (www.nokia.com).

Normann, A., and Jansson, U. (2004), "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident," *International Journal of Physical Distribution and Logistics Management*, Volume 34, Article 5, pp. 434-456.

Ray, B., Apte, C., McAuliffe, K., Deleris, L., and Cope, E. (2008), "Harnessing Uncertainty: The Future of Risk Analytics," IBM Research Report, IBM Research Division, Yorktown Heights, NY.

Sheffi, Y. (2005), *The Resilient Enterprise*, MIT Press, Cambridge, MA.

Tang, C., and Lau, H. (2011), "A Rule-Based System Embedded with Fuzzy Logic for Risk Estimation," *Eighth International Conference on Fuzzy Systems and Knowledge Discovery*, pp. 50-54.

Trkman, P., and McCormack, K. (2009), "Supply chain risk in turbulent environments—A conceptual model for managing supply chain network risk," *International Journal of Production Economics*, Volume 119, pp. 247-258.

Upbin, B. (2007), "The Next Billion; Nokia covers the globe, but its phones are a flop in the U.S. and it's a weakling on the Web. There's a plan to change all that," Forbes, November 12, 2007.

Veverka, M. (2010), "Nokia's Smartphone Blunder," Barron's, July 26, 2010.

Zadeh, L. (1965), "Fuzzy Sets," *Information and Control,* pp. 338-353.

Zsidisin, G., and Smith, M. (2005), "Managing Supply Risk with Earlier Supplier Involvement: A Case Study and Research Propositions," *The Journal of Supply Chain Management*, Volume 41, Issue 4, pp. 44-57.