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A risk assessment framework for the supplier of manufacturing services.

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A Risk Assessment Framework for the Supplier of Manufacturing Services

by

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ABSTRACT

Keywords: service-based manufacturing, manufacturing service provider, risk assessment, simulation

The practice of service-based manufacturing, utilized in various industries, especially in electronics, pharmaceuticals, and automotive, is on a rise as it enables increased enterprise effectiveness in dynamic contexts [1].

In such scenario, two different actors can often be distinguished: the End User (EU) and the Manufacturing Service Provider (MSP). Depending on the nature of the manufacturing service supplied and the relative power of the two parties, the MSP has to consider various risk factors, which can potentially jeopardize its success with the contract.

This thesis describes a risk assessment approach for the contractual relationship of an MSP and an EU, in the three most risky scenarios. The effects of the risk factors on the success of the relationship are stochastically simulated and the simulation results are analyzed. The developed framework can be utilized by the suppliers of different manufacturing services to help them with their risk assessment and management activities.

DEDICATION

To my family and friends.

ACKNOWLEDGEMENTS

My entire master thesis has come to completion through the steady and invaluable support of the academic guidance for which I am eternally grateful to my supervising advisor, Dr. Z. J. Pasek. Without him, this thesis could not have been fulfilled. I also wish to express my gratitude to the other members of my master thesis committee, Dr. L. Oriet, Dr. F. Rieger, and Dr. G. Zhang for their helpful advice and critical readings during this work.

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LIST OF ABBREVIATIONS AND ACRONYMS

CDM: Contract Design Manufacturer

CM: Contract Manufacturer

CRO: Contract Research Organization

EMS: Electronic Manufacturing Service

EU: End User

MSP: Manufacturing Service Provider

NPV: Net Present Value

ODM: Original Design Manufacturer

OEM: Original Equipment Manufacturer

RBV: Resource-based View

SDRF: Software Development Risk Factor

StdDev: Standard Deviation

TCE: Transaction Costs Economics

CHAPTER 1 Introduction

1.1 General Overview

1.1.1 Service-based Manufacturing

Today's markets in many industrial sectors have reached such an unprecedented high degrees of volatility, competitiveness, and globalization, that it has made many traditional manufacturing paradigms and business models, such as vertical integration and mass production, practically infeasible. Leasing manufacturing related services, including not only manufacturing itself but also other services such as product design, process design, research and development, after-sales services, and maintenance, is a quite new solution which has proved to be successful in different market sectors, especially in electronics, automotive and pharmaceuticals.

In general, two main actors can be identified in a service-based setting [14]:

- The End User (EU) who interacts with the market of finished goods as a market supplier. The EU's core business is its interaction with the market itself. The EU often adds its value to the product through innovation, design, marketing and branding.
- The Manufacturing Service Provider (MSP), who is made responsible for the manufacturing response to the market and for customization. Its core business, then, is manufacturing itself, which allows concentrating on the needed competencies and, consequently, increasing effectiveness. The MSP has to acquire, operate and maintain

the manufacturing facility [1].

The MSP may be known under various names, such as, for example, Contract Research Organization (CRO), Contract Manufacturer (CM), Electronic Manufacturing Service (EMS), Contract Design Manufactures (CDM), or Original Design Manufacturer (ODM), among others, and have different functionalities[14]. In some cases, the MSP is even handed over everything from design to fulfillment [18].

Leasing a manufacturing related service provides the EU with considerable savings and cost reduction mainly as it requires no investment and capital tied in physical assets and allows it to focus on its core competencies and improve its agility [1]. According to a survey of companies in U.S., U.K., and Continental Europe, top five reasons of outsourcing operations are:

- Achieving best practices,
- Access to new technologies and skills,
- Cost discipline and control,
- Improve service quality, and
- Focus on core competencies [20].

This probably justifies why many well-known companies, such as, for example, HP, Microsoft, and Ericson [18], are among the extensive users of manufacturing services.

The MSP, on the other hand, can enjoy better capacity utilization, expertise and knowledge accumulation, economy of scale and scope, and ability to smoothen demand fluctuations across several clients [2]. Thus, new generations of companies which are suppliers of different manufacturing services have emerged in the last couple of decades, such as, for example, Flextronics (electronics), Ideo (design), Delphi (automotive), and Foxconn (electronics).

The inter-firm relationship of the two actors is governed by a contract signed for a defined time horizon [14]. Each actor typically has to manage a large number of contracts signed with different parties. This is especially important for the MSPs as they often have to handle a large number of contracts signed with different EUs each with different requirements, power, and located in a different part of the world.

1.1.2 Risk Assessment and Management

There is no doubt that risk management is an integral part of every decision making process as uncertainty is an integral part of life. Uncertainty of decision outcomes and the decision making environment can lead to risk, the potential of loss [7]. The categories of uncertainty (Table 1) provide a better understanding of various uncertainties involved in different projects.

To be more precise, risk can be defined as "a measure of probability and severity of adverse effects" [15]. In other words, risk is "a concept that denotes a potential negative impact to an asset or some characteristic of value that may arise from some present process or future event" [22].

Table 1. Managerial categories for uncertainty [28]

Type of Uncertainty	Definition
In time	Uncertainty about when certain events may occur or the ability to react to them
In control	Inadequate authority to make or influence decisions or inconsistency in processes
In information	Inadequate or inaccurate information on which decisions are based

"Risk Assessment" involves identifying sources of potential harms, assessing the likelihood of their occurrence and consequences [22]. In fact, the main focus of "Risk Assessment" is finding answers to the following questions:

What can go wrong?

What is the likelihood that it would go wrong?

What are the consequences?[15]

"Risk Analysis" is any qualitative or quantitative method used for assessing the impacts of risks on decision situations [29]. On the other hand, "Risk Management" involves finding ways to mitigate these consequences through evaluating possible alternatives and their associated trade-offs in terms of all potential costs, benefits and risks [15]. Risk management can be carried out through different activities, and the following are usually considered as typical risk management activities:

Risk mitigation - risk reduction - preventative measures that can be implemented for some risks to significantly reduce the probability of the risk occurring.

Risk mitigation - impact reduction - involves reducing the impacts of the risks in case preventing the risk from happening is not possible.

Contingency planning - plans for how to survive a problem. Contingency plans say what is to be done after the risks are actualized. A particularly important form of contingency plan is a disaster recovery plan [30].

The practice of "Total Risk Management (TRM)" covers both "Risk Assessment" and "Risk Management" and addresses a set of four sources for failure within a hierarchical-multi-objective framework. These four sources of failure are hardware failure, software failure, organizational failure, and human failure [15].

One means of managing risks is to characterize risky scenarios and identify the factors in those scenarios. To analyze these scenarios, first, the contributing factors have to be identified and quantified. Then, these risk factors can be arranged in different scenarios and, by propagating their uncertainties, can be related to system outcomes [7].

In general, risk management models can be classified into two categories:

Classical models which involve statistical analysis. Examples of classical models are Monte Carlo simulation and influence diagrams, and

Conceptual models which incorporate fuzzy set analysis. An example of conceptual models is fuzzy sets [27].

Holistic Risk Management [9] is a rather new and more comprehensive process which differs from conventional Risk Management in two ways:

It considers all the risks which threaten the objectives of an organization and not only those which are 'insurable' or 'fortuitous'.

It considers minimizing risk and the impact of risk as a main management function which must be an integral part of everyone's job within an organization.

Holistic Risk Management takes into account risk such as, for example, risks threatening an organization's brand value, and public and trade reputation as well as the organization's intellectual property, legal rights and employees and risks associated with the wide usage of IT in today's world such as computer crashes [9] which are inevitable risk factors in today's digital world.

1.2 Proposed Research

1.2.1 Motivations of the proposed research

Managing the life cycle of the signed contracts is a high priority for any company and a high percentage of executive managers believe that their top pressure is to better assess and mitigate external (supplier and customer) and internal risks [19]. A manufacturing service contract is no exception and requires special attention to risk assessment and mitigation activities to be managed effectively. In fact, outsourcing and utilizing service-based manufacturing strategies are, in essence, adopted to manage risks of investment, technological changes and supply chain risks.

This is especially important for the MSP as it has to make extensive investments in capacity and human resources and has to work with maximum efficiency to keep its service attractive to the EUs and be profitable, at the same time. It has to do more than simply reducing labor costs by moving production to low-wage areas, which incorporates its own risks. The MSP has to take advantage of technologies such as, for example, reconfigurable manufacturing, leveraging the modularity (both hardware and software) and standardization [1]. Moreover, a single MSP has multiple contracts with multiple clients each having different degrees of relative power and requirements.

In order to be able to asses and mitigate risks associated with the supply of manufacturing related services, the MSP has to consider both its internal and external risk factors. A risk assessment framework is required to help the MSP identify the risk factors, determine their inter-relationships and asses their probability of occurrence and negative impacts in a standard systematic way.

Risk assessment and management literature related to this research is primarily focused on software development and construction projects. While a fair amount of the methods and risk factors discussed in the literature ([10][9][7][11][15][17]) are also relevant to MSPs, as the nature of manufacturing services is different and unique, a new framework for identifying and assessing the effects of its associated risk factors is required. Moreover, the characteristics of the service supplier, or the software development team, and its relative power and the service under contract, which give rise to certain risk factors, are not considered in the literature.

1.2.2 Assumptions of the proposed research

This thesis is going to provide a general framework for the supplier of manufacturing services (MSP) to perform quantitative risk analysis through identifying, assessing, and mathematically modeling the external risk factors associated with a supply contract regarding supply of a given manufacturing service for a given EU.

The proposed framework considers the attributes of the contracted service and the parties' relative balance of power as the root causes of risk factors and follows a hierarchical holistic approach to evaluate the MSP's chances of success with a given contract. Using Monte Carlo simulation, the developed stochastic mathematical model is simulated and analyzed for numerical examples.

The conducted analysis can be used to devise risk intervention and mitigation plans as part of the risk management process. The outcomes of the devised risk intervention and mitigation plans can be also evaluated by adjusting the developed model using new parameters for the simulated examples.

Note that, in our model, we only consider risks of the contractual relationship of the MSP with the EU. MSP's internal risk factors, which are present regardless of its contractual commitment to the EU, such as general managerial challenges or incorrect strategic choices, are not taken into account.

Moreover, other external risk factors related to MSP's suppliers or environment are not considered. However, incorporating these risk factors in the model is quite straight forward. Also, a stochastic mathematical model is only developed for the three riskiest scenarios. Nevertheless, generalizing the model and using that for other scenarios is also possible and straightforward.

1.2.3 Applications of the Proposed Model

The developed model can be of great help to MSPs' executives before and after bidding or signing off contracts with their clients. It provides a far-sighted holistic tool which helps identifying, modeling and assessing the impacts of risk factors on the MSP's success with the contract and improves Contract Lifecycle Management (CLM) process.

Contract or risk managers can use the developed model to have a clear understanding of their position, relative to their clients, and categorize the service they are committing to deliver and the risk factors they are probably going to face. Such understanding will help them make better choices about the type of the contract, and be more proactive while negotiating the terms of the contract. Moreover, such framework model will make the risk managers better able to evaluate and predict the efficiency of their risk mitigation and risk management plans.

In summary, the proposed model will help the managers of manufacturing- service suppliers efficiently perform risk assessment and analysis and, therefore, be able to be more efficient at risk management.

CHAPTER 2 Review of literature

2.1 Service-based Manufacturing

Service-based manufacturing can be considered as an extension of traditional outsourcing. Outsourcing emerged as a popular operational strategy in the 1990s and research on it started at about the same time. Since outsourcing IT/IS related activities is now an almost standard practice for many companies [8], extensive research has been conducted on different aspects of outsourcing different IT/IS activities.

In 1998, Currie and Willcocks studied four types of IT sourcing arrangements, total outsourcing; multiple-supplier sourcing; joint venture/strategic alliance sourcing; and insourcing. They specified the relationship between the scale of IT market used and level of client/supplier interdependency, on one hand, and each type of arrangement on the other hand and described the risks associated with each resulting situation. They also included case studies to show the importance of contextualization of IT sourcing decisions by market, industry sector and managerial/technical skills [34].

In 2000, Plambeck and Taylor studied the effect of outsourcing manufacturing to contract manufacturers on profitability and investment in capacity and innovation. They showed that even though contract manufacturing can increase profit through more efficient capacity utilization, it may reduce profit by weakening the incentives for innovation.

They concluded that contract manufacturing improves profitability for the industry as a whole if and only if Original Equipment Manufacturers (OEMs) are in a strong bargaining position vis-à-vis the Contract Manufacturer (CM). They proposed pooling capacity between OEMs through supply contracts or a joint venture as a more desirable alternative solution for week OEMS, although this may result in overinvestment in innovation and capacity.

In 2005, Rohde studied the outsourcing practices of very small through to medium-sized manufacturing organizations. Her research revealed that while the decision to outsource was similar across all firms, the manner in which functions were outsourced differed depending on the size of the firm [23]. The results of many of such research efforts can be generalized and extended to outsourcing other functions and services, including manufacturing-related services.

A quite comprehensive literature survey on outsourcing was done by Jiang & Qureshi in 2005 along with suggestions regarding future opportunities in this area. They identified three gaps in outsourcing research literature: little attention to outsourcing impacts on firms' performance and value, reliance on managers' estimates in place of tangible metrics, and focus on cost savings rather than outsourcing decision's ultimate benefits (firms' value) for company investors [21].

Also in 2005, Kakabadse & Kakabadse surveyed U.S., U.K., and Continental Europe companies regarding current and future outsourcing trends in 2005. They concluded that the existing trend of effectively managing relationships with key trusted suppliers is the main difference between current and future outsourcing trends and that the best-run companies of the future will focus more on establishing meaningful contractual relationships with a number of key business partners. They identified studying the relationship between the outsourcing results and the outsourcing contract as a promising research area [20].

In 2006, Barthélemy & Quélin used Transaction Cost Economics (TCE) and the Resource-Based View (RBV) of the firm to study outsourcing agreements. They stressed the critical nature of the relationships between outsourcing clients and their vendors, especially with regard to support activities and services that have direct connections with manufacturing and the 'core businesses'. They showed how some characteristics of the contract (e.g. penalties, incentives and monitoring) can offset any opportunism risks and mitigate hazards.

The concept of service-based supply of manufacturing services was introduced by Urbani et al, in 2002. They proposed manufacturing capacity supply as an extension of traditional outsourcing and an enabler for improved responsiveness and effectiveness. They highlighted the drivers for this evolution in the manufacturing capacity supply and studied the 8 feasible scenarios where the service provider becomes responsible for the supply, operation and maintenance of the manufacturing capacity needed by the customer, for the time horizon of the service along with real-life examples [1].

In 2007, Akbarzadeh & Pasek developed an analytical framework for analyzing the behaviors of the actors towards a manufacturing service supply contract. They classified the possible contractual relationship cases into 6 categories based on the attributes of the service under contract and power structure. They analyzed the negotiation space and equilibrium point in each case and concluded that the more balanced the power of the parties and the more standard the service contracted, the better the efficiency of a service-based supply approach for the whole industry in long term [14].

2.2 Risk Assessment and Management

Risk assessment, management and analysis of outsourced activities are quite extensively studied in the literature, qualitatively or quantitatively, in many different fields, including health care, environmental and safety engineering, and information technology. There is also a fair amount of research conducted on assessing and managing risks involved in outsourcing different activities, especially IT related activities. Most of such studies are focused on the risk factors the end users and buyers of outsourced activities have to take into account and perform risk analysis from the buyers' perspective. However, software development and construction projects are exceptions since the software development team's and contractor's risk factors are also widely studied and modeled in the literature ([7][9][10][11][14][27][26]).

In the field of software development, a variety of approaches have been used to investigate Software Development Risk Factors (SDRFs). There are prioritized lists, taxonomies, questionnaires and matrices, for assessing software development risks. There exist SDRFs lists numbering to the orders of 150 or more factors [10]. Houston et al found twenty-nine of these factors were cited most often in the literature and were more important according to their survey respondents [7].

In the field of construction, Mustafa & Al-bahar, in 1991, investigated the subject of risk assessment and developed a scheme of classifying the various sources of risk in construction projects. They applied Analytic Hierarchical Process (AHP) in assessing the riskiness of a real-life constructing project [26].

In 1998, Miles & Wilson explored risk management in the development of a power subsystem given the need to push the performance envelope. They described sources of project risk as complexity and novelty of the development process and proposed a risk space analysis tool for objectively identifying risk factors [17].

In 1999, Mulholland and Christian developed a schedule risk assessment process for construction projects involving typical inputs and expected output to base on the past experience. They defined five dimensions of uncertainty in schedule of construction project and considered the variance of the performance time distribution of a project as a measure schedule risk. The developed computer-based system in this paper provides a structured approach for identifying the sources of risk in a project and determining the range of schedule outcomes based on these risks [33].

In 2000, Sumner described the risk factors associated with enterprise-wide/ERP (enterprise resource planning) projects and identified the risk factors in ERP projects which are unique to these projects and grouped them into different categories. Also, she organized these risk factors within the context of the stages of an ERP project and assigned individuals responsible for managing risk factors at each phase and provided strategies for controlling risk factors [25].

In a key paper published in 2001, Houston et al described an approach for modeling and simulating the effect of risk factors as a means of supporting risk management activities of assessment, mitigation, intervention and contingency planning. They found the six most important SDRFs through qualitative and quantitative surveys and studied their effects. They then produced a base model for stochastically simulating the effects of these risk factors [7].

Bryson and Sullivan, in 2003, explored ERP outsourcing in terms of the application service provider (ASP) approach, in which a third-party vendor hosts, manages and maintains various data and ERP applications, and presented a framework to analyze incentive schemes and design ERP outsourcing contracts for the mutual gain of the parties. This framework has three phases. The first two, outsourcer business analysis and vendor business analysis, include identifying business objectives of parties, identifying risks, their impacts and possible risk resolution actions. The third phase, outsourcing alternatives analysis, focuses on development of effective outsourcing contract using transaction cost theory and based on the outputs of the first two phases [6].

In 2006, Osei-Bryson & Ngwenyama stressed the importance of managing the IS/IT outsourcing vendors' performance using incentive contracts and pointed out the fact that to develop an outsourcing contract the IS manager must quantify risks and benefits. They offer a method and some mathematical models for analyzing risks and constructing incentive contracts for IS outsourcing [8].

Also in 2006, Suri & Soni studied the potential impact of "low morale"- a risk factor, on project outcomes, and proposed an approach to simulate Low Morale to analyze its effect on certain software development risk management activities. Their simulator randomly generates a Schedule Pressure level from empirical distribution and computes average morale level and then Efficiency level based on that[10].

Table 2 summarizes the key papers and their associated limitations which this thesis attempts to complement and contribute to.

Table 2. Key papers summary

No	Paper	Method	Limitations
1	Mustafa & Al-bahar (1991)	AHP	• Deterministic model • Too specific (to a certain construction project)
2	Miles & Wilson (1998)	Risk space analysis	• Too specific (to certain power plant project) • Focuses only on novelty and complexity as sources of risk • Does not precisely define customer/ stakeholder satisfaction considered as outcomes
3	Mulholland & Christian (1999)	PERT, information technology of HyperCard and Excel	• Focuses only on construction projects • Only considers schedule risks
4	Houston et al (2001)	Stochastic simulation, surveys	• Focuses only on software development projects • Does not consider project and arrangement properties • Is only concerned about project time and budget (not holistic and far-sighted)
5	Suri & Soni (2006)	Stochastic simulation	• Only considers and models "Low morale" and its effect on efficiency level • Focuses only on software development projects

			• Does not consider project and arrangement properties
6	Akbarzadeh & Pasek (2007)	Mathematical analysis of negotiation space and equilibrium point	• Only considers the bottom-line • Does not specifically focus on the risks

As shown in the table, there is a gap in the risk assessment literature with regard to considering risks threatening an enterprises image and contractual relationship with its clients. In other words, almost all similar papers in the literature do not have a holistic approach and only focus on risks jeopardizing the project time and budget. Moreover, almost all the papers listed in the table, except number 6 and to some extent number 2, are either too general or too specific to a certain project.

This thesis attempts to address these limitations and gaps in the current literature and provide a framework which takes into account the context of performing risk assessment with a far-sighted holistic point of view.

CHAPTER

3 Design and methodology

3.1 Scenarios Studied

Considering the balance of power and the attributes of the manufacturing service under contract, six possible extreme scenarios can be considered [14]. Figure 1 shows the sources of different types of power [13] whose weighted sum determines parties' relative power. The negative signs indicate an adverse relationship.

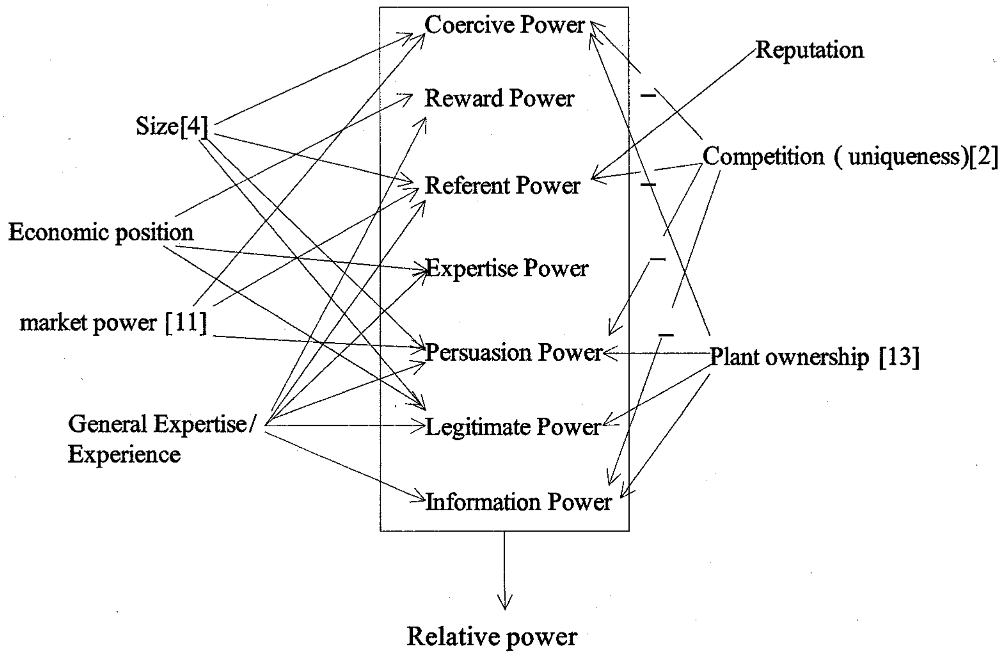

Figure 1. Different types of power and their sources

The relative balance of power is influenced by the following factors:

- Previous relationship[2]
  - Trust
  - Loyalty
- Continuation probability[3]
- Parties culture
  - Organizational Culture
  - Industry
  - Geographic region
- Regulated environment

On the other hand, the service under contract can be a commodity service or a specific and unique service. Factors defining specificity are illustrated in Figure 2.

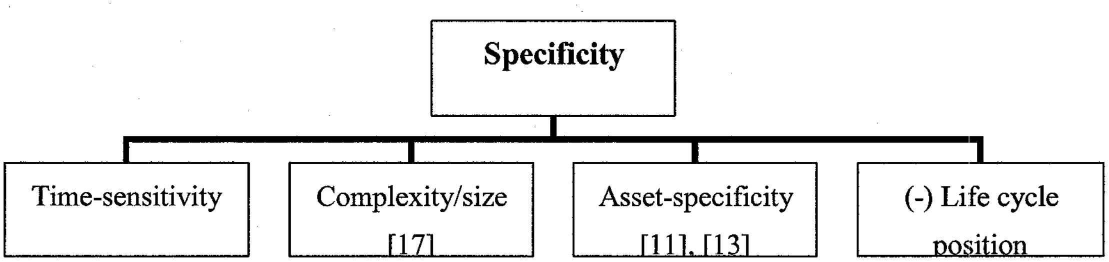

Figure 2. Definition of specificity

The six possible combinations of these two factors, i.e. service attributes and the balance of power, can be considered as six scenarios as illustrated in Figure 3.

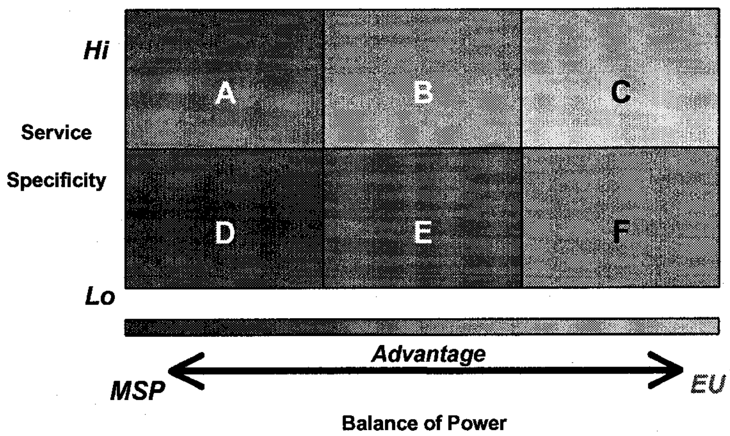

Figure 3. Different possible scenarios

Mathematical analysis performed in [14] shows the amount of hypothetical risk involved in each scenario. According to that, the riskiest scenarios are Scenario C, Scenario A, and Scenario F. The least risky scenarios, on the other hand, are Scenario E, Scenario B, and Scenario D (Figure 4). Thus, we focus on the riskiest scenarios and apply the given framework to them to assess the probability of failure for each, and then compare the results.

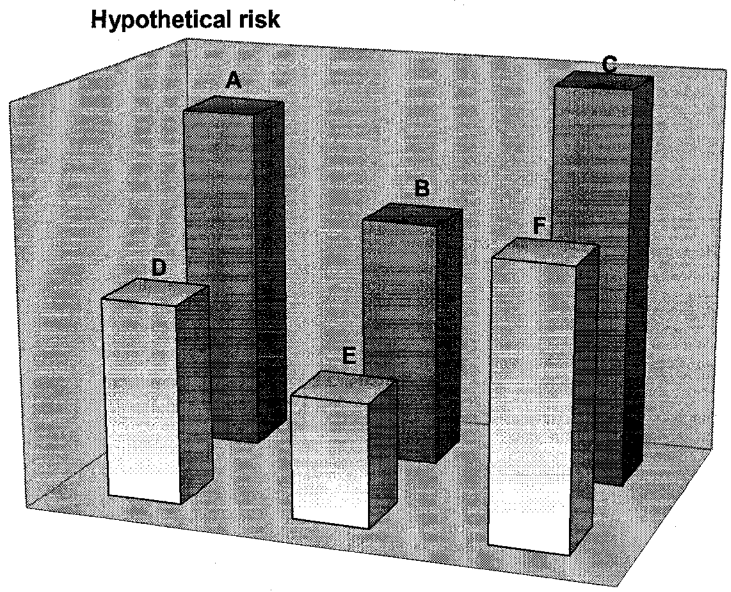

Figure 4. Hypothecial riskiness of scenarios

3.2 Cost Breakdown Structure

To calculate the costs the MSP incurs we basically use the cost structure described in [14]. The MSP rents its service to the EU for a defined period of time, $\bar{t}$, and a leasing price, L. MSP's net present value (NPV) can be formulated as [14]:

$$NPV_{MSP} = \begin{cases} \int_0^{\bar{t}} (L - C_{MSP}) \cdot e^{-\rho t} dt & \text{if } \overline{C}_{MSP} < L \\ \int_0^{\bar{t}} \left|(L - C_{MSP})\right| \cdot (e^{-\rho t} - 2) dt & \text{Otherwise} \end{cases} \quad (1)$$

where $\overline{C}_{MSP}$ is MSP's total costs of delivering the service, ρ is the opportunity cost of money for the MSP, $B = \frac{1-e^{-\rho}}{\rho}$, and $\bar{t}$ is the time horizon of the contract. To Normalize, we consider of the MSP's cost items as their percentage of L, and let L=100, and $\bar{t}=1$. Thus, we will have the percentage of net present value as:

$$NPV_{MSP} = \begin{cases} B(100 - \overline{C}'_{MSP}) & \text{if } \overline{C}'_{MSP} < 100 \\ (B-2)(\overline{C}'_{MSP} - 100) & \text{Otherwise} \end{cases} \quad (2)$$

where, $\overline{C}'_{MSP} = \sum_i \frac{C^i_{MSP}}{100}$.

Using this formula the losses will be magnified in the same way the profits are reduced as a result of lost opportunities and considering opportunity costs.

Considering the implications of Transactions Costs Economy (TCE), $\overline{C}_{MSP}$ can be broken down as follows:

- Production costs (C_{prod})
  - ➢ Investment (machinery, human resources, processes, peripheral)
  - ➢ Operational costs
    - o Adjustment costs (in response to changes in volume or product specifications)[24]
- Transaction costs (C_T)
  - ➢ Ex ante (deterministic/fixed)

    Bidding, negotiation, legal, and contracting costs, and other charges that might be incurred to set up the relationship [8].
  - ➢ Ex post (stochastic)

    Reporting, communication, transition [8], renegotiation, conflict resolution, penalties, law suits, publicity, marketing, and adaptation costs.

• Opportunity costs (ρ) [14]

We assume that the ex ante transaction costs, $C_{ex-ante}$, have been already incurred and are inputs to our model, and that opportunity costs, ρ, are also given and remain constant during the contract's time horizon. These three main categories of costs are going to be considered in the model and the costs resulting from the actualization of risk factors are added to appropriate cost categories in a linear manner.

3.3 Probability of Failure

The objective of the model is to study the probability of failure of the contract. Thus, we first need to define success or failure. Here, failure is defined as the occurrence of one or more than of the following fatal risk factors, defined in terms of binary variables:

- Financial loss (*FLo*)

$$FLo=\begin{cases} 1 & \text{if } SG_{MSP} < \varepsilon \\ 0 & \text{Otherwise} \end{cases} \tag{3}$$

- Incomplete contract (*IC*)

$$IC=\begin{cases} 1 & \text{if } P_{IC} \geq \hat{P}_{IC} \\ 0 & \text{Otherwise} \end{cases} \tag{4}$$

- Loss of partner (*LoP*)

$$LoP=\begin{cases} 1 & \text{if } P_{LoP} \geq \hat{P}_{LoP} \\ 0 & \text{Otherwise} \end{cases} \tag{5}$$

- Loss of image/reputation (*LoI*)

$$\text{LoI}=\begin{cases} 1 & \text{if } P_{LoI} \geq \hat{P}_{LoI} \\ 0 & \text{Otherwise} \end{cases} \tag{6}$$

Failure of the contract can be defined as the weighted sum of the above random variables:

$$P_{Failure}= FLo*W_{FLo} + IC*\ W_{IC} + LoP*\ W_{LoP} + LoI*\ W_{LoI} \tag{7}$$

where, $W_{FLo} + W_{IC} + W_{LoP} + W_{LoI} =1$, and, therefore, $0<P_{Failure}<1$.

Note that considering the linear cost accumulation formula and the definition of Financial Loss and Failure, convert the continuous total costs, and therefore NPV, to discrete step-wise probabilities of financial loss and failure. In other words, first, costs are accumulated and the NPV is calculated using equation (2). Then, if the obtained NPV is less than a pre-defined threshold, *FLo* will be equal to 1, which will, in turn, lead to an increase in $P_{Failure}$ by W_{FLo}.

3.4 General Methodology and Model Description

The generic risk assessment process utilized in [7] is going to be used as a roadmap. This process is composed of the following stages:

1. **Identifying the risk factors.** This stage involves analyzing the power structure and the attributes of the service under contract to identify the most important risk factors which can potentially lead to the failure of the contract.
2. **Modeling the system to incorporate the risk factors.** In this stage, the inter-

relationships between the risk factors are described and modeled.

3. **Quantifying risk factor uncertainties.** Here, random variables are defined to quantify the uncertainties associated with each risk factor. Afterwards, the a distribution function is assigned to each defined random variables using various methods, such as, for example, fitting distributions to historical data or using the opinions of experts.
4. **Propagating the uncertainties.** At this stage the model is exercised to output the probability of failure.
5. **Sensitivity analysis.** Having the probability of failure resulting from previous stages, the model can be used to find alternatives which help decreasing the probability of failure.

Each step is going to be completely customized to incorporate the unique requirements and characteristics of the manufacturing related services.

3.5 Proposed Methodology

To model the contractual relationship of the MSP and the EU, who is leasing the manufacturing services for a defined time horizon, a hierarchy of risk factors is developed using a mixture of bottom-up and top-down methods. Figure **5** illustrates the way risk factors are organized in a three-level hierarchy. The hierarchy illustrated in this figure is the output of the risk identification process and is used as the input of risk quantification and modeling process.

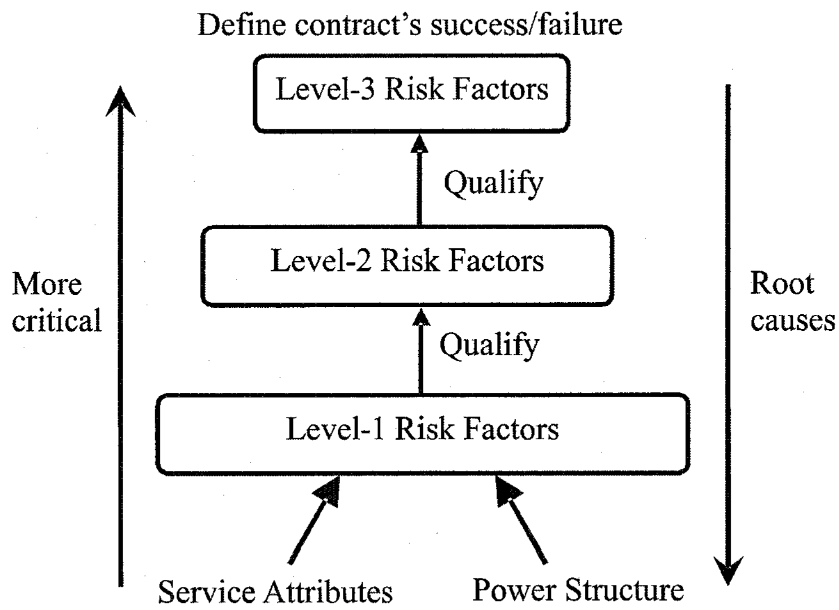

Figure 5. Risk Factors Structure

Such hierarchy, in which each level qualifies the next level, if it passes a defined threshold, makes devising risk mitigation, and management plans easier and more efficient since it considers the root cause of each risk factor. Moreover, each Level-2 and Level-3 risk factor can be traced back to one or more Level-1 risk factor. Thus, if the root cause Level-1 risk factors of each higher level risk factor are controllable, the higher level risk factor can be also managed and controlled through managing and controlling its root cause.

The generic process described in the previous chapter is customized as follows.

3.5.1 Identifying Risk Factors and Modeling the system

As mentioned before, in this stage the three-level hierarchy of risk factors is constructed using a mixed method, i.e. a combination of top-down and bottom-up methods. This means that, first, starting from the top, Level-3 risk factors are identified, then, from the bottom, the first level of the structure is built, and, finally, by connecting these two levels, the second level of the structure is constructed.

The steps followed in this stage are as follows:

Step 1_ Identifying and Modeling Level-3 risk factors

1. Considering the objective function and the definition of failure, provided in the previous chapter, list Level-3 risk factors. From our definition these fatal risk factors are as follows:
    - Financial loss
    - Loss of image/reputation
    - Loss of partner
    - Incomplete contract
2. Find the cause-and-effect relationships between the identified risk factors.

Step 2_ Identifying and Modeling Level-1 risk factors

1. List the attributes of the service under contract and the direction of the power.
2. Consider the attributes listed in sub-step 1, brainstorm their possible implications and effects, and list the most important relevant risk factors, in terms of both the probability of occurrence and the severity of the potential outcomes, resulting from each attribute. These risk factors form the fist level of risk factors of the model.
3. Find the cause-and-effect relationships between the identified risk factors.
4. List the impacts of each Level-1 risk factor.

Step 3_ Identifying and Modeling Level-2 risk factors

1. Consider Level-1 and Level-3 risk factors and find out how the Level-3 risk factors can be resulting from the Level-1 ones, considering the impacts of Level-1 risk factors found in step 2. List the most important risk factors resulting from the actualization of Level-1 risk factors which can potentially lead to Level-3 risk factors, considering their potential impacts. These risk factors form the Level-2 risk factors of the model.
2. Find the cause-and-effect relationships between the identified risk factors.

Figure 6 illustrates the process of identifying the risk factors and modeling the system. To identify the risk factors, their impacts, and their interrelationships, risk factor lists mentioned in the literature (for example in ([7][8][9][10][11][15][14])), brainstorming sessions, Delphi method, or experts' opinions can be used as guidelines, depending on their availability.

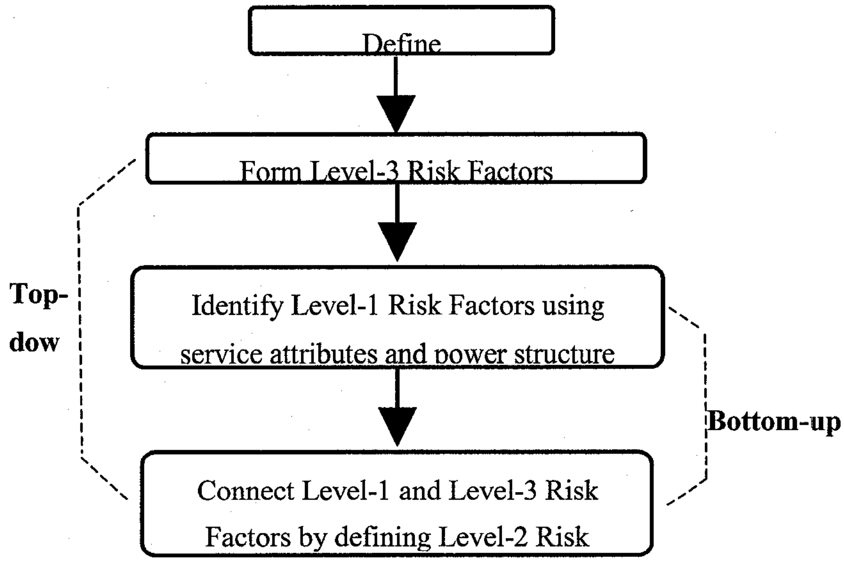

Figure 6. Identifying and Modeling Risk Factors Process

3.5.2 Quantifying Risk Factor Uncertainties

1. Start from the Level-1 risk factors and move in a bottom-up manner to higher levels. Define quantified measures for each risk factor in terms of random variables using their impacts, similar to what is done for the fatal risk factors in defining the objective function. Note that one risk factor can be translated into more than one random variable.
2. Consider the cause-and-effects relationships between the risk factors and translate these relationships into qualification relationships between the random variables defined in the previous sub-step. Also, consider that co-movements of variables in the same direction and in the opposite direction i.e. situations when a high value of one variable means a high or low value for another variable, and quantify these co-movements by setting up a correlation matrix.
3. Assign a probability distribution function to each random variable associated with each risk factor, along with the correlations between each two correlated random variable.
4. For each qualification relationship, define a threshold, whose violation activates the dependent risk factor(s), using either brainstorming or available data.

To quantify the risk factors, various methods including analysis of historical data, brainstorming, surveys, and questioners can be used. Also, some risk factors already modeled in the literature (especially in [7] and [11]) can be reused.

To model correlated variables, since different variable follow different distributions, the so called "distribution-free" approach or Spearman's rank order correlation coefficients should be used (For more information on this approach refer to Appendix A).

Before describing the simulation method used in this thesis, a brief overview of Monte Carlo simulation approach is presented.

3.5.3 Monte Carlo Simulation

In general, "Monte Carlo methods" are used to solve problems which are too complex to solve analytically (e.g. do not have closed-form solutions) through generating suitable random numbers and observing that fraction of the numbers obeying some property or properties [22]. Monte Carlo simulation is a widely used tool in many fields, including classical risk management models utilized to simulate the behavior of the system considering uncertainties of risk factors.

Monte Carlo simulation is a method for iteratively evaluating a model using sets of random numbers as inputs. It is useful for analyzing uncertainty propagation, where the goal is to determine how random variation, lack of knowledge, or errors affect the modeled system. Monte Carlo simulation is a sampling method because the inputs are randomly generated from probability distributions to simulate the sampling from an actual population. Figure 7 shows a schematic view of Monte Carlo simulation [31], note that $f(x)$ is a function of vector $x=(x_1, x_2, x_3)$.

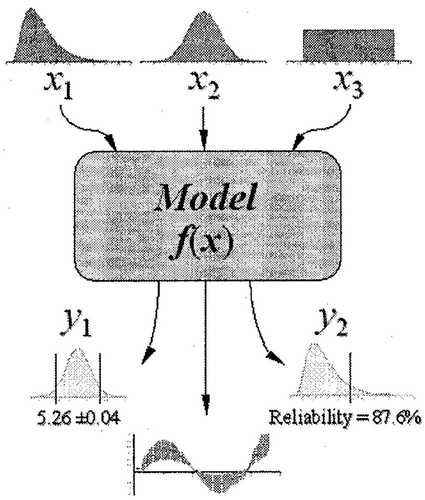

Figure 7. The Base of Monte Carlo Simulation [31]

Monte Carlo Simulation is useful method for risk assessment and management because it helps studying the behavior of the system given the uncertainties of risk factors. It allows for studying the outcomes (success or failure) of the system in the event of various possible values of random variables associated with risk factors. Thus, a Monte Carlo Simulation method is proposed to propagate the uncertainties of risk factors identified, modeled and quantified in the previous steps of the proposed methodology.

3.5.4 Propagating Uncertainties Using a Multi-stage Monte Carlo Method

Using the proposed multi-stage Monte Carlo simulation technique, stochastically simulate the model using the random variables of the first level of risk factors as the inputs, and the Level-3 risk factors, and the failure probability, as the outputs of the simulations model. Figure 8 summarizes the simulation process.

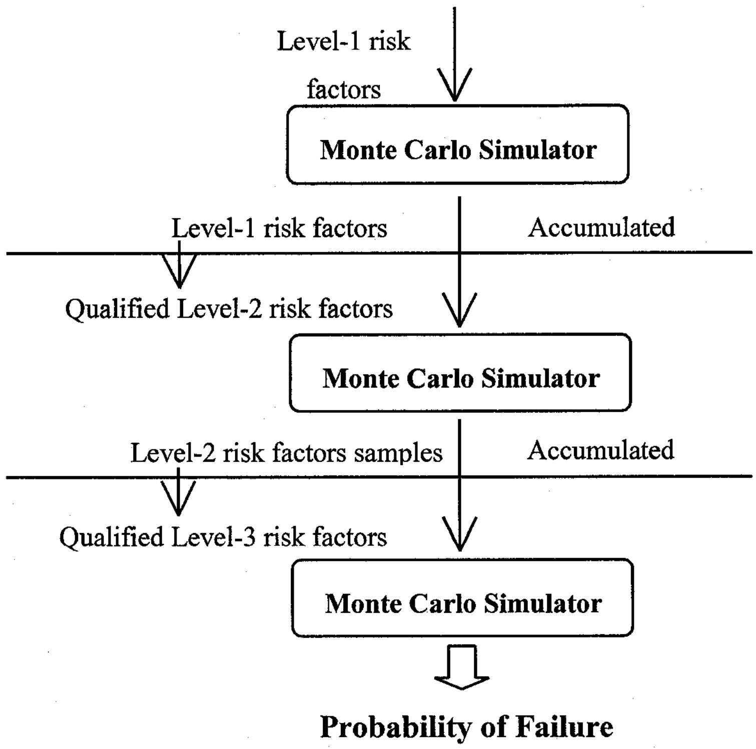

Figure 8. Proposed Monte Carlo simulation Method

To specify the required number of simulations the jack-knife technique can be used. Jack-knife technique works as follows: start with an arbitrary number of simulations, N, and run the simulation twice to get two answers. Compare the answers; and if the difference between the two results is more than a predefined limit, ê, double the simulations to 2*N. Keep doubling the number of simulations until the error is smaller than ê [15].

It should be pointed out that using Monte Carlo Simulation implies that the proposed framework model falls in the category of classical risk management models.

To implement the simulation model, we utilize @Risk, which is a Microsoft Excel add-on used for performing risk analysis using Monte Carlo simulation [29].

3.5.5 Sensitivity Analysis

The objective of this stage is to identify the most significant root causes of failure, evaluate their impacts, and check if they can be controlled, and if yes, assess the impact of controlling them on the probability of failure. This means that in this stage, the main attempt is to find the Level-1 risk factors which contribute the most to failure of the contractual relationship.

To do this we perform regression sensitivity analysis using tornado graphs and analyze the results. To perform regression sensitivity analysis, a multiple linear regression[1], based on the results of simulation runs, is done using the selected outputs (e.g. Probability of failure) as the dependent variable and the values of random variables, defined to quantify risk factors, as the independent variables. The standardized regression coefficients (or beta) of independent variables are, then, graphed in decreasing order in a tornado diagram.

The beta coefficient of an independent variable shows the number of standard deviations by which the independent variable increases by one standard deviation, having fixed all other independent variables. The bigger the absolute value of a beta coefficient, the most influential the associated random variable.

---

[1] Regression is a term for fitting data to a theoretical equation. In the case of linear regression, the input data is fit to a line. Multiple regression tries to fit multiple input data sets to a planar equation that could produce the output data set. [29]. In other words, The objective of multiple linear regression analysis is to find the best b coefficients to be model the relationship between an independent variable, Y, and n independent variables, x_i, i=0,..,n, as follows:

$$Y = b_0 + b_1x_1 + b_2x_2 + \ldots + b_nx_n + \varepsilon$$

where b_0 is the intercept ("constant" term), b_is are the respective parameters of independent variables, and ε is the involved error.

The R-squared value can be used as a measurement of the percentage of variation explained by the linear relationship. If R-squared is less than ~ 60%, the relationship between the inputs and outputs can not assume to be linear.

Hence, using the generated tornado graph, it is possible to visually identify the most significant random variable in terms of their impact on the selected output. Since each random variable is associated with a certain risk factor, this means that the most influential risk factors can be also identified. Furthermore, from previous stages, it is known which Level-1 risk factor(s) are the root cause(s) of each Level-2 and 3 risk factors. Thus, tornado graphs resulting from regression sensitivity analysis can be used to help identifying the main root causes of failure (as the main output of the simulation model) and evaluating their severity.

In summary, this stage can be summarized as follows:

1. Find out the most influential random variables using regression sensitivity analysis.
2. Trace back these most influential variables to their root cause Level-1 risk factors.
3. Check if each of the identified most influential Level-1 risk factors are controllable.
4. Examine the effect of controlling controllable Level-1 risk factors.

As mentioned before, due to the structure of the risk factors, where each risk factor can be tracked back to a Level-1 risk factor, uncontrollable higher level risk factors rooted in controllable lower level ones can be managed and mitigated through controlling the root cause Level-1 risk factor(s).

Here, we model the three riskiest possible scenarios, analyze and compare the results. Such comprehensive sensitivity analysis can be very useful in defining risk mitigation and intervention plans for companies; once they realize in which category their contractual buyer-supplier relationship falls.

CHAPTER 4 Applying the Proposed Methodology to Scenarios

4.1 Scenario C

4.1.1 Description

As mentioned before, Scenario C is the riskiest scenario as it involves supplying a specific service for an EU which is in superior position power wise. Start-up companies providing innovative services will most likely fall into this category.

In scenario C, according to the definition of specificity, the service under contract is a complex, novel service which involves a high degree of asset specificity, for both physical and human resources related assets. Also, as a result of the market conditions or the nature of the service, it has to be delivered to the EU, and to the market, in a short time, or otherwise its value will depreciate significantly over time.

Note that as in this scenario the balance of power is in favor of the EU, all managerial categories of uncertainties, i.e. uncertainty in time, in information, and in control[7], have to be considered. This means that the risk factors associated with this scenario have higher likelihood and severity and are less controllable.

In 2003, when Flextronics was trying to market its Phone 4 phones to major cell phone market players, who would brand, market and distribute the product, its situation can fall under this scenario. Flextronics, who has long worked as only a contract manufacturer of cellphones designed by OEMs, was now offering a new and rather complex product, especially in terms of intellectual property rights, to the same OEMs who had a well-established position in the market and were therefore in a better bargaining position. This marketing effort proved to be risky in reality as the customers (OEMs) were trying to impose difficult terms and conditions on Flextronics and the company had to spend a very long time finding interested customers and negotiating contracts [31].

4.1.2 Identifying Risk Factors and Modeling the System

This section describes how the risk factors associated with this scenario are identified, and are modeled using the methodology described in Chapter 3.

Step 1_ Level-3 risk factors

Already completed in 3.5.1.

Step 2_ Level-1 risk factors

The risk factors directly resulting from the attributes of the contracted manufacturing service, which form the main part of the first level of our hierarchy, are represented in Figure 9 (The risk factors are put in boxes). The influence diagram in Figure 9 represents the cause-and-effect relationships between these risk factors[2].

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[2] Regarding notation arrows indicate cause-and-effect relationships and a – sign indicates adverse relationship, i.e. the effect decreases as the cause increases and vice versa. Also, a "leads to" relationship means that the cause risk factor can potentially result in the effect risk factor.

Moreover, as the balance of power is in favor of the EU, it will probably behave opportunistically to maximize its own profit. Thus, "EU's Opportunistic Behavior" is the most important risk factor resulting form EU's superior power.

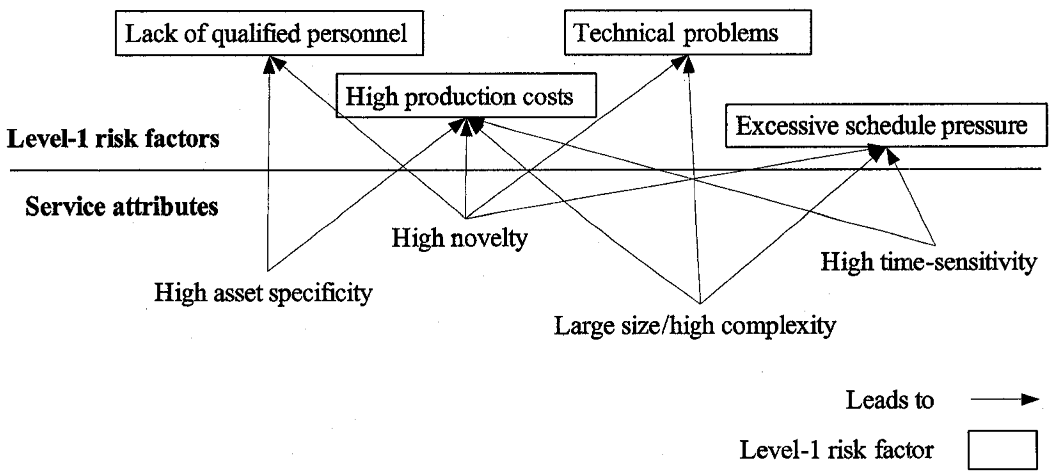

Figure 9. Level-1 risk factors rooted in nature of contracted service in Scenario C [3]

The identified Level-1 risk factors are inter-related and their relationships are shown in Figure 10. These relationships indicate that the random variables defined to model these risk factors will be correlated.

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3 Technical problems are in fact a group of risk factors which can be considered as a whole, these risk factors include:

- Inadequate technology
- Little or no task programmability (knowledge of the process)[11]
- Technical/configuration errors

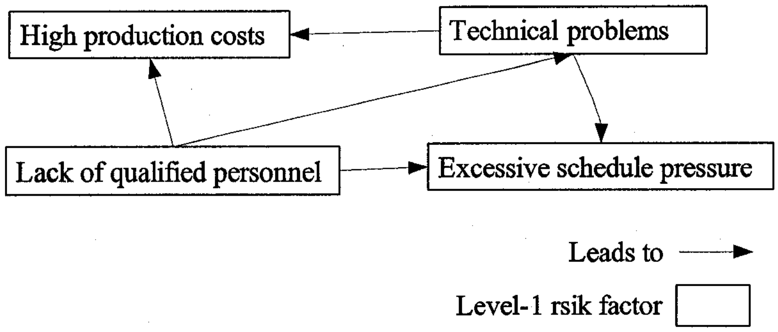

Figure 10. Interrelationships between Level-1 risk factors resulting from the nature of the contracted service

Figure 11 illustrates the risk factors resulting from EU's superior power.

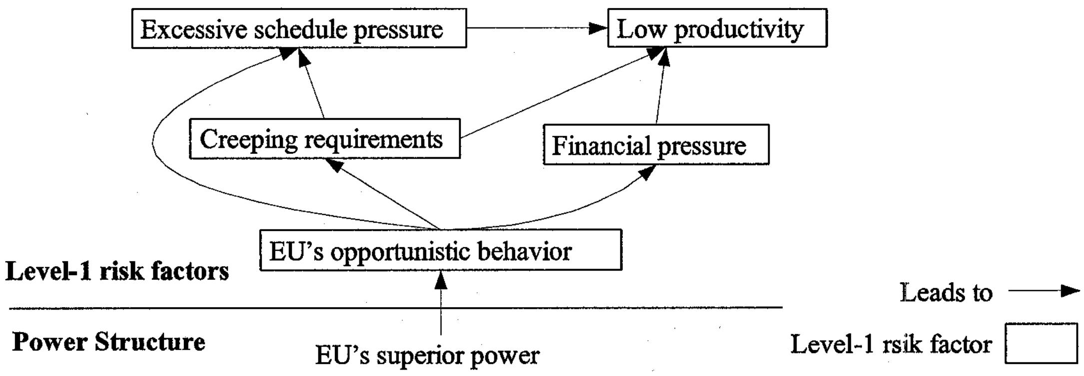

Figure 11. Level-1 of risk factors resulting from EU's superior power in Scenario C

The impacts of Level-1 risk factors are listed in Table 3. Studying the potential impacts of Level-1 risk factors helps with identifying Level-2 risk factors.

Table 3. Impacts of Level-1 risk factors

Risk Factor	Effects
Lack of qualified personnel [7]	• Lost time to find and hire qualified personnel • Training, hiring, and adapting costs • Continuing with under qualified personnel
Technical problems	• Technical/configuration errors • Defects • Cost of defects/errors • Time to fix defects/errors
Excessive schedule pressure[7]	• Excessive effort to meet deadlines which may lead to low moral and attritional losses[7] • Costs of overtime, incentives, etc
Low Productivity[7]	More time and effort, inferior results (in terms of meeting requirements[4])
Low commitment	Low productivity
EU's opportunistic behavior	Time and cost pressure, creeping requirements [7], overdependence on the EU

Lack of qualified personnel [7] and lack of experience is a result of the fact that the service is new and in the early stages of its life cycle. This causes costs of hiring, training and adapting employees, and triggers the risk of loosing time before the human resources obtain the required degree of expertise. Lack of sufficient experience and expertise also bears technical risks and the time lost in searching for qualified people and training may lead to excessive schedule pressure and delays.

Technical problems can lead to technical/configuration errors and defects in the product.

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[4] The term requirement is used in its broad sense and includes all functional, non-functional, quality, time and budget requirements of the EU, as specified in the contract

These errors or defects take some time to be fixed and can lead to excessive schedule pressure. They can also cause costs of rework and/or wastes.

Excessive schedule pressure is also an important risk factor, especially because of the time-sensitive nature of the manufacturing service contracted. Excessive schedule pressure incorporates tight deadlines, and forces the personnel to put more effort than average to meet the deadlines. This can result in exhaustion and low morale[7] and, therefore, low productivity of the personnel. Moreover, excessive schedule pressure can increase the likelihood of making errors and technical problems.

High production costs actually means that as a result of inaccurate cost estimation, significant unexpected additional costs, or any other reason, the production costs are much higher over initial estimates at the time of bidding and negotiating the contract.

On the other hand, as the EU is in a better position than the MSP and has more relative power, it may pressure the EU for doing more in less time and for substantially lower prices. In fact, the agreed price imposed by the contract may be far too low and the time-line may be unrealistically short in the first place, and the EU might be able to exert even more pressure the MSP.

Step 3_ Level-2 risk factors

The first level of risk factors, if actualized, give rise to the second level of risk factors, which are more fatal and can directly cause the MSP to fail. For simplicity, this step is illustrated using three figures (Level-2 risk factors are in bold boxes). Figure 12 illustrates Level-2 risk factors resulting from the actualization of risk factors associated with the service under contract.

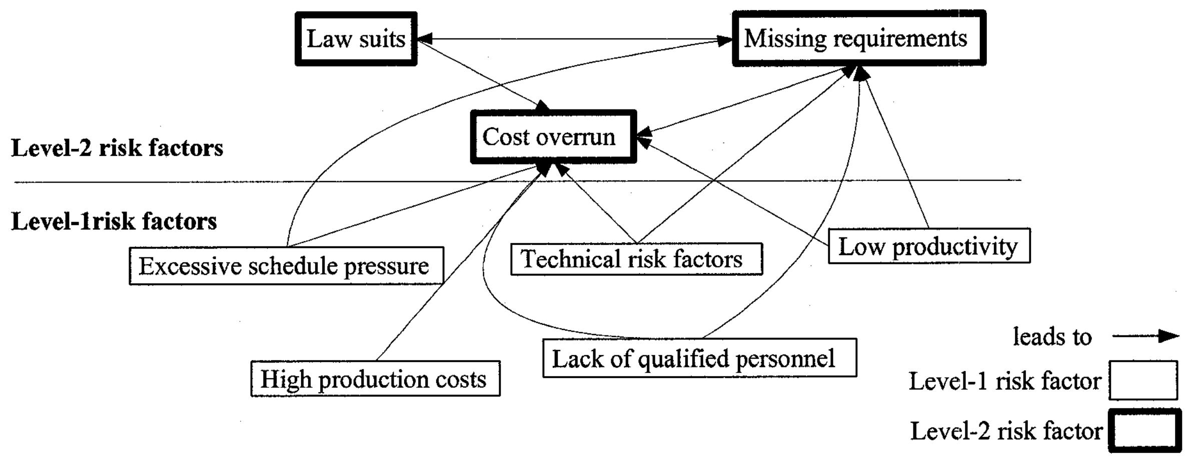

Figure 12. Level-2 risk factors rooted in service attributes in Scenario C

Figure 13 shows Level-2 risk factors resulting from the fact that the balance of power is in favor of the EU, and, therefore, it may behave opportunistically.

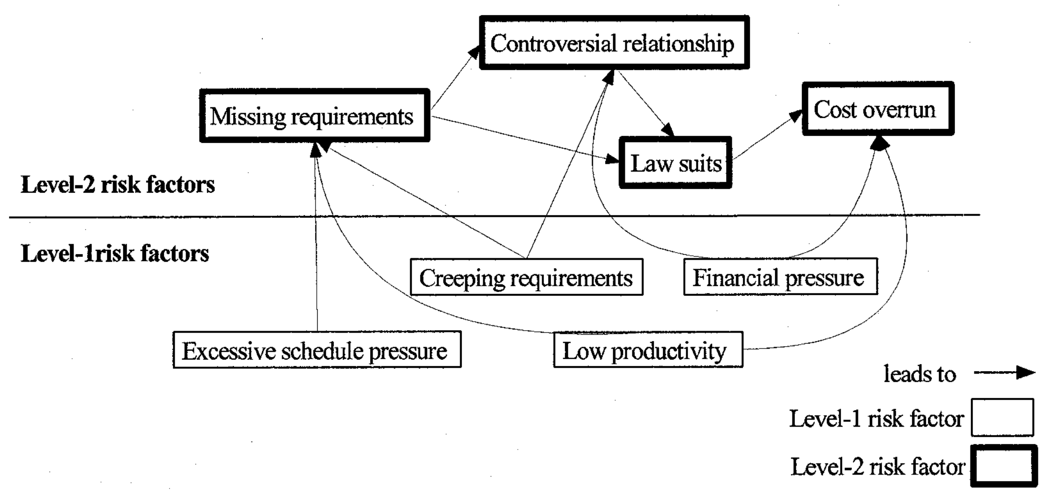

Figure 13. Level-2 risk factors rooted in power structure in Scenario C

Figure 14 represents the relationship between Level-2 and Level-3 risk factors and how realization of Level-2 risk factors can cause the MSP to fail with respect to its contractual relationship with the EU. (Rounded bold boxes indicate Level-3 risk factors and some of the repetitive relationships are omitted).

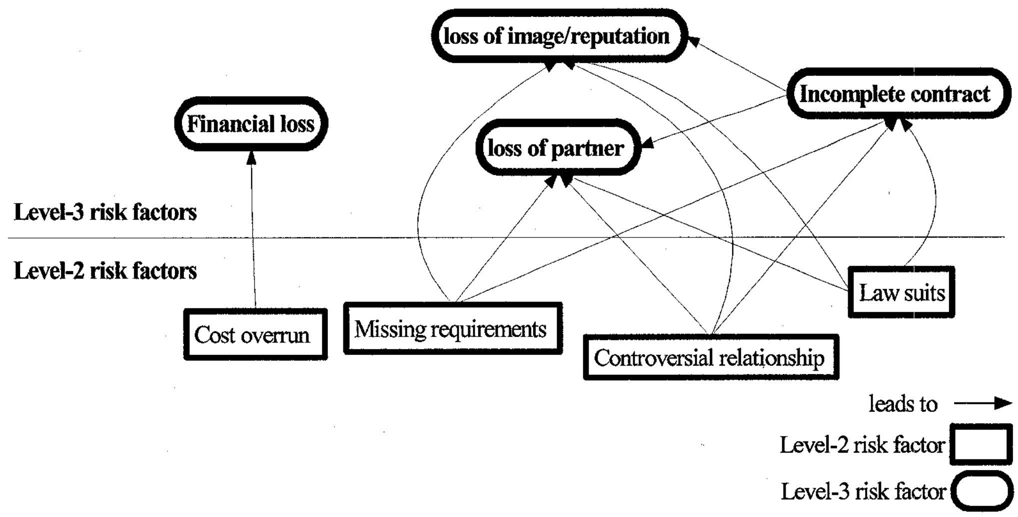

Figure 14. Level-2 and Level-3 Risk factors in Scenario C

Table 4 summarizes the negative effects of Level-2 risk factor which can potentially lead to Level-3 risk factors.

Table 4. The impacts of Level-2 risk factors in Scenario C

Risk Factor	Effects
Missing requirements	• A percentage of agreed requirements will not be met • Renegotiation costs, penalties
Cost overrun	No/little margins gained in the job
Controversial relationship	• Large number of sever conflicts • Conflict resolution costs
Law suits	• Bad publicity • Publicity, court costs and penalties

4.1.3 Quantifying Risk Factor Uncertainties

Model General Notations

- Initial values or thresholds are specified with hats, for example $\hat{C}_{PR}$ indicates the lower bound of the C_{PR}, costs of doing PR.

- P indicates the probability of its subscript, for example $P_{Failure}$ indicates the probability of the failure (of the contract).

- All total costs are indicated with letter C and their nature is indicated in the subscript. For example, C_{PR} indicates costs of PR (public relations). Note that all costs are in terms of percentage of total costs.

- All times are indicated with letter T and their nature is indicated in the subscript. For example, T_{tech} indicates time wasted for fixing technical problems/errors[5].

- All random distribution functions are represented by f.

- D indicates degree, for example $D_{controversy}$ indicates degree of controversy in the relationship.

Also, whenever a 1 to 7 scale is used, the numbers indicate qualitative values as follows:

1	Very Low
2	Low
3	Fairly low
4	Average
5	Fairly high
6	High
7	Very high

A 1 to 4 scale, whenever used, covers the last four of the above degrees, as follows:

1	Average
2	Fairly high
3	High
4	Very high

Level-1 risk factors

In this section, we explain the way Level-1 risk factors are quantified. Considering the impacts and implications of each risk factor a number of random variables are defined to

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[5] We have considered a normal distribution for the T variables which is consistent with the project management and scheduling practices and literature (e.g. [33]).

quantify each risk factor. Also, an example distribution is considered for each random variable to be used in the example simulation run.

- Lack of qualified personnel[7]
  - Total percentage of lost time ($T_{Personnel} \sim$ 1 to 7 scale)
  - Total percentage of additional costs of personnel hiring, training,…($C_{Personnel} \sim f(C_{Personnel})$)[6]
  - Continuation with under qualified personnel ($P_{underqualified}$)

$$P_{underqualified} = \begin{cases} 1 & \text{if } T_{Personnel} > 4 \text{ OR } C_{Personnel} > \hat{C}_{Personnel} \\ \hat{P}_{underqualified} & \text{Otherwise} \end{cases} \quad (8)$$

$T_{Personnel}$ and $C_{Personnel}$ are strongly correlated. In the simulated example, we consider the following distributions:

- $T_{Personnel} \sim$ Binomial (3, 0.5, shift (+1))
- $C_{Personnel} \sim N(5, 2)$
- $\hat{C}_{Personnel}=5$ [7], $\hat{P}_{underqualified}=0.1$

- Technical problems
  - Total % cost of errors/defects ($C_{tech} \sim f(C_{tech})$)
  - Total % time to fix errors/defects ($T_{tech} \sim f(T_{tech})$)

These two random variables are strongly correlated and have positive correlation with continuation with under qualified personnel and negative correlation with productivity

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[6] This is in addition to ordinary labour costs which are considered as part of the production costs

[7] $\hat{C}_{Personnel} = \mu(C_{Personnel}) + \sigma(C_{Personnel})$

level. In the simulated example, we consider the following distributions:

- $C_{tech} \sim$ N (8, 5)
- $T_{tech} \sim$ Binomial (6, 0.5, shift (+1))

- Excessive schedule pressure [7]
  - Degree of schedule pressure ($D_{schedule}$) ~1 to 7 scale (where higher degrees have higher probabilities)
  - Total % cost to make up schedule pressure ($C_{schedule} \sim f(C_{schedule})$)

These two random variables are positively correlated; $D_{schedule}$ is also positively correlated with T_{tech} and $T_{Personnel}$. In the example we consider:

- P($D_{schedule}$= {1,2,3,4,5,6,7})=({0.05,0.05,0.1,0.15,0.23,0.22,0.2})
- $C_{schedule} \sim$ N(5, 2.5)

- Low Productivity[7]
  - Degree of productivity ($D_{productivity}$)~ 1 to 7 scale

$D_{productivity}$ has strong negative correlation with degree of schedule pressure, percentage of added requirements and is negatively correlated with $D_{EUopportunism}$. In the example we consider that $D_{productivity}$ follows a binomial (6, 0.5) distribution, shifted one unit to the right. Figure 15 represents the Binomial (6, 0.5, shift (+1)) distribution's graph. It is clear from the graph that the closer the degree to average, the more the probability. In fact, the graph can be approximated by a normal distribution which is traditionally considered to model natural phenomena.

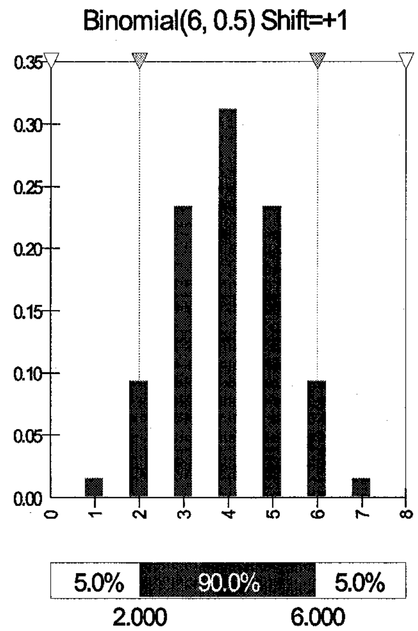

Figure 15. Binomial (6, 0.5, shift(+1)) distribution

- EU's opportunistic behavior
  - Degree of EU's opportunism ($D_{EUopportunism}$)~ 1 to 7 scale

Note that as EU has superior power, the probabilities of higher degrees of opportunism are considered to be greater. $D_{schedule}$ is positively correlated with $D_{opportunism}$ since the EU can pressure the MSP to complete what is committed to do in shorter time.

In the example, P($D_{EUopportunism}$ ={1,2,3,4,5,6,7}) = ({0.05,0.1,0.1,0.15,0.22,0.2,0.18})

- Creeping requirements
  - Costs of extra requirements *(C_{XRq}~f (C_{XRq}))* (is added to production costs)

C_{XRq} is strongly correlated with *MRq,* and $D_{EUopportunism}$.

In the numerical example, $f\ (C_{XRq})$ is assumed to follow Exponential (20) distribution [7][8].

- Financial pressure
  - The imposed price cut on the MSP (L^-), defined as a percentage of original L, leasing price stated in the original contract, which follows a $f(L^-)$ distribution.

$f(L^-)$ is considered to be N(10, 5) in the example.

Table 5 summarizes how the effects of Level-1 risk factors and the relationships between Level-1and Level-2 risk factors are mathematically formulated.

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[8] Houston et al found out that the percentage of additional work to do as a result of requirements creep follows an exponential distribution [7]. Assuming a linear relationship between these additional work and their associated costs, we can assume an exponential distribution for costs of extra requirements as well.

Table 5. Relationships between Level-1 and Level-2 risk factors

Level-1 risk factor	Level-2 risk factor formulation
Lack of qualified personnel[7]	• $C_{Personnel}$ is added to production costs (HR investment) • Qualifies *MRq* if $P_{underqualified}=1$
Technical problems	• C_{tech} is added to production costs • Qualifies *MRq* if $C_{tech} > \hat{C}_{tech}$ OR $T_{tech} > 4$. (In the example $\hat{C}_{tech}$=20 [9]).
Excessive schedule pressure	• $C_{schedule}$ is added to production costs (HR investment) • Qualifies *MRq* if $D_{schedule} > 4$
Low productivity	Qualifies *MRq* if $D_{productivity} < 4$
EU's opportunistic behavior	Qualifies *XRq, MRq,* $D_{controversy}$ and L^- if $D_{EUopportunism} > 4$

Level-2 risk factors

In this section we describe the way Level-2 risk factors are mathematically formulated.

- Missing requirements
  - % of requirements missed ($MRq \sim f\,(MRq)$)
  - Costs of missing requirements ($C_{MRq} \sim f\,(C_{MRq})$) (added to ex post transaction costs)

These two random variables are strongly correlated with each other, $D_{opportunism}$, $D_{schedule}$ and *XRq*.

- Cost overrun

  Already defined.

[9] $\hat{C}_{tech} = \mu\,(\hat{C}_{tech}) + \sigma\,(\hat{C}_{tech})$

- Controversial relationship
  - Degree of controversy ($D_{controversy}$)~ 1 to 4 scale
  - Cost of conflicts (added to ex post transaction costs)

$$C_{conflict} = \begin{cases} \sim f(C_{conflict}) & \text{if } D_{controversy} > 0 \\ 0 & \text{Otherwise} \end{cases} \quad (9)$$

These 2 random variables are strongly correlated and positively correlated with $D_{EUopportunism}$

- Law suits
  - Additional court costs ($C_{lawsuits}$) (added to ex post transaction costs)

$$C_{lawsuits} = \begin{cases} \sim f(C_{lawsuits}) & \text{if } D_{controversy} = 4 \text{ or MRq} > \hat{MRq}1 \\ 0 & \text{Otherwise} \end{cases} \quad (10)$$

$C_{lawsuit}$ is strongly correlated with MRq.

In the simulated example, we consider the following distributions:

- MRq~ N(30, 20)
- C_{MRq}~ N(15, 8)
- $D_{controversy}$~ binomial(3,0.5), shifted one unit to right
- Clawsuits ~ N(70, 20)

The second level of risk factors can directly lead to failure of the contract. The stochastic relationships between the second level risk factors and the fatal risk factors, whose occurrence mean the failure of the contract, are summarized in Table 6.

Table 6 . Qualification Relationships of Level-2 risk factors[10]

Level-2 risk factor	Qualification Relationships
Missing requirements	IF MRq > $\hat{MRq}2$ [11] THEN qualifies • Controversial relationship *($D_{controversy}$)* • Incomplete contract (P_{IC}^{MRq} =1) • Loss of partner (P_{LoP}^{MRq} =1) • Loss of image (P_{LoI}^{MRq} =1)
Cost overrun	Already defined
Controversial relationship	IF $D_{controversy}$ >=3 THEN qualifies • Incomplete contract ($P_{IC}^{Controversy}$ =1) • Loss of partner($P_{LoP}^{Controversy}$ =1) • Loss of image ($P_{LoI}^{Controversy}$ =1)
Law suits	IF occur at all ($C_{lawsuits}$ >0) THEN qualifies: • Incomplete contract ($P_{IC}^{LawSuits}$ =1) • Loss of image ($P_{LoI}^{LawSuits}$ =1) • Loss of partner ($P_{LoP}^{LawSuits}$ =1)

The weighted sum of the probability of each Level-3 risk factor caused by each Level-2 one defines the probability of its occurrence, as follows:

$$P_{IC} = w_{IC}^{LawSuits} * P_{IC}^{LawSuits} + w_{IC}^{controversy} * P_{IC}^{controversy} + w_{IC}^{MRq} * P_{IC}^{MRq} \quad (11)$$

$$P_{LoP} = w_{LoP}^{LawSuits} * P_{LoP}^{LawSuits} + w_{LoP}^{Controversy} * P_{LoP}^{Controversy} + w_{LoP}^{MRq} * P_{LoP}^{MRq} \quad (12)$$

$$P_{LoI} = w_{LoI}^{LawSuits} * P_{LoI}^{LawSuits} + w_{LoI}^{Controversy} * P_{LoI}^{Controversy} + w_{LoI}^{MRq} * P_{LoI}^{MRq} \quad (13)$$

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10 All *P* variables in this table are equal to 0 if not qualified.

11 $\hat{MRq}1 > \hat{MRq}2$

Even though "Incomplete contract" leads to "Loss of partner" and "Loss of image" as the root causes of all these Level-3 risk factors are the same Level-2 risk factors, their interrelationship is already modeled. In other words, occurrence of "Incomplete contract" means that a law suit has happened, and/or the percentage of missing requirements or the degree of controversy is greater than a limit which is also the precondition for "Loss of partner" or "Loss of Image". Thus, if the contract is incomplete, the probability of losing the partner or the company's reputation is automatically higher.

In the simulated example, we consider the following values for the model:

ε=\$0; $\hat{P}_{IC}=\hat{P}_{LoP}=\hat{P}_{LoI}$=0.5; $\hat{MRq}1$=70; $\hat{MRq}2$=30[12]; $w_{IC}^{LawSuits}$=0.5; $w_{IC}^{controversy}$=0.3; w_{IC}^{MRq}=0.2; $w_{LoP}^{Controversy}$=0.1; w_{LoP}^{MRq}=0.5; $w_{LoP}^{LawSuits}$=0.4; $w_{LoI}^{LawSuits}$=0.4; $w_{LoI}^{Controversy}$=0.1; w_{LoI}^{MRq}=0.5.

4.1.4 Propagating the Uncertainties

Figure 16 shows the schematic presentation of the simulation model.

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12 $\hat{MRq}1 = \mu$ (MRq)+ 2σ (MRq), $\hat{MRq}2 = \mu$ (MRq)

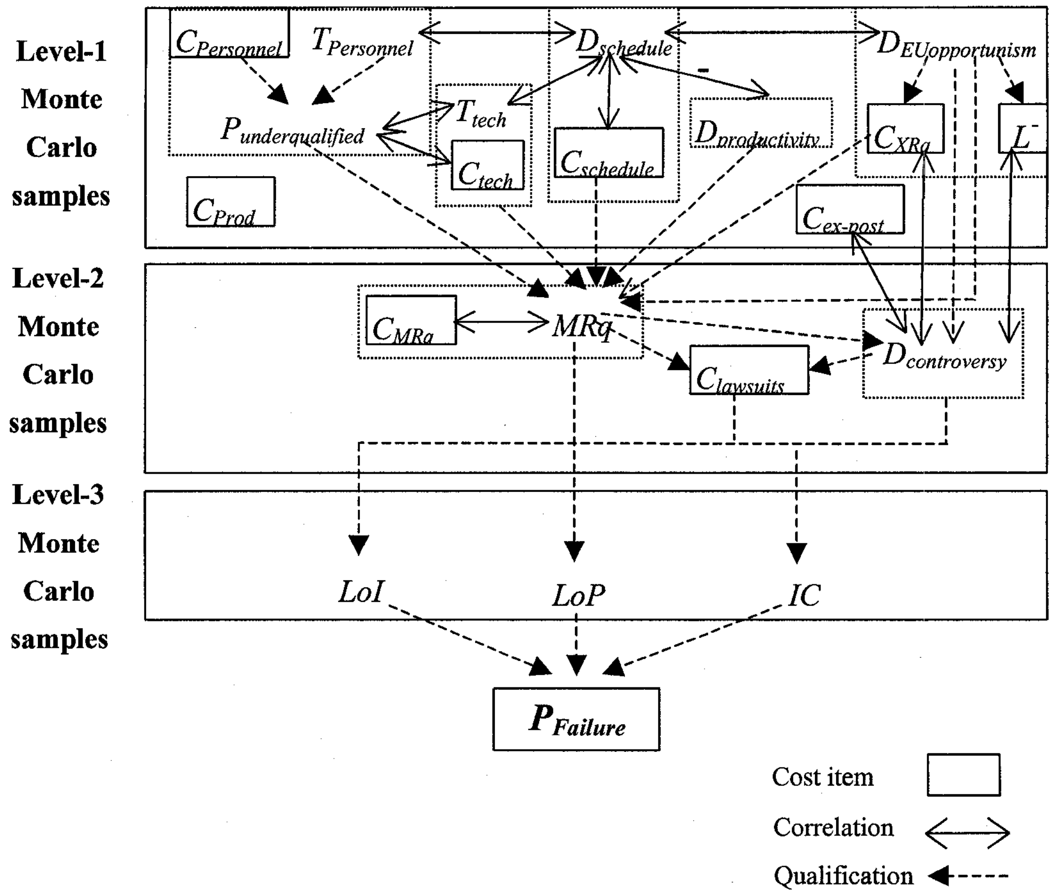

Figure 16. Schematic view of the simulation model

Figure 17 shows the cost breakdown structure of each cost category, without considering opportunity costs. All the cost items under Total C_{prod} and Total $C_{ex\text{-}ante}$ are in addition to the original C_{prod} and $C_{ex\text{-}ante}$. Total costs ($\overline{C}_{MSP}$) are subtracted from (100-L^-) and are applied to equation (2) to calculate the Net Present Value (NPV) of delivering the manufacturing service for the MSP.

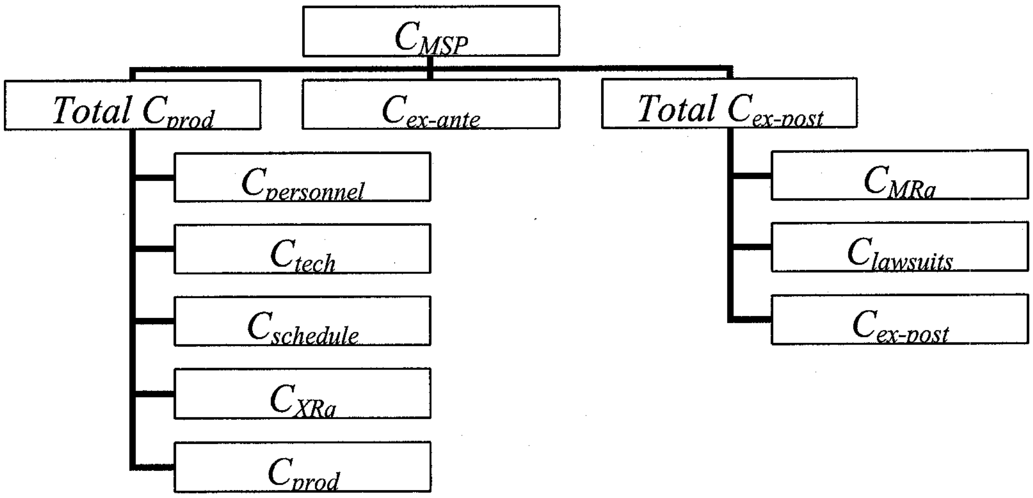

Figure 17. Cost breakdown structure

Considering W_{FLo}=0.15; W_{IC}=0.25; W_{LoP}=0.4; W_{LoI}=0.2, ρ=\$0.5 [11], $\hat{e}$=0.005, and that production costs (C_{prod}) follows N (50, 20) distribution, the following results were obtained after running 40,000 simulations.

Note that as in Scenario C the MSP is offering a novel complex service to a more powerful and reputable EU, the weight of Financial Loss is considered less than the weight of Loss of Partner and Loss of Image. This is consistent with what is seen in real world when start-up companies even accept some monetary loss to build relationship with promising customers and to establish a good reputation in the market.

Table 7 represents the results of simulating the developed model for Scenario C, plugging in sample distributions.

Table 7. Simulation results for Scenario C numerical example

Name	Minimum	Mean	Maximum	x1	p1	x2	p2
			Outputs				
Total C_{prod}	8.199	72.526	190.088	37.251	5%	119.634	95%
Total $C_{ex\text{-}post}$	0.033	35.894	190.173	10.569	5%	117.394	95%
C_{MSP}	14.599	120.072	371.825	63.435	5%	225.161	95%
% NPV	-329.741	-27.660	67.206	-151.874	5%	28.768	95%
FLo	0	0.599	1	0	5%	1	95%
LoP	0	0.323	1	0	5%	1	95%
IC	0	0.132	1	0	5%	1	95%
LoI	0	0.323	1	0	5%	1	95%
Failure Probability	**0**	**0.317**	**1**	**0**	**5%**	**1**	**95%**
			Inputs				
C_{prod}	0.058	40.057	106.042	15.592	5%	64.784	95%
$C_{ex\text{-}post}$	0.002	10.040	26.148	3.685	5%	16.571	95%
$T_{Personnel}$	1	5	7	2	5%	7	95%
$C_{Personnel}$	0	5.049	13.282	1.808	5%	8.315	95%
$P_{underqualified}$	0	0.036	1	0	5%	0	95%
C_{tech}	0	8.597	32.717	1.651	5%	16.350	95%
T_{tech}	1	5	7	1	5%	7	95%
$D_{schedule}$	1	5	7	1	5%	7	95%
$C_{schedule}$	0	5.116	16.113	1.344	5%	9.119	95%
$D_{productivity}$	1	4	7	2	5%	6	95%
$D_{EUopportunism}$	1	5	7	2	5%	7	95%
L-	0	11.140	30.769	3.582	5%	18.858	95%
C_{XRq}	0	22.956	99.829	1.785	5%	63.535	95%
MRq	0	33.431	119.572	6.397	5%	64.066	95%
C_{MRq}	0	15.746	47.488	3.853	5%	28.430	95%
$C_{lawsuits}$	12.383	81.728	147.260	50.785	5%	112.492	95%
$D_{controversy}$	1	3	4	1	5%	4	95%

4.1.5 Analysis and Conclusions

As shown in the table, the probability of failure is very high and is approximately 32 percent. Moreover, the probability of financial loss is also very high and, on average, there is a 60% chance that the contract results in negative NPV, especially because the EU might be able to impose price cuts of up to 30% of the original price.

Table 8 provides interesting information about the number and percentage of times Level-2 risk factors are qualified which, in turn, can provide useful information on the root causes of these risk factors. For instance, the statistics show that only in 4% of the simulation runs there has been no missing requirements.

Table 8. Level-2 risk factors qualification statistics

Variable	No of times not qualified	% of times not qualified
$P_{underqualified}$	26348	65.87
L-	16116	40.29
C_{XRq}	16116	40.29
MRq	1806	4.515
C_{MRq}	1806	4.515
$C_{lawsuits}$	34705	86.7625
$D_{controversy}$	8948	22.37

According to the regression sensitivity analysis performed to identify the most influential risk factors on Financial Loss, Figure 18, EU's opportunistic behavior, which is a Level-1 risk factor and is the root cause of several other risk factors, is the most dangerous risk factor, followed by high production costs, represented by C_{prod}, and costs of missing and creeping requirements, C_{MRq} and C_{XRq}, respectively.

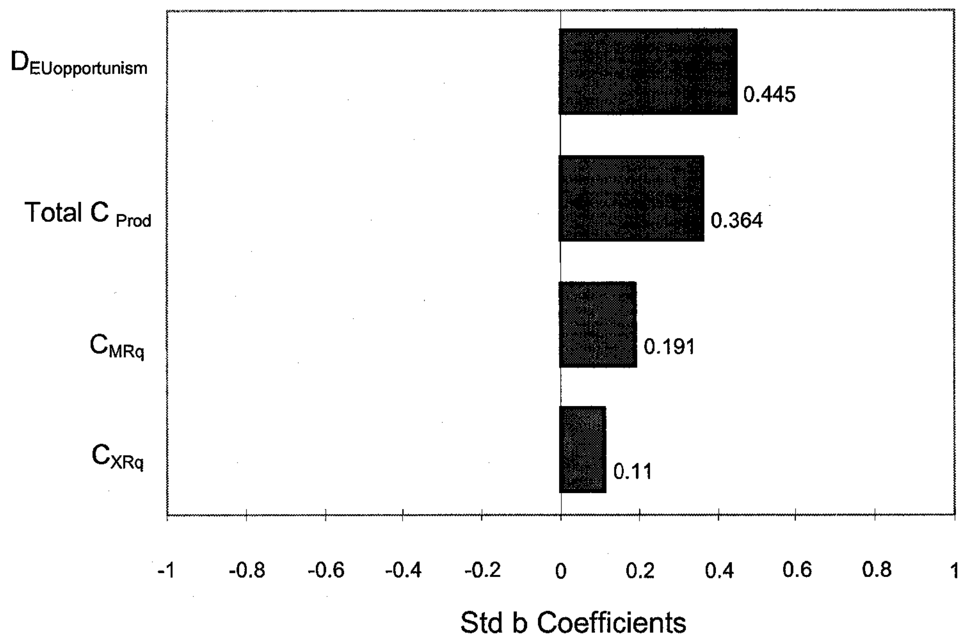

Figure 18. Regression Sensitivity analysis for Financial Loss

On the other hand, since on average 33% of the original and creeping requirements of the EU, mostly in terms of time and budget, are not met, and the degree of controversy is most probably "high", the mean of $D_{controversy}$=3, on the defined 1-4 scale, the chances of losing the EU and not being able to establish a good reputation, referring to the success of such contract, are also relatively high.

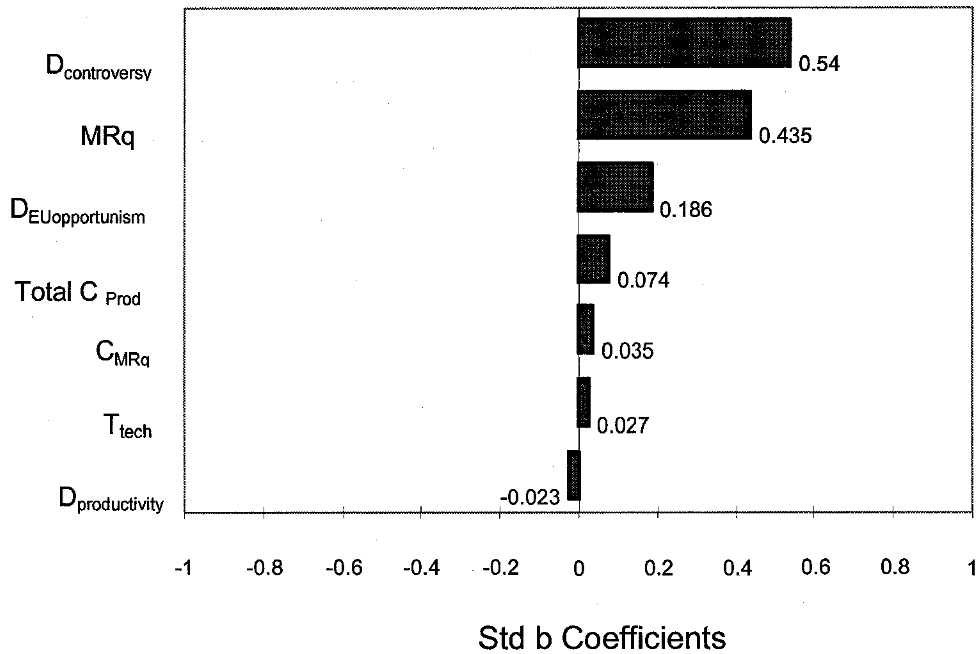

Figure 19. Regression Sensitivity analysis for probability of failure

According to Figure 19 and considering the fact that controversial relationship is partially a result of missing requirements, it can be concluded that "Missing Requirements" is the most influential risk factor that can cause the contract to fail. However, since "Missing Requirements" is a Level-2 risk factor, "EU's opportunistic behavior" and "High production costs" are the main root causes of failure.

As the only controllable Level-1 risk factor whose controlling can potentially save the contract is "high production costs". Assuming that production costs are substantially kept low, through for example taking full advantage of modularity, standardization and reusability [1] or moving the production to low-wage areas, according to Figure 19 and Table 9, and the definition of Std b, each 25.11 units decrease in Total C_{prod} can result in

0.026 (0.074*0.355) decrease in probability of failure. This small decrease indicates the fact that not only Scenario C is the riskiest scenario but also its corresponding risk factors are mostly uncontrollable.

Table 9. Summary statistics for probability of failure and production costs of Scenario C

Statistic	Value for Failure Probability	Value for C_{prod}
Minimum	0	8.198
Maximum	1	190.088
Mean	0.316	72.526
Std Dev	**0.355**	**25.112**
Variance	0.126	630.619
Skewness	0.800	0.774
Kurtosis	2.055	3.887
Median	0.150	69.350
Mode	0	43.104

4.2 Scenario A

4.2.1 Description

Scenario A is the second riskiest scenario. In this scenario, similar to Scenario C, the MSP provides the EU with a specific service, which means that service under contract is a complex, novel service which involves a high degree of asset specificity, for both physical and human resources related assets. However, opposite to Scenario C, in this scenario the MSP has superior power compared to the EU.

Since the balance of power is in favor of the MSP in this scenario, the managerial categories of uncertainties which are hypothetically more significant are uncertainty in time, and in information [7] and uncertainty in control is probably less significant. This means that the risk factors associated with this scenario probably more controllable.

EADS (Airbus S.A.S.) contracts with many airlines for delivering A380 "superjumbos" can be put in this category, especially considering the fact that EADS' only competitor Boeing had no comparable plane to offer the airlines which gave EADS more bargaining power. Manufacturing and delivering the largest passenger airliner in the world has been an unprecedented and complex project which has been subject to series of delays, weight problems (missing requirements), and $1.9bn of over budget (high production costs and cost overrun) which, in turn, has lead to customers' withdrawals (incomplete contracts) and has hurt to Airbus image (loss of image) [22][32].

Some researchers believe that as the past vertically integrated companies lose their manufacturing and other expertise and their ownership of the facilities and process over time, the balance of power more and more shifts to the MSPs. This has been the case in, for example, electronics where according to a report, as a result of the emergence of a small number of large CMs, "bargaining power has shifted to tier-one contract manufacturers". These researchers believe that this power structure is also very risky for the industry as a whole in terms of profitability [3].

4.2.2 Identifying Risk Factors and Modeling the system

Step 1_ Level-3 risk factors

Already completed in 3.5.1.

Step 2_ Level-1 risk factors

Since in Scenario A, similar to Scenario C, the service under contract is a specific service, all risk factors resulted from the attributes of the service which were modeled for Scenario C are applicable here as well.

On the other hand, the fact that the MSP has superior power relative to the EU, can lead to two other significant first level risk factors. The first one is MSP's opportunistic behavior, which can be reflected in MSP's pressurizing the EU for more money and/or time, not being responsive enough, lower quality than agreed on in contract, shirking, etc. The other risk factor resulted from the MSP's superior power, according to our definition, is that MSP's management, and consequently staff, do not really care about the contract and show low levels of commitment to its success, as shown in Figure 20.

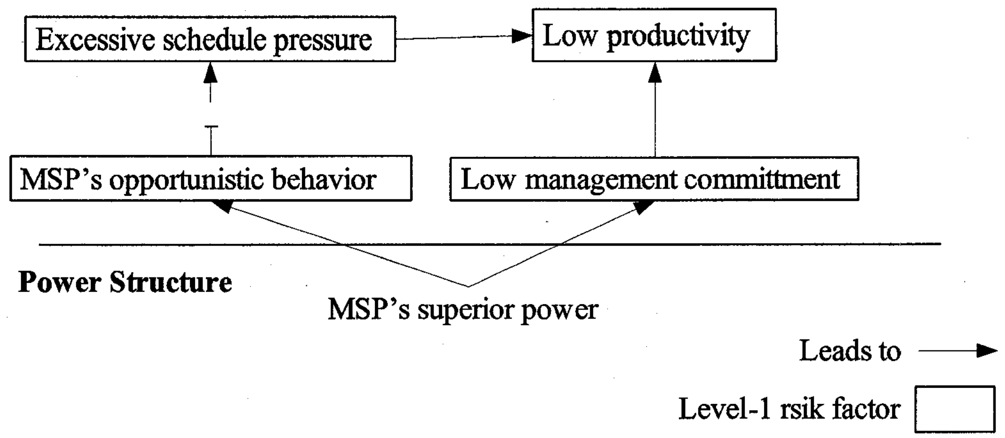

Figure 20. Level-1 risk factors resulted from MP's superior power in Scenario A

Along with the impacts listed in Table 3, listing the impacts of risk factors resulted from the specificity of the service under contract; the impacts of MSP's opportunistic behavior and low commitment are listed in Table 10.

Table 10. Impacts of MSP's opportunistic behavior and low commitment

Risk Factor	Effects
MSP's opportunistic behavior	Low responsiveness, not meeting EU's requirements, and shirking which will ultimately leave the EU unsatisfied.
Low commitment	Shirking, Low productivity, low responsiveness

Step 3_ Level-2 risk factors

Level-1 risk factors, if actualized, may give rise to Level-2 risk factors, which are more fatal and can directly cause the MSP to fail. Along with Figure 12, which shows Level-2 risk factors resulted from service attributes,

Figure 21 represents Level-2 risk factors resulted from the actualization of MSP's opportunistic behavior and low commitment. Again, repetitive relationships which are already shown are omitted from these influence diagrams.

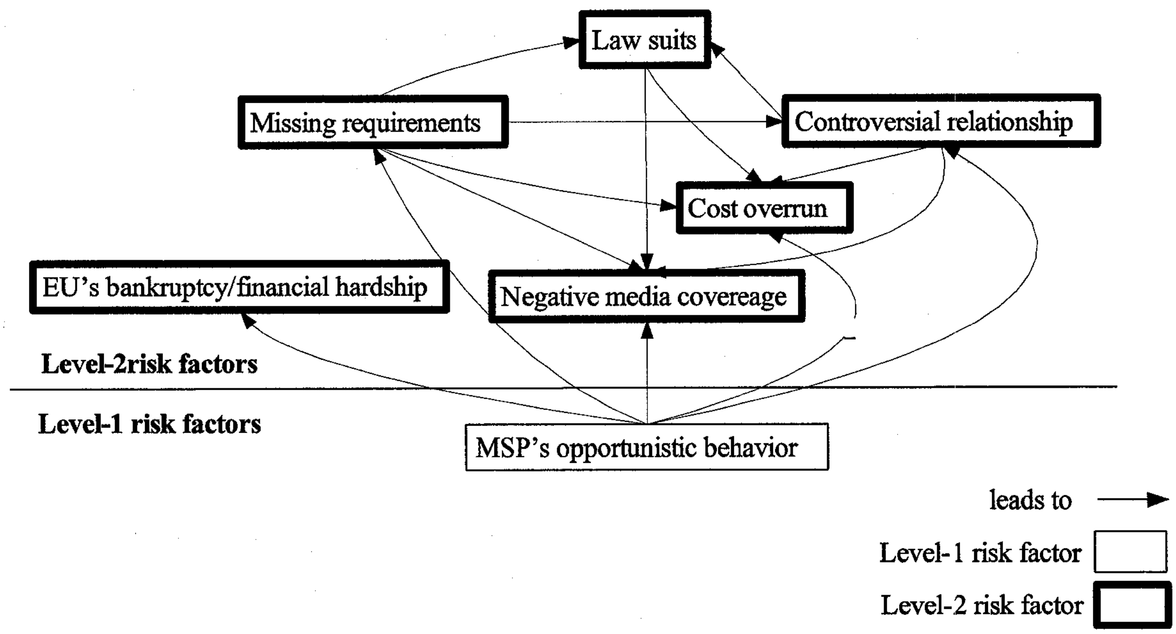

Figure 21. Level-2 risk factors rooted in MSP's opportunistic behavior and low commitment

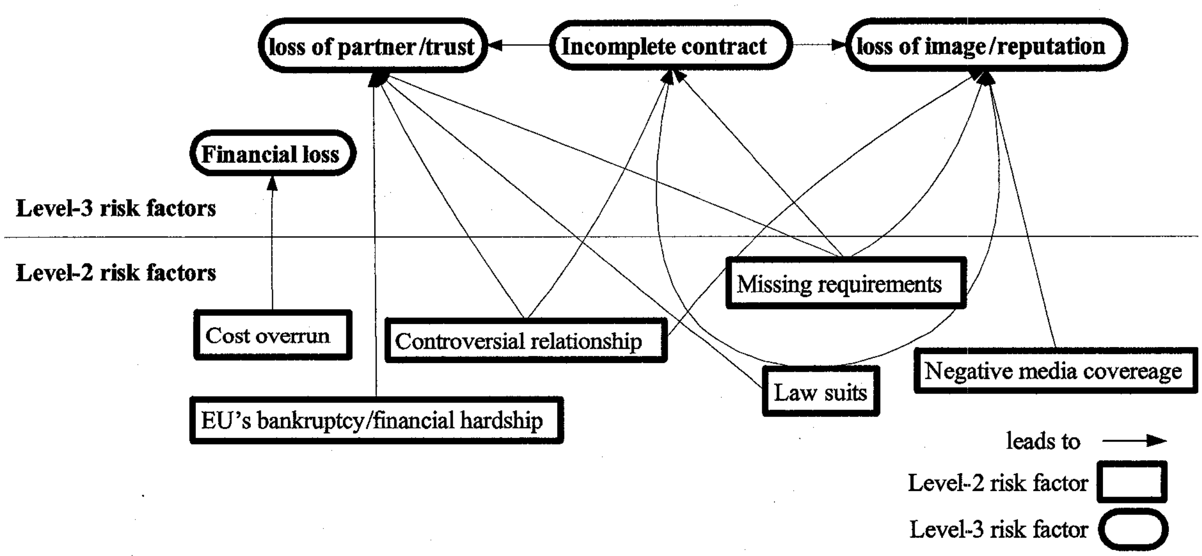

Figure **22** represents the relationship between Level-2 and Level-3 risk factors and how realization of Level-2 risk factors can cause the MSP to fail with respect to its contractual relationship with the EU.

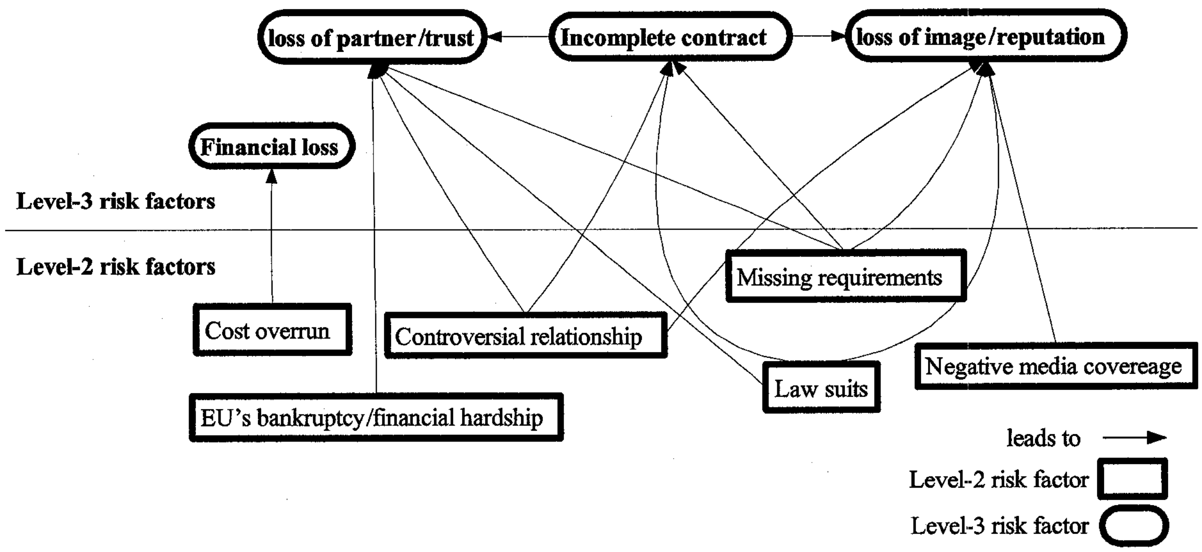

Figure 22. Level-2 and Level-3 risk factors of Scenario A

Table 11 summarizes the negative effects of Level-2 risk factor which can potentially lead to Level-3 risk factors.

Table 11. The impacts of Level-2 risk factors in Scenario A

Risk Factor	Effects
Missing requirements	• A percentage of agreed requirements will not be met • Renegotiation costs, penalties
Cost overrun	No/little margins gained in the job
Controversial relationship	• Large number of sever conflicts • Conflict resolution costs
EU's bankruptcy or financial hardship	EU will not be able to continue business with MSP

Negative media coverage/ word of mouth	• Negative comments about the company in the media (within the industry or mass media) • Additional publicity, marketing costs
Law suits	• Bad publicity • Publicity, court costs and penalties

4.2.3 Quantifying Risk Factor Uncertainties

Level-1 risk factors

In this section, similar to what was done for Scenario C, we explain how Level-1 risk factors are quantified. Since the risk factors resulting from the specificity of the manufacturing service under contract are similar to Scenario C, they are not described in this section to avoid redundancy. However, considering the fact that in Scenario A, unlike Scenario C, the MSP has superior power, the values assigned to the model parameters in the numerical example are considered different, as follows[13]:

- $\hat{P}_{underqualified}=0.2$
- $C_{Personnel} \sim$ Normal(4, 2), $\hat{C}_{Personnel}=4$
- $C_{tech} \sim$ Normal (6, 4), $\hat{C}_{tech}=6$
- P($D_{schedule}$= {1,2,3,4,5,6,7})=({0.05,0.1,0.1,0.15,0.25,0.2,0.15})
- $C_{schedule} \sim$ Normal(3, 2)
- $$D_{productivity} = \begin{cases} \sim f_1\,(D_{productivity}) & \text{if } D_{commitment}<4 \\ f_1\,(D_{productivity}) & \\ \sim f_2\,(D_{productivity}) & \text{Otherwise} \end{cases} \qquad (14)$$

---

[13] Note that as in this scenario, the MSP has more power than the EU, the agreed leasing price, L, is considered to be greater, which results in smaller values for mean percentages of costs, compared to Scenarios C and F. Also, this superior power will potentially result in less tolerance for costs and therefore, smaller values for upper bounds.

$D_{productivity}$ has strong negative correlation with degree of schedule pressure. In the example, we consider f_2 ($D_{productivity}$) as a Binomial (6, 0.5, shift(1)) distribution and f_1 ($D_{productivity}$) as a discrete distribution where P($D_{productivity}$= {1,2,3,4,5,6,7})= {0.15,0.15,0.25,0.2,0.1,0.1,0.05}).

- Low commitment
    - Degree of commitment ($D_{commitment}$)~ 1 to 7 scale

In the example, P($D_{commitment}$={1,2,3,4,5,6,7}) = {0.18,0.2,0.22,0.15,0.1,0.1,0.05})

- MSP's opportunistic behavior
    - Degree of opportunism ($D_{MSPopportunism}$)~ 1 to 7 scale

In the example, P($D_{MSPopportunism}$ ={1,2,3,4,5,6,7} = {0.05,0.1,0.1,0.15,0.22,0.2,0.18})

Note that as MSP has superior power, the probabilities of higher degrees of opportunism and lower degrees of commitment are considered to be greater. $D_{schedule}$ is negatively correlated with $D_{opportunism}$ since the MSP can relatively easier get extensions from the EU. Also, the MSP can take advantage of its superior power to make the EU pay an extra amount of money added to the original L (denoted by L^+ which follow a $f(L^+)$ distribution which is considered to be Normal(8, 4) in the example).

Table 12 summarizes how Level-1 risk factors resulting from MSP's opportunistic behavior and Level-2 risk factors are mathematically formulated. Since MSP's low commitment leads to low productivity and does not directly to result in any Level-2 risk factor, the table only contains MSP's opportunistic behaviour.

Table 12. Relationships between MSP's opportunistic behavior and Level-2 risk factors in Scenario A

Level-1 risk factor	Level-2 risk factor formulation
MSP's opportunistic behavior	Qualifies $L+$ and other associated Level-2 risk factors (except law suits) if $D_{MSPopportunism} > 4$

Level-2 risk factors

In this section, we describe the way Level-2 risk factors are mathematically formulated. Again, the risk factors already modeled for Scenario C are omitted and only the two Level-2 risk factors unique to Scenario A are described.

- EU's bankruptcy or financial hardship
  - Degree of EU's financial difficulty ($D_{EUHardship}$)~ 1 to 4 scale

$D_{EUHadrship}$ is positively correlated with $D_{opportunism}$ and L^+.

- Negative media coverage/word of mouth
  - Degree of negative coverage (D-coverage)~ 1 to 4 scale
  - Additional publicity costs (added to ex post transaction costs)

$$C_{PR} = \begin{cases} \sim f(C_{PR}) & \text{if } D_{-coverage} > 0 \\ 0 & \text{Otherwise} \end{cases} \qquad (15)$$

The 2 random variables are strongly correlated with each other, $D_{opportunism}$, MRq and $D_{controversy}$.

In the simulated example, we consider the following distributions:

- MRq~ Normal(40, 20), $\hat{MRq}1$=80, $\hat{MRq}2$=40, $\hat{MRq}3$=30

- C_{MRq}~ Normal(10, 5)
- $D_{controversy}$~ Binomial(3,0.5, shift(1))
- $D_{EUHardship}$ ~ Binomial(3,0.5, shift(1))
- $C_{lawsuits}$ ~ Normal(50, 20)
- L^{+} ~ Normal(8, 4)
- C_{PR} ~ Normal(20, 8)
- $D_{-coverage}$ ~ Binomial(3,0.5, shift(1))

The second level of risk factors can directly lead to failure of the contract. The stochastic relationships between the second level risk factors and the fatal risk factors, whose occurrence mean the failure of the contract, are summarized in Table 13.

Table 13 . Qualification Relationships of Level-2 risk factors[14]

Second level risk factor	**Relationship with Level-3 risk factors**
Missing requirements	IF MRq > $\hat{M}Rq3$ THEN qualifies • Incomplete contract (P_{IC}^{MRq} =1) • Loss of partner (P_{LoP}^{MRq} =1) IF MRq > $\hat{M}Rq2$ [15] THEN qualifies • Loss of image (P_{LoI}^{MRq} =1)
Cost overrun	Already defined
Controversial relationship	IF $D_{controversy}$ >=3 THEN qualifies • Incomplete contract ($P_{IC}^{Controversy}$ =1) • Loss of partner ($P_{LoP}^{Controversy}$ =1) • Loss of image ($P_{LoI}^{Controversy}$ =1)
EU's bankruptcy or financial hardship	IF $D_{EUHardship}$ >=2 THEN qualifies • Loss of partner ($P_{LoP}^{EUhardshipy}$ =1) • Incomplete Contract($P_{IC}^{EUHardship}$ =1) IF $D_{EUHardship}$ >=3 THEN qualifies • Loss of image ($P_{LoI}^{EUHardship}$ =1)
Negative media coverage	IF $D_{-coverage}$ >4 THEN qualifies loss of image ($P_{LoI}^{-coverage}$ =1)
Law suits	IF occur at all ($C_{lawsuits}$ >0) THEN qualifies: • Negative media coverage • Incomplete contract ($P_{IC}^{LawSuits}$ =1) • Loss of image ($P_{LoI}^{LawSuits}$ =1) • Loss of partner ($P_{LoP}^{LawSuits}$ =1)

[14] All *P* variables are equal to 0 if not qualified.

[15] $\hat{M}Rq1 > \hat{M}Rq2 > \hat{M}Rq3$

The probabilities of Level-3 risk factors can be obtained using the following weighted sums:

$$P_{IC} = \hat{w}_{IC}^{LawSuits} * P_{IC}^{LawSuits} + \hat{w}_{IC}^{controversy} * P_{IC}^{controversy} + \hat{w}_{IC}^{MRq} * P_{IC}^{MRq} \quad (16)$$

$$P_{LoP} = w_{LoP}^{LawSuits} * P_{LoP}^{LawSuits} + \hat{w}_{LoP}^{Controversy} * P_{LoP}^{Controversy} + \hat{w}_{LoP}^{MRq} * P_{LoP}^{MRq} \quad (17)$$

$$P_{LoI} = \hat{w}_{LoI}^{LawSuits} * P_{LoI}^{LawSuits} + \hat{w}_{LoI}^{EUDifficulty} * P_{LoI}^{EUDifficulty} + \hat{w}_{LoI}^{Controversy} * P_{LoI}^{Controversy} + \hat{w}_{LoI}^{MRq} * P_{LoI}^{MRq} \quad (18)$$

$$P_{LoI} = \hat{w}_{LoI}^{LawSuits} * P_{LoI}^{LawSuits} + \hat{w}_{LoI}^{EUDifficulty} * P_{LoI}^{EUDifficulty} + \hat{w}_{LoI}^{Controversy} * P_{LoI}^{Controversy} + \hat{w}_{LoI}^{MRq} * P_{LoI}^{MRq} \quad (18)$$

In the simulated example, we consider the following values for the model:

ε=\$10; $\hat{P}_{IC} = \hat{P}_{LoP} = \hat{P}_{LoI}$=0.5; $w_{IC}^{LawSuits}$=0.5; $w_{IC}^{controversy}$=0.3; w_{IC}^{MRq}=0.2; $w_{LoP}^{EUHardship}$=0.6; $w_{LoP}^{Controversy}$=0.2; w_{LoP}^{MRq}=0.2; $w_{LoI}^{LawSuits}$=0.2; $w_{LoI}^{EUHardship}$=0.1; $w_{LoI}^{Controversy}$=0.15; w_{LoI}^{MRq}=0.25; $\hat{P}_{LoI}^{-coverage}$=0.3.

4.2.4 Propagating the Uncertainties

Considering W_{FLo}=0.35; W_{IC}=0.15; W_{LoP}=0.1; W_{LoI}=0.4, ρ=\$0.2, and $\hat{e}$=0.005, and that production costs (C_{prod}) follows an N (35, 10) distribution, $C_{ex\text{-}post}\sim$ N(7,2) and $C_{ex\text{-}ante}$=3, the following results were obtained after running 40,000 simulations.

It should be pointed out that in Scenario A, as a result of MSP's superior power which, according to the definition of power, means better reputation and market position, the weight of Loss of Image is considered the most followed by Financial Loss and Incomplete Contract. On the other hand, as the EU is a relatively weak enterprise with less reputation and worse market and economic position, Loss of Partner is considered the least significant element of failure.

Figure **23** shows the schematic presentation of the simulation model for Scenario A.

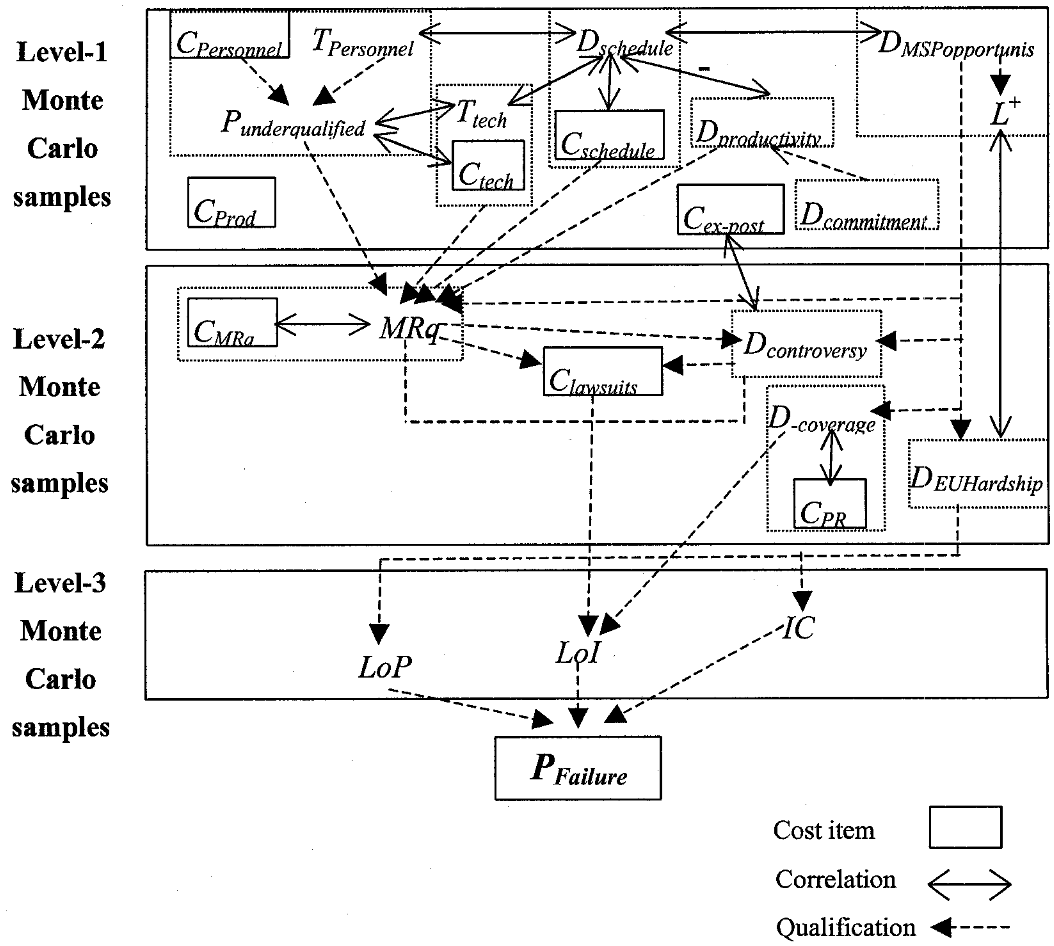

Figure 23. Schematic view of the simulation model for Scenario A

Also, the cost structure is similar to Scenario C, illustrated in Figure 17, except that C_{XRq} is replaced by C_{PR}. The results of simulation runs using the sample distributions are summarized in Table 14.

Table 14. Simulation results for the sample problem of Scenario A

Name	Minimum	Mean	Maximum	x1	p1	x2	p2
Outputs							
Total C_{Prod}	7.183	48.929	97.219	30.536	5%	67.479	95%
Total $C_{ex\text{-}post}$	0.564	32.336	169.909	8.930	5%	107.667	95%
C_{total}	18.946	84.265	234.118	51.045	5%	160.602	95%
% NPV	-132.676	18.206	76.767	-54.758	5%	47.223	95%
FLo	0	0.194	1	0	5%	1	95%
LoP	0	0.559	1	0	5%	1	95%
IC	0	0.274	1	0	5%	1	95%
LoI	0	0.336	1	0	5%	1	95%
Failure Probability	**0**	0.300	**1**	**0**	**5%**	**1**	**95%**
Inputs							
C_{Prod}	0.180	34.968	74.000	18.360	5%	51.262	95%
$C_{ex\text{-}post}$	0.002	6.998	15.059	3.703	5%	10.296	95%
$T_{Personnel}$	1.0	2.494	4	1	5%	4	95%
$C_{Personnel}$	0	4.114	12.342	1.077	5%	7.313	95%
$P_{underqualified}$	0	0.203	1	0	5%	1	95%
C_{tech}	0.000	6.557	23.944	1.164	5%	12.738	95%
T_{tech}	1	2	4	1	5%	4	95%
$D_{schedule}$	1	5	7	2	5%	7	95%
$C_{schedule}$	0.000	3.290	11.558	0.597	5%	6.375	95%
$D_{productivity}$ (Low comitment)	1	3	7	1	5%	6	95%
$D_{productivity}$	1	4	7	3	5%	6	95%
$D_{MSPopportunism}$	1	5	7	2	5%	7	95%
L+	0.011	9.112	24.621	3.172	5%	15.321	95%
$D_{commitment}$	1	3	7	1	5%	7	95%
MRq	0.006	41.550	118.718	11.530	5%	73.514	95%
C_{MRq}	0.003	10.433	35.325	2.949	5%	18.329	95%
$C_{lawsuits}$	17.489	70.492	119.672	47.584	5%	93.244	95%
$D_{controversy}$	1	3	4	1	5%	4	95%
$D_{EUHardship}$	1	3	4	1	5%	4	95%
$D_{-coverage}$	1	4	7	2	5%	6	95%
C_{PR}	0.009	11.391	29.996	3.886	5%	19.026	95%

4.2.5 Analysis and Conclusions

As shown in the table, the probability of failure is again high and is 30 percent. Moreover, the probability of loss of partner, *LoP*, is also high and, on average, in 56% of the time, the EU will have less than 50% chance of being able to continue doing business with the MSP, mainly as a result of having financial difficulties caused by MSP's opportunistic behavior and additional costs it imposes on the EU, denoted by L^+.

The probability of financial loss is also relatively high and, on average, in approximately 19% of the time, the contract does not result in the desired profit, at least 10%, even though the MSP might be able to impose additional costs of up to 25% of the original price on the EU. The probabilities of incomplete contract and loss of image are also rather high, on average in 27 and 33 percent of the time above 50%, respectively.

Table 15 provides interesting information about the number and percentage of times Level-2 risk factors are qualified which, in turn, can provide useful information on the root causes of these risk factors. For instance, the statistics show that only in 40% of the simulation runs L+ is not qualified, which means that there is a 60% chance that the MSP ask for more money that what originally agreed on in the contract.

Table 15. Qualification statistics of Level-2 risk factors in Scenario A

Variable	No of times not qualified	% of times not qualified
$P_{underqualified}$	21795	54.4875
L+	15862	39.655
MRq	1199	2.9975
C_{MRq}	1199	2.9975
$C_{lawsuits}$	35279	88.1975
$D_{controversy}$	15862	39.655
$D_{EUHardship}$	15862	39.655
$D_{-coverage}$	15779	39.4475

As mentioned before, loss of image is the most important risk factor for the MSP in this scenario, and the regression sensitivity analysis indicates that its main reason is "MSP's opportunistic behavior" and "Negative media coverage/word of mouth". The threat of MSP's opportunistic behavior is further realized when it is identified as the first and most important reason of failure (Figure 24).

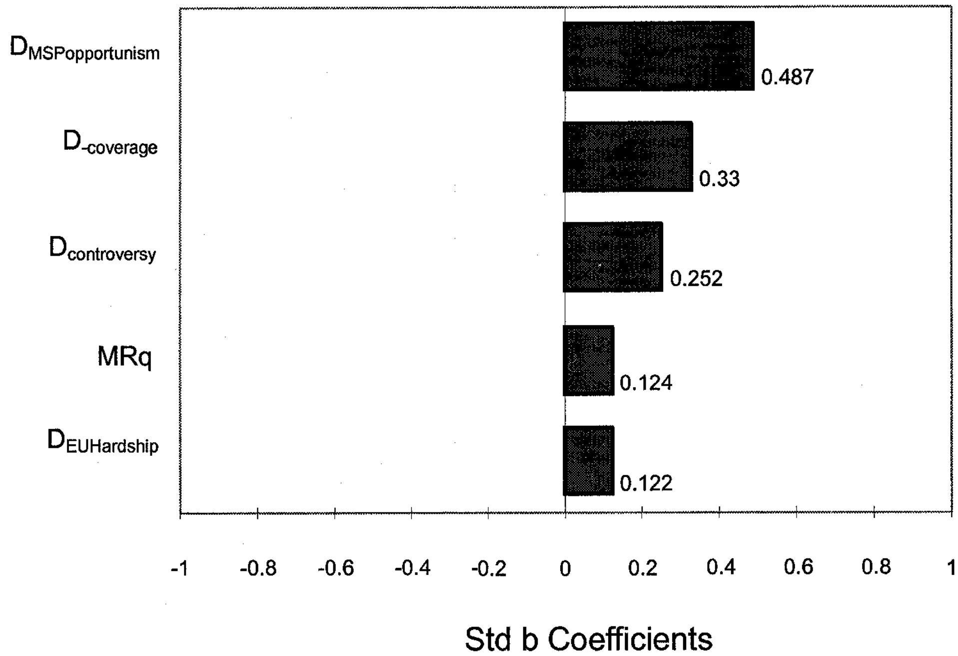

Figure 24. Regression Sensitivity Analysis for Loss of image in Scenario A

According to the tornado graph in Figure 25, MSP's opportunistic behavior, and high production costs are the most influential Level-1 risk factors on the probability of failure. As mentioned before, both of these risk factors can be practically controlled. In practice, MSPs have begun to recognize the importance of controlling opportunistic behavior and in many sectors, such as, for example, electronics, successful MSPs seek collaborative, long-term partnerships with their EUs [3]. In fact, a significant industry trend in recent years has been moving from single contracts to partnerships and risk sharing arrangements [20].

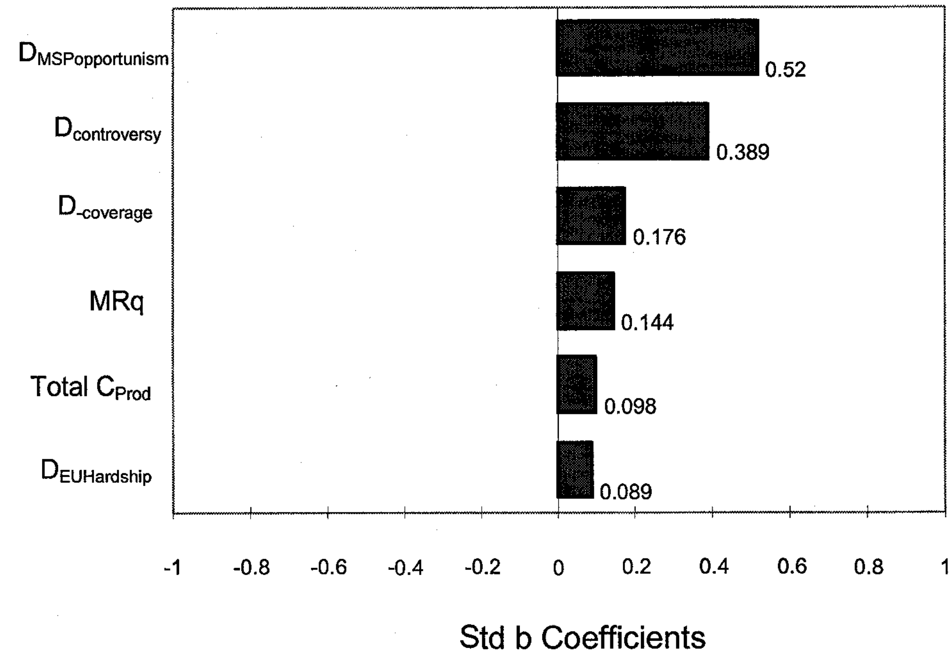

Figure 25. Regression Sensitivity Analysis for Failure Probability in Scenario A

If we assume that the MSP's opportunistic behavior is controlled, for example in a highly regulated environment or through long-term, collaborative arrangements, the probability of failure is radically decreased. According to the two tornado graphs, Table 16 and definition of Std b, probability of failure and loss of image can be reduced by approximately 0.19 (0.520*0.357) and 0.23 (0.478* 0.473), respectively, if $D_{MSPopportunism}$ is decreased by one Std Dev, i.e. 1.756.

According to Figure 25, "high production costs", denoted by C_{prod}, is the second most influential Level-1 risk factor on the probability of failure. Assuming that production costs are substantially kept low, through for example taking full advantage of modularity, standardization and reusability [1] or moving the production to low-wage areas, and running the simulation again the probability of failure can be cut down by 0.035 (0.357*0.098), for each 11.27 units decrease in production costs.

Table 16. Summary statistics for Scenario A

Statistic	Value for Failure Probability	Value for LoP	Value for C_{prod}	Value for $D_{MSPopportunism}$
Minimum	0	0	7.183	1
Maximum	1	1	97.219	7
Mean	0.300	0.336	48.929	4.710
Std Dev	**0.357**	**0.472**	**11.270**	**1.756**
Variance	0.127	0.223	127.019	3.086
Skewness	0.862	0.693	0.0277	-0.461
Kurtosis	2.281	1.480	2.987	2.233
Median	0.100	0	48.845	5
Mode	0	0	31.431	5

4.3 Scenario F

4.3.1 Description

Scenario F is the third riskiest scenario. In this case, similar to Scenario C, the balance of power is in favor of the EU and unlike both scenarios A and C, the MSP provides the EU with a standard, commodity service.

Similar to Scenario C, since the balance of power is in favor of the EU, all managerial categories of uncertainties, i.e. uncertainty in time, in information, and in control[7], are significant and have to be considered. Thus, risk factors associated with this scenario are also less likely to be controllable.

In electronics, most of the arrangements Contract Manufacturers (CM) or Electronics Manufacturing Services (EMS) (which CMs have evolved to) are involved in can be categorized under this category. There are several rival large CM or EMS companies who all offer a more or less similar set of manufacturing services to Original Equipment Manufacturers (OEM) which are mostly well-established market players with strong market position and brand names (companies such as, for example, HP, Microsoft and Cisco). Their business is often a risky, low margin business which is always potentially threatened by new disruptive technologies.

4.3.2 Identifying Risk Factors and Modeling the System

Step 1_ Level-3 risk factors

Already completed in 3.5.1.

Step 2_ Level-1 risk factors

Since in Scenario F, similar to Scenario C, the balance of power is favor of the EU, all risk factors resulted from the power structure, which were modeled for Scenario C, are applicable here as well and, therefore, are not repeated in this section.

On the other hand, the fact that the service provided by the MSP is not a specific service and can be considered a mature commodity service which can be also provided by many other MSPs dictates other risk factors as illustrated in Figure 26.

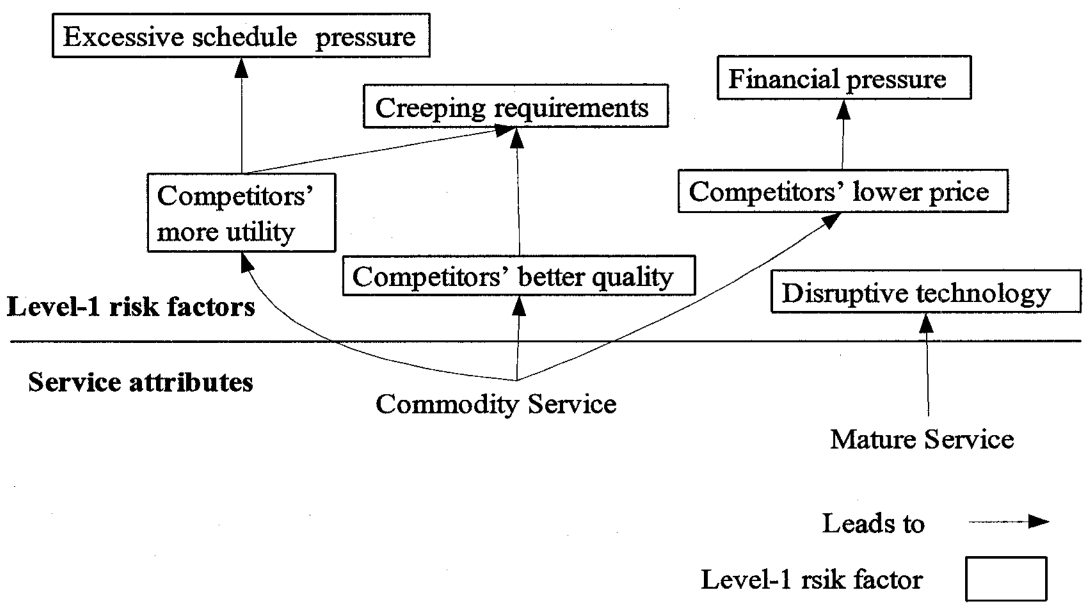

Figure 26. Level-1 risk factors resulted from service attributes in Scenario F[16]

A **disruptive technology** or **disruptive innovation,** an expression coined by Clayton M. Christensen and used in contrast with **sustaining technology** or **innovation,** is "a

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[16] A commodity service is a non-complex, which is not very asset specific or time sensitive.

technological innovation, product, or service that eventually overturns the existing dominant technology or status quo product in the market." It dominates an existing market by either filling a role in a new market that the older technology could not fill (for example more expensive, lower capacity but smaller-sized hard disks used in newly developed notebook computers in the 1980s) or by successively performance until finally replacing the older technology (as digital photography has begun to replace film photography) [22].

The impacts of the identified Level-1 risk factors are listed in Table 17.

Table 17. Impacts of Level-1 risk factors of Scenario F

Risk Factor	Effects
Competitors' better quality	• EU's financial pressure • EU's creeping requirements[7]
Competitors' lower price	
Competitors' more utility	
Disruptive technology	EU's new expectations asking for new technology
EU's opportunistic behavior	Time and cost pressure, creeping requirements [7], overdependence on the EU

Step 3_ Level-2 risk factors

Level-1 risk factors, if actualized, give rise to the second level of risk factors, which can directly cause the MSP to fail.

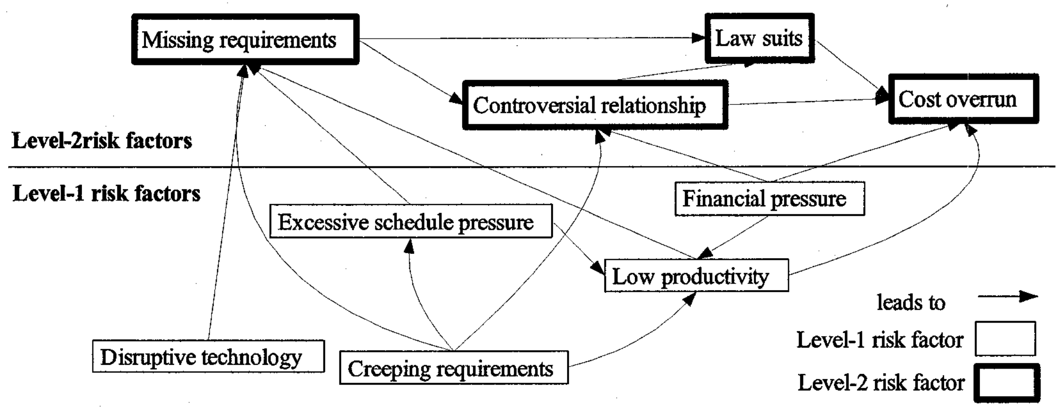

Figure 27. Level-2 risk factors of Scenario F

Even though the identified Level-2 risk factors in Scenario F are similar to the ones identified in Scenario C and, therefore, they will have the same effects (Table 3), the risk factors associated with each scenario should be quantified and modeled differently since they are rooted in different sources.

Figure **28** represents the relationship between Level-2 and Level-3 risk factors and how realization of Level-2 risk factors can cause the MSP to fail in its contractual relationship with the EU.

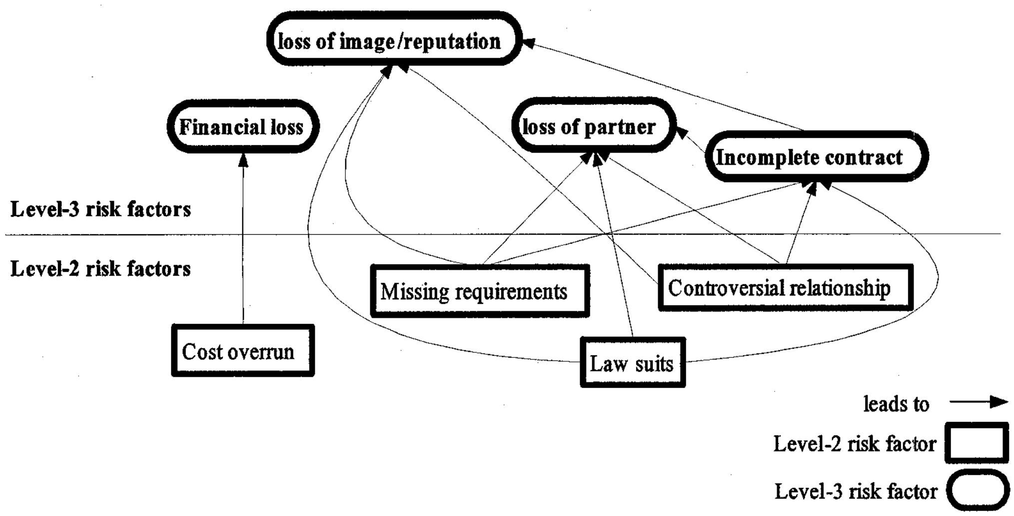

Figure 28. Level-2 and Level-3 Risk factors in Scenario F

4.3.3 Quantifying Risk Factor Uncertainties

Level-1 risk factors

In this section, we explain the way Level-1 risk factors are quantified. Considering the impacts and implications of each risk factor a number of random variables are defined to quantify each risk factor. Also, an example distribution is considered for each random variable to be used in the example simulation runs. Again the risk factors already modeled for Scenario C are omitted to avoid redundancy.

- Disruptive technology
  - Disruptive Technology occurrence (*DisTech* where $P_{DisTech} = P_{DisTech}$)

In the example, $P_{DisTech}$ is considered equal to 0.01.

- Competitors' lower price
  - Competitors' price ($P_{comp} \sim f(P_{comp})$)

In the example, $f\,(P_{comp})$ is set to Normal (100, 10), which implies that the average price of the competitors is the same as your leasing price.

- Competitors' better quality
    - Competitors' quality ($Q_{comp} \sim$ 1 to7 scale[17])

In the example, it is assumed that Q_{comp} follows a Binomial (6, 0.5, shift(1)) distribution.

- Competitors' more utility
    - Competitors' lead-time ($LT_{comp} \sim$ 1 to7 scale)
    - Competitors' peripheral services ($PS_{comp} \sim$ 1 to7 scale)

In the example, it is assumed that both LT_{comp} and PS_{comp} follow a Binomial (6, 0.5, shift(1)) distribution.

- EU's opportunistic behavior
    - Degree of EU's opportunism ($D_{EUopportunism} \sim$ 1 to 7 scale)

Note that as EU has superior power, the probabilities of higher degrees of opportunism are considered to be greater. $D_{schedule}$ is positively correlated with $D_{opportunism}$ since the EU can pressurize the MSP to complete what is committed to do in shorter time. In the example, P($D_{EUopportunism}$ ={1,2,3,4,5,6,7}) = {0.05,0.05,0.1,0.15,0.23,0.22,0.2}).

- Creeping requirements
    - Costs of extra requirements ($C_{XRq} \sim f\,(C_{XRq})$) (added to production costs and is

---

[17] The comparative 1 to 7 scale is defined as follows:
1: much worse, 2: worse, 3: rather worse, 4: same, 5: rather better, 6: better, 7: much better

qualified if $DisTech$=1 or $D_{opportunism}$>4 or Q_{comp} >4 or PS_{comp}>4.)

$$C_{XRq} = \begin{cases} M & \text{if } DisTech=1 \\ \sim f(C_{XRq}) & \text{Otherwise} \end{cases} \qquad (19)$$

where M is a large number. This ensures that if a disruptive technology comes around, assuming that the MSP will not be able to offer that immediately, it certainly will not be able to provide the EU with its new requirements.

C_{XRq}, in the absence of disruptive technology, qualifies MRq if it is greater than $\hat{C}_{XRq}$. Also, C_{XRq} is strongly correlated with MRq, Q_{comp} and PS_{comp} and is added to production costs. In the numerical example, $f(C_{XRq})$ is assumed to be exponential(15) and $\hat{C}_{XRq}$=0.

- Financial pressure
  - The imposed price cut on the MSP (L^-), defined as a percentage of original L, leasing price stated in the original contract, defined as follows:

$$L^- = \begin{cases} \sim f_1(L^-) & \text{if } D_{EUopportunism} > 4 \text{ OR } P_{comp} < 85 \\ \sim f_2(L^-) & \text{Otherwise} \end{cases} \qquad (20)$$

Obviously, the mean of $f_1(L^-)$ is greater than the mean of $f_2(L^-)$. In the example, $f_1(L^-)$ and $f_2(L^-)$ are considered as Normal(10, 5) and Normal(5,2), respectively. L^- has strong negative correlation with P_{comp} . C_{XRq} and L^- are qualified if $D_{EUopportunism}$> 4.

- Excessive schedule pressure [7]
  - Degree of schedule pressure ($D_{schedule}$ ~1 to 7 scale).

$$D_{schedule} = \begin{cases} f_1(D_{schedule}) & \text{if } D_{EUopportunism} < 4 \text{ AND } LT_{comp} < 5 \\ f_2(D_{schedule}) & \text{Otherwise} \end{cases} \quad (21)$$

  - Total % cost to make up schedule pressure which MSP incurs if $D_{schedule}$ >4 ($C_{schedule} \sim f(C_{schedule})$)

($C_{schedule} \sim f(C_{schedule})$)

These two random variables are positively correlated; $D_{schedule}$ is also positively correlated with LT_{comp} and C_{XRq}. In the example, we consider $f_1(D_{schedule})$ as a binomial (6, 0.5, shift(1)) distribution and $f_2(D_{schedule})$ as a discrete distribution where $P(D_{schedule}=\{1,2,3,4,5,6,7\}) = \{0.05,0.1,0.1,0.15,0.25,0.2,0.15\}$.

  - $C_{schedule} \sim$ Normal(2, 1)

Defining $D_{schedule}$ as described above, insures higher probabilities for actualization of excessive schedule pressure in case the EU behaves opportunistically or the competitors provide the same service with shorter lead times.

- Low Productivity[7][10]
  - Degree of productivity ($D_{productivity}$)~ 1 to 7 scale

$D_{productivity}$ has strong negative correlation with $D_{schedule}$, C_{XRq} and L^-, $D_{EUopportunism}$. In the example, we consider that $D_{productivity}$ follows a binomial (6, 0.5, shift(1)) distribution.

The rest of the model is similar to that of Scenario C, except the following differences:

- Missing requirements
  - % of requirements missed (*MRq*)

$$
MRq = \begin{cases} 100 & \text{if } DisTech=1 \\ \sim f(MRq) & \text{Otherwise} \end{cases} \tag{22}
$$

  - Costs of missing requirements ($C_{MRq} \sim f\ (C_{MRq}\ )$) (added to ex post transaction costs)

$$
C_{MRq} = \begin{cases} 0 & \text{if } DisTech=1 \text{ or } MRq=0 \\ \sim f(C_{MRq}) & \text{Otherwise} \end{cases} \tag{23}
$$

In the absence of disruptive technology, these two random variables are strongly correlated with each other, $D_{opportunism}$, $D_{schedule}$ and *XRq*.

- Law suits
  - Additional court costs ($C_{lawsuits}$) (added to ex post transaction costs)

$$
C_{lawsuits} = \begin{cases} \sim f(C_{lawsuits}) & \text{if } D_{controversy} = 4 \text{ or } (MRq > \hat{M}Rq1 \text{ and } DisTech=0) \\ 0 & \text{Otherwise} \end{cases} \tag{24}
$$

$C_{lawsuit}$ is strongly correlated with *MRq* and f ($C_{lawsuits}$) is considered Normal (70, 20) in the example.

Moreover, as invention of a disruptive technology is a radical change that can potentially change all the equations, we need to change some of the *w* multipliers as follows:

$$
w_{LoP}^{Controversy} = \begin{cases} 0 & \text{if } DisTech=1 \\ 0.1 & \text{Otherwise} \end{cases} \tag{25}
$$

$$W_{LoP}^{MRq} = \begin{cases} 1 & \text{if } DisTech=1 \\ 0.5 & \text{Otherwise} \end{cases} \quad (26)$$

$$W_{LoP}^{LawSuits} = \begin{cases} 0 & \text{if } DisTech=1 \\ 0.4 & \text{Otherwise} \end{cases} \quad (27)$$

$$W_{LoI}^{LawSuits} = \begin{cases} 0 & \text{if } DisTech=1 \\ 0.4 & \text{Otherwise} \end{cases} \quad (28)$$

$$W_{LoI}^{Controversy} = \begin{cases} 0 & \text{if } DisTech=1 \\ 0.1 & \text{Otherwise} \end{cases} \quad (29)$$

$$W_{LoI}^{MRq} = \begin{cases} 1 & \text{if } DisTech=1 \\ 0.5 & \text{Otherwise} \end{cases} \quad (30)$$

Different formulations in the case of disruptive technology ensure that in case of disruptive technology, the short term interests of the MSP with regard to the contract under study (profit margin and completing the contract) are not endangered as much as its long-term benefits (continuing business with the EU and keeping its image and market share). This is especially important since we have assumed that time horizon of the contract is short.

Thus, since disruptive technology is such a radical change that requires a different model, two different models are simulated in parallel to reflect what is likely to happen in reality. One model assesses the probability of success if the dominance of the current technology offered by the MSP remains untouched during the time horizon of the contract, and the other one attempts to assess MSP's chances of success in case a disruptive technology gains dominance in this period. Simulating these two models as the two states the system may have with different probabilities allows for a more realistic risk assessment process.

Similar to Scenario C, the probabilities of Level-3 risk factors are calculated as follows:

$$P_{IC} = w_{IC}^{LawSuits} * P_{IC}^{LawSuits} + w_{IC}^{controversy} * P_{IC}^{controversy} + w_{IC}^{MRq} * P_{IC}^{MRq} \quad (31)$$

$$P_{LoP} = w_{LoP}^{LawSuits} * P_{LoP}^{LawSuits} + w_{LoP}^{Controversy} * P_{LoP}^{Controversy} + w_{LoP}^{MRq} * P_{LoP}^{MRq} \quad (32)$$

$$P_{LoI} = w_{LoI}^{LawSuits} * P_{LoI}^{LawSuits} + w_{LoI}^{Controversy} * P_{LoI}^{Controversy} + w_{LoI}^{MRq} * P_{LoI}^{MRq} \quad (33)$$

Also, we consider the following values for the model parameters:

ε=\$5; $\hat{P}_{IC} = \hat{P}_{LoP} = \hat{P}_{LoI}$=0.5; $\hat{MRq}1$=50; $\hat{MRq}2$=20; $w_{IC}^{LawSuits}$=0.5; $w_{IC}^{controversy}$=0.3; w_{IC}^{MRq}=0.2 and M=100.

4.3.4 Propagating the Uncertainties

40,000 simulations were run assuming that W_{FLo}=0.3; W_{IC}=0.15; W_{LoP}=0.4; W_{LoI}=0.15, ρ=\$0.5 [11], $\hat{e}$=0.005, $C_{ex\text{-}ante}$=8, and that production costs (C_{prod}) follows an N(25, 5) distribution and $C_{ex\text{-}post}$~N(7,4).

Figure 29 shows the schematic presentation of the simulation model. The cost structure is also the same as that of Scenario C.

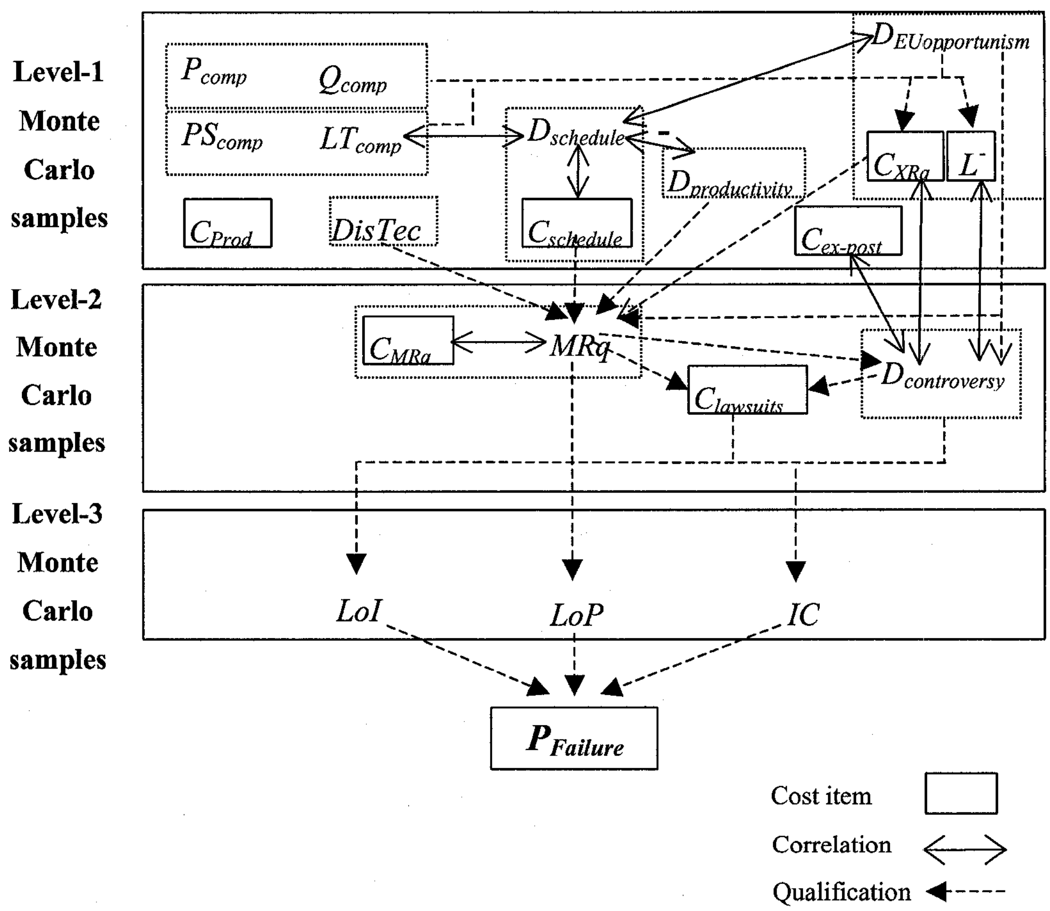

Figure 29. Schematic view of Scenario F simulation model

Since the contracted service is a commodity service, production costs are considered less than the other two scenarios. Also, the main objective of the MSP is considered satisfying the EU so that it continues leasing MSP's services and does not switch to other similar MSPs. This is the reason why W_{LoP} is considered the greatest of other weights, which are assumed to be of equal importance.

Table 18 represents the results of simulating the developed model for Scenario F, using the sample distributions.

Table 18. Simulation results for Scenario F numeric example

Name	Minimum	Mean	Maximum	x1	p1	x2	p2
			Outputs				
Total C_{Prod}	7.558	41.075	142.931	21.272	5%	75.360	95%
Total $C_{ex\text{-}post}$	0.002	27.783	194.870	5.303	5%	108.575	95%
C_{MSP}	14.967	71.858	290.839	33.831	5%	158.709	95%
% NPV	-262.569	14.426	66.916	-80.776	5%	51.833	95%
FLo	0	0.219	1	0	5%	1	95%
LoP	0	0.283	1	0	5%	1	95%
IC	0	0.118	1	0	5%	1	95%
LoI	0	0.283	1	0	5%	1	95%
Failure Probability	**0**	**0.239**	**1**	**0**	**5%**	**1**	**95%**
			Inputs				
C_{Prod}	4.416	25.024	44.822	16.814	5%	33.26075	95%
$C_{ex\text{-}post}$	0.001	7.352	22.662	1.601	5%	13.67758	95%
DisTech	0	0.0107	1	0	5%	0	95%
P_{comp}	59.055	100.026	147.508	83.383	5%	116.538	95%
Q_{comp}	1	4	7	2	5%	6	95%
LT_{comp}	1	4	7	2	5%	6	95%
PS_{comp}	1	4	7	2	5%	6	95%
$D_{schedule}$	1.000	4	7	2	5%	5	95%
$D_{schedule}$	1	5	7	2	5%	7	95%
$C_{schedule}$	0.004	2.204	6.257	0.697	5%	3.788	95%
$D_{productivity}$	1	4	7	2	5%	6	95%
$D_{EUopportunism}$	1	5	7	2	5%	7	95%
L_{-1}	0.002	5.106	12.925	1.960	5%	8.253	95%
L_{-2}	0.017	11.382	29.328	3.671	5%	19.398	95%
C_{XRq}	0.000	16.721	99.361	1.297	5%	46.825	95%
MRq	0.038	21.106	58.444	5.946	5%	36.904	95%
C_{MRq}	0.002	12.004	47.222	2.045	5%	23.912	95%
$C_{lawsuits}$	5.290	82.764	156.334	49.640	5%	115.262	95%
$D_{controversy}$	1	3	4	1	5%	4	95%

4.3.5 Analysis and Conclusions

The simulation results (Table 18) indicate that there is an approximately 22% chance that the contract bring in no financial profit and there is 24% chance of failure. Also, there is a

28% chance that the EU switches to other similar MSPs, with the probability of 50%, after completing this contract.

Table 19 contains useful information on the number and percentage of times Level-2 risk factors are not qualified and can provide useful information on the root causes of these risk factors. For instance, the statistics show that only in 17% of the simulation runs extra requirements in addition to what mentioned in the original contract are not imposed on the MSP (creeping requirements). Also, there is only 11% chance that there are no missing requirements.

Table 19. Level-2 risk factors qualification statistics in Scenario A

Variable	No of times not qualified	% of times not qualified
C_{XRq}	7124	**17.81**
MRq	4501	**11.2525**
C_{MRq}	4501	**11.2525**
$C_{lawsuits}$	35274	**88.185**
$D_{controversy}$	5449	**13.6225**

Figure 30 illustrates the results of performing regression sensitivity analysis on "Loss of Partner".

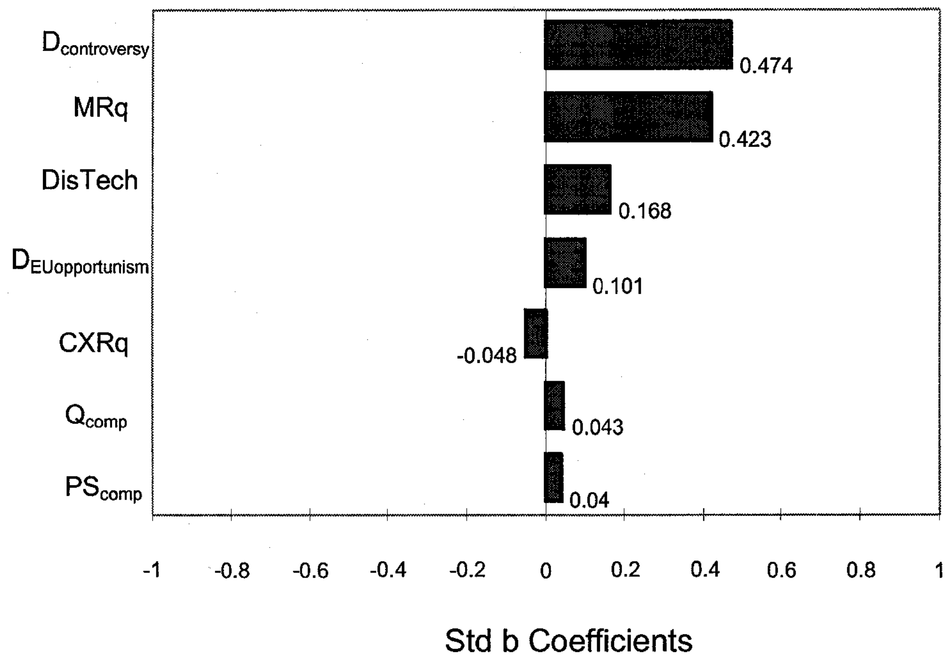

Figure 30. Regression Sensitivity analysis for Loss of Partner in Scenario F

As expected, one of the main reasons for losing the EU is that the MSP will not be able to meet all EU's short-term and long-term requirements. Given that we can trace back missing requirements to MSP's competition, disruptive technology and EU's opportunistic behavior, and that "controversial relationship" is also rooted in EU's opportunistic behavior, it can be concluded that EU's Opportunistic behavior amplified by MSP's competitors and emergence of a disruptive technology are the most significant reasons for loss of partner. In fact, these two risk factors are also the main reasons of MSP's failure (Figure 31).

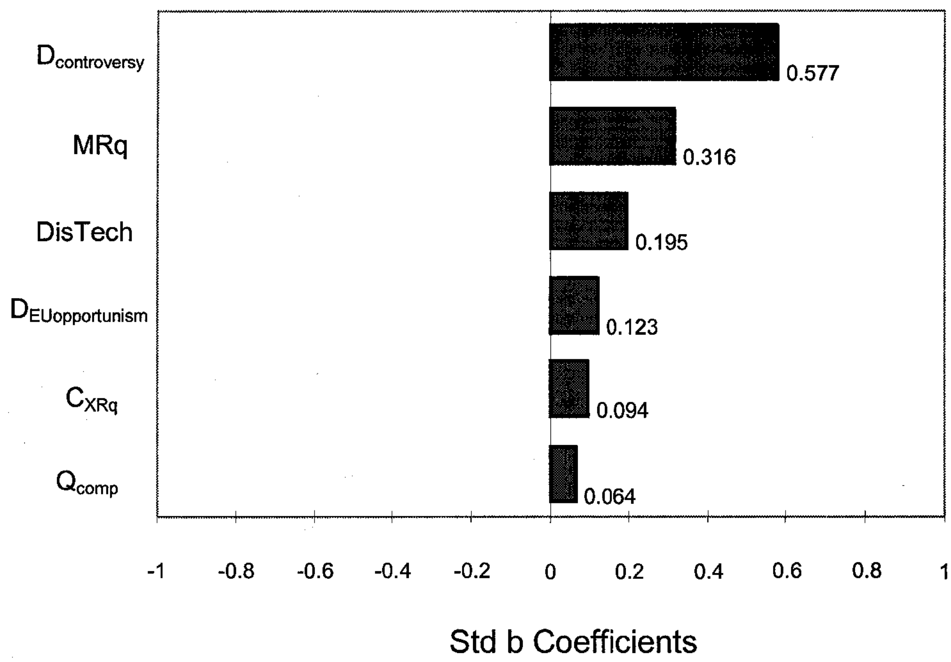

Figure 31. Regression Sensitivity analysis for Failure Probability in Scenario F

The analysis shows that the risk factors associated with Scenario F are the least controllable of the three scenarios. Figure 31 shows that even high production costs, C_{prod}, is not a major reason for failure. However, it should be kept substantially low in order to to stay competitive and to keep MSP's services attractive to the EUs.

CHAPTER 5 Conclusions and Recommendations

5.1 Comparison of Scenarios

In this section the simulation results of the three scenarios are compared and analyzed. Even though the numerical examples are based on made up data, the distributions used in the simulations are designed in a way to be reasonably realistic. Table 20 summarizes the distributions used in the simulated numerical example; the random variables common between more than one scenario are shaded to be distinguishable.

Table 20. Distributions used in scenarios

Variable \ Scenario	**C**	**A**	**F**
$C_{ex\text{-}ante}$	5	3	3
$C_{ex\text{-}post}$	N(10,4)	N(7,2)	N(7,4)
C_{prod}	N(40,15)	N(35,10)	N(25,5)
$T_{Personnel}$	Binomial(3, 0.5, Shift(1))	Binomial(3, 0.5, Shift(1))	
$C_{Personnel}$	N(5, 2)	N(4,2)	
$\hat{P}_{underqualified}$	0.1	0.3	
T_{tech}	Binomial(3, 0.5, Shift(1))	Binomial(3, 0.5, Shift(1))	
C_{tech}	N(8, 5)	N(6,4)	

Variable \ Scenario	**C**	**A**	**F**
$D_{schedule}$	P({1,2,3,4,5,6,7})= {0.05,0.05,0.1,0.15, 0.23,0.22,0.2}	P({1,2,3,4,5,6,7})= {0.05,0.1,0.1,0.15,0.25,0.2,0.15}	IF($D_{EUopportunism}$ <4 & LT_{comp} <=4), Binomial(6, 0.5, Shift(1), else P({1,2,3,4,5,6,7})= {0.05,0.1,0.1,0.15,0.25,0.2,0.15}
$C_{schedule}$	N(5, 2.5)	N(3,2)	N(2,1)
$D_{productivity}$	Binomial(6, 0.5, Shift(1))	If $D_{commitment}$ <4, P({1,2,3,4,5,6,7})= {0.15,0.15,0.25,0.2, 0.1,0.1,0.05}, else Binomial(6, 0.5, Shift(1))	Binomial(6, 0.5, Shift(1))
$D_{EUopportunism}$	P({1,2,3,4,5,6,7})= {0.05,0.1,0.1,0.15,0.22,0.2,0.18}		P({1,2,3,4,5,6,7})= {0.05,0.05,0.1,0.15, 0.23,0.22,0.2}
L-	N(10, 5)		If ($D_{EUopportunism}$ <4, (if (P_{comp} >90 & Q_{comp} <5), N(5,2), else N(10,5))else 0
C_{XRq}	Exponential(20)		Exponential(15)
MRq	N(30,20)	N(40,20)	N(20,10)
C_{MRq}	N(15,8)	N(10,5)	N(10,8)
$C_{lawsuits}$	N(70,20)	N(60,15)	N(75,20)
$D_{controversy}$	Binomial(3, 0.5, Shift(1))	Binomial(3, 0.5, Shift(1))	Binomial(3, 0.5, Shift(1))

Scenario / Variable	C	A	F
$D_{MSPopportunism}$		P({1,2,3,4,5,6,7})= {0.05,0.1,0.1,0.15,0.22,0.2,0.18}	
L^+		N(8,4)	
$D_{commitment}$		P({1,2,3,4,5,6,7})= {0.18,0.2,0.22,0.15, 0.1,0.1,0.05}	
$D_{EUHardship}$		Binomial(3, 0.5, Shift(1))	
$D_{-coverage}$		Binomial(6, 0.5, Shift(1))	
C_{PR}		N(10,5)	
$\hat{P}_{DisTech}$			0.01
P_{comp}			N(100,10)
Q_{comp}			Binomial(6, 0.5, Shift(1))
LT_{comp}			Binomial(6, 0.5, Shift(1))
PS_{comp}			Binomial(6, 0.5, Shift(1))

For instance, it is assumed that C_{prod} has the smallest mean and standard deviation in Scenario F since the manufacturing service contracted in this scenario involves low degrees of asset specificity, and, therefore, requires less investment and enjoys higher economy scales and salvage value for the manufacturing facilities. This is also due to the fact that the manufacturing service in this scenario is a commodity, mature service.

However, C_{prod} is not considered too low since the leasing price of the service, L, cannot be too high because of the competitive market and because the EU is in a better bargaining position.

The simulation results are consistent with the hypothesis mentioned in [14], and the probability of failure in Scenario C is the most, followed closely by Scenario A, and lastly Scenario F. Table 21 summarizes the summary of results obtained from simulating the numerical examples of the three scenarios.

Table 21. Three Scenarios results summary

Scenario / **Output**	**C**	**A**	**F**
Probability of failure	32%	30%	24%
Main failure root cause	EU's opportunistic behaviour	MSP's opportunistic behaviour	EU's opportunistic behaviour
Most influential risk factor	Controversial relationship	MSP's opportunistic behaviour	Controversial relationship

Interestingly, in all the three scenarios, even in scenarios C and A, where the manufacturing service contracted is a highly specific one, the most influential risk factor is not high production costs but it is the opportunistic behavior of the more powerful party. The potential long-term and short-term threats of controversial relationships resulting from one party's opportunistic behavior, shirking, and pressuring are widely known and many pieces of research are focused on finding ways to manage and control these risk factors (e.g. [3][6][8]). This is also consistent with current industry trends in sourcing arrangements which is moving towards partnerships and joint ventures to set off the effects of lack of balance and help both partners benefit equally from the contract (e.g. [3][20][34][14]).

5.2 Recommendations and Future Research

The main limitation of this research is probably the fact the simulations rely on arbitrary data. To overcome this and to further streamline this research, the following can be done:

- Evaluating the real performance of the model through applying on real-life data
- Completing the model to incorporate internal risk factors as well as external ones
- Using agent-based modeling to simulate Scenario F which is highly influenced by the behaviour of autonomous competitors
- Developing a comprehensive risk assessment model which simultaneously considers both actors and studied the risk factors threatening the probability of a win-win contract which benefits both parties in long-term
- Completing the definition of failure by incorporating other Level-3 risk factors, such as loss of intellectual property

APPENDIX A

Rank Order Correlation

The rank order coefficient was developed by Spearman in early 1900's. It is calculated based on the rankings of values, i.e. their position within the min-max range of their possible values, without making any assumptions about the distribution of the variables, and not the actual values themselves[29]. The rank order coefficient, usually denoted by ρ, is a number between -1 and +1, where -1 means a perfect negative correlation, 1 indicates a perfect positive correlation and a ρ value between -0.5 and 0.5 indicates a week correlation [35].

@RISK allows for creating rank order correlation matrices using its RISKCORRMAT function. It generates rank-correlated pairs of sampled values in a two step process prior to simulation, as follows:

1. It generates a set of randomly distributed "rank scores" for each variable. For example, if *n* iterations are to be run, *n* scores are generated for each variable. In fact, rank scores are simply values of varying magnitude between a minimum and maximum. These rank scores are then rearranged to give pairs of scores which generate the desired rank correlation coefficient. In each simulation run, there is a pair of scores, one score for each variable.
2. It generates a set of random numbers (between 0 and 1) to be used in for each variable. Again, if there are *n* simulation runs, *n* random numbers are generated for each variable. These random numbers are then ranked in increasing order. For each variable, the smallest random number is then used in the iteration with the smallest rank score, the second smallest random number is used in the iteration with the

second smallest rank score and so on. This ordering based on ranking continues for all random numbers until the largest random number is used with the largest rank score.

The result of this procedure is a set of paired random numbers that can be used in sampling values from the correlated distributions in each iteration of the simulation[29].

When setting up a correlation matrix, it is very important to make sure that the resulting matrix is not invalid and is self-consistent. An invalid matrix involves inconsistent simultaneous relationships between three or more inputs. For instance, if input **A** and **B** are correlated with a coefficient of +1, **B** and **C** with a coefficient of +1, and **C** and **A** with a coefficient of -1, the resulting correlation matrix will be oclearly invalid[29].

@RISK can correct any invalid matrix and generate the closest valid matrix to the entered invalid one.

REFERENCES

[1] Urbani, A., Molinari-Tosatti, L., Pasek, Z.J., "Manufacturing Practices in Dynamic Markets: Reconfigurability to Enable a Service-Based Manufacturing Capacity Supply", *Proceedings of the IMECE: 2002, ASME International Mechanical Engineering Congress and Exposition*, New Orleans, Louisiana, November 17-22, 2002.

[2] Zhang, C., Dey, D., Fan, M.N., "Outsourcing Software Development: A Contract Theoretic Analysis", *15th Annual Workshop on Information Technologies & Systems (WITS),* 2006.

[3] Plambeck, E.L., Taylor, T.A., "Sell the Plant? The Impact of Contract Manufacturing on Innovation, Capacity and Profitability", Management Science Vol. 51, No. 1, pp. 133–150, 2005.

[4] Barthélemy, J., Quélin, B.V., "Complexity of Outsourcing Contracts and Ex Post Transaction Costs: An Empirical Investigation", Journal of Management Studies, Vol. 43, No. 8, December 2006.

[5] Argyres, N.S., Liebekind, J.P., "Contractual Commitments, Bargaining Power, and Governance Inseparability: Incorporating history into Transactions Cost Theory", Academy of Management Review, Vol 24, No. 1, pp.49-63, 1999.

[6] Osei-Bryson, K., Sullivan, W.E., "Designing effective incentive-oriented contracts for application service provider hosting of ERP systems", Business Process Management Journal, Vol. 9 No. 6, pp. 705-721, 2003.

[7] Houston, D.X., Mackulak, G.T., Collofello, J.S., "Stochastic simulation of

risk factor potential effects for software development risk management", Journal of Systems and Software, Volume 59, Issue 3, Pages 247-257, 2001.

[8] Osei-Bryson, K., Ngwenyama, O.K., "Managing risks in information systems outsourcing: An approach to analyzing outsourcing risks and structuring incentive contracts", European Journal of Operational Research, Vol. 174 pp. 245–264, 2006.

[9] Davies, D., "Holistic Risk Management", Computer Law and Security Report, Vol. 13, No. 5, 1997.

[10] Suri, P.K., Soni, R, "Stochastically Simulating Low Morale - A Risk Factor Effect on Risk Management", Journal of Computer Science, Vol. 2, No. 4, pp. 370-372, 2006.

[11] Boehm, B.W., "Software Risk Management: Principles and Practices," IEEE Software, vol. 08, No. 1, pp. 32-41, Jan_Feb, 1991.

[12] Karhade, P., Subramanyam, R., Susarla, A., "Contract Term and Extensibility: An Empirical Analysis of IT Outsourcing Contracts", University of Illinois at Urbana's working papers, 2005.

[13] Neves, M.F., "Contract Analysis as a Marketing Educational Tool", http://www.ifama.org/conferences/2000Congress/Forum%20-%20Final%20 PAPERS/Area%20I/Neves_Marcos.PDF, retrieved in Dec 19, 2006.

[14] Akbarzadeh, N., Pasek, Z.J., "An Analytical Model for Manufacturing Service Supply Contracts", *Proceedings of CARV 2007 Conference*, Toronto, ON, July 2007.

[15] Haimes, Y.Y., "Risk Modeling, Assessment, and Management", John Wiley

& Sons, Inc., 1998.

[16] http://www.barringer1.com/MC.htm, retrieved in April 16, 2007.

[17] Marshall Miles, F., Wilson, T.G. Jr., "Managing Project Risk and the Performance Envelope", *Proceedings of Applied Power Electronics Conference and Exposition*, 1998.

[18] O'Brien, J.B., "The Making of the Xbox". Wired Magazine, Vol. 9, 2001. http://www.wired.com/wired/archive/9.11/flex.html

[19] "Contract Lifecycle Management and the CFO_ Optimizing Revenues and Capturing Savings", Aberdeen Group, April 2007.

[20] Kakabadse, A., Kakabadse, N., "Outsourcing: Current and Future Trends", Thunderbird International Business Review, Vol. 47, No. 2, pp. 183–204, April-May 2005.

[21] Jiang, B., Qureshi, A., "Research on outsourcing results: current literature and future opportunities", Management Decision, Vol. 44, No. 1, pp. 44-55, 2006.

[22] http://en.wikipedia.org , retrieved in May 16, 2007.

[23] Rohde, F.H., "IS/IT Outsourcing Practices Of Small- And Medium-Sized Manufacturers", International Journal of Accounting Information Systems, Vol. 5, pp. 429– 451, 2004.

[24] Walker, G., Weber, D., "Supplier Competition, Uncertainty, and Make-Or-Buy Decisions", Academy of Management Journal, Vol. 30, No. 3, pp. 589-598, 1987.

[25] Sumner, M., "Risk Factors in Enterprise-Wide/ERP Projects", Journal of Information Technology, Vol. 15, pp. 317–327, 2000.

[26] Mohammad, A.M., Al-Bahar, J.F., "Project Risk Assessment Using the Analytic Hierarchy Process", IEEE Transactions on Engineering Management, Vol. 38, No. 1, February 1991.

[27] Kangary, R., Riggs, L.S., "Construction risk assessment by linguistics", IEEE Transactions on Engineering Management, vol. 36, No. 2, pp. 126-131, May 1989.

[28] Gemmer, A., "Risk management: moving beyond process", IEEE Software, Vol. 30, Issue. 5, pp. 33_43, May 1997.

[29] Guide to Using @Risk, Version 4.5, Dec. 2004.

[30] http://www.businesslink.gov.uk/bdotg/action/ , retrieved in May 19, 2007.

[31] Huckman, R.S., Pisano, G.P., "Flextronics International, Ltd.", Harvard Business School, March 2005.

[32] http://news.bbc.co.uk/2/hi/business/4488361.stm, retrieved in June 4, 2007.

[33] Mulholland B., Christian J., "Risk Assessment in Construction Schedules", Journal of Construction Engineering and Management, Vol. 125, No. 1, January-February 1999.

[34] Currie W.L., Willcocks L.P., "Analyzing four types of IT sourcing decisions in the context of scale, client/supplier interdependency and risk mitigation", Information Systems Journal, Vol. 8, No. 2, pp 119–143, 1998.

[35] http://www.revision-notes.co.uk/revision/181.html, retrieved on July 10, 2007

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