MASTER

An Outsourcing Decision Framework Integrating a Qualitative and Quantitative Approach
A Case Study at Prodrive Technologies B.V.

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An Outsourcing Decision Framework Integrating a Qualitative and Quantitative Approach: A Case Study at Prodrive Technologies B.V.

Master Thesis

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Preface

It is with great pleasure and pride that I present my thesis report as the result of my Master's degree in Operations Management and Logistics, which was conducted at Prodrive Technologies B.V. This thesis marks the end of my academic journey, following the completion of my Master's degree in Finance at Tilburg University in the summer of 2022. The process of this thesis was not an easy one, as it required balancing a nearly full-time job with the demands of academic research and writing. Nevertheless, the demanding work was worth the effort, as this year’s steep learning curve allowed me to develop in a meaningful way.

I would like to take this opportunity to express my deep gratitude to Collin and Melvin Drent from TU Eindhoven, who provided me with valuable support, insights, critical feedback, and their time throughout the process. Their mentorship helped me to write in a more effective and structured and without question improved the overall quality of my thesis. Moreover, I want to thank dr. Tan for her time and effort spent in assessing my thesis. Moreover, I am indebted to my company supervisor, Sietze de Jong, for giving me the opportunity to conduct my master's thesis on this impactful strategic project. His time, critical feedback, trust, and flexibility were instrumental in successfully completing this thesis. I would also like to thank to my colleagues Rick Hendriks and Robbert Louwers for their critical reviews.

Finally, I would like to thank my family, friends, and girlfriend for their incredible support and motivation throughout my entire academic career. It is my sincere hope that this study will contribute to the existing literature and provide value to both the academic and Prodrive Technologies B.V. I hope you will enjoy reading the report!

Lucas van de Ven
March 2023

Abstract

This master thesis has been conducted in collaboration with Prodrive Technologies B.V. The study focuses on developing a decision framework for selecting the best governance structure in production context. The company embedded vertical integration as a major strategy over the years. The effectiveness of this process-oriented operating structure is under question and therefore the company aims to reassess the governance structure of its production processes.

This study contributes to the current literature by integrating the main existing literature streams regarding outsourcing versus in-house production; transaction cost economics and the resource-based view. With that, it gives a new dimension to this frequently discussed operations management problem. Moreover, it integrates a qualitative and quantitative methodology into a newly developed outsourcing decision framework. This decision framework integrates the outcomes of the strategic (qualitative) and cost benchmark (quantitative) analysis into a supplier selection model; thereby effectively reducing a vastly complex strategic problem with various important quantitative and qualitative aspects into a decision model that can subsequently be used to guide this strategic problem. Throughout the study the value of integrating the qualitative and quantitative methodologies became more and more clear as this combination resulted in valuable insights from multiple perspectives. The decision framework and corresponding methodologies have been made generally applicable in practice which is illustrated by the case study conducted. Noteworthy is this study's practical contribution to Prodrive Technologies B.V.

List of Abbreviations

Abbreviation	Meaning
Prodrive	Prodrive Technologies B.V.
PTNL	Prodrive Technologies The Netherlands (Son)
PTCN	Prodrive Technologies China (Suzhou)
PTUS	Prodrive Technologies United States (Boston)
FTE	Full-Time Equivalent
NPI	New Product Introduction
CHM	Cable Harness Manufacturing department
TCE	Transaction Cost Economics
RBV	Resource-Based View
COPQ	Costs Of Poor Quality
TCO	Total Costs of Ownership
BSC	Balanced Scorecard
BWM	Best-Worst Method
MCDM	Multi-Criteria Decision-Making
WACC	Weighted Average Costs of Capital
P&L	Profit and Loss Statement

Management Summary

Introduction

Prodrive Technologies B.V. (Prodrive) is a Dutch high-tech manufacturing and development company that has been achieving a continuous organic growth of more than 22% for the past 20 years. The company aims to further grow in the upcoming years with 30% on annual basis bringing along challenges in sustaining operational output, quality, and efficiency. To address this, the company investigates a shift in its operations structure from process-oriented to product-oriented. The company's initial strategy was vertical integration for all production processes, which resulted in acquiring a diverse range of production competencies. Nonetheless, the company is currently uncertain about the competitiveness of some of these production processes, which necessitates a re-evaluation of outsourcing decisions based on qualitative (strategic) and quantitative (cost) factors. This is considered crucial to enhance sustainable productivity and profitability, resulting in the following problem statement:

> *To address declining productivity and operating margins, there is a need to evaluate the competitiveness of Prodrive's in-house production departments and determine the best governance structure for the production processes.*

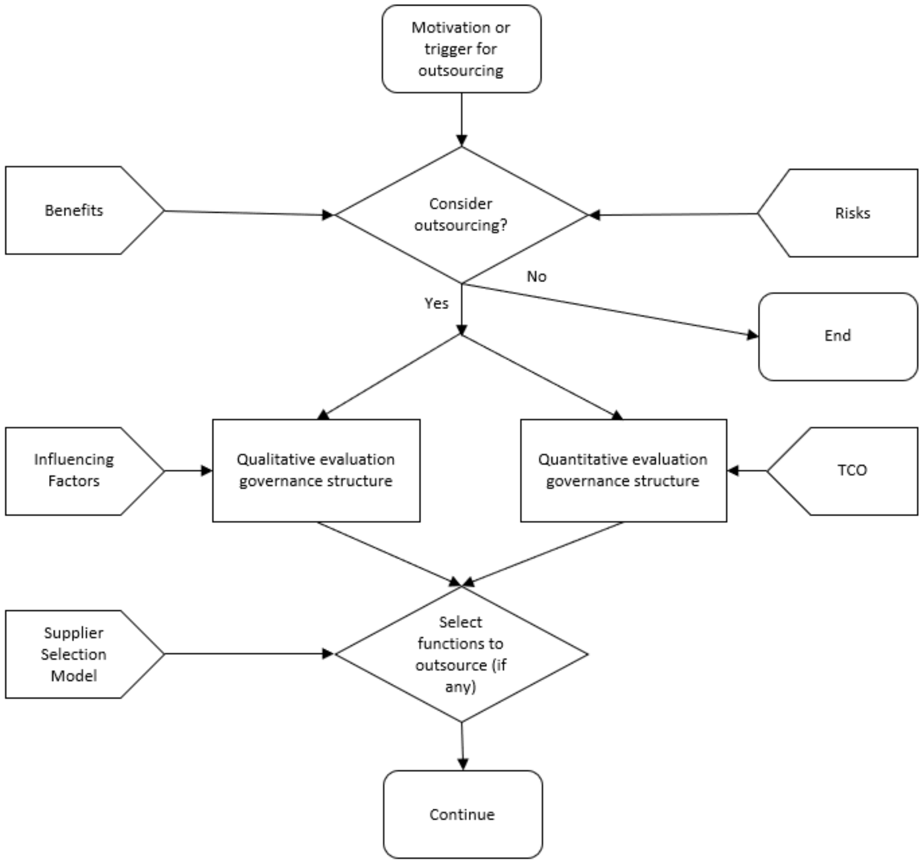
This problem statement is further specified into four main objectives namely: 1) develop a generally applicable outsourcing decision framework including a qualitative and quantitative assessment 2) develop a transparent cost price calculation method for Prodrive 3) benchmark the company in a case-study to assess the practicability of the framework and 4) create product-level supplier selection model based on the qualitative and quantitative inputs.

Solution Design

This study scientifically contributes by integrating two main outsourcing theories, Transaction Cost Economics and Resource-Based View. This enhances the study's comprehensiveness by providing a more in-depth understanding of the concept. The study further identifies and examines the benefits, risks, and influencing factors related to outsourcing decisions. These insights serve as crucial inputs for the development of a newly developed outsourcing decision-making framework, which integrates both qualitative and quantitative methodologies for assessing the outsourcing decision. Specifically, the newly developed framework, presented in

Figure 1 below, uses these inputs from the theoretical background and total costs of ownership to provide a comprehensive assessment that serves as input for the supplier selection model. By incorporating these elements, it combines qualitative and quantitative methodologies for assessing outsourcing. Therefore, the framework extends the current literature and has the potential to be used by other firms that face the difficult decision of outsourcing as well.

Figure 1: Outsourcing decision-making framework.



The qualitative assessment concerns semi-structured interviews with a multi-disciplinary sample of stakeholders within the company from executive level to mid-management. The interviews are analyzed using elaborative coding resulting in valuable insights, presented on the next page. Alongside these interviews a balanced scorecard, with statements based on the influencing factors presented in the theoretical background, is filled in by the interviewees and assessed using the Best-Worst Method. In the quantitative assessment we first develop a new cost price calculation model for Prodrive as my independent analysis revealed that the current cost prices are not representative of reality, which necessiated a new approach to accurately calculate cost prices and conduct a fair benchmark analysis. Moreover, requests for quotations have been done at potential suppliers and compared to the internal prices concluding the cost benchmark. To conclude, a weighted multi-objective fuzzy boundary supplier selection model is developed incorporating important influencing factors from the strategic analysis and results from the cost benchmark.

Findings

The strategic analysis presents four main findings namely:

1) Human resource scarcity in the Brainport region might be a bottleneck for Prodrive's growth due to ASML's growth making it favorable to use the scarce human resources for more value-adding activities in PTNL.
2) The China-US technology decoupling causes a high supply risk of products assembled in China containing US origin components which might require a (partial) transfer of cable assembly production to PTNL, suppliers or a new factory.
3) Quality and flexibility are the drivers preferring in-house cable production for quality-critical cables and prototypes due to short ties between CHM and R&D.
4) Building up a more sophisticated supply chain for cable assemblies in which non-quality critical demand can be outsourced. A supplier which strategically fits the company is preferred as it mainly concerns low volume high diversity demand in contradiction to general cable assembly parties (high volume, low diversity).

The quantitative analysis indicates that Prodrive is not competitive on multicore cables. While Prodrive is competitive on more complex cables (wire harnesses) compared to European suppliers, it is not competitive with Chinese suppliers on these complex labor-intensive cables due to their low labor wages. Generally, neither PTNL nor PTCN are competitive with the Chinese suppliers on lowest acquisition value due to the huge difference in labor wages. Further research is required into the qualitative aspects of the potential suppliers.

The supplier selection model divides demand between PTNL and the Chinese supplier in the across the globe comparison, which is intuitive as PTNL serves for satisfying the performance indicators whereas the Chinese supplier depresses the costs. While simulating the human resource scarcity in PTNL by adding a capacity constraint demand partially shifts from PTNL and the Chinese supplier to PTCN and the European suppliers to satisfy performance indicators and political stability respectively. To conclude, a robustness analysis has been performed on all constraints and input parameters resulting in intuitive behavior. This, in combination with the results confirm the practical applicability of the model.

Recommendations

In order to create the best governance structure for the CHM department Prodrive should:

1) **Maintain prototype and quality critical production at PTNL.**

Prototypes should remain in PTNL for operational flexibility and proximity to Research and Development. Complex cable assemblies are required for the most value-adding products with high quality standards and expensive rework costs making in-house assembly preferrable.

2) **Assess which cable assemblies must be transferred from PTCN due to US-CN technology decoupling and take appropriate action.**

A new law results in a high supply risk for products made in China with US origin components.

3) **Explore the feasibility of establishing a low-wage factory in Europe.**

Political instability in PTCN and human resource scarcity in PTNL requires a sustainable long-term solution. Opening a factory in a low-wage part of Europe for low value-adding activities mitigates the China-US decoupling risk and offers the opportunity to use PTNL's scarce human resources for more value-adding activities, maintaining quality and flexibility in own-hands.

4) **Expand research on cost-efficient suppliers which strategically fit to enhance the supply base and use these to outsource in-competitive cable assembly categories.**

Prodrive has a limited cable assembly supply base, so they should find cost-efficient suppliers with a strategic fit to outsource in-competitive product groups, like multicore cables.

5) **Evaluate qualitative indicators of proposed potential suppliers.**

Assumptions have been made on the performance indicators of potential new suppliers. Prodrive is recommended to rerun the supplier selection model after obtaining more insights.

6) **Extent, further customize and apply the supplier selection model.**

Prodrive is recommended to extend the supplier selection model by including scale prices, additional costs due to performance decreases and a multiple period horizon.

The outsourcing decision framework is simultaneously applied to other production processes determining their make-or-buy strategy. Moreover, recommendation 1 is considered, 2 is finished, projects are started for 3-5 and 6 is pending, emphasizing this study's practical applicability and its huge strategic contribution to Prodrive Technologies B.V.

Table of Contents

List of Figures

List of Tables

1 Introduction

The decision to produce in-house or outsource has been a subject of ongoing debate in the field of operations management and has become significantly more important in company strategies over the past years (Holcomb & Hitt, 2007). The literature on this topic has typically employed two dominant theoretical perspectives, namely transaction cost economics (Williamson, 1975) and resource-based view (Wernerfelt, 1984), to interpret the underlying rationales. However, these theoretical frameworks have often been used in isolation from one another, resulting in a fragmented understanding of the outsourcing decision. Furthermore, while some studies have focused on qualitative methods to explore the outsourcing decision, others have used quantitative techniques to analyze the decision. Nevertheless, the existing literature falls short in terms of an integrated approach combining both qualitative and quantitative methodologies. Moreover, the importance of such an integrated approach does not only lie in this theoretical gap, but also – as we shall see in this study – in practice as decision makers in practice view such an in-house versus outsourcing decision as one that should consider both quantitative and qualitative aspects.

This study's primary aim is to address these theoretical and practical gaps by developing an outsourcing decision framework that integrates the two main theories and combines qualitative and quantitative methodologies. By doing so, this study will provide a more comprehensive understanding of the outsourcing decision and offer practical insights. Moreover, the study will contribute to a better understanding of this key issue in operations management and supply chain management.

It is important to note that the present study focuses on developing a governance structure decision framework in a production context. The framework will encompass the decision to choose between in-house production, make-and-buy, and outsourcing (Williamson, 2008) and will assess competitiveness versus the market, based on qualitative and quantitative criteria. The following sub-chapter will introduce the company under investigation, Prodrive, and Chapter 2 will further elaborate on the problem definition, objectives, and research questions.

1.1 Prodrive Technologies

This sub-chapter introduces the company under investigation, Prodrive, providing sufficient context for the problem definition in Chapter 2. Prodrive, founded 30 years ago at TU Eindhoven, will serve as a base for this study. Prodrive is a high-tech company, which develops and manufactures high-end electronics, software, and mechanics. With a passion for technology, Prodrive operates under the healthy ambition to be of relevance and to contribute to meaningful innovation that tackles major challenges in society. Prodrive has shown impressive and continuous organic growth of more than 22% per year over the last 20 years. With over 2.400 FTE globally and a local-for-local strategy (manufacturing demand in a specific geographic location locally), the company's headquarters is in Eindhoven (PTNL) with its two other main facilities in Suzhou (PTCN) and Boston (PTUS). Prodrive embedded vertical integration, sometimes referred to as in-house production, as a core strategy. The company has a unique portfolio of four technology programs acting on several markets underpinned by three megatrends: digitization, energy transition and advanced and affordable healthcare.

Prodrive Technologies' product turnover for 2022 stands at 350 million Euros. The company aims to increase its growth to 2 billion by 2030, while ensuring continued profitability. Productivity is a crucial performance metric for Operations and is calculated by dividing operational output by full-time equivalent (FTE) and aimed to be 1 million for Operations by 2030. Prodrive has a wide diversification in products and production competences. Currently ~1400 products and ~8500 in-house sub-assemblies are distributed to over 100 customers. Prodrive's factory is process-oriented, due to vertical integration it has a wide diversity of production processes. This wide range of production competencies and Prodrive's diverse design competences result in a wide range of products making it convenient for customers to assess everything they need within one company (a one-stop-shop). In the past ten years six new production processes have been integrated. An overview of all production processes and the evolution over the years is presented in Table 10 (cf. Appendix I).

2 Problem Definition

In the previous chapter, we introduced Prodrive, a company that specializes in the development and production of electronic and mechatronic systems. In this chapter, we dive deeper into the challenges faced by the company, with a focus on a specific problem that needs to be addressed. This problem will be carefully analyzed, and a problem statement will be formulated based on the insights gained. The problem definition will serve as input for the objectives, which will guide the research questions that need to be answered.

2.1 Problem definition

Prodrive's organizational structure is characterized by a complex matrix, which consists of four technology programs on one axis and thirteen production processes on the other, leading to significant product and process diversification. However, the ambitious 30% year-on-year growth plan brings challenges in maintaining productivity and operating profits, Prodrive is investigating a strategic transition from a process-oriented to a product-oriented enterprise, with a specific emphasis on enhancing production output, quality, and efficiency. Particularly given the youthful nature of the company and the immaturity of some of its production processes, which presents significant potential for improvement. However, managing such a wide range of competencies poses a challenge in terms of effectively allocating improvement focus, which may undermine the competitiveness of the production processes and contributing to the decline in productivity. Accordingly, the company is exploring the possibility of benchmarking its production processes to assess the viability of vertical integration as the best strategy for each process. Moreover, my independent analysis revealed that the current cost prices in the system are not representing reality; thereby necessitating a new approach to accurately calculate cost prices and subsequently conduct a fair benchmarking analysis.

Despite this, in-house production at the headquarters offers strategic advantages, including the ability to maintain quality standards, customize production processes to meet customer requirements, and fully integrate them with all business information systems. All production processes are present in the Netherlands, which is questionable due to labor and facility costs. However, the company benefits from the close relationship between development and operations, facilitating new product introductions (NPI), flexibility and enhancing quality.

These strategic aspects add offshoring and opening a new facility to the solution spectrum of the governance structure decision defined at the start of Chapter 2.

Being competitive on a worldwide scale is crucial to Prodrive's future competitive advantage. Therefore, it is important to understand which processes are competitive. To make an informed decision about the appropriate governance structure, there is a need for a method to assess the competitiveness of Prodrive's production processes. So, the problem can be formulated as:

> *To address declining productivity and operating margins, there is a need to evaluate the competitiveness of Prodrive's in-house production departments and determine the best governance structure for the production processes.*

The reconsideration of one of the major company strategies, vertical integration of production department(s), has significant implications. Hence, a comprehensive assessment involving both qualitative (strategic) and quantitative (cost benchmark) evaluations is necessary. This is not available in existing literature. After consulting with the management, given the impact the study is scoped to CHM to ensure the right focus. Success in this process will pave the way for expansion to other processes. Moreover, this allows for a deep-dive on department level by developing a product-level supplier selection model as the governance decision might be different amongst product groups.

2.2 Objectives

According to the problem definition, Prodrive must reassess the competitiveness of their in-house production processes. To achieve this, a decision framework is required that incorporates both qualitative and quantitative criteria. In addition, we must develop a new cost price calculation method specifically for Prodrive's quantitative assessment. To delve further beyond the department level, a product-level supplier selection model must be created. These requirements from the problem definition result in the four primary objectives below:

1. Develop a generally applicable framework facilitating the selection of the right governance structure considering qualitative (strategic) and quantitative (cost benchmark) criteria.
2. Develop a transparent methodology for Prodrive's cost price calculations.

3. Benchmark costs in a case study to assess the practicality of the decision-making framework and determine the governance structure for the Cable Harness Manufacturing department (CHM).
4. Create a product-level supplier selection model based on the strategic and cost inputs.

The models should be generally applicable beyond the scope of this study, as Prodrive intends to evaluate the competitiveness of all production processes and wider applicability increases the value of the model to the existing literature.

2.3 Research questions

This sub-chapter translates the problem definition and corresponding research objectives to the research questions. The main research question is derived from the problem statement and presented below:

> *How to determine the governance structure while integrating qualitative and quantitative aspects?*

The main research question is supported by sub-questions derived from the objectives presented in Chapter 2.2. First, sub-question 1, defining a governance structure is addressed in Chapter 3.1. Consequently, sub-question 2 presents and intertwines the main literature streams regarding outsourcing versus in-house production in Chapter 3.2. To conclude the theoretical background, Chapter 3.3 presents a newly developed outsourcing decision framework answering sub-question 3. The fourth and fifth sub-question individually develop a methodology for making governance structure decisions qualitatively and quantitatively. These methodologies are presented and applied to Prodrive's case study in Chapter 5-I and 5-II respectively. In Chapter 6, a supplier selection model is presented and will assess Prodrive's case study. General insights on the governance structure decision derived from the supplier selection model are presented in Chapter 6.1 answering sub-question 6. General insights from this model, in combination with the conclusions from the case study in 5-I and 5-II will answer sub-question 7 in Chapter 7.6.

1. ***What are the definitions of a governance structure and outsourcing?***
2. ***What theories on outsourcing versus in-house production have been defined in the literature and how do these intertwine?***

3. *What are the key factors that should be considered when making outsourcing decisions and how can an outsourcing decision framework be tailored to include and balance qualitative and quantitative methodologies?*

4. *How to qualitatively determine the best governance structure?*

5. *How to quantitatively determine the best governance structure?*

6. *What insights can be derived from the supplier selection model developed using inputs from both quantitative and qualitative analysis?*

7. *What governance structure is recommended for Prodrive Technologies' CHM department?*

3 Theoretical Background

This chapter is structured to provide a comprehensive understanding of the outsourcing decision-making process in organizations. The chapter begins with definitions for a governance structure and outsourcing, addressing sub-question 1. Chapter 3.2 delves deeper into the existing literature on outsourcing versus in-house production and seeks to contribute to the research base by intertwining these theories, answering sub-question 2. Chapter 3.3 enlightens benefits, risks, influencing factors and potential quantitative methodologies for the outsourcing decision. After which, these are integrated into an extended outsourcing decision framework. This framework contributes to the current literature by integrating qualitative and quantitative methodologies and answers sub-question 3. The theoretical background's significance lies in providing a strong foundation for the research design in Chapter 4 as the outsourcing decision framework will be the backbone of this study. Understanding the theoretical background is crucial in conducting research, and this chapter provides the essential theoretical framework required to explore the outsourcing decision-making process.

3.1 Governance Structure

Before defining outsourcing and in-house production it is necessary to grasp the continuum of governance structures. A governance structure is a continuum that ranges from obtaining products fully from the market or completely manufacturing it within firm (Williamson, 2008). In this context outsourcing and in-house production are polar modes to which the make-and-buy strategy is an intermediate mode in which the production process is partially vertically integrated. This answers the first part of sub-question 1. Contracting out, however, refers to a situation in which the party intends to have a job-by-job rather than a long-term relationship (Embleton & Wright, 1998), another option, offshoring is the process of delocalization (Farrell et al., 2003). Outsourcing is a vital strategy in operations management and increasingly adopted in firms' overall business strategies. (Holcomb & Hitt, 2007; Gunasekaran et al., 2015; Liaw et al., 2020). The push for more efficiency and cost savings compels firms to specialize in key competencies and therefore outsource non-specialized key operations (McIvor, 2009). This study focuses on strategic outsourcing for long-term strategic positioning and maintaining competitive advantage, rather than tactical outsourcing which aims for short-term cost reduction (Sanders et al., 2007).

Academics employ a broad range of definitions for outsourcing. For example, it is defined as the procurement of something that was (or could have been) vertically integrated, regardless of the decision to outsource (Gilley & Rasheed, 2000). The definition of outsourcing evolved over the years (Hätönen & Eriksson, 2009). The transformational phase, which is the process of outsourcing a whole organizational activity to an outside vendor, was recognized in the 10s. In the past resource seeking (90s) and reducing transaction costs (80s) were the drivers (Williamson, 1975; Lei & Hitt, 1995). Bilderbeek (2011) defines outsourcing as "the management of the day-to-day execution of an entire business function by an independent third-party service provider". The concepts of Gilley and Rasheed (2000) and Bilderbeek (2011) are integrated and altered for this study to the following definition, answering the second part of sub-question 1:

> *"**Outsourcing** is the management of a day-to-day execution of an entire business function which was (or could have been) vertically integrated notwithstanding the decision to go to an independent third-party (make-or-buy)."*

3.2 Theories

This chapter explains and intertwines two main outsourcing theories in current literature: transaction cost economics and the resource-based view. First, transaction cost economics will be elaborated after which the research-based view is discussed. To conclude, both theories will be intertwined and serve as a basis for a comprehensive understanding of the outsourcing decision factors and the corresponding benefits, risks, influencing factors and decision framework. So, sub-chapter 3.2 facilitates answering sub-question 2.

3.2.1 Transaction cost economics

Transaction cost economics (TCE) facilitates the selection between in-house production and outsourcing by minimizing overall costs, especially transaction costs. (Williamson, 1975; Walker & Weber, 1984; Williamson, 1985). Transactional costs, such as negotiation, contracting, monitoring, enforcement, and dispute resolution, are inherent to outsourcing (Holcomb & Hitt, 2007). Firms minimize these costs by adjusting their governance structures (Williamson, 2008). Outsourcing transaction costs are estimated by considering ***asset specificity***, ***small number bargaining***, and ***technological uncertainty*** (Williamson, 1975). Bounded rationality of actors in transactional relationships necessitates renegotiations due to the inability to account for all possible contract contingencies (Geyskens et al., 2006). Opportunistic supplier behavior, acting in their self-interest, can delay transactions.

Asset specificity is a key factor contributing to transaction cost discrepancies between transactions (Riordan & Williamson, 1985; Holcomb & Hitt, 2007). An asset is considered specific when it is procured exclusively for a single transaction (Williamson, 1985; Holcomb & Hitt, 2007), reflecting “the degree to which an asset can be redeployed to alternative uses and by alternative users without sacrificing productive value” (Williamson, 1991). Low asset specificity limits suppliers' bargaining power due to the availability of numerous suppliers having the same assets. However, highly specified assets create bilateral interdependence and pose trade risks, resulting in transaction costs (Holcomb & Hitt, 2007). Specific assets give suppliers leeway for opportunistic behavior in contract negotiations making contracting expensive and counterproductive (Poppo & Zenger, 1998; Holcomb & Hitt, 2007). Asset specificity is positively related to vertical integration (Williamson, 1985; Poppo & Zenger, 1998), but it can promote interfirm cooperation. Mutual investment in specific assets can lead to reciprocal interdependence discouraging opportunistic behavior (Holcomb & Hitt, 2007). Maintaining supplier relationships can mitigate asset specificity (Borys & Jemison, 1989).

Small numbers bargaining impacts transaction costs as in-competitive supplier markets limit outsourcing options and strengthen suppliers’ bargaining power (Williamson, 1975; 1985). Bargaining power is the ability to influence negotiation outcomes (Schelling, 1956). This incentivizes supplier opportunism leading to hold-ups, contract updates, financial losses, and transaction costs, favoring vertical integration (Williamson, 1975; 1985). So, with less (more) competition, suppliers have less (more) incentive to share costs (Walker & Weber, 1984).

Williamson (1975) contends that firms dislike vertical integration in ***technological uncertainty*** because large resource commitments are vulnerable to negative shocks. Whereas outsourcing provides a predictable pattern of inter-firm exchange (Holcomb & Hitt, 2007). Moreover, it allows for flexibility and rapid change (Walker & Weber, 1984). However, uncertainty increases information deficits diminishing cost economies and worsening returns, which can be mitigated by good supplier relationships (Borys & Jemison, 1989). Geyskens et al. (2006) argue that firms prefer increased control over business processes and performance indicators during times of technological uncertainty. Vertical integration can enhance control and performance assessment, making it beneficial under these circumstances. Holcomb and Hitt

(2007) suggest a non-linear relationship between technological uncertainty and outsourcing, with a positive effect in low or moderate uncertainty and a negative effect in high uncertainty.

To summarize, TCE is relevant in determining the best governance structure, as contract contingencies resulting from bounded rationality may lead to opportunistic hold-ups and high costs. Small number bargaining increases the risk of opportunism and costly hold-ups, making in-house production more attractive. The amount of transaction costs incurred is affected by asset specificity (positively), small number bargaining (positively), and technological uncertainty (ambiguously). The best governance structure of a firm may change over time.

TCE posits that firms in similar industries make similar outsourcing decisions based on comparable circumstances and transactional characteristics. However firms are heterogeneous and economic motives alone do not fully explain outsourcing decisions, necessitating a more comprehensive theoretical framework (Holcomb & Hitt, 2007). Additionally, TCE focuses solely on transaction costs and assumes that if there are no costs, outsourcing is always favored, without comparing the capabilities of the outsourcing and supplying firms. Furthermore, TCE only considers single transactions, neglecting the influence of past experiences on future behavior and outcomes. Thus, a broader and more dynamic approach is required, integrating other theories to fully understand the outsourcing decision process.

3.2.2 Resource-based view

The resource-based theory challenges TCE's assumption that firms with similar exchange situations will have the same governance structures. This is because firms have unique skills (Holcomb & Hitt, 2007). Instead, the theory focuses on using a firm's strengths to respond to external opportunities (Wernerfelt, 1984). Understanding a firm's capabilities is crucial in determining the most effective governance structure for gaining a competitive advantage (Barney, 1991). This study covers three key resource-based literature streams: ***the resource-based theory*** (inter-firm capabilities), ***core competence theory*** (Hamel & Prahalad, 1994), and ***knowledge-based theory*** (Grant, 1996; Maskell, 2001).

The ***resource-based theory*** states that inter-firm capabilities enable firms to attain and sustain competitive advantage (Dyer & Singh, 1998; Poppo & Zenger, 1998). For a firm to gain this advantage, it must possess valuable, rare, inimitable, and non-substitutable capabilities

(Barney, 1991). Holcomb and Hitt (2017) outline four resource-based outsourcing factors: strategic relatedness, complementary capabilities, relational capability-building, and cooperative experience.

Strategic relatedness refers to the similarity between firms, including their production and supply chain systems, technologies, and end-markets (Holcomb & Hitt, 2007). This concept is related to goal congruence, which describes the extent to which firms' objectives align and incentivizes cooperative behavior (Parkhe, 1993). By reducing the likelihood of opportunistic behavior, goal congruence strengthens relationships between firms (Granovetter, 1985). Firms are less likely to outsource to those that differ strategically from them, as incongruent goals make it difficult to leverage capabilities through outsourcing (Holcomb & Hitt, 2007).
Complementary capabilities are distinct, supportive and create novel synergy (Harrison et al., 2001). Integrating them between an outsourcer and a third-party can enhance competitive advantage. Moreover, they allow firms to improve economies of scale, responsiveness, innovation, and quality (Holcomb & Hitt, 2007). Inimitability of complementary capabilities can lead to a valuable, rare, inimitable, and non-substitutable competitive advantage while outsourcing (Barney, 1988). To conclude, complementary capabilities enhance outsourcing.

Relational capability-building mechanisms enable firms to synthesize and leverage specialized capabilities (Holcomb & Hitt, 2007). Contracting experience increases performance in transactional relationships (Granovetter, 1985), and competent firms are more adaptable to changes (Leiblein & Miller, 2003). Investing in inter-firm relationships can reduce coordination and integration costs and achieve synergies, improving performance. Consequently, preserving relational capability-building mechanisms is positively associated with outsourcing (Holcomb & Hitt, 2007).
Cooperative experience involves repeated ties with specialized firms and is crucial in determining governance structures when outsourcing. These ties are important in determining the governance structure when outsourcing requires collaboration with a third party. Transactional relationships provide information about supplier performance and dependability, reducing information asymmetry, adverse selection, and opportunistic behavior, leading to better outsourcing outcomes (Granovetter, 1985; Parkhe, 1993; Holcomb & Hitt, 2007).

The ***core-competence theory*** (Hamel & Prahalad, 1994) proposes that a firm's core capabilities distinguish it from competitors and contribute more to its competitive advantage. Non-core capabilities are less important, outsourcing these to specialized firms can generate synergy and free up resources for core competencies, to expand and preserve the competitive advantage.

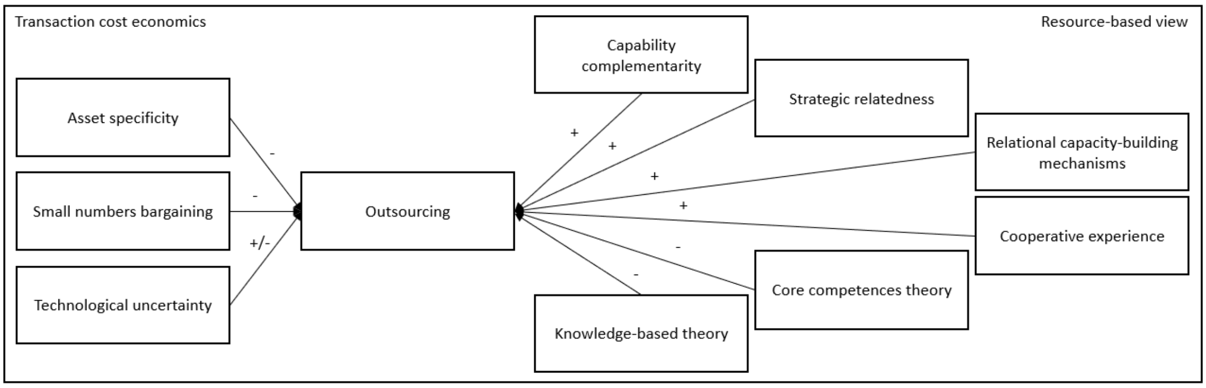
Knowledge-based theory emphasizes knowledge importance as a core resource in determining governance structures (Grant, 1996; Maskell, 2001). Outsourcing decisions should take into account the knowledge requirements of a process. Processes in which the result matters but knowledge does not can be outsourced. However, if the process knowledge is strategic and immature, there is a more incentive to keep it in-house to maintain a competitive advantage.

To conclude, the resource-based view (RBV), core competence theory, and knowledge-based theory are complementary and mutually reinforcing perspectives on gaining competitive advantage. While resource-based theory focuses on capabilities and strategic resources, the core competence theory emphasizes core competencies, and the knowledge-based theory highlights knowledge as a critical resource. It is more effective to apply these theories together than individually. However, the resource-based view has limitations, including its exclusive focus on resources and its subjective nature. Examples for the latter are inputs such as knowledge and strategic relatedness. Other factors, such as macroeconomic conditions and governance policies, can also affect governance decisions. Nonetheless, the resource-based view helps firms to identify core resources and gain a competitive edge. However, the theory fails to address macroeconomic factors and might conclude on subjective inputs.

3.2.3 Theory interactions

The preceding chapters discuss the outsourcing decision using two principal theories, namely TCE and RBV. Each theory identifies benefits and limitations. TCE's primary shortcoming is its narrow focus on transaction costs between firms, neglecting capacity comparison. In contrast, RBV focuses solely on a firm's capabilities and fails to account for macroeconomic factors. Both theories possess strengths that complement the weaknesses of the other. First, the gap in TCE can be covered by applying RBV to compare firm capabilities. Additionally, by including transaction costs, TCE can broaden the perspective of RBV's sole focus on capacity. The main theories on outsourcing and relations with respect to outsourcing are visualized below in Figure 2, answering the first part of sub-question 2. Below the figure we will delve deeper into the interaction between the theories, answering the second part of sub-question 2.

Figure 2: Theoretical model on outsourcing.



Academics have studied the interaction between TCE and the resource-based view. McIvor (2009) proposed a sequence in which RBV triggers the outsourcing decision based on capabilities, followed by TCE determining the best governance structure. Both perspectives can be used in tandem because vertical integration is positively related to asset specificity and core closeness. and there is a positive interaction effect between asset specificity and core closeness presenting the competence on vertical integration.

Other scholars note significant differences between TCE and RBV. TCE emphasizes reducing transaction costs and creating efficient governance structures (Williamson, 1975; Williamson, 2008), while RBV emphasizes a firm's specific capabilities as the source of competitive advantage (Barney, 1991; Holcomb & Hitt, 2007). The application of TCE and RBV to outsourcing decisions may result in different outcomes in similar situations. RBV encourages firms to collaborate to gain access to complementary capabilities in resource-constrained situations (Harrison et al., 2001; Holcomb & Hitt, 2007) or to focus on core competencies (Hamel & Prahalad, 1994). However, this approach may increase governance costs, which TCE would advise against. In general, TCE focuses on reducing transaction costs, while RBV emphasizes creating a competitive advantage through a firm's capabilities (Conner, 1991).

3.3 Outsourcing decision framework

As now, we have a comprehensive understanding of the theories behind the outsourcing decision, it is key to develop an outsourcing decision framework integrating qualitative and quantitative aspects as stated in the objectives. Kremic et al. (2006) defines an outsourcing decision framework which we will adapt to include qualitative and quantitative aspects, covering a gap in the current literature. The decision framework consists of benefits, risks and influencing factors which will be discussed in sub-chapters 3.3.1 and 3.3.2 answering the first part of sub-question 3. After discussing these, the adapted outsourcing decision framework will be presented in Chapter 3.3.3 which will serve as the backbone for the remainder of the study and answer the second part of sub-question 3.

3.3.1 Benefits & Risks

Outsourcing is still primarily motivated by cost reduction (Quinn & Hilmer, 1994; Kakabadse & Kakabadse, 2000a; McIvor, 2000; Ehie, 2001; Kremic et al., 2006; Gewald & Dibbern, 2009). The decision to outsource is based on the comparative cost-effectiveness of in-house production versus external purchase, with the supplier often benefiting from higher efficiency and economies of scale. Suppliers often add value and improve quality as the outsourced process is a core competence (Hamel & Prahalad, 1994; Kakabadse & Kakabadse, 2000a; Kremic et al., 2006). Also, shifting long-term capital investments to suppliers reduces indirect expenses (Quinn & Hilmer, 1994; Kakabadse & Kakabadse, 2000a; Holcomb & Hitt, 2007). Finally, outsourcing transfers risks to suppliers, which can reduce overhead costs and increase flexibility (Kakabadse & Kakabadse, 2000a; Kremic et al., 2006; Holcomb & Hitt, 2007).

Outsourcing also increases focus on growth, innovation, and core competencies enhancing performance (Hamel & Prahalad, 1994; Kakabadse & Kakabadse, 2000a). In-house production, on the other hand, may lead to increased costs and bureaucratic complexity due to information asymmetry and overhead (Holcomb & Hitt, 2007). Developing core competencies can increase market entry barriers and provide a competitive advantage (Ehie, 2001). Outsourcing can also facilitate access to technical innovation and reduce the time required to develop new competencies (Quinn & Hilmer, 1994; Gewald & Dibbern, 2009, while dependency risks can be reduced by engaging multiple suppliers (Quinn & Hilmer, 1994).

Outsourcing also has risks, such as supplier dependency (Quinn & Hilmer 1994). Poor supplier selection is a major risk as insourcing outsourced activities is difficult and costly (Kremic et al., 2006). While initial contracts may be competitive, inevitable changes can be costly, and third parties often perform better at the beginning of a contract, which can lead to hold-up costs (Embleton & Wright, 1998; Schwyn, 1999; Williamson, 1975; Williamson, 1985). Changes in a supplier's business situation can also create difficulties for the outsourcing firm (Quinn & Hilmer, 1994). Scholars view supplier issues such as poor performance, bad relations, and opportunistic behavior as a significant risk (Kremic et al., 2006). Having multiple suppliers can mitigate supplier dependency and reduce the likelihood of poor performance as suppliers' pressure to perform increases (Gupta & Zhender, 1994). However, if a firm decides to produce in-house, supplier-related risks and benefits are limited to raw material suppliers.

Often, outsourcing firms are overly optimistic about cost savings, leading to unrealized savings and hidden costs (Kremic et al., 2006; Quinn & Hilmer, 1994; Kakabadse & Kakabadse, 2000a,b). Additionally, sharing sensitive information in outsourcing transactions is a strategic risk, as suppliers may expand their business into that of the outsourcing firm (Gupta & Zhender, 1994). Furthermore, outsourcing can increase supply manageability (Lonsdale & Cox, 1997).

Employees generally view outsourcing negatively, according to Lonsdale and Cox (1997). Kremic et al. (2006) argue that outsourcing can reduce employee morale and quality due to the lack of incentive and loyalty among suppliers' employees. Embleton and Wright (1998) suggest that quality is monitored by suppliers, and outsourcing may decrease costs of poor quality (COPQ). Despite this, outsourcing may result in a loss of skills and core knowledge, as well as cross-functional skills and contact (Kakabadse & Kakabadse, 2000a,b; McIvor, 2000; Kremic et al., 2006; Quinn & Hilmer, 1994; Lonsdale & Cox, 1998). All benefits and risks are divided into three categories based on Elfring and Baven (1994) and summarized in Table 1.

Table 1: Benefits and Risks of outsourcing.

Strategic benefits	**Strategic risks**
Focus on core competencies	Supplier dependency
Spread and transfer risks	Supplier expanding to outsourcers market
Decrease long-term capital investments	Employee morale
	Loss of skills and knowledge
Operational benefits	**Operational risks**
Reducing direct production costs	Unrealized savings or hidden costs
Production costs become variable	Quality problems
Higher quality	Poor supplier selection
Efficiency, performance, and economies of scale	
Environmental benefits	**Environmental risks**
Enhance competitive advantage and market position	Supply chain complexity
Increased flexibility	Changing business situation
Access to new technologies	Supplier problems (bad relations, poor performance, opportunistic behavior)
Time to market	

3.3.2 Influencing factors

Kremic et al. (2006) identify four categories of factors that influence outsourcing decisions: cost, strategy, function characteristics, and environment. Cost is particularly important, as outsourcing is typically favored if it is more cost efficient than in-house production (Quinn & Hilmer, 1994; McIvor, 2000; Ehie, 2001; Kremic et al., 2006; Gewald & Dibbern, 2009).

Continuing with strategic factors, in line with the core-competence theory, core closeness is a strategic factor (Hamel & Prahalad, 1994; Kakabadse & Kakabadse, 2000a; Ehie, 2001; Kremic et al., 2006; Holcomb & Hitt, 2007). Furthermore, a function requiring critical knowledge is less (more) likely to be outsourced (produced in-house) whereas human resources scarcity increases (decreases) the likelihood. Moreover, quality is an important influencing factor (Kakabadse & Kakabadse, 2000a; Kremic et al., 2006). If the outsourcer is recognized as high (low) quality, it is less likely to outsource (produce in-house). Lastly, operational flexibility is a strategic influencer (Kremic et al., 2006).

Complexity is a functional characteristic. Complex functions are less eligible for outsourcing due to difficulties in formulating requirements. Next, integration is negatively (positively) related to outsourcing (in-house production) and refers to the degree to which the function is linked to other functions in the organization (Prencipe, 1997). Another functional characteristic, asset specificity, is negatively (positively) related to outsourcing (in-house production) (Williamson, 1975; Holcomb & Hitt, 2007). Lastly, the number of employees impacted is ambiguously related to outsourcing depending on whether the firm's objective is to minimize or maximize employee displacement (Kremic et al., 2006).

The final category is the environment, starting with political influences. External political influences are mostly of interest to public companies. The internal political environment may influence decisions, especially the opinions of influential people, even without the authority to decide (Kremic et al., 2006). The legal environment influences the outsourcing decision as more (fewer) legal hurdles decrease (increase) outsourcing likelihood. TCE showed that the influence of technological uncertainty on the outsourcing decision is either positive (Williamson, 1975: Holcomb & Hitt, 2007), or negative (Walker & Weber, 1984). Lastly, Prodrive identifies supply chain disruptions as a factor since it faced heavy supply chain disruptions in 2021 and 2022. These disruptions are expected to continue in 2023, directly impacting production and results. A summarized overview is presented below in Table 2.

Table 2: Influential factors of outsourcing versus in-house production.

Cost	Strategy	Functional Characteristics	Environment
Costs	Core closeness	Complexity	Supply chain
	Critical knowledge	Integration	External politics
	Human resources scarcity	Asset specificity	Internal politics
	Quality	Employees impacted	Legal
	Flexibility		Technological uncertainty

3.3.3 Total Cost of Ownership

A methodology for quantifying governance structure decisions is required for the extended decision framework. Alvarez and Stenbacka (2003) propose a real option approach for selecting best organizational models, but it lacks cost details and is not suitable for this study. Qi (2009) and Choi & Lee (2011) present a two-stage production scheduling method, but it is not relevant as production capacity is out of scope for Prodrive. Game theoretical models have been used to quantify outsourcing decisions (Bae et al., 2009), but they are not suitable as a cost benchmark as they focus on interfirm relationships rather than product-level costs.

Total costs of ownership (TCO) provide a comprehensive view of costs associated with make and buy alternatives, fulfilling the company's requirement for transparency (Ellram & Maltz, 1995). This approach helps identify areas for improvement and cost savings and serves as a benchmarking tool for major process changes and evaluations. However, data availability poses a risk, and the process can be labor-intensive, especially for firms lacking activity-based costing (Ellram, 1993; 1995). The framework for TCO implementation involves the steps presented below and will be applied in Chapter 5-II.

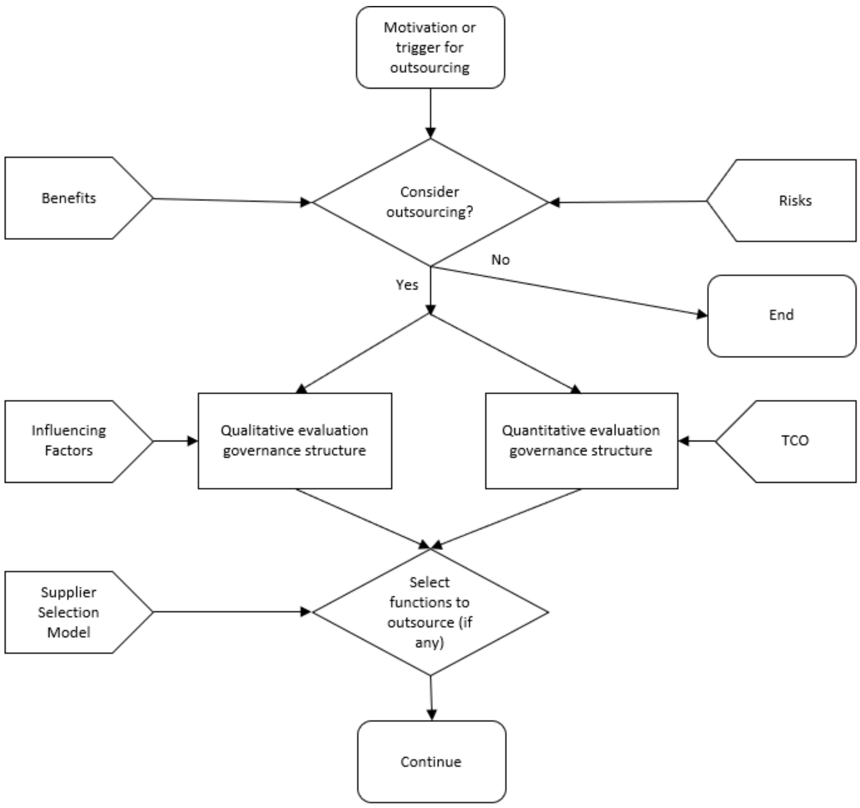
1. Identify need
2. Determine scope
3. Form team
4. Identify relevant costs
5. Test and implement model
6. Fine tune model
7. Link to other systems
8. Continue, update, monitor and maintain

To ensure reliable benchmarking, it is important to identify all relevant costs and define ways to measure them accurately (Ellram & Maltz, 1995). Process flow diagrams can be useful in this regard to ensure all process steps and associated costs are included.

3.3.4 Extended Outsourcing Decision Framework

This literature study has described main theories regarding selecting the best governance structure in production context. The benefits, risks and influential factors of outsourcing are presented in Chapters 3.3.1 and 3.3.2. Tables 1 and 2 serve as input for the extended model in Figure 3 and answer the first part of sub-question 3. Separately, TCO is discussed as the best fit for internal cost calculations allowing cost benchmarks on product level. Lastly, the solution design will develop a supplier selection model using results from the quantitative and qualitative analysis. Currently, research combines both quantitative and qualitative approaches into one model. The importance of such an integrated approach does not only lie in this theoretical gap, but also – as we shall see in this study – in practice as decision makers in practice view such an in-house versus outsourcing decision as one that should consider both quantitative and qualitative aspect. The importance of intertwining these aspects is emphasized in Chapter 3.2.3. Therefore, we extend the outsourcing decision framework of Kremic et. al. (2006) with additional benefits, risks and influencing factors, a cost benchmark using TCO and a supplier selection model. The newly proposed decision framework is presented below in Figure 3 and answers the second part of sub-question 3. The decision framework will act as the primary input for the research design in Chapter 4 and is the fundamental element of this study.

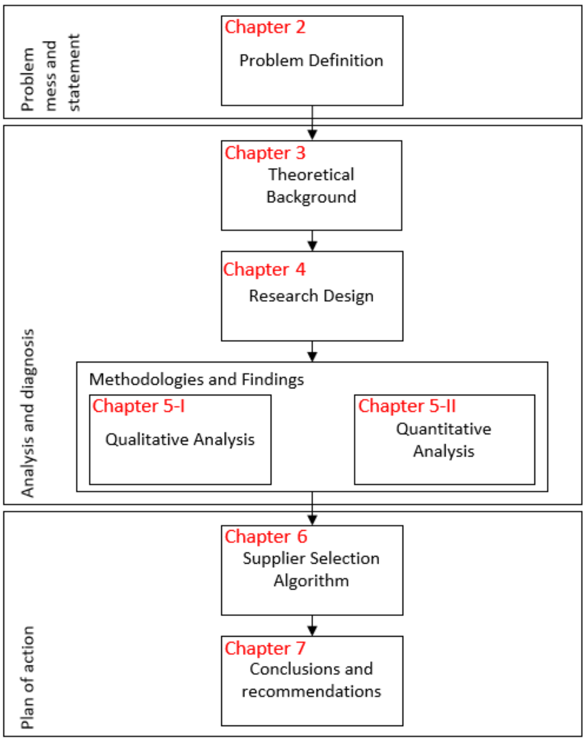
Figure 3: Outsourcing Decision Framework.



4 Research Design

This chapter outlines the design of the study and provides the reader with a main thread through the report. The design integrates the regulative cycle of van Strien (1997) with the extended outsourcing decision framework. The study is set up according to the schematic presentation in Figure 4 below. The intervention and evaluation phase of Van Strien (1997) are out of scope due to time limitations as this regards implementing the desired governance structure.

Figure 4: Research design.



The study starts with a problem statement in Chapter 2 where the context, the problem and the research questions are introduced. After that, a literature study is conducted to provide sophisticated theoretical background answering sub-question 1-3 followed-up by the research design. After this chapter, the study will be separated into PART I and PART II. The first part is a qualitative assessment with semi structured interviews guided by statements based on the theoretical model assessed on a 7-point Likert scale. PART II concerns a quantitative assessment. This case study starts with a thorough and transparent calculation methodology for internal costs, after which these are compared with quotes from potential new suppliers obtained in the market followed-up by a robustness analysis. To conclude, a supplier selection model is built with the strategic analysis and cost benchmark from both parts as input. Findings from these parts are integrated in the conclusion and recommendations.

5 Methodologies & Findings

This chapter reports the results of the qualitative and quantitative study and interpret them in the light of the research questions and builds upon the decision framework presented in Figure 3 (cf. Chapter 3) and the research design presented in Figure 4 (cf. Chapter 4). From now on, the division mentioned in the research design will be applicable. Part I will address the qualitative study and will answer the corresponding sub-question 4. First, the methodology will be explained, followed by the presentation of the findings, and conclusion of the analysis. After that, Part II addresses the quantitative analysis starting with a methodology, followed by the setup of the case study, and concluded with the findings and a corresponding conclusion regarding sub-question 5.

PART I

5-I.1 Methodology

The qualitative study is a part of the outsourcing decision framework presented in Chapter 3, Figure 3. The study will gather qualitative data by interviews in which the influential factors of outsourcing presented in Chapter 3.3.2 will serve as main input. The results of this qualitative study will serve as an input for the supplier selection model in Chapter 6 and are a main input for the final conclusion in Chapter 7.2.

The research methodology used in this study is qualitative and falls under the category of theory-supported inductive research. The data is collected through semi-structured interviews, which are based on a balanced scorecard (BSC) framework. The study targets a multidisciplinary sample of managers from various levels, including middle, top, and executive management summarized in Appendix II. The sampling technique used is purposive and non-probability, with a deliberate selection of participants to represent the different levels and areas of expertise within the organization. The BSC consists of statements derived from the influential factors from the theoretical model presented in Chapter 3. To enhance the reliability of the research, a plenary session was held to explain the statements to all interviewees, resulting in consensus on definitions. Moreover, CHM stakeholders can be emotionally biased, therefore these are taken along during the entire study to establish trust and shared understanding, preventing emotional bias. The BSCs were analyzed using Rezaei's (2015)

Best-Worst Method (BWM), a Multi-Criteria Decision-Making model (MCDM) known for its ability to yield consistent comparisons with less required comparison data than other methods.

The BSC presented in Figure 15 (cf. Appendix II) shows PTNL and PTCN on the horizontal and influential factors in statements on the vertical axis. Respondents are instructed to assess these statements on a 7-point Likert scale during semi-structured interviews, allowing for follow-up questions to elicit more comprehensive insights (Kallio et al., 2016). The interviews will be recorded with the interviewee's consent to facilitate notetaking on non-content aspects such as expressions and interpretations (Ciesielska & Jemielniak, 2018). The BWM is a multi-criteria decision model commonly employed in academic research for comparing suppliers. However, this study uses the BWM model to evaluate the strategic benefits of outsourcing for each plant (PTNL and PTCN), without comparing them. The resulting score, ranging from 1 to 7, is used to assess each plant's outsourcing eligibility where a lower score indicates higher eligibility. The BWM process involves five steps and is repeated on group level after which an overall score per plant is determined. Sub-groups make the ranking methodology simple and accurate. Group weights are determined in consultation with stakeholders and presented alongside the groups and entire process in Figure 14 (cf. Appendix II).

Moreover, the interviews are qualitatively assessed by elaborative coding. Coding aims to notice relevant phenomena to find structures, patterns, differences, and commonalities in qualitative data (Seidel & Kelle, 1995). The grounded-theory approach of Strauss and Corbin is applied and uses insiders' perspectives and open coding. After which the groups are reduced by clustering categories and new theories are developed (Strauss & Corbin, 1990). To conclude, this methodology answers sub-question 4. The findings in the next sub-chapter will serve as input for answering sub-question 7.

5-I.2 Findings

This sub-chapter reports and discusses the findings of Part I, strategy, functional characteristics and environment are discussed consecutively below. The 23 interviewees assessed all statements on a 7-point Likert scale, and the average scores of the influential factors are presented in Figure 5 (cf. Chapter 5-I.3). The figure will be complemented with relevant quotes that are grouped according to the respective influencing factors. For a comprehensive overview of all results per interviewee, please refer to Figure 16 (cf. Appendix II). 293 relevant quotes were identified from a review of all interview recordings and notes. These quotes were condensed into 100, categorized under the 14 influencing factors and a group for general conclusions. The overview of consolidated quotes is confidential and therefore not included in the report. All consistency ratios are of an acceptable level; thus, the weighting process has been reliable. The weights are presented in Figure 14 (cf. Appendix II).

5-I.2.1 Strategy

Prodrive Technologies’ ***core*** business is the design and production of entire systems, being a one-stop shop is a major unique selling point. Electronics manufacturing and System Assembly are the closest to Prodrive’s core business. Most products contain cables and being a one-stop shop is a unique selling point. Although cables are required, cable manufacturing itself is not a unique selling point nor value adding. 30% of interviewees state that cables can be purchased. Directors mention that CHM is less high-tech and therefore less close to core business, partly due to limited investments in process automation. The score for PTCN is higher, a director mentions “for our China facility CHM is core business as if we would sell the plant, we would sell a factory with production capacity rather than the entire business”.

In both plants the score favors outsourcing for ***critical knowledge*** as intellectual property is not in the cable assemblies, and general competences can be obtained from other processes and the supply chain. Respondents noted that better alignment between development and production results in shorter feedback loops, improved design integration, efficient production, better quality, and a shorter time to market. One director suggests that integrating cable development and production does not enhance product value and that quality knowledge is of utmost importance. Outsourcing may result in more cost-efficient solutions due to different design requirements, but it can also increase transaction costs since all communication is with an external party. PTCN scored more extremely in this regard as the internal transaction costs between PTNL's development and PTCN's production are greater.

The majority expects a significant ***human resources scarcity*** soon in the Brainport region resulting in a score of 1,95 for PTNL. The score for PTCN is 5,24 as “technicians are not scarce and we are competitive in the market”. Nevertheless, in both cases “technicians must be used for more value-adding activities.” Labor costs in the PTNL rise due to inflation making it hard to remain competitive on labor intensive processes, automation could be a solution. Another solution would be low-wage countries, however, there is a tradeoff between the employee quality and costs. PTCN faces cultural and language barriers are in engineering resources.

Initially, CHM is vertically integrated for ***quality*** control as cables are quality critical in the majority of Prodrive's most valuable products. A technical expert mentions that Prodrive has a track-record of winning business because of its high quality. "Top customers in our segment prefer quality and delivery performance over costs". Moreover, tight connections between service and production decrease the likelihood of turnover and NPI project delays. In addition, close collaboration between service and production reduces the likelihood of turnover and NPI project delays. A practical example demonstrating the importance of cable quality is that cables connect all modules in a system and are difficult and labor-intensive to replace, resulting in high costs of poor quality. Outsourcing CHM would raise transaction costs for quality control, as Prodrive would still be liable for the quality of end products, necessitating constant monitoring of suppliers' quality standards. Nonetheless, there are concerns about the disparity in quality between in-house and supply chain production. 41% of respondents stated that, if selecting the right supplier, cable assembly outsourcing would not necessarily result in more quality problems. The latter is confirmed by a purchaser. Some stakeholders suggest that cables, aside from quality critical ones, can be outsourced. Results regarding quality are inconclusive, but slightly favor in-house production (mean scores of 4.30 and 4.35). However, stakeholders find it challenging to assess the effect of outsourcing, as quality critical cables have been produced in-house for many years.

The results indicate that Prodrive values in-house production for CHM the most due to the importance of ***flexibility***. This enables Prodrive to prioritize and focus on production planning, leading to quick resolution of customer delivery issues. In contrast, PTCN has transportation lead times of at least six weeks, making it less flexible. Dual production between PTNL and PTCN prevents customer delivery delays. In PTNL, a short feedback loop between work preparation and development decreases time to market as design mistakes can be solved quickly. Development Directors acknowledge the theoretical benefits of in-house prototype production but highlight practical challenges such as long internal lead times on prototyping due to limited work preparation engineering capacity, and potential constraints on production scalability as the company grows. The human resource developments in the Brainport region further compounds the challenge. The challenge of outsourcing cable assemblies lies in the configuration flexibility rather than lead time flexibility. Prodrive operates in an industry where customers require frequent end-product revisions, which makes it difficult to standardize cable assemblies resulting in high transaction costs due to design revisions. One director suggests that the focus should be on reducing the requirement for flexibility and gaining more control.

5-I.2.2 Functional Characteristics

The CHM process, while the assembly steps on itself are not ***complex***, is complex and hard to control due to the diversity of products, production steps, tools, and manual labor. Cable bundles are particularly complex, while single wires are simpler to manufacture. Additionally, the handling of raw material cables with different unit measurements in SAP, mm instead of eaches, can result in material supply mistakes and stock discrepancies. Overall, the complexity score is slightly below average. This aligns with the conclusion that PCBA, System Assembly, and Advanced Packaging are the most complex processes, followed by Magnetics, CHM, Mechanics, Injection Molding, and HVP in decreasing order of complexity. There are no differences in complexity between plants, as the copy-exact strategy is followed.

The scores of 2.35 and 2.30 indicate that CHM's level of ***integration*** does not prevent outsourcing. The low integration is due to the department being an internal supplier located in a different building that produces make-to-stock items. Furthermore, the cables are tracked by batch rather than unit-specific serial numbers, as common. The machines are not yet integrated with the MES (manufacturing execution system), and specific tests performed at CHM can also be done at System Assembly for outsourced cables.

Outsourcing is not hindered by ***asset specificity*** concerns, as reflected in the low scores. The machines and tools used in CHM are common in the cable market. Prodrive's most expensive machine, the Komax Alpha, is available in Europe but scarce in China. A former manager states that the machine can be substituted by manual or combined machine-based steps.

Outsourcing will have different ***impact on employees*** at PTNL (1.90) and PTCN (4.90). In the future, there is expected to be a shortage of human resources in the Brainport region, so if outsourcing occurs, technicians can be transferred to other departments with similar competences, with the remaining employees absorbed from the flex scale. This requires change management and works council approval. Outsourcing has a significant impact on PTCN as CHM represents half of the technicians and there are fewer other business opportunities.

5-I.2.3 Environment

Large cable suppliers have more bargaining power on raw materials than Prodrive due to economies of scale. Outsourcing reduces direct purchasing labor as absolute less products are purhcased but requires setting up a new ***supply chain*** and developing supplier coordination competence. A number of interviewees have acknowledged Prodrive's lack of competence in establishing and sustaining strategic alliances with suppliers, which would result in a substantial increase in overhead costs. Supply chain experts mention “Bargaining power is key to material allocation. High-volume suppliers have an advantage over Prodrive, while small suppliers struggle with material availability due to limited bargaining power”. A manager noted that raw materials are machine-made while cable assemblies require more human labor. The current labor market instability makes relying on human labor risky and could cause supply chain disruptions. Moreover, outsourcing results in supplier dependency which can result in supply fluctuations. A supply chain expert notes that modern planning emphasizes end-to-end integration with suppliers and customers to reduce transaction costs and information asymmetry. Prodrive has some level of end-to-end planning from the supply side by supplying their own factory. In-house production is slightly favored from a supply chain perspective. However, the key to avoiding disruptions is a supplier that fits on strategy and demand.

Vertical integration is viewed as a means to achieve goals, not an end in itself, by the executive board. Proper communication can mitigate resistance to change, according to the majority of interviewees. Recent program mergers serve as a practical example. However, emotionally invested personnel in CHM may resist outsourcing as well as R&D due to an increase in their transaction costs. Technical experts suggest that outsourcing the entire process is met with ***internal politics***. However, outsourcing for specific products is acceptable as long as complex, quality-critical, and prototype assemblies remain in-house. It's important to obtain works council consent for decisions that affect numerous employees. PTCN has slightly lower resistance due to China’s more hierarchical culture.

External politics favor in-house production in PTNL (4.27) and outsourcing in PTCN (2.79). However, inflation increased technician wages, increasing outsourcing likelihood in PTNL. To mitigate geopolitical risks and remain competitive, outsourcing to a low-wage country in Europe or opening a new facility there could be a viable strategy as a Director mentions that: “There is no single similar sized company within our market without a factory in eastern-Europe”. But there will always be a trade-off between a country's labor costs and the associated political risks. The high political risk of global technology decoupling between U.S. and China significantly accelerates in scale and growth making full focus on China unfavorable. Practically, this means that there is a high supply risk of products assembled in China containing US origin components in it. Therefore, the company needs to figure out to which cable assemblies this is applicable as the production of these must be transferred. So external politics are crucial in determining CHM’s strategy. An experienced purchaser researched the impact of the Russia-Ukraine conflict on the raw material supply and found no direct risks.

The score shows that ***legal*** issues shouldn't be a problem for outsourcing CHM. A major customer stated that cables can be outsourced as long as all requirements are met. However, some cables require mandatory raw material suppliers as per customer requirements. Changing to purchasing parts instead of manufacturing in-house will require administrative tasks.

Technological uncertainty in cable production technology represents the lowest score of all aspects and therefore is of no concern. An expert mentioned: “The market is conservative, there are barely differences between now and ten years ago”. Moreover, no technological breakthrough eliminating cables in Prodrive’s products is expected.

5-I.3 Conclusion

This sub-section will present the results of the strategic analysis and will be one of the main inputs for the supplier selection model and the general conclusion and recommendations to Prodrive. Figure 5 shows scores and weights, indicating a slight preference for outsourcing in PTNL and in-house production in PTCN. Differences are driven by the scarcity in human resources at PTNL. In summary, retaining CHM in-house is driven by strategic considerations such as quality and flexibility, while PTNL's concerns over future human resource scarcity present a challenge. Apart from the impact on the employees in PTCN, functional characteristics do not significantly impact the outsourcing decision for CHM. In the environmental factors the technological decoupling between China and US is a huge risk which requires further investigation on for which products this is applicable. Whereas, the supply chain is expected to be better manageable while producing in-house.

Figure 5: Results Balanced Scorecard.

	Weight	PTNL	PTCN		Weight	PTNL	PTCN
Core Closeness	0,07	3,96	4,13	Strategy	0,50	4,50	4,81
Critical Knowledge	0,12	3,86	3,67				
Human Resources Scarcity	0,16	1,95	5,24				
Quality	0,24	4,30	4,35				
Flexibility	0,42	5,87	5,35				
Complexity	0,28	3,45	3,45	Functional Characteristics	0,25	2,41	3,89
Integration	0,14	2,35	2,30				
Asset Specificity	0,09	2,04	2,04				
Employees Impacted	0,49	1,90	4,90				
Supply Chain	0,37	4,53	4,50	Environment	0,25	3,72	3,38
Internal Politics	0,08	3,52	3,48				
External Politics	0,21	4,37	2,79				
Legal	0,21	2,93	2,93				
Technological Uncertainty	0,14	1,89	1,89				
Average:		**3,35**	**3,64**	**Weighted Overall Score:**		**3,79**	**4,22**

In an overall conclusion, it is important to note that prototype production is preferred to remain in PTNL due to the R&D-Operations relationship. Dual sourcing is an option, in which the own factories, PTNL and PTCN must compete with suppliers as in the “GE model”. In this case, a diversification on cable type, especially quality criticallity, is crucial in the decision. It is desired to built a strategic alliance with the suppliers as Prodrive has quality critical demand and relatively large transaction costs. Therefore, a supplier must strategically fit the company to meet all requirements. Moreover, Prodrive has to grow its supplier coordination competence. It is questionnable whether Prodrive’s low-wage facility must remain in China as transferring PTCN production to a low-wage country in Europe offers more flexibility and eliminates the significant US-China technology decoupling risk. To conclude, the strategic advice is to keep prototype production in PTNL and open a “PTEU” factory to have cost benefits while reducing political risk, to dual source series production between “PTEU” and strategic. The results indicate that flexibility, quality supply chain and political risks are main influencing factors for Prodrive. The majority of these will also serve as an input for the supplier selection model in Chapter 6. Furthermore, the overall analysis, conclusions and implications of the qualitative analysis will be input for the final conclusion and corresponding reccommendation to Prodrive in Chapters 7.2 and 7.4, answering sub-question 7.

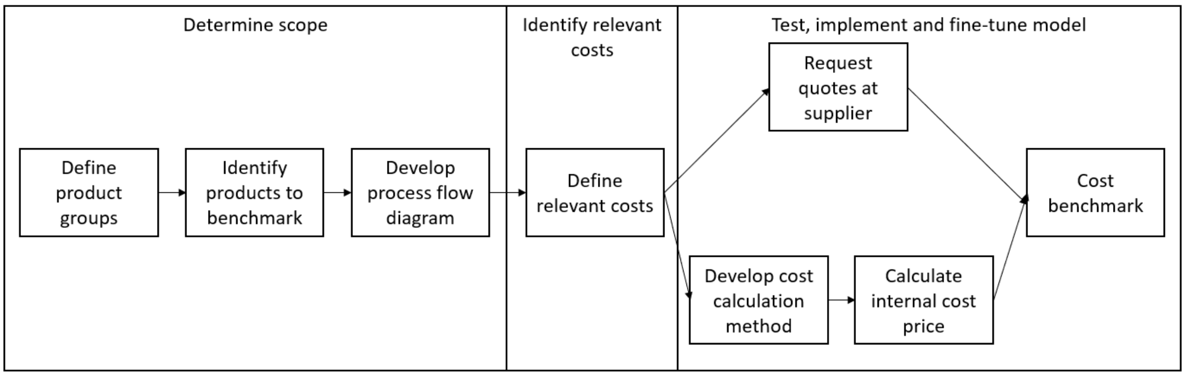
PART II

Part II addresses the quantitative study in which Prodrive will be benchmarked with potential suppliers based on costs. This is important as the theoretical background in Chapter 3.3.1 emphasized that costs are outsourcing's main benefit and motivation. This chapter is therefore a part of the outsourcing decision framework presented in Figure 3 (cf. Chapter 3). The methodology and set up of the case study in sub-chapters 5-II.1 and 5-II.2 will answer sub-question 5. The findings serve as input for the supplier selection model in Chapter 6 and the final conclusion and recommendation in Chapters 7.2 and 7.4, answering sub-question 7.

5-II.1 Methodology

This part consists of a case study including a cost benchmark with potential suppliers. Therefore, a method to determine internal cost prices must be developed, based on TCO, and transparent supplier quotations are requested. TCO is the foundation of our methodology and is already discussed in more detail in Chapter 3.3.3. TCO's main risk is data availability, which is no concern in the case study as Prodrive has a state-of-the-art data infrastructure. Chapter 3.3.3 discussed the importance of presenting a process flow diagram (Ellram & Maltz, 1995). This process flow diagram is integrated with steps 2-6 of Ellram's (1995) TCO framework resulting in the methodology shown below in Figure 6, answering sub-question 5.

Figure 6: Methodological framework case study.



5-II.2 Set up: Case Study

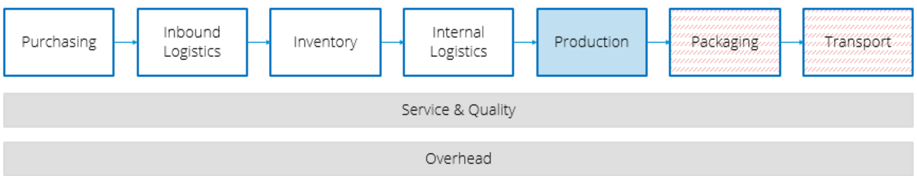
This chapter demonstrates the set-up of the case study by following the steps as presented in Figure 6. In Step 1, we determine the scope by assigning the products to a group (multicore, single wire, wire harness or wired component). Product subsets are selected for benchmarking from each group based on demand and complexity (number of components) diversity. The sample is shown below in Table 3. Alongside the product number and group the table presents the annual demand for 2023 and 'comp.' which is an abbreviation for the number of components required for one assembly of the product. This serves as a proximity for the complexity of the product.

Table 3: Case study sample PTNL

PTNL				**PTCN**			
Name	Product Group	Demand	Comp.	Name	Product Group	Demand	Comp.
Product 1	Multicore	1.270	14	Product 10	Multicore	11.816	14
Product 2	Multicore	2.470	5	Product 11	Multicore	5.082	12
Product 3	Single Wire	1.476	2	Product 12	Multicore	15.400	5
Product 4	Wire Harness	560	49	Product 13	Single Wire	13.187	8
Product 5	Wire Harness	1.454	30	Product 14	Single Wire	1.320	16
Product 6	Wire Harness	1.470	12	Product 15	Single Wire	14.000	7
Product 7	Wire Harness	565	19	Product 16	Wire Harness	8.100	6
Product 8	Wired Comp.	20.304	3	Product 17	Wire Harness	226	16
Product 9	Wired Comp.	1.896	4	Product 18	Wire Harness	2.508	7

In Step 2, we determine the relevant costs using the process flow diagram in Figure 7. The stages in this process flow diagram are used as basis for the cost price model in Chapter 5-II.3. Transport and packaging costs are only applicable if the product is manufactured at a different location than the end-product. Step 3 is performed sub-chapter 5-II.3 as this presents the cost calculation methods. Finally, results and robustness are presented in sub-chapter 5-II.4

Figure 7: Process flow diagram



5-II.2.1 Cost Price Model

We develop a new method for accurate cost price calculation per unit of Prodrive's products representing the third step of the methodological framework used to perform this case study. The process flow diagram presented in Figure 7 above serves as basis for determining the cost factors of this cost price calculation. Costs are determined by multiplying a price and a quantity. This sub-section will first outline the cost factors after which the approach for recalibrating the set-up and production times (quantity) will be elaborated. To conclude, the developed cost price calculation method will serve as input for the internal cost price calculations and therefore the cost benchmark of which the findings will be presented in sub-chapter 5-II.3.

First, ***purchasing*** costs are presented in Equation (1.1) and calculated by summing the moving average purchasing price of the past 12 months for all components in the product.
Logistics costs are presented in Equation (1.2) as the sum of the inbound logistics, holding and internal logistics costs. The first part of the equation represents the inbound logistics costs. These are calculated by multiplying the average time per inbound logistics booking by the number of inbound logistics bookings per product in the period of interest and the internal man tariff. The number of inbound logistics bookings for a product is the sum of the inbound logistic bookings for all corresponding components. The number of bookings per component is calculated by dividing the required quantity of the component for the product in the period of interest by the average order quantity of the component.

Holding costs consists of costs of capital, storage, and risks for obsolescence (Nahmias & Olsen, 2015). In this case study, the latter is included in the quality costs. Storage costs are presented in the second part of Equation (1.2). The holding costs of a product are the sum of the holding costs for all its components. The holding costs for a component are calculated by multiplying the average stock level of the component with the yearly storage costs. The financing costs are calculated by multiplying the purchasing costs with the weighted average costs of capital (WACC) translated to the average holding period of the components in years. The WACC is calculated using the approach from Modigliani and Miller (1985). Internal logistics consists of movements from inbound logistics to stock and from stock to production, this is represented in the third part of Equation (1.2). The first are calculated by multiplying the internal man costs by the average amount of time per put away task by the number of inbound logistic bookings of the product. The latter is calculated by multiplying the internal man costs by the average amount of time per picking task by the number of picking tasks for the product. The number of picking tasks is equal to dividing the number of components in the product by its batch size.

The ***production*** costs are calculated based on the router of the product and presented in Equation (1.3). A router consists of different production steps based on the product configuration. Each step, consist of a set-up time and process time for machines and/or man.

Production costs are calculated by multiplying the times and tariffs of a router step. This is also visualized in the left bottom corner of Figure 8. The cost prices are calculated by unit and therefore the set-up times are divided by the production batch size. ***Quality*** costs are presented in Equation (1.4) and calculated by dividing the COPQ from a product in a specific period by the demand of that period. **Overhead** costs are excluded as these are assumed to switch between departments but remain equal between outsourcing and in-house production. Important to note is that all formulas are determined in consultation with the Prodrive process representative. To conclude, the cost price of a product excluding overhead is calculated by summing the purchasing, logistics, production, and quality costs and presented in Equation (1.5). The model and corresponding notation is presented below.

I_j	Bill of material from product j	C_j	Cost price of product j
J	Set of all products	$c^p{}_j$	Purchasing costs of product j
j	Product j	$c^l{}_j$	Logistics costs of product j
i	Component in product j	$c^{pr}{}_j$	Production costs of product j
p_i	Purchasing price of component i	$c^q{}_j$	Quality costs of product j
m	Current month	c^s	Storage costs per year
$c^{man}{}_r$	Internal man production costs per hour	$WACC$	Weighted average costs of capital
$c^{mch}{}_r$	Internal machine costs per hour for router step r	v_e	Market value of equity
$q_{i,j,t}$	Quantity of component i required for product j in period t	v_d	Market value of debt
$q^o{}_i$	Order quantity of component i	c^e	Costs of equity
$q^b{}_j$	Production batch size of product j	c^d	Costs of debt
$D_{j,t}$	Demand of product j in period t	T_C	Corporate tax rate
$b_{j,t}$	Number of inbound logistics bookings for product j	$\bar{t}_{il}$	Average time per inbound logistics booking
$\bar{s}_i$	Average stock level of component i	$\bar{t}_{pa}$	Average time per putaway action
$COPQ_{j,t}$	Costs of poor quality for product j in period t	$\bar{t}_p$	Average time per picking action
$t_{st,man,r}$	Man setup time for router step r	$t_{pt,man,r}$	Man process time for router step r
$t_{st,mch,r}$	Machine setup time for router step r	$t_{pt,mch,r}$	Machine setup time of router step r

Model 1: Cost price model

$$c_j^p = \sum_i^N \frac{p_{i,m-11}+p_{i,m-10}+\dots+p_{i,m}}{12}, \qquad for \quad i \in I_j \qquad (1.1)$$

$$c_j^l = \left(c_r^{man} \cdot \bar{t}_{il} \cdot b_{j,t} \right) \qquad (1.2)$$

$$+ \left(\sum_i^I \bar{s}_{i,j} \cdot c^s + c_j^p \cdot (WACC)^{t_j} \right)$$

$$+ (c_r^{man} \cdot \bar{t}_{pa} \cdot B_j + c_r^{man} \cdot \bar{t}_p \cdot \frac{i_j}{q_j^b}) , \quad for \quad i \in I_j$$

$$b_{j,t} = \sum_i^I \frac{q_{i,j,t}}{q_i^o} \tag{1.2.1}$$

$$\bar{s}_i = (SS_i + \frac{q_{i,t-1}^o}{2}) , \quad for \quad i \in I_j \tag{1.2.2}$$

$$WACC = \frac{v_e}{v_e+v_d} \cdot c^e + \frac{v_d}{v_e+v_d} \cdot c^d \cdot (1 - T_c) \tag{1.2.3}$$

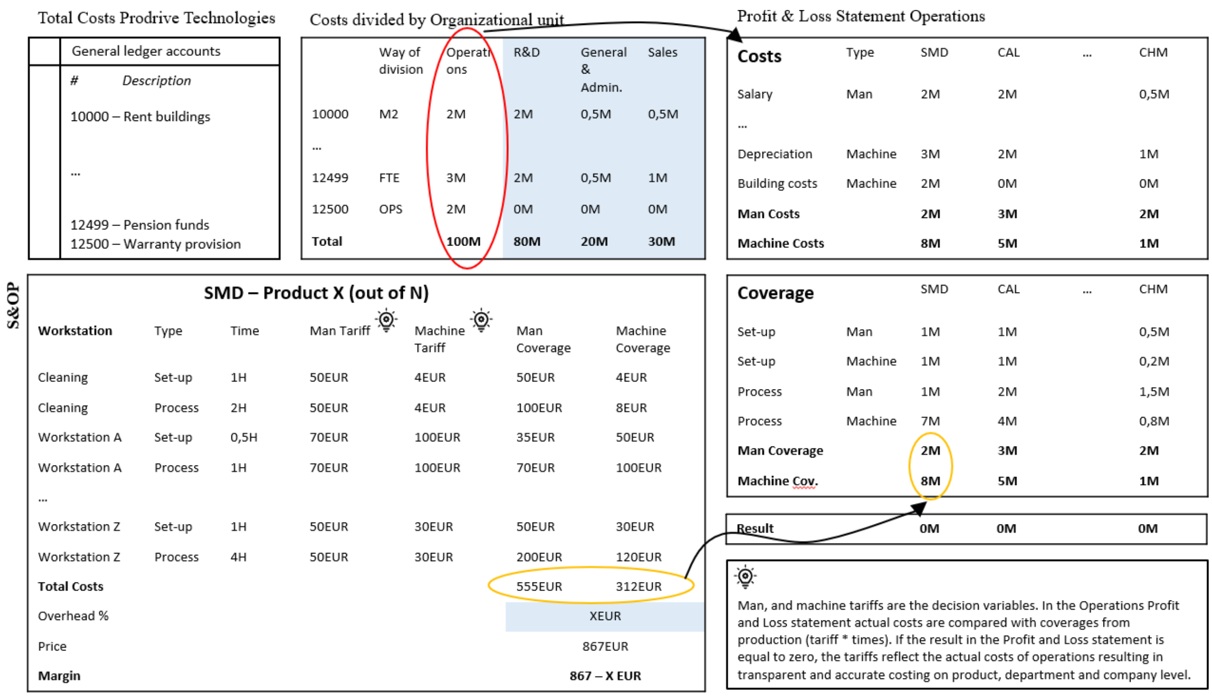
$$c_j^{pr} = \sum_r^R \frac{t_{st,man,r}}{q_j^b} \cdot c_r^{man} + \frac{t_{st,mch,r}}{q_j^b} \cdot c_r^{mch} + t_{pt,man,r} \cdot c_r^{man} + t_{pt,mch,r} \cdot c_r^{mch} \tag{1.3}$$

$$c_j^q = \frac{COPQ_{j,t}}{D_{j,t}} \tag{1.4}$$

$$C_j = c_j^p + c_j^l + c_j^{pr} + c_j^q \tag{1.5}$$

Times are currently incorrect in Prodrive's system and therefore remeasured by stopwatch for accurate costing. The tariffs are determined with the help of our newly developed framework presented below in Figure 8. We book all costs on general ledger accounts per cost category and divided between operations, R&D, general and sales. We divide operating costs amongst production departments and serve as cost input for the operations profit and loss statement (P&L). On the other side, each product has a router with production steps. Multiplying the times and tariffs of these steps results in coverage allocated to the corresponding department and serves as profit in the P&L. The P&L's result must be zero, as in this case, the tariffs cover the costs allocated to operations, resulting in transparent and accurate costing and margins.

Figure 8: Framework to determine internal tariffs (van de Ven, 2022).



5-II.3 Findings

The overall results for PTNL are presented below in Table 4. Four quotes for Product 7-9 are not received. Suppliers EU1 and EU2 are suppliers from respectively Romania and Bosnia. PTCN results are presented in Table 5. Suppliers 3 and 4 are Chinese suppliers.

Prodrive is not competitive on multicore cables. For wire harnesses Prodrive is relatively competitive for the PTNL cables compared to the European suppliers as these cables are quite complex. However, for the wire harnesses manufactured in PTCN, the Chinese suppliers are way more competitive as these are labor intensive. Prodrive is more competitive than European suppliers on single wires, whereas the Chinese suppliers are superior. Moreover, difficulties are experienced while requesting quotations for wired components. For a full conclusion, assessments on qualitative aspects as quality and reliability are required.

Table 4: Consolidated Results PTNL

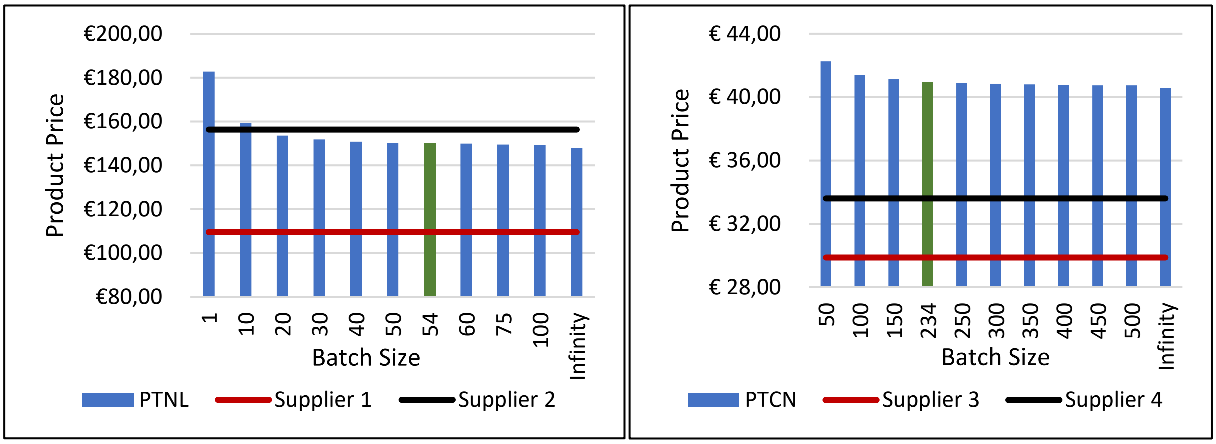
Name	Product Group	Demand	Unit Price			
		2023	PTNL	PTCN	Supplier EU1	Supplier EU2
Product 1	Multicore	1.270	€ 153,39	€ 119,67	€ 109,50	€ 156,30
Product 2	Multicore	2.470	€ 21,11	€ 9,11	€ 11,36	€ 21,20
Product 3	Single Wire	1.476	€ 8,18	€ 7,06	€ 8,90	€ 8,80
Product 4	Wire Harness	560	€ 395,28	€ 307,78	€ 554,40	€ 404,70
Product 5	Wire Harness	1.454	€ 246,00	€ 180,78	€ 273,00	€ 167,10
Product 6	Wire Harness	1.470	€ 94,31	€ 67,23	€ 99,56	€ 111,80
Product 7	Wire Harness	565	€ 115,75	€ 86,47	N.A.	€ 151,10
Product 8	Wired Comp.	20.304	€ 10,10	€ 8,68	N.A.	€ 42,60
Product 9	Wired Comp.	1.896	€ 12,45	€ 7,48	N.A.	N.A.

Table 5: Consolidated Results PTCN

Name	Product Group	Demand	Unit Price			
		2023	PTCN	PTNL	Supplier CN1	Supplier CN4
Product 10	Multicore	11.816	€ 41,11	€ 51,96	€ 30,90	€ 34,67
Product 11	Multicore	5.082	€ 50,18	€ 62,26	€ 37,50	€ 41,18
Product 12	Multicore	15.400	€ 3,11	€ 4,84	€ 1,77	€ 1,57
Product 13	Single Wire	13.187	€ 10,81	€ 14,89	€ 6,34	€ 6,35
Product 14	Single Wire	1.320	€ 81,04	€ 91,78	€ 66,80	€ 68,89
Product 15	Single Wire	14.000	€ 2,37	€ 3,30	€ 1,03	€ 0,90
Product 16	Wire Harness	8.100	€ 9,93	€ 13,38	€ 6,32	€ 6,60
Product 17	Wire Harness	226	€ 226,31	€ 266,45	€ 161,63	€ 191,83
Product 18	Wire Harness	2.508	€ 14,47	€ 22,00	€ 6,61	€ 8,24

Moreover, we examine the impact of organizational maturity on the competitiveness of PTCN facility by investigating the current imbalance between direct and indirect personnel. The findings suggest that an increased ratio of direct personnel in the facility's workforce, because of organizational development, will barely lead to lower average labor costs, making the effect negligible. Concluding, for PTCN it is impossible to compete on acquisition value with these low-wage region suppliers (~7 EUR/h), as Suzhou is the most expensive region of China (~25EUR/h), and CHM is labor driven. Set-up times per product can be reduced by increasing production batch sizes as presented in Chapter 5-II.2.1, Equation (1.3). Find below in Figure 9 a visualization of the comparison of Product 1 (PTNL) and 10 (PTCN) with the batch size being variable. The current batch sizes are marked green and near optimal from a cost perspective and do not affect the benchmark conclusions. Infinity refers to a batch size of one million applying the big M principle with $M=10^6$.

Figure 9: Robustness analysis on batch size from Product 1 and 10.



5-II.4 Conclusion

In conclusion, the cost benchmark has revealed that Prodrive is not competitive on multicore cables. Moreover, it is competitive on wire harnesses compared to European suppliers due to its complexity, but not competitive compared to Chinese suppliers due to their low wages and the labor intensity of this category. Chinese suppliers are also superior on single wires. In general, neither PTNL nor PTCN can compete with the Chinese suppliers on lowest acquisition value due to the substantial difference in labor wages. Overall, these findings give valuable insights for CHM’s future strategy and serve as input for answering sub-question 7 in Chapter 7.6. Moreover, it emphasizes the need for a delving into the product level with the supplier selection model developed in Chapter 6 for which the obtained cost prices serve as input.

6 Solution Design

In this chapter we will develop a supplier selection model, which is the last step of the outsourcing decision framework presented in Figure 3 (cf. Chapter 3). The results of this model answer sub-question 6 and serve as input for sub-question 7, providing a complete solution to the problem statement. Moreover, the model and corresponding robustness analysis will be used to create general insights regarding the outsourcing decision process to add to the existing literature.

6.1 Supplier Selection Model

In the previous chapter a qualitative and quantitative analysis is performed. These serve as input for setting up the supplier selection model. The qualitative analysis identified important strategic factors and their implications for Prodrive. These factors will form the basis of the models' objectives. The objectives obtained from the qualitative analysis are quality, political stability, lead time and delivery reliability. Political stability represents external politics in the qualitative analysis with China-US technology decoupling as main driver. Lead time and delivery reliability represent flexibility from the qualitative analysis. Moreover, the quantitative analysis performed a cost benchmark in which the internal cost prices are recalibrated and external quotations are gathered at potential suppliers. The internal and suppliers' cost prices serve as input parameters for the model. Cost minimization is an objective for Prodrive as well. Moreover, this is identified in Chapter 3.3.1 as the most important reason for outsourcing in general. The objectives, however, do not have the same importance, therefore the model must incorporate weights. Lastly, the model needs to have constraints that can fall within a range because the objectives are not limited to a single integer value.

Sawik (2011) proposes a bi-objective supplier selection model under supply disruption. However, this model is not multi-objective and focuses on supply disruptions. Basnet and Lueng (2005) propose a multi-period multi-supplier lot sizing model, however this model solely focuses on the cost objectives, lot-sizing, and order timing, which is out of scope for this study. The goal of this study's model is to compare multiple suppliers based on costs, quality, political stability, lead time and delivery reliability, taking its corresponding weights into account. It is important to note that, in this problem, multiple suppliers must be compared and therefore the model must be formulated as a multi-supplier model. Supplier selection decision makers often do not have complete information related to decision criteria and boundaries.

Therefore, it is important that these boundaries are fuzzy such that the objectives are allowed to fall in a range and deal with insecurity or subjectivity in input parameters. Fuzzy goal programming is a technique that helps make decisions when there are multiple goals that conflict with each other. In traditional fuzzy goal programming, all goals are equally important. Amid et al. (2006) developed a weighted additive fuzzy model for supplier selection to deal with imprecise inputs and determining relative weights. However, in this method the ratio of the membership function achievement levels is not equal to the objective weights. Amid et al. (2011) applies a weighted max-min fuzzy multi-objective model from Lin (2004) to supplier selection. This paper proposes a new approach, the weighted max-min model, where each goal is given a weight based on its importance. This method aims to optimize the goals by minimizing the deviation from each goal, while considering the weights. Therefore, this model combines all requirements as it matches the achievement level of the objective functions with the relative importance of the objective functions, includes multi-objectives and the fuzzy boundaries allow the objectives to fall within ranges. Moreover, it is a multi-supplier model.

We build upon the model presented in Amid et al. (2011) and extend it to incorporate the findings of Parts I and II by changing and incorporating objectives. Below, the multi-objective model for supplier selection (Model 2) and corresponding notation are presented.

D	*Demand per year*	R_i	*% of delivery reliability of supplier i*
x_i	*Number of units purchased from supplier i*	LT_i	*Lead time of supplier i*
P_i	*Per unit purchase costs from supplier i*	PS_i	*Political Stability Factor of supplier i*
C_i	*Capacity of supplier i*	n	*Number of suppliers*
Q_i	*% of quality level of supplier i*	w_j	*Weight of constraint j*

Model 2: Multi-objective supplier selection model

$$Min\ Z_1 = \sum_{i=1}^{n} P_i \cdot x_i \quad (2.1)$$

$$Max\ Z_2 = \sum_{i=1}^{n} Q_i \cdot x_i \quad (2.2)$$

$$Max\ Z_3 = \sum_{i=1}^{n} R_i \cdot x_i \quad (2.3)$$

$$Min\ Z_4 = \sum_{i=1}^{n} LT_i \cdot x_i \quad (2.4)$$

$$Max\ Z_5 = \sum_{i=1}^{n} PS_i \cdot x_i \quad (2.5)$$

S.t.

$$\sum_{i=1}^{n} x_i = D \quad (2.6)$$

$$x_i \leq C_i, \qquad i = 1, 2, \ldots, n \quad (2.7)$$

$$x_i \geq 0, \qquad i = 1, 2, \ldots, n \quad (2.8)$$

Five objective functions are formulated in the model, costs (2.1), quality (2.2), delivery reliability (2.3), lead time (2.4) and political stability (2.5) are formulated to minimize total costs, total lead time, and maximize total quality, service, and political stability levels. Constraint 2.6 ensures that the ordered quantity is equal to the demand, constraint 2.7 ensures that order quantities to each supplier are equal to or less than its capacity and constraint 2.8 prohibits negative orders. First a general multi-objective model for supplier selection is presented below in Model 3. Equations (3.1) and (3.2) represent the negative and positive objectives respectively. X_d is the set of feasible solutions satisfying the set of constraints.

Model 3: Generic multi-objective supplier selection model

$$Min\ Z_1,\ Z_2, \dots, Z_k \tag{3.1}$$

$$Max\ Z_{k+1},\ Z_{k+2}, \dots, Z_p \tag{3.2}$$

S.t.

$$x \in X_d, X_d = \left\{\frac{x}{g_s(x)} \leq b_s,\ s = 1,2, \dots, m\right\} \tag{3.3}$$

This general model is converted to a fuzzy goal problem by defining the goals as fuzzy sets using Lin (2004)'s approach. The objectives in Equations (3.1) and (3.2) are presented as membership functions which capture the degree of satisfaction for each objective. The function $f_{\mu z_j}(x)$ measures the degree of satisfaction of the goal, in which $\mu_{zj}(x)$ is the membership grade of the fuzzy set associated with the *j*th goal. To account for weights, the paper proposes λ as new decision variable representing the overall degree of goal satisfaction. Weights w_j are incorporated by multiplying them with λ, as presented in Equation (4.2) ensuring that each goal is satisfied to a certain degree based on its weight. Equation (4.3) represents the original linear constraints, while Equation (4.4) constrains λ to a range between 0 and 1. Equation (4.5) ensures that the weights sum to 1, and Equation (4.6) prevents negative orders.

Model 4: Weighted max-min model (Lin, 2004)

$$Max\ \lambda \tag{4.1}$$

S.t.

$$w_j * \lambda \leq f_{\mu z_j}(x), \quad J = 1, \dots, q \tag{4.2}$$

$$g_r(x) \leq b_r, \quad r = 1, \dots, m \tag{4.3}$$

$$\lambda \in [0,1] \tag{4.4}$$

$$\sum_{j=1}^{q} w_j = 1, \quad w_i \geq 0 \tag{4.5}$$

$$x_i \geq 0, \qquad i = 1, \dots, n \tag{4.6}$$

This model is equivalent to solving Model 3 above with the following membership functions:

$$\mu'_{zk}(x) = \begin{cases} \frac{1}{w_k}\ for\ Z_k \leq Z_k^- \\ \frac{f_{\mu zk}(x)}{w_k}\ for\ Z_k^- \leq Z_k(x) \leq Z_k^+ \quad (k = 1,2,\dots,p) \\ 0\ for\ Z_k \geq Z_k^+ \end{cases} \qquad (3.4)$$

$$\mu'_{zl}(x) = \begin{cases} \frac{1}{w_l}\ for\ Z_l \geq Z_l^+ \\ \frac{f_{\mu zl}(x)}{w_l}\ for\ Z_l^- \leq Z_l(x) \leq Z_l^+ \quad (l = p+1,\dots,q) \\ 0\ for\ Z_l \leq Z_l^- \end{cases} \qquad (3.5)$$

Solving Model 3 with the linear membership functions as presented above in Equation (3.4) and 3.5 in the context of the applied multi-objective supplier selection model as presented in Model 2 results in the adapted weighted max-min fuzzy multi-objective supplier model presented in Model 5 below. This model incorporates the Prodrive specific objectives and translates them into the corresponding linear membership functions in Equation (5.2 – 5.6). Moreover, constraint 5.7 ensures that the total order quantity equals the demand, constraint 5.8 ensures capacity that the order quantity at a supplier is less than or equal to the suppliers' capacity, and constraint 5.9 prohibits negative orders. Moreover, an added application is that the model is infeasible or unbounded, the cost lower bound is increased with 0.01 until the first feasible solution is found. This is done because, although cost is the most important objective as reflected by the weights, it is the only objective in which concessions can be made.

Model 5: Weighted max-min fuzzy multi-objective supplier selection model

$$Max\ \lambda \qquad (5.1)$$

S.t.

$$w_1 * \lambda \leq \frac{Z_1^+ - (\sum_{i=1}^{n} P_i \cdot x_i)}{Z_1^+ - Z_1^-} \qquad (5.2)$$

$$w_2 * \lambda \leq \frac{(\sum_{i=1}^{n} Q_i \cdot x_i) - Z_2^-}{Z_2^+ - Z_2^-} \qquad (5.3)$$

$$w_3 * \lambda \leq \frac{(\sum_{i=1}^{n} R_i \cdot x_i) - Z_3^-}{Z_3^+ - Z_3^-} \qquad (5.4)$$

$$w_4 * \lambda \leq \frac{Z_4^+ - (\sum_{i=1}^{n} LT_i \cdot x_i)}{Z_4^+ - Z_4^-} \qquad (5.5)$$

$$w_5 * \lambda \leq \frac{(\sum_{i=1}^{n} PR_i \cdot x_i) - Z_5^-}{Z_5^+ - Z_5^-} \qquad (5.6)$$

$$\sum_{i=1}^{n} x_i = D \qquad (5.7)$$

$$x_i \leq C_i, \qquad i = 1, 2, \dots, n \qquad (5.8)$$

$$x_i \geq 0, \qquad i = 1, 2, \dots, n \qquad (5.9)$$

6.2 Findings

This sub-chapter presents the findings from the supplier selection model presented in sub-chapter 6.1. Cost inputs and demand are obtained from quantitative analysis in Tables 4 and 5 (cf. Chapter 5-II). Remaining input parameters are presented in Tables 12, 13, and 14 (cf. Appendix III). Lead times are based on supplier predictions and internal lead times. The political stability factor is sourced from (The Global Economy, n.d.). Due to uncertainty in quality and delivery reliability, assumptions are made in consultation with stakeholders at Prodrive. Also, the objective weights are determined with them and set to: Costs: 0.35, Quality: 0.20, Delivery Reliability: 0.20, Political Stability: 0.20, and Lead Time: 0.5. The results are presented separately for products manufactured in PTNL and PTCN. Thereafter, an across the globe comparison will be presented followed up by an example with capacity constraint.

Tables 6 and 7 below present the results for PTNL and PTCN. In PTNL, demand is mainly divided between PTNL and PTCN as the European suppliers lack cost competitiveness. Moreover, due to lack of cost competitiveness multicore cables (Product 1 and 2) are partly allocated to EU1, which is in line with the findings in Chapter 5-II. PTCN demand is mainly divided among PTNL, PTCN, and CN2, with CN2 preferred over CN1 due to performance. Products 10, 11, and 17 are assigned to CN1 for cost advantages. PTNL is used for political stability, while PTCN is a cost-effective solution for meeting other constraints. For PTCN, no big differences in product categories are identified. This is also partly caused by the fact that all performance indicators have the same constraints for each product group. A robustness analysis on input parameters and constraints is performed in the next sub-chapter to get more comprehensive insights and practical implications regarding this manner.

Table 6: Results supplier selection model PTNL.

Product	PTNL	PTCN	EU1	EU2	Pi	R_i	Q_i	LT_i	PS_i
1	264	395	611	0	121,80	0,94	0,96	7,64	0,3
2	0	1295	1175	0	10,20	0,93	0,96	8,85	0,0
3	908	568	0	0	7,70	0,97	0,98	2,31	0,38
4	354	206	0	0	363,10	0,97	0,98	2,21	0,4
5	556	0	0	898	197,30	0,94	0,97	4,94	0,12
6	507	963	0	0	76,60	0,97	0,98	3,93	0,0
7	240	325	0	0	98,90	0,97	0,98	3,45	0,11
8	9998	10306	0	0	9,40	0,97	0,98	3,05	0,21
9	651	1245	0	0	9,20	0,97	0,98	3,94	0,0

Table 7: Results supplier selection model PTCN.

Product	PTCN	PTNL	CN1	CN2	Pi	R_i	Q_i	LT_i	PS_i
10	4058	1214	903	5641	€ 41,00	0,93	0,95	12,0	0,0
11	1749	514	377	2442	€ 49,10	0,93	0,95	12,0	0,0
12	5283	1254	0	8863	€ 2,80	0,93	0,95	12,0	0,0
13	4537	1056	0	7594	€ 9,60	0,93	0,95	12,0	0,0
14	454	106	0	760	€ 77,70	0,93	0,95	12,0	0,0
15	5751	382	0	7867	€ 1,90	0,93	0,95	11,4	0,1
16	2783	654	0	4663	€ 9,20	0,93	0,95	12,0	0,0
17	78	62	82	4	€ 216,10	0,93	0,95	10,71	0,0
18	862	202	0	1444	€ 13,50	0,93	0,95	12,0	0,0

In the research, the cost benchmark was separated between PTNL and PTCN facilities. The supplier selection model is run for PTNL products with CN2 as an additional supplier, using estimated prices (Appendix III, Table 15) to get a global cost comparison. All other input variables remain the same. The results are presented in Table 8 below. Demand for products is divided between CN2 and PTNL. PTCN and EU1 are highly competitive for Product 1, claiming a significant portion of the demand. Other products balance cost-efficient CN2 while maintaining sufficient demand in PTNL to avoid constraint violations. CN2's cost competitiveness leads to lower average prices per product than Table 6.

Table 8: Results supplier selection model across the globe.

Product	PTNL	PTCN	EU1	EU2	CN2	Pi	R_i	Q_i	LT_i	PS_i
1	241	409	620	0	0	€ 121,10	0,93	0,96	7,79	0,28
2	1118	22	0	0	1330	€ 9,80	0,94	0,95	10,82	0,15
3	937	0	0	0	539	€ 7,60	0,95	0,96	7,3	0,41
4	363	0	0	0	197	€ 346,80	0,95	0,96	7,04	0,43
5	695	0	0	2	757	€ 192,50	0,94	0,95	10,42	0,19
6	699	0	0	0	771	€ 72,00	0,94	0,95	10,49	0,19
7	277	0	0	0	288	€ 96,90	0,94	0,95	10,19	0,21
8	10914	0	0	0	9390	€ 9,30	0,94	0,96	9,25	0,27
9	785	49	0	0	1062	€ 8,80	0,93	0,95	11,36	0,1

Human resource constraints in the Brainport region, identified by the strategic analysis, led to the need to slow CHM's growth in the Netherlands. The supplier selection model was updated with a capacity constraint of 30% maximum production for a specific PTNL product in consultation with relevant stakeholders, aligning with the department's vision. Results in Table

9 show a noteworthy increase in the average price resulting from the capacity constraint and the shift in demand from PTNL and CN2 to PTCN and EU1. PTCN is preferred over CN2 due to its performance, while EU1 is favored over EU2 due to its political stability, mitigating political risk. Products 7 and 8 are shifted to EU2 since no pricing data is available for EU1. Product 1 remains unchanged as PTNL's allocated capacity was already under 30%. Product 9 has no feasible solution. Except for lead time, all performance indicators generally decrease. Again, as constraints are kept equal amongst products, no specific product group behavior is spot. Behavior based on input parameters and constraint changes will be elaborated in the robustness chapter.

Table 9: Results supplier selection model across the globe including capacity constraint.

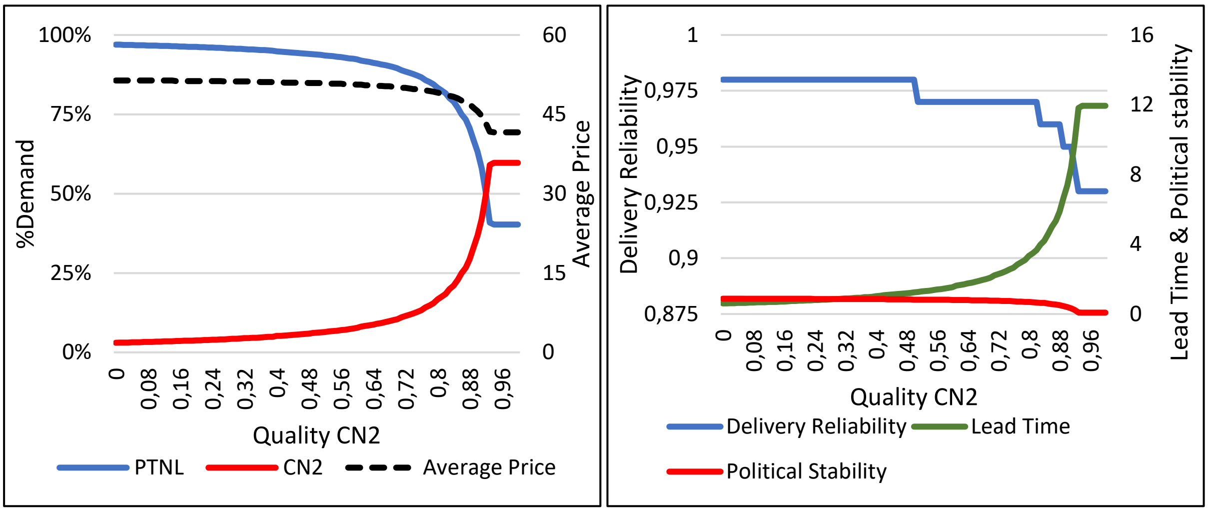
Product	PTNL	PTCN	EU1	EU2	CN2	Pi	R_i	Q_i	LT_i	PS_i
1	241	409	620	0	0	€ 121,10	0,93	0,96	7,79	0,28
2	741	347	393	0	989	€ 9,80	0,93	0,95	10,76	0,1
3	442	277	405	0	352	€ 7,80	0,94	0,95	9,19	0,22
4	168	91	120	1	180	€ 370,90	0,93	0,95	9,99	0,16
5	436	0	187	336	495	€ 196,30	0,93	0,95	10,2	0,09
6	441	199	214	0	616	€ 73,60	0,93	0,95	10,94	0,09
7	169	0	0	396	0	€ 140,50	0,94	0,97	5,61	0,01
8	6091	0	0	12406	1807	€ 29,80	0,94	0,96	6,67	0,0
9	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

6.3 Robustness

This chapter conducts a robustness analysis of the supplier selection model to evaluate the sensitivity of input parameters and constraints and provide a more comprehensive understanding of the solution. The analysis focuses on Product 10 and compares the performance of PTNL and CN2. The aim is to gain general insights on the supplier selection problem. The report includes plots for political stability and quality in the main body as these are of major strategic importance, other plots are presented in Appendix III.

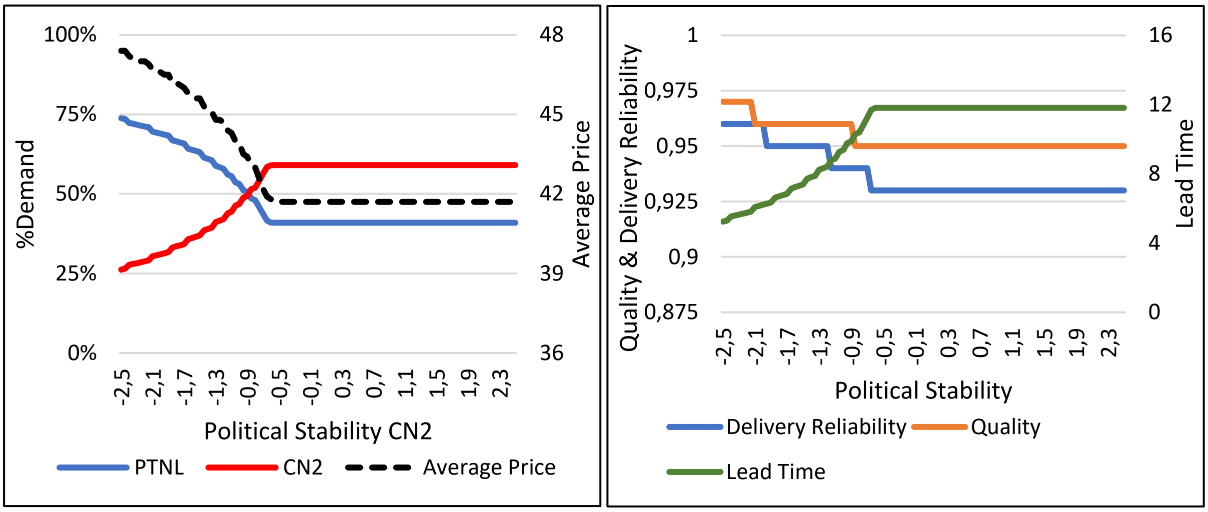
First, parameter robustness is examined. Figure 10 presents how allocated demand, price, and performance indicators change as the quality level of the Chinese supplier increases. Increases in quality levels result in a larger allocation of demand to CN2, decreasing the average price. Demand is equally divided at a quality level of approximately 92%. The behavior is stabilized at a quality level of 94% resulting in 60% of the demand allocated to the Chinese supplier at an average price of 41.6 Euros, delivery reliability of 93%, lead time of 11.94 days and a political risk factor of 0.08. The lead time constraint prevents the model from allocating more demand to PTCN as it is near the boundary while other constraints still have space. So, in practice, if the company wants to allocate more demand to the supplier because the quality level increases further than 94%, the lead time upper bound must be increased.

Figure 10: Robustness on Quality of supplier CN2 for Product 10.



Political stability is critical, especially with the China-US technological decoupling mentioned in the qualitative analysis. Improving a supplier's political stability increases supplier demand allocation, decreases price, lengthens lead time, and reduces quality and delivery reliability, as presented in Figure 11. This behavior is intuitive as a better political stability allows the company to allocate more demand to the supplier as risks are lower. All other parameters equal, this will decrease other performance indicators as the suppliers' performance indicators are worse compared to PTNL. At a political stability factor of -0.55, demand allocation stabilizes at 59% for the supplier, with an average price of 41.7, delivery reliability of 93%, quality level of 95%, and lead time of 11.81. The quality level is near the lower bound, and therefore the model does not allocate more demand to the supplier after the political stability factor of -0.55. So, if in practice the political stability improves, and all other parameters remain equal, the company must sacrifice quality to allocate more demand to lower the costs by allocating more demand to the supplier. Further increasing the supplier allocation also requires relaxation of the lead time boundary as it is 11.81 whereas the upper bound is 12.

Figure 11: Robustness on Political Stability of supplier CN2 for Product 10.



Figures 17 and 18 (cf. Appendix III) illustrate the impact of delivery reliability and lead time on the robustness analysis. Higher supplier delivery reliability increases supplier demand allocation and lead time but decreases price, quality, and political stability. This behavior is intuitive as increasing delivery reliability makes the supplier more favorable increasing supplier demand allocation. This negatively affects all other performance indicators as PTNL is superior on all other performance indicators. Costs however decrease as the supplier is more cost competitive. The model stabilizes at a supplier delivery reliability of 85%, with 59% supplier demand allocation, an average price of 41.7 Euros, delivery reliability of 90%, a quality level of 95%, a lead time of 11.81 days, and a political stability factor of 0.09. Again, the quality boundary is blocking a further increase of supplier demand allocation. Supplier allocation reacts inverse to lead time compared in comparison with the previously discussed parameters and stabilizes at a supplier lead time of 20 days. At this point, the supplier's demand allocation remains constant at 59%, with an average price of 41.7 Euros, delivery reliability of 93%, quality level of 95%, lead time of 11.81 days, and political stability factor of 0.09. Increasing supplier lead time reduces supplier demand allocation, but increases price, delivery reliability, quality, and political stability. This inverse relation compared to the robustness of other parameters is intuitive as the other constraints, except costs, aim for maximization whereas the lead time constraint aims for minimization.

A robustness analysis on constraints is conducted by running the constraints from the lowest to the maximum of both suppliers. The quality and political stability constraints are shown in Figures 12 and 13, while other constraints are presented in Figures 19 and 20 (cf. Appendix III). Supplier demand allocation remains constant at 60%, with a price of 41.6 Euros, delivery reliability of 93%, quality level of 95%, lead time of 11.94 days, and political stability of 0.08, until a quality lower bound of 94.9%. Increasing the quality lower bound decreases supplier demand allocation. This behavior is intuitive as more PTNL demand is required to satisfy the increased quality lower bound. Moreover, it confirms the insights obtained from the qualitative analysis in which experts emphasized that quality critical parts must be produced in PTNL. Moreover, it improves performance indicators at the expense of a price increase as PTNL is superior on performance but less cost competitive than the supplier. Decreasing the quality lower bound further than 94.9% does not change the supplier demand allocation as the lead time is near the upper bound. Thus, in practice, if the company aims to further decrease costs by allocating more demand to the supplier, it has to relax the lead time upper bound as well, after which the other bounds will follow. Political stability presents similar behavior being stable at 59% supplier demand allocation until a political stability level of 0.08 at an average price of 41.7 Euros, delivery reliability of 93%, quality level of 95%, lead time of 11.77 days and a political stability of 0.1. A further increase in supplier demand allocation is only possible if the company also relaxes the quality lower bound.

Delivery reliability presents similar behavior and remains stable until a lower bound of 93.2% at a price of 41.7 Euros, delivery reliability of 93%, quality level of 95%, lead time of 11.81 days and political stability of 0.09. So, the practical implication is that if the company further relaxes the delivery reliability lower bound, it also has to relax the quality lower bound in order to allocate more demand to the supplier while meeting constraints. For lead time, the robustness is performed on the upper bound, as this perforance indicator aims for minimization, resulting in inverse behavior compared to the other constraints. Results are stable from an upper bound of 12 days, which is equal to the initial upper bound, while all other indicators being equal to the equilibrium of delivery reliability. This implies that relaxing the lead time constraint does not change the supplier demand allocation because the quality level is near its lower bound. Decreasing the upper bound logically decreases supplier demand allocation and lead time while increasing the price, quality, delivery reliabilty and political stability. Again, this behavior is intuitive as outsourcing to the supplier is less attractive with higher lead times.

Figure 12: Constraint Robustness on Quality for Product 10.

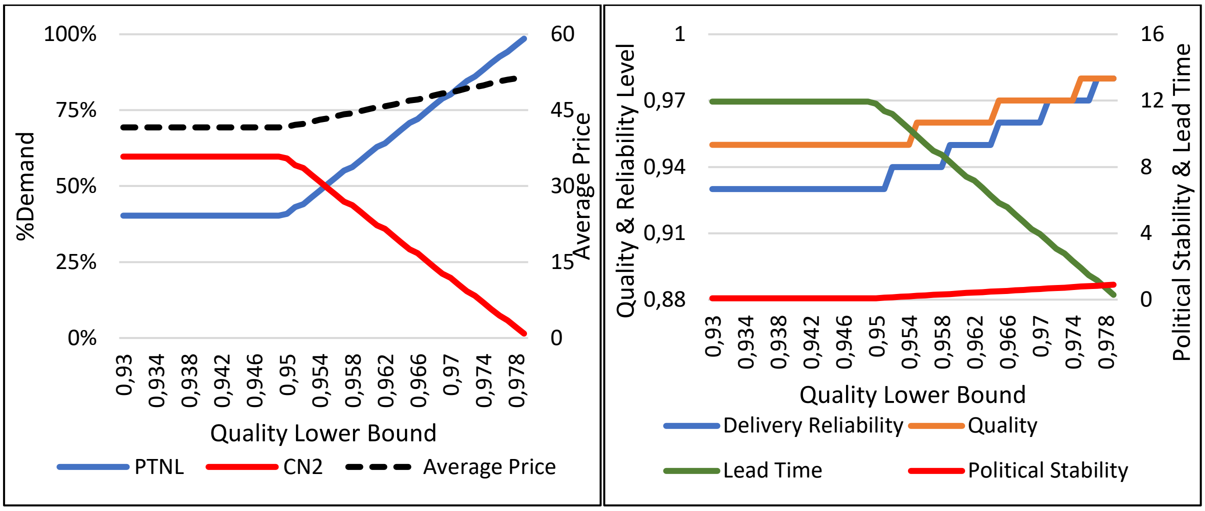
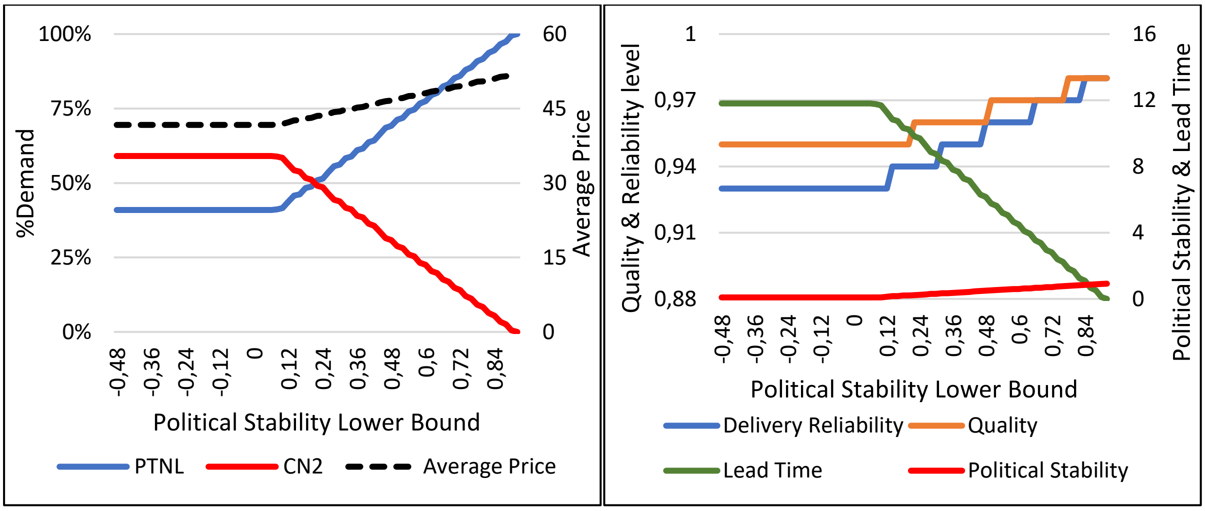


Figure 13: Constraint Robustness on Political Stability for Product 10.



6.3.4 Conclusion

To conclude, this chapter presents a supplier selection method including the main requirements for this case study namely, multi-suppliers, multi-objectives, fuzzy boundaries, and weighted objectives. The findings provide a more comprehensive understanding of the case study at Prodrive and provide an answer to sub-question 7. For the PTNL comparison, demand is mainly divided between PTNL and PTCN due to lack of cost competitiveness of the European suppliers, except for the Multicore cables. For the PTCN comparison, demand is divided between PTNL, PTCN and CN2. The Chinese suppliers are more cost competitive than the European resulting in more outsourcing, which is in line with the conclusion of Chapter 5-II.

After this comparison, an across the globe comparison is conducted presenting a division between PTNL and CN2 as CN2 is way more cost competitive than PTCN and the other European suppliers. This is also in line with the conclusion of Chapter 5-II which concluded that it is impossible to compete on lowest acquisition value with the Chinese suppliers due to the low labor wages. Lastly, as presented in the qualitative analysis, human resources are a potential bottleneck in the Brainport region. Therefore the across the globe model is rerun with a capacity constraint of 30% of demand in PTNL. In this case, demand is mostly divided between PTNL, PTCN, EU1 and CN2. PTNL and PTCN are preferred to respect the performance constraints, EU1 for the political stability while maintaining lower costs and CN2 for decreasing the average acquisition value.

The robustness analysis presents intuitive behavior on input parameter robustness. Increasing performance indicators of the supplier increase supplier demand allocation as far as no other constraints are violated, and therefore decrease the average acquisition value. From that moment on, the demand division stabilizes. Due to its criticality, quality is often the constraint, which is in line with the qualitative analysis. Moreover, the constraint robustness confirms that quality critical parts are preferred to be produced in PTNL. The same applies to the other performance indicators, as PTNL's performance indicator inputs are superior. Other constraint robustness presents intuitive behavior as well. As this model presents intuitive behavior, it is applicable in industry for companies that need to make decisions regarding outsourcing or supplier selection based on multiple objectives with relative weights. The significance of general applicability is amplified by the increasing attention to resilience sentiment.

7 Conclusion and Discussion

The conclusion chapter serves as the closing section of this research study, where we present our final conclusions and provide recommendations for future research. This chapter will be organized into several sections, beginning with an assessment of the quality of our research. We will then discuss the scientific contribution of this study, followed by a comprehensive conclusion. Next, we will present our recommendations based on the findings, and conclude with a discussion on the limitations of the study, including directions for further research. This chapter is intended to provide a concise summary of our research and its implications for future studies in this area.

7.1 Research quality

In addition to the importance of research results, rigor in conducting the research must also be considered. Rigor refers to the measures taken to enhance the quality of the study, which includes ensuring validity and reliability. Validity is the accuracy of the measurement of a concept, while reliability is the consistency of results from a research instrument (Heale & Twycross, 2015). Validity is further classified into three categories: construct validity, internal validity, and external validity (Yin, 2009).

Construct validity, as defined by Yin (2009), is the establishment of correct operational measures for the studied concepts. Whereas internal validity is defined as establishing causal relationships where specific conditions are shown to lead to other conditions, as distinguished from spurious relationships. This is addressed by reviewing conclusions made from data by TU/e and Prodrive experts. Moreover, all methodologies used are grounded by literature.
External validity is described as the extent to which study findings can be generalized. This study's non-contrived research setting increases generalizability, and both quantitative and qualitative models are barely customized to maximize generalizability and contribute to the existing literature. The supplier selection model will also undergo a robustness analysis to provide general insights. Moreover, reliability and validity is increased by employing data triangulation, integrating various data sources, such as balanced scorecards, databases, interviews, cost analysis, and observations. To ensure reliability in the qualitative research, a plenary session is conducted to explain the statements to all interviewees beforehand.

7.2 Final Conclusion

This chapter serves as the culmination of the research conducted, integrating the findings from the theoretical background, qualitative analysis, quantitative analysis, and solution design. We aim to provide a comprehensive general conclusion that will inform the recommendations for CHM's governance structure presented in sub-chapter 7.6, answering sub-question 7.

The study first defines a governance structure and outsourcing, answering sub-question 1. A governance structure is defined as "*A continuum that ranges from obtaining products fully from the market or completely manufacturing it within firm"* and outsourcing as "*the management of a day-to-day execution of an entire business function which was (or could have been) vertically integrated notwithstanding the decision to go to an independent third-party (make-or-buy)*". To obtain a comprehensive understanding of the outsourcing decision main theories, are discussed and intertwined. This study suggests that RBV can cover the gap in TCE by comparing firm capabilities. Whereas TCE broadens the perspective of RBV, limited to firms' capabilities, by including transaction costs. So, the theories can be used in sequence. RBV triggers the outsourcing decision based on capabilities followed by TCE determining the best governance structure. This answers sub-question 2.

This study's main contribution is that we developed and outsourcing decision framework integrating theoretical background, qualitative and quantitative methodologies, answering sub-question 3 and satisfying the first objective. It builds upon Kremic et al. (2006) and we extend the outsourcing decision into a simultaneously performed qualitative and quantitative analysis for which the influencing factors and TCO respectively serve as input. Influential factors are costs, core closeness, critical knowledge, human resources scarcity, quality, flexibility, complexity, integration, asset specificity, employees impacted, supply chain, external politics, internal politics, legal and technological uncertainty. The outcomes of the qualitative and quantitative analysis serve as input for the supplier selection model presented in Chapter 6. The outsourcing decision framework is presented in Figure 3 (cf. Chapter 3.3.4).

Sub-question 4 and 5 are answered by the methodologies in Chapter 5-I.1 and 5-II.1. The main findings of the strategic analysis are presented below:

1) Human resource scarcity in the Brainport region might be a bottleneck for Prodrive's growth due to the growth of ASML and corresponding suppliers making

it favorable to use the scarce human resources for more value-adding activities in PTNL.

2) The China-US technology decoupling causes a high supply risk of products assembled in China containing US origin components which might require a (partly) transfer of cable assembly production to PTNL, suppliers or a new factory.
3) Quality and flexibility are the drivers preferring in-house cable production for quality-critical cables and prototypes due to short ties between CHM and R&D.
4) Building up a more sophisticated supply chain for cable assemblies in which non-quality critical demand can be outsourced. A supplier which strategically fits the company is preferred as it mainly concerns low volume high diversity demand in contradiction to general cable assembly parties (high volume, low diversity).

The quantitative analysis presents a Prodrive customized cost price model in Chapter 5-II.2 which was required as in the problem statement an independent analysis revealed that the current cost prices are not representative of reality, necessitating a new approach to accurately calculate cost prices and subsequently conduct a fair benchmark analysis. After which, the findings present that Prodrive is not competitive on multicore cables, competitive for wire harnesses compared to European suppliers as these are complex, but not competitive with Chinese suppliers as these are labor intensive as well. In general, neither PTNL nor PTCN can compete with the Chinese suppliers on lowest acquisition value due to the substantial difference in labor wages. Further research into qualitative aspects of the suppliers is required.

Chapter 6 presents a supplier selection model that considers multiple weighted objectives, multiple suppliers, fuzzy boundaries, and qualitative and quantitative inputs. The PTCN comparison results in more outsourcing than the PTNL comparison as the Chinese suppliers are more cost competitive than the European suppliers. An across the globe comparison divides demand between PTNL and the Chinese supplier, which is intuitive as PTNL serves for satisfying the performance indicators whereas the Chinese supplier is depresses costs due to its competitiveness compared to PTCN and the European suppliers. Adding capacity constraints to PTNL to simulate the potential human resource scarcity results in a partial shift of demand allocation from PTNL and CN2 to PTCN and the European supplier to satisfy performance indicators and political stability respectively. To conclude, these results and the intuitive behavior of the robustness analysis for all input parameters and constraints confirm the practical applicability of the model.

7.3 Scientific contribution

This study provides a significant contribution to the field of outsourcing by developing a more comprehensive understanding of the links between existing literature and the outsourcing decision. Through the integration of main outsourcing theories such as TCE and RBV, as well as other theoretical perspectives, this study bridges the gap between the fragmented understanding of the outsourcing decision. Furthermore, while some studies have focused on qualitative methods to explore the outsourcing decision, others have used quantitative techniques to analyze the decision. However, this study found that the existing literature fell short in an integrated approach that combines both qualitative and quantitative methodologies. It is noteworthy that the importance of such an integrated approach does not only lie in this theoretical gap, but also lies in – as shown in this study – in a practical gap because decision makers in practice view such an in-house versus outsourcing decision as one that should consider both quantitative and qualitative aspect. This study addresses the gap in literature by integrating both methodologies into one outsourcing decision framework. This is crucial as decision makers in practice view such a decision as one that should consider both quantitative and qualitative aspects. Moreover, this study develops a supplier selection model that incorporates both qualitative and quantitative inputs. The model provides a practical tool for organizations seeking to make informed outsourcing decisions.

7.4 Limitations

This study provides valuable insights, but it is important to acknowledge its limitations. First, the BWM to determine the weights within the qualitative study is performed by a selected group of stakeholders. While these stakeholders are carefully chosen, the input is subjective and may have differed if other stakeholders had been involved. The quantitative analysis' first limitation is that several requests for quotations for Product 7-9 were not timely honored. Secondly, the cost price methodology Prodrive specific requiring other firms to have accurate cost prices before applying the framework. Moreover, assumptions are made on performance indicators of suppliers in the supplier selection model. In practice thorough supplier research must be done before applying the model. Moreover, the supplier selection model does not use scale prices while in practice suppliers often offer scale prices and transaction costs per product increase if order sizes decrease. Moreover, the model does not take the costs of a performance decrease into account. Lastly, this research focused on a single-period window whereas in practice multiple order windows are common.

7.5 Future Research

Four directions of future research are proposed. First, this study only applies the framework in production context while it might also be applicable for other business functions. Therefore, it is valuable to assess the practicability on other business functions or industries. Specifically, it might be interesting to test the applicability on business-to-consumer companies as these might face other strategic influencing factors. In addition, examples of other business functions can be in the organizational support groups such as marketing. Moreover, further research is advised to extend the supplier selection model on 1) including scale prices, 2) depending costs on performance indicators and 3) extending the model to a multiple-period horizon. Extending the model in this manner might give additional valuable insights on the outsourcing decision.

7.6 Recommendations

This sub-chapter synthesizes the insights gathered from the various research methods employed. We hope to provide a clear and actionable set of recommendations that will assist Prodrive in choosing the best governance structure for its CHM department.

1. **Maintain prototype and quality critical production at PTNL.**

Quality and flexibility are the main reasons that produces cables in-house. Therefore, prototypes and quality-critical cables must remain in PTNL. First, as ~96% of the R&D organization is located in PTNL having operational flexibility and short ties between R&D and operations during prototyping. Quality critical cables are mostly sub-assemblies for the most valuable end-products, with high quality standard, and corresponding high COPQ due to expensive rework. These findings result in recommendation 1 above.

2. **Assess which cable assemblies must be transferred from PTCN due to US-CN technology decoupling and take appropriate action.**

The China-US technology decoupling caused new regulations which result in a high supply risk for assemblies made in China with US origin components, therefore Prodrive is strongly recommended to assess which cables need to be transferred, and act upon that.

3. **Explore the feasibility of establishing a low-wage factory in Europe.**

The above-mentioned political instability for PTCN in combination with the human resource scarcity in the Brainport region for PTNL requires a sustainable long-term solution. Opening a low-wage factory for low value-adding competencies offers the possibility to use scarce human resources in PTNL for high value-adding activities and mitigate the China-US technology decoupling risk while maintaining flexibility and quality in own-hands. Moreover, it might be a cost-efficient solution as labor wages are lower than in PTNL.

4. **Expand research on cost-efficient suppliers that align with the company's strategy to enhance the current supply base and use these to outsource in-competitive cable assembly categories.**

Prodrive's current cable assembly supply base is extremely limited while the above-mentioned risks are quite significant. Therefore, instead of fully focusing on vertical integration Prodrive is recommended to further expand the research on cost-efficient suppliers who strategically fit with the company. These suppliers can be used to outsource product groups in which Prodrive is not competitive, such as multicore cables.

5. **Evaluate qualitative indicators of proposed potential suppliers.**

As mentioned in the limitations, assumptions are made on the qualitative indicators as there were no performance insights yet on the potential suppliers. So, Prodrive is recommended to rerun the supplier selection model after obtaining additional performance insights.

6. **Extent, further customize and apply the supplier selection model.**

Prodrive is recommended to extend the supplier selection model incorporating the limitations presented in Chapter 7.4. Scale prices are advised to be implemented as most suppliers use scale prices. Moreover, additional costs due to performance decreases are advised to be integrated as for example lower quality results in scrap costs, which in its turn results in ordering new products. Lastly, the model can be extended to multiple periods to include the effect of order sizes and timing. Nevertheless, the supplier selection model is illustrated to be applicable in practice for Prodrive and therefore can already be used without the extensions to compare different suppliers based on input parameters and proposed objectives.

Summarizing, a make-and-buy strategy is advised for CHM based on producing prototypes and quality critical assemblies in PTNL. Moreover, it is advised to mitigate its critical risks by exploring the possibilities for opening a factory in a low-wage part of Europe and expanding the current cable-assembly supply base. This summary answers sub-question 7.

7.7 Contribution at Prodrive

The study addresses a complex problem that has a significant strategic impact on Prodrive. The outsourcing decision is one that involves both qualitative and quantitative aspects, making it a challenging task for decision-makers. The study contributes to Prodrive as we develop an outsourcing decision framework that considers all these aspects, resulting in a supplier selection model that can be used to guide future outsourcing decisions. The impact of this study is not limited to the case study presented in this work, as the framework has already been applied to several other production departments to define their make or buy strategy, resulting in a significant impact on the defined future strategy of these departments. Additionally, the study has identified a lack of transparency in cost prices at Prodrive and has developed a new, more accurate methodology for cost price calculations in collaboration with the relevant process owners resulting in more transparent cost insights for Prodrive.

Several of the recommendations made in Chapter 7.6 have already been implemented or are in progress. For instance, Recommendation 1 is being considered as part of the future vision for the CHM department. Recommendation 2 has been fully executed, and cables that are not allowed to be produced in PTCN due to new regulations have been identified and will be moved to PTNL. Recommendation 3 has led to the initiation of a serious project to explore the possibility of opening a new factory in a low-wage country other than China. Recommendation 4 resulted in a project to expand the cable assembly supply base. Additionally, Recommendation 5 is being put into practice, with samples being ordered from potential suppliers identified in this study and currently being tested for quality requirements. Finally, Recommendation 6 can be considered once the aforementioned recommendation has been implemented to have actual performance indicators as input instead of assumptions.

In summary, this study has developed an outsourcing decision framework that considers both qualitative and quantitative aspects, resulting in a supplier selection model that can be used to guide future outsourcing decisions at Prodrive. Additionally, the study has identified and addressed the lack of transparency in cost prices, resulting in more accurate cost insights. The recommendations made in this study have already had a significant impact on Prodrive's defined future strategy, with several recommendations already implemented or in progress.

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Appendix I: Generic

Table 10: Mapping production departments per site.

	2012	2022		
Production Department	NL	NL	CN	US
SMD PCBA Manufacturing	X	X	X	X
CAL PCBA Manufacturing	X	X	X	X
Machining	X	X		
Injection Molding		X		
Magnetics		X	X	
Cable Harness Manufacturing		X	X	
System Assembly Series	X	X	X	X
System Assembly Cleanroom	X	X		
System Assembly Robotics		X		
System Assembly High Volume		X	X	X
Advanced Packaging		X		
Packaging	X	X	X	X
Logistics	X	X	X	X

Appendix II: Qualitative Analysis

Best Worst Methodology – 5 steps

<u>Step 1:</u> Determines a set of criteria resulting in the set of criteria: $\{c_1, c_2, \ldots, c_n\}$ which is used to facilitate the decision process. The criteria are the influential factors derived from the qualitative model presented in Chapter 3.3.4 which is derived from relevant literature.

<u>Step 2:</u> This step determines the best (most important) and the worst (least important) criteria. This and the next step are performed by a team of experts from Prodrive.

<u>Step 3:</u> This step determines the preferences of the best criteria over all the other criteria using a number between 1 and 9, the higher the number the higher the preference of the best criteria compared to criteria j. This results in a best-to-others vector: $A_B = (a_{B1}, a_{B2}, \ldots, a_{B3})$, in which a_{Bj} presents the preference of best criteria B over criteria j. So, $a_{BB} = 1$.

<u>Step 4:</u> This step determines the preferences of other criteria over the worst criteria. These preferences are identified by a number between 1 and 9, which results in the others-to-worst vector: $A_W = (a_{1W},\ a_{2W}, \ldots, a_{nW})^T$, in which a_{jW} presents the preference of criteria j over the worst criteria W. So, $a_{WW} = 1$.

<u>Step 5:</u> This step finds the optimal weights: $(w_1^*, w_2^*, \ldots, w_n^*)$, these weights will be multiplied by the scores in step 6 resulting in a weighted average score per factor. For finding the optimal weights the following condition must be satisfied for all criteria j: of w_B/w_j and w_j / w_W, there is $w_B / w_j = a_{Bj}$ and $w_j / w_W = a_{jW}$. To satisfy this condition for all j, problem 1 must be solved:

Model 6: Best Worst Methodology

$$\min \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\} \quad (6.1)$$

s.t.

$$\sum_j w_j = 1 \quad (6.2)$$

$$w_j \geq 0, \text{for all } j \quad (6.3)$$

The problem above is mathematically transformed to the problem below:

$$\min \xi \qquad (6.4)$$

s.t. (6.5)

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \text{for all } j \qquad (6.6)$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi, \text{for all } j \qquad (6.7)$$

$$\sum_j w_j = 1 \qquad (6.8)$$

$$w_j \geq 0, \text{for all } j \qquad (6.9)$$

By solving Equation (6.4), the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ and ξ^* are computed. The latter is used to calculate the consistency ratio, the bigger ξ^*, the higher the consistency ratio, the lower the comparison quality (Equation (6.11)). The overall score of the plants can be calculated by summing the scores of the factor p_{ij} multiplied by the corresponding weights, presented below in Equation (6.10).

$$V_i = \sum_{j=1}^{n} w_j p_{ij} \qquad (6.10)$$

$$Consistency\ Ratio = \frac{\xi^*}{Consistency\ Index} \qquad (6.11)$$

Figure 14: Results BWM influential factors.

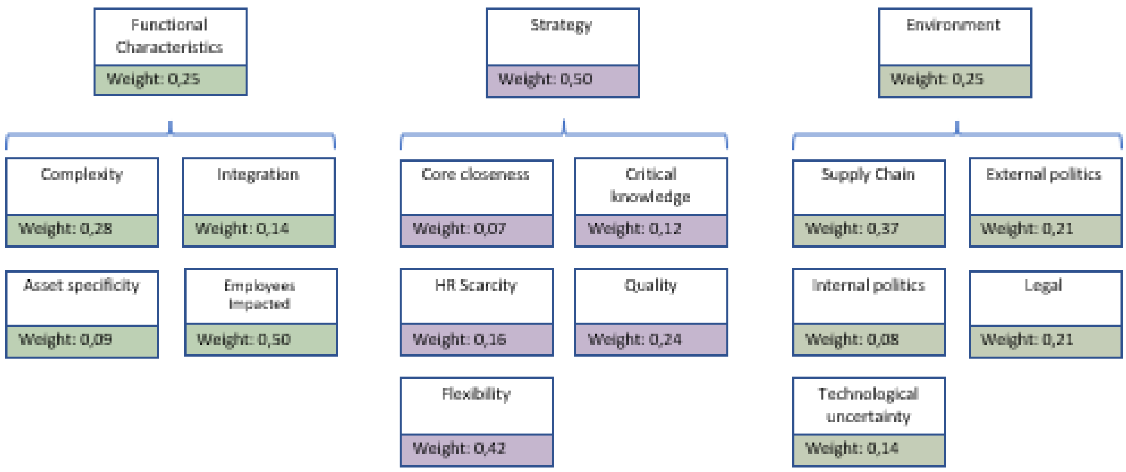

Table 11: Interview participants.

#	Function	Tier[1]	Responsibility	Date	Recorded
1.	Chief Operations Officer	A	Global	07-12-2022	Yes
2.	Technical Director	B	Global	07-12-2022	Yes
3.	Commercial Director	B	Global	21-12-2022	No
4.	Project Director	B	Global	05-12-2022	Yes
5.	Director Planning	C	Global	15-12-2022	Yes
6.	Director Ventures	C	Global	05-12-2022	Yes
7.	Director Sourcing	C	Global	16-12-2022	No
8.	General Manager Operations	C	PTCN	09-12-2022	Yes
9.	Manager Organizational Sup.	C	PTCN	14-12-2022	Yes
10.	Manager System Assembly	C	PTNL	12-12-2022	No
11.	Manager Human Resources	C	PTNL	07-12-2022	Yes
12.	Manager Quality	C	Global	21-12-2022	Yes
13.	Manager Logistics	C	PTNL	14-12-2022	Yes
14.	Manager Service	C	Global	12-12-2022	Yes
15.	Manager Business Continuity	C	Global	16-12-2022	Yes
16.	Manager Mechanics & CHM	C	PTNL	30-11-2022	Yes
17.	Manager Magnetics	C	Global	14-12-2022	Yes
18.	Sourcing Manager	D	PTNL	07-12-2022	Yes
19.	Product Line Manager	D	PTNL	20-12-2022	No
20.	Competence Owner CHM	D	PTNL	20-12-2022	No
21.	Global Process Owner CHM	D	Global	07-12-2022	Yes
22.	Financial Risk Manager	D	PTNL	30-11-2022	Yes
23.	Operations Controller	D	PTNL	19-12-2022	No

[1] *A = Executive Management   B = Program Management   C = Functional Management*
D = Operational Responsible

Figure 15: Balanced Score Card.

Personal Information
Function:
Date:

Please fill in the matrix on a 7-point Likert scale based on the questions at the right.

0 = Insufficient knowledge to answer
1 = Strongly disagree
2 = Disagree
3 = More or less disagree
4 = Neutral
5 = More or less agree
6 = Agree
7 = Very strongly agree

			CHM		
			PTNL	PTCN	**Statements on Influencing Factors**
Influential Factors	Strategy	**Core Closeness**			*Process X is close to Prodrive Technologies' core business.*
		Critical Knowledge			*Process X corresponding knowledge is critical for Prodrive Technologies.*
		Human Resources Scarcity			*A lack of internal human resources is likely in the near future. If so, we prefer to use the human resources for, other, more value-adding processes increasing overall results.* [1]
		Quality			*Outsourcing process X results in quality problems.*
		Flexibility			*Keeping process X in-house gives valuable operational flexibility.*
	Functional Characteristics	**Complexity**			*Process X is complex compared to Prodrive Technologies' other production processes.*
		Integration			*High integration of process X with other (production) processes or systems makes outsourcing difficult.*
		Asset Specificity			*Process X has high asset specificity resulting in large bargaining power for a potential supplier while outsourcing.*
		Employees Impacted			*Outsourcing process X will result in a significant employee lay-off.*
	Environment	**Supply Chain**			*Outsourcing process X will decrease supply chain disruptions.* [1]
		Internal Politics			*Outsourcing process X will be prevented by internal politics.*
		External Politics			*External politics favor in-house production of process X.* [1]
		Legal			*Outsourcing process X will have legal difficulties.*
		Technological Uncertainty			*Process X and its correspondign market is subject to high technological uncertainty.*

Figure 16: Total overview results balanced scorecard.

Respondent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Influential Factors \ Plant	PTNL																						
Core Closeness	3	2	3	4	3	5	5	5	2	3	5	5	5	5	3	3	5	5	5	2	7	2	4
Critical Knowledge	2		3	3	6	5	6	5	2	2	5	3	5	4	5	2	2	6		3	4	5	3
Human Resources Scarcity[1]	2	2	2	2	1	2	2	2	1	2	2	2		4	2	2	2		1	1		3	
Quality	2	4		4	2	4	6	4	4	3	4	1	5	6	4	5	4	7		5	5	7	
Flexibility	7	7	6	7	6	6	5	6	3	5	7	6	7	7	6	6	2	4	7	7	6	6	6
Complexity		5	3	4	6	4	5	3	2	2	3	2	5	4	4	1	3	3	2	6	3	4	2
Integration	1	1	2	2	5	2	5	2	1	1	2	2	5	3	2	2	1	2	3	2	3	2	3
Asset Specificity	2	2	2	2	1	4	2	3	1	1	2	2	2	2	2	3	3	2	1	1	2	2	3
Employees Impacted	2	1	2	2	5	2	1	1	1	1		1	3	2	1	3	1	2	3	2		2	
Supply Chain[1]	6		6		2		4	4	4	4	4	4		6	6	6	4	4		7	2	4	
Internal Politics	6	2	3	4	2	3	6	3	2	4	6	3	4	2	3	3	3	6	2	1	4	4	5
External Politics[1]	6	7	3		1		3	6	6		2	3		6	3	7	3	4	3	6	5	2	7
Legal	1				6		5	2	1	1		1			4	2			5	1	2	5	5
Technological Uncertainty	1	1	2	2			2	2	1	2	1	2	2	3	3		2	3		1	2	2	

Respondent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Influential Factors \ Plant	PTCN																						
Core Closeness	3	2	3	4	5	5	5	7	2	3	5	5	5	5	3	3	5	5	5	2	7	2	4
Critical Knowledge	2		3	3	6	5	6	2	2	2	5	3	4	4	5	2	2	6		3	4	5	3
Human Resources Scarcity[1]	6	2	6	6	6	4	6	6	7	4	6	5		4	4	6	2		6	5	7	5	7
Quality	2	4		4	3	4	6	4	4	3	4	1	5	6	4	5	4	7		5	5	7	
Flexibility	7	5	2	7	6	6	5	6	2	5	7	6	7	7	6	4	2	4	7	7	6	3	6
Complexity		5	3	4	6	4	5	3	2	2	3	2	5	4	4	1	3	3	2	6	3	4	2
Integration	1	1	2	2	4	2	5	2	1	1	2	2	5	3	2	2	1	2	3	2	3	2	3
Asset Specificity	2	2	2	2	1	4	2	3	1	1	2	2	2	2	2	3	3	2	1	1	2	2	3
Employees Impacted	7	5	6	6	7	3	5	3	7	6		3		2	5	6	1	4	5	5	6	4	7
Supply Chain[1]	6	8	3	8	2	8	4	4	4	4	4	4	8	6	6	6	4	4	8	7	2	4	7
Internal Politics	6	2	3	4	2	3	6	3	2	4	6	1	4	2	3	3	3	6	2	1	4	5	5
External Politics[1]	2	4	3		1		3	4	1		2	3		4	1	1	3	4	1	2	5	2	7
Legal	1				6		5	2	1	1		1			4	2			5	1	2	5	5
Technological Uncertainty	1	1	2	2			2	2	1	2	1	2	2	3	3		2	3		1	2	2	

[1]Results of this statement are presented transposed.

Appendix III: Solution Design

Table 12: Price upper bounds per product supplier selection model.

Product	Upper Bound (Z_1^+)	Product	Upper Bound (Z_1^+)
1	€ 125,00	10	€ 35,00
2	€ 10,00	11	€ 45,00
3	€ 8,00	12	€ 2,50
4	€ 385,00	13	€ 7,50
5	€ 200,00	14	€ 75,00
6	€ 75,00	15	€ 2,00
7	€ 100,00	16	€ 9,00
8	€ 9,50	17	€ 210,00
9	€ 9,00	18	€ 12,00

Table 13: Generic input supplier selection model.

Supplier	P_i	Qi	R_i	LT_i	PS_i	C_i
PTNL	Not generic	0,98	0,98	0	0,92	Infinity
PTCN	Not generic	0,98	0,96	6	-0,48	Infinity
Supplier EU1	Not generic	0,93	0,90	12	0,53	Infinity
Supplier EU2	Not generic	0,96	0,92	8	-0,38	Infinity
Supplier CN1	Not generic	0,90	0,85	24	-0,48	Infinity
Supplier CN2	Not generic	0,93	0,90	20	-0,48	Infinity
Weight	0,35	0,20	0,20	0,05	0,20	N.A.

Table 14: Fuzzy boundaries supplier selection model.

Objective	[Z_i^-, Z_i^+]	Objective	[Z_i^-, Z_i^+]
Quality	[0,95; 1,00]	Lead Time	[0; 12]
Delivery Reliability	[0,90; 1,00]	Political Stability	[0; 2,5]

Table 15: Price estimations Supplier CN2 for PTNL products.

Product	1	2	3	4	5	6	7	8	9
CN2	€ 105,01	€ 7,81	€ 6,57	€ 257,55	€ 143,45	€ 51,75	€ 78,79	€ 8,32	€ 6,16

Figure 17: Robustness on Delivery Reliability of supplier CN2 for Product 10.

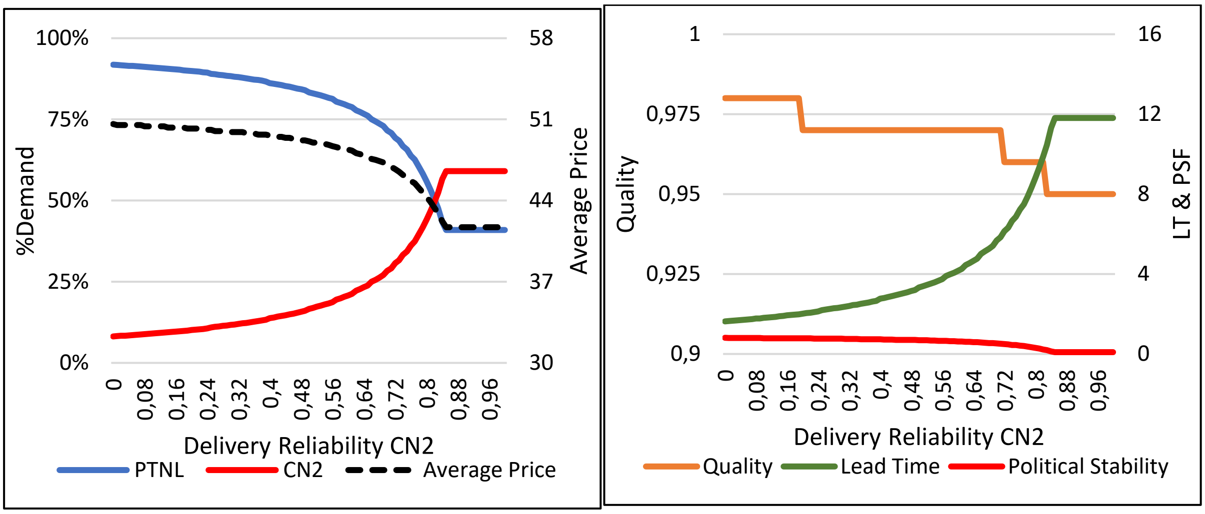

Figure 18: Robustness on Lead Time of supplier CN2 for Product 10.

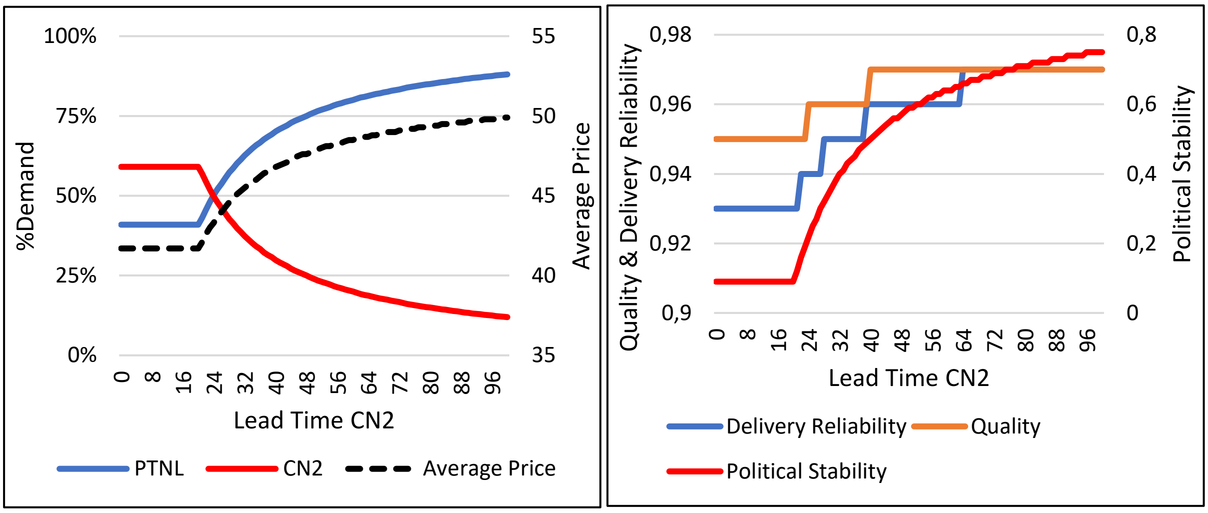

Figure 19: Constraint Robustness on Delivery Reliability for Product 10.

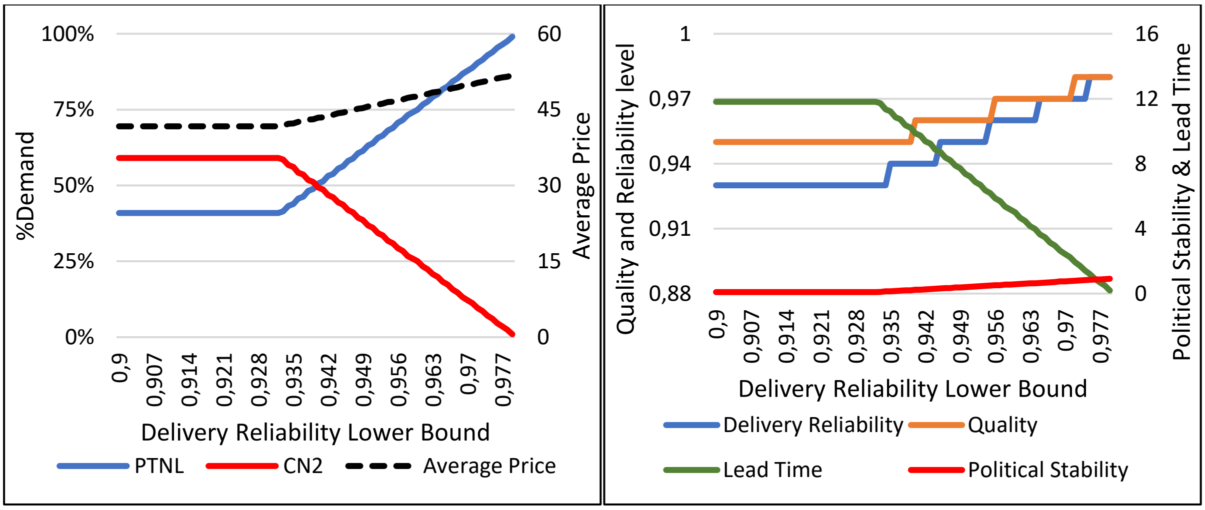

Figure 20: Constraint Robustness on Lead Time for Product 10.