CRANFIELD UNIVERSITY

DAMILOLA OGUNDANA

THE DEVELOPMENT OF A DESIGN AND DEVELOPMENT FRAMEWORK BETWEEN OEM AND SUPPLIER

SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING

PhD THESIS
Academic Year: 2015 - 2019

Supervisor: Dr. Ahmed Al-Ashaab and Dr Patrick McLaughlin
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ABSTRACT

Suppliers are of great importance to OEMs because of the benefits that can be gained from collaborating with them. But for the OEM to select the appropriate supplier for the specific job they want accomplish, they must first create criteria that can be used to evaluate the supplier. The purpose of this thesis is to develop a design and development framework between OEM and supplier. The framework is focused only on the design and development activities and not manufacturing.

This research was able to identify the right criteria for OEMs to use to assess, select and evaluate suppliers. Moreover, it was able to clarify the difference in criteria for each of the three aforementioned activities.

The construction of the framework commenced with the use of an extensive literature review which was followed by an industrial field study consisting of 5 interviews with four companies who specialise in different sectors of engineering. The outcomes were integrated to generate the contents of the supply chain framework. A case study was simulated in order to verify the framework.

The design and development framework provides the necessary means by which an OEM can assess, select and evaluate suppliers during product design and development processes. As a result of this, a functionally feasible and enhanced design and is more efficient can be realised.

The framework that was developed as a result of this is very comprehensive and is able to mitigate the challenges faced in the industry today, regarding a outsourcing of OEMs' product development activities to supplier. The contributions to the knowledge are as follows: (1) The developed framework provides a clear understanding of what constitutes as assessment criteria, selection criteria and evaluation criteria in product design and development within the supply chain. (2) The framework mitigates the evolving challenges faced by OEM and suppliers when product design and development is outsourced. (3) The developed framework encompasses all the activities involved in assessing, selecting and evaluating suppliers throughout the outsourcing process.

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First and foremost, I would like to give thanks to God because without Him, none of this would have been possible.

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I would like to thank my dad who was there with me when we started this journey together but is sadly no longer with us. I would also like to thank my mom who has supported my needs and guided me since my father’s passing.

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LIST OF ABBREVIATIONS

IT	Information Technology
NHS	National health service
OEM	Original equipment manufacturer
NPD	New product development
CAD	Computer aided design
CAE	Computer aided engineering
SCM	Supply chain management
MCDM	Multiple criteria decision making
DEA	Data envelopment analysis
AHP	Analytical hierarchy process
ANP	Analytical network process
TOPSIS	Technique for order of preference by similarity to idea solution
ESI	Early supplier involvement
NPD	New product development
PD	Product development
DM	Decision maker
SWOT	Strengths, weaknesses, opportunities and threats
DFM	Design for manufacture
DFA	Design for assembly

1 INTRODUCTION

1.1 **Research Background**

Constant growth in global competitiveness and socio-technical developments has increased pressure on companies to populate the required proficiencies to address the needs that the changing market requires in order to sustain their businesses. An organisation's long-term survival depends on their New Product Development (NPD) and its significance indicated via decreased product lifecycles and increased global demands (Zhang & Sharifi, 2000). Financial aspects of design are fundamental to the success of a business (Ulrich, 2011). This has given rise to the importance of design and development. Therefore, original equipment manufacturers (OEM) are constantly looking for avenues to improve the design and development process.

The traditional methods used to select suppliers are focused mainly on cost as the driving factor. Conversely, OEMs have even eventually come to understand that having cost as the main focus or criterion, is no longer efficient and requires a change. It is at this moment that multiple criteria methods become more attractive. In recent times, the multiple criteria decision making (MCDM) methods have increased in complexity as other factors such as social, environmental and uncontrollable factors have been added to the conventional criteria such as quality, cost, performance history, etc (Parthiban et al., 2013).

Several researchers have expressed interest in supplier selection (Abdolshah, 2013; Kamath & Liker, 1994; Melander, 2014; Nellore & Balachandra, 2001; Petersen, et al., 2005) within the supply chain. The term "supply chain" can be defined as the presence of all the stages that are involved in the satisfaction of customer demands. The main stages of a typical supply chain are suppliers, manufacturers, wholesalers, retailers and finally customers. In terms of the business aspects of a supply chain, there are several aspects of an organisation that are involved, and they are marketing, purchasing, finance, customer support and operations (Petersen et al., 2005).

OEMs have, in more recent times, been seeking out ways to improve the earlier stages of their supply chain. The main stage for which improvements have been sought is the design and development stage of the supply chain process(Le Dain et al., 2011). One way to improve product design and development within the supply chain is to involve suppliers early in the product development process. Early supplier involvement is a well-established notion which suggests that when OEMs collaborate closely with their suppliers, it brings about benefits such as development cost reductions, faster time to market and higher quality products (Mikkelsen & Johnsen, 2019).

1.2 **Research Rationale**

Competition is currently on the rise in the international markets. This increase is driving companies to raise the focus on their product development. The goal is to use high value products to increase their overall market share and maintain that increase. Many OEMs have sought to achieve this goal by outsourcing their product development activities. This has led to a swift increase in component outsourcing during NPD where suppliers play large roles. Previous research has shown that NPD performance is greatly affected by the selection of appropriate suppliers as well as the level and time of involvement.

A significantly noteworthy change in hypotheses of current production management is the fact that corporations do not compete anymore as exclusively independent units, but as whole supply chains (Mentzer et al., 2001). The term supply chain management soared to more notoriety in the last 20 years.

The OEMs who partake in the design and development outsourcing with suppliers express a need for the right tools and methods that will enable effective management of the outsourcing of design and development to suppliers (Le Dain et al., 2011). There are several tools and methods that have been developed in the past that mainly focus on OEM outsourcing their manufacturing activities but the proper procedures to outsource design and development is still not clear (De Toni & Nassimbeni, 2001). In response to this there is a need for a comprehensive framework that manages the activities that occur when OEMs outsource product design and development activities to suppliers.

1.3 **Research Aim**

Develop a framework for OEMs to perform the activities involved in assessing suppliers, selecting suppliers and evaluating suppliers when they involve suppliers during the product development process.

1.4 **Research Objectives**

1. Identify the criteria used to assess, select and evaluate suppliers for outsourcing in product development.
2. Capture the challenges that occur when OEMs outsource design and development activities to suppliers.
3. Develop a framework that encompasses all the activities involved in assessing, selecting and evaluating suppliers in product design and development.
4. Validate the framework via an industrial case study.

1.5 **Thesis Structure and Summary**

The potential impact of this research is in filling the gap in the product design and development sector by providing a framework which makes it easier and more straight forward for OEMs to determine the most suitable suppliers to collaborate with.

Chapter 1 makes an introduction of the research and discusses in detail, the background, motivation, aim and objectives.

Chapter 2 depicts the methodology of the research adopted. An analysis is presented which showcases the research approaches and strategies, followed by a justification for the methodology that was chosen.

Chapter 3 presents the details of an extensive scientific literature review. The areas covered in the literature review are (1) the history and definitions of supply chain management, followed by (2) an overview of the product development process, then (3) the process of assessing, selecting and evaluating suppliers and finally, (4) a review previous design and development process models.

Chapter 4 presents the industrial perspective of product design and development where the design of the questionnaire is established, followed by the field study results and finally the analysis of the field study data.

Chapter 5 describes the design and development framework that consists of three phases and is supported with tools and details on how to utilise the framework in the most optimal manner.

Chapter 6 presents the case study verification. It details the simulated framework that allows the capabilities of the framework to be realised.

Finally, Chapter 7 synthesises the outcomes of the research and discusses them. The contributions to the knowledge, the limitations and the future research are also presented. The final sections discuss the conclusions drawn with information about the achievement of the research aim and objectives.

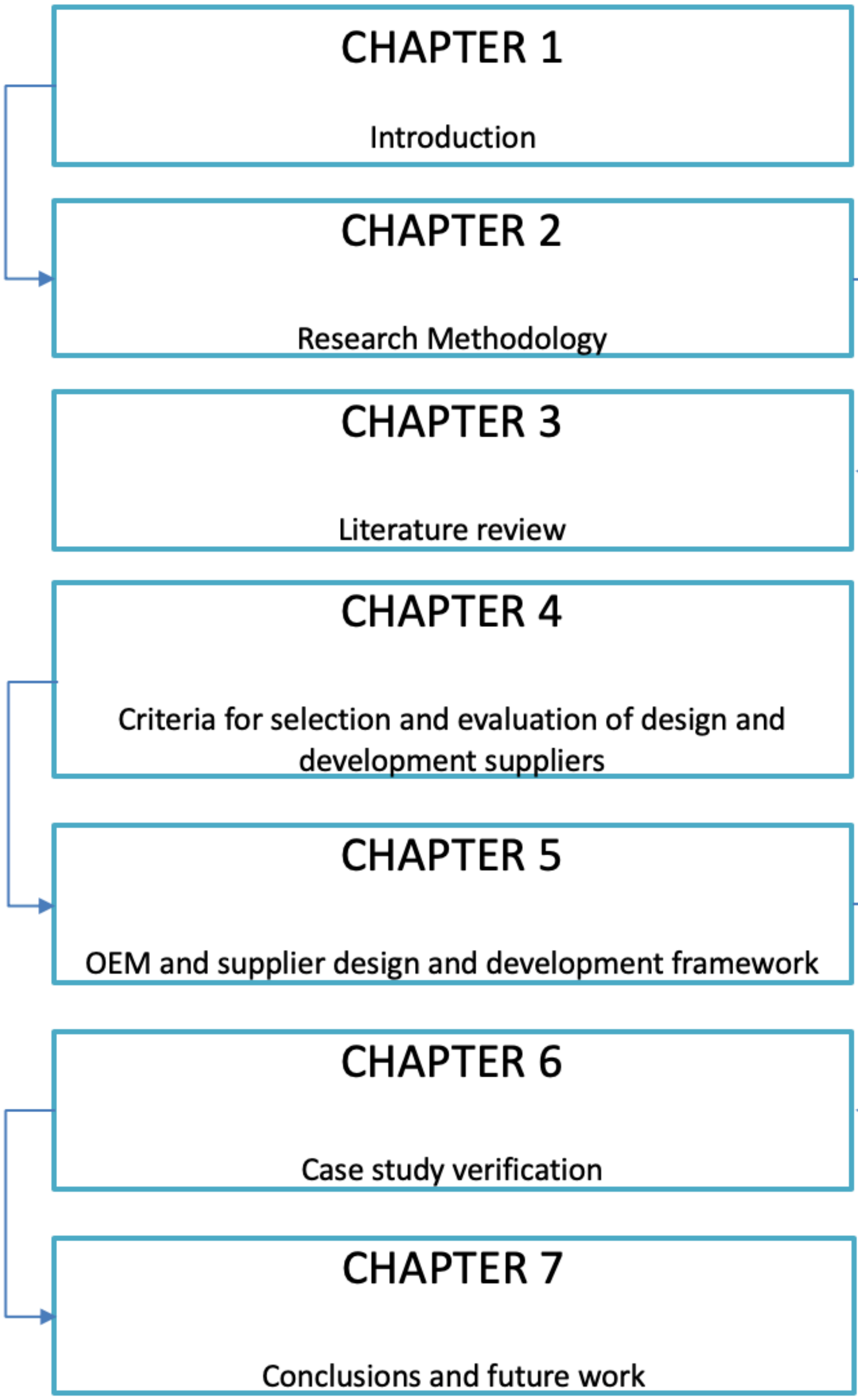

Figure 1-1 Thesis structure

2 RESEARCH METHODOLOGY

2.1 Introduction

The main aim of this chapter is to illustrate the followed methodology of this research in order to guarantee the aim and objectives were achieved. This chapter has been divided into four sections. The first section is the introduction which is followed by section 2.2 the research methodology adopted for this research, which follows the objectives of the research, is explained. Section 2.4 contains the summary which completes the chapter.

2.2 Research methodology overview

At the commencement of this research, the research background, research rationale and research questions were established and are illuminated in Chapter 1. The chapter provides a description of the research methodology that was adopted in order to accomplish a successful research. Research methods allow researchers comprehend, envisage and govern the environment in which they partake the research (Bryman , 2006). It was noted from Mackenzie & Knipe , (2006) that research paradigms are characterised into four perspectives namely: epistemology, ontology, methodology and method. This research concentrates on an industrial application, therefore epistemology is the most ideal paradigm for this research. Audi (2010) noted that epistemology is a philosophy of justification and knowledge. Moreover, Cohen et al., (2007) noted that epistemological assumptions rely on creating, acquiring and communicating knowledge.

In a deductive research approach, the research is transformed from broad to specific as the conclusion is led by the data available. The use of deductive approach in research is generally in quantitative research. A quantitative research strategy usually makes use of positivism through experimental methods in order to test hypotheses (Mackenzie & Knipe , 2006). However, qualitative research is based on facts and creates situations where the information derived from numbers can be enumerated and summarised. This is articulated through the analysis of statistical data (Malterud, 2001).

In an inductive research, the research transforms from one precise opinion to a generality and theory where principles generally serve as the basis of the conclusion. The main drive of an inductive approach is to permit research outcomes to materialise from the recurrent, dominant, or noteworthy topics found in raw data, exclusive of structured methodology restraints (Thomas , 2006). Inductive research is most commonly used in many forms of qualitative data analyses, more so in grounded theory (Strauss & Corbin, 1998). It can therefore be concluded that procedures such as observations, interviews and surveys are more central in the interpretivist. Therefore, research performed in this region must occur during the event in order to record the variations before and after the event. Malterud, (2001) remarked that the conclusion of an inductive analysis is category development into a framework or model that reviews the raw data and delivers key themes and processes. Thomas (2006) stated that the inductive approach can be found relative to other strategies in qualitative analysis and populated the information in table 2-1 to buttress the statement.

Table 2-1 Dissimilarities between qualitative approaches (Robson, 2002)

	General Inductive Approach	Grounded Theory	Discourse Analysis	Phenomenology
Analytic strategies and questions	What are the core meanings evident in the text, relevant to evaluation or research objectives?	To generate or discover theory using open and axial coding and theoretical sampling	Concerned with talk and texts as social practices and their rhetorical or argumentative organization	Seeks to uncover the meaning that lives within experience and to convey felt understanding in words
Outcome of analysis	Themes or categories most relevant to research objectives identified	A theory that includes themes or categories	Multiple meanings of language and text identified and described	A description of lived experiences
Presentation of findings	Description of most important themes	Description of theory that includes core themes	Descriptive account of multiple meanings in text	A coherent story or narrative about the experience

2.2.1 The establishment of trustworthiness

Validity and generalisability are the two main areas that need to be focussed on when complying with trustworthiness in a qualitative research study. According to Robson (2002), the identification of correctness and accuracy of research are the aspects that support its validity. There are several threats to a validity research. The most common of these are (Robson, 2002):

- Researcher bias – the personality of the researcher which determines the choices made such as individuals to interview and the nature of the questions asked.
- Reactivity – the nature of the participants behaviours affected by the interference of the researcher's presence in an ecosystem
- Respondent bias – occurring when a respondent causes obstruction by concealing information for various reasons such as company policy in order to mitigate threats to their organisation

The approaches that may be utilised to mitigate the aforementioned risks include (Creswell, 1998):

- Peer debriefing – interviewing of peers after extensive sessions has the ability to rejuvenate the research ecosystem and atmosphere
- Triangulation – enrich the consistency of the research via a multitude of resources, theories and settings
- Prolonged involvement – in order to guarantee that causal relationships are not formed as these relationships may have an impact on the outlook and therefore create an upsurge in researcher bias, time spent in an individual environment must be limited
- Negative case analysis – the regular application of the hypothesis/theory of an unfavourable case, or receiving unflattering advice, leading to theory refinement
- Audit trail – the collation of scientific articles, transcripts, notes and all activities performed as well as regular reviews. All of the aforementioned provide clarity

Generalisability of a research focuses on how applicable the study of the research is in erstwhile circumstances, environments and moments which do not involve the research (Maxwell, 2002). There are two types of generalisability; internal generalisability and external generalisability – internal generalisability relates to research outside the margins of those involved outside the study such as persons, organisations, society. External generalisability has a much broader reach while providing generalisation to other conditions and institutions. The focus of this research will remain as internal generalisation as the external generalisation will prove too difficult to achieve, given the scope of the research.

The overview of the research tools and methods seen in figure2-1 was illustrated by Araci (2017). This illustrates the direction of this research as it represents the research paradigm, approaches of research, types of research and research strategies. This research will the path depicted in figure 2-1.

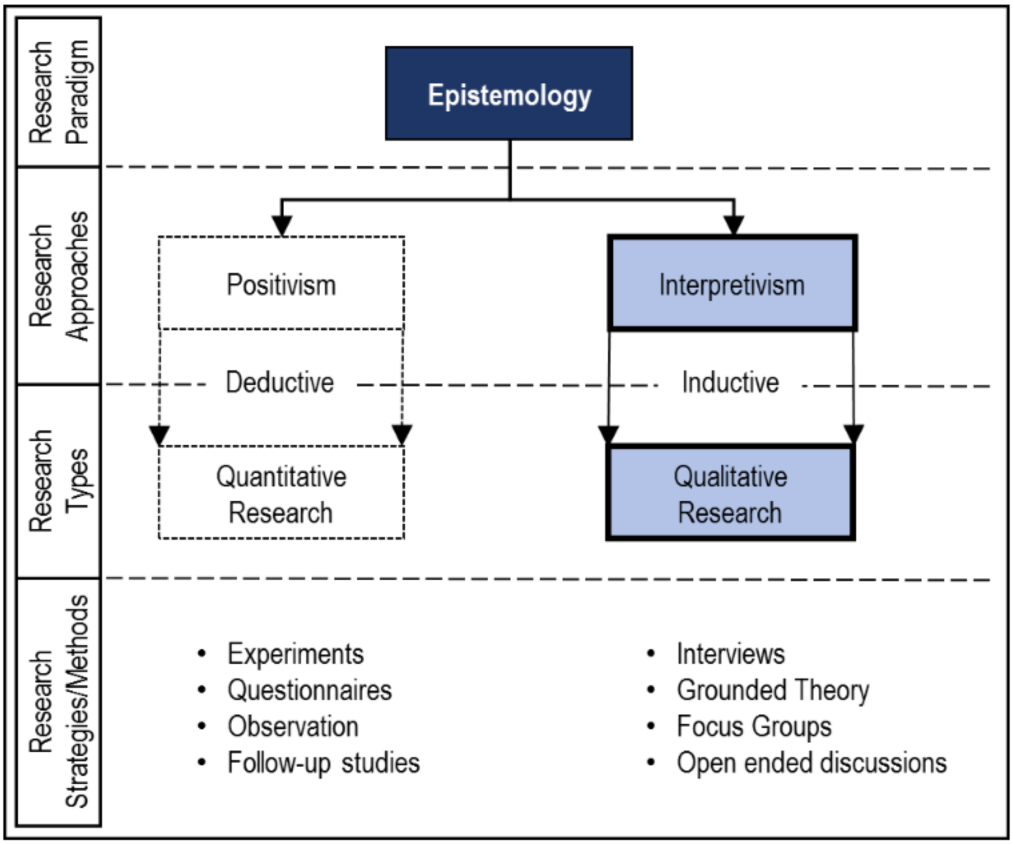

Figure 2-1 Overview of research tools and methods (Araci, 2017)

2.2.2 Methods of data collection

The main methods used to gather data for this research are literature review, interviews and surveys.

A. Literature reviews: In order to successfully complete a research, the researcher must first complete a literature review. Literature review is a type of research that critiques, reviews and synthesises in a style that results in new understanding of the topic (Torraco, 2005). A literature review should be used as an opportunity to learn, understand and critique, rather than an opportunity to summarise and present information from the literature (Burns, 2000). The first stage of the research is therefore to gain a general understanding around the topic by sourcing good quality literature from trusted sources such as Scopus, EBSCO, Science Direct and Emerald insight.

B. Interviews: There are two main types of interviews in regard to research, semi-structured and fully structured. Both variations act as an avenue for the researcher to gain more information about the research area by interacting with others. Semi-structured interview is a method of obtaining information using prearranged questions but with some flexibility which allows the interviewer some room to discuss around the topics at hand (Burns, 2000). Fully structured interviews also have prearranged question but do not allow for any flexibility.

C. Surveys: Questionnaires are the method used to collect data during surveys. There are three methods used to administer questionnaires, they are: face to face, telephone and a scenario where the respondent completes the questionnaire in their own time (Robson , 2002). The third method presents an advantage because respondents are more likely to complete the questionnaire knowing that pressure is not being force upon them as it would be in a face to face interview.

2.3 Research methodology adopted

The defined methodology for this research comprises of three main phases which are based on the research objectives. Each phase has fundamental tasks, methods to complete these tasks, and deliverables as shown in table 2-2.

Table 2-2 Research methodology

Phase	Key Tasks	Method	Deliverables
1. State of the art	1.1 Identify the criteria used to select and evaluate suppliers in the outsourcing OEMs' PD to suppliers 1.2 Capture the design and development outsourcing challenges within SC	• Literature review	• Selection criteria • Challenges
2. Industrial field study	2.1. Design questionnaire 2.2. Perform industrial field study with a range of companies within their supply chain 2.3. Data analysis	• Questionnaire • Face to face interviews	• Industrial perspective of PD within SC
3. Product design and development framework within the supply chain	3.1. Use data gathered to define a suitable supply chain process to facilitate good outsourcing of PD within SC 3.2. Develop the Framework to facilitate PD outsourcing within SC	• Activity modelling and definitions	• The developed framework
4. Validation	4.1 Case study validation	• Case study	• Validated framework

2.3.1 Phase 1: State of the art

State of the art is the first phase of the research methodology and it aimed to deliver contextual grounds of the research. Merriam-Webster (2019) defines state of the art as the level of development (as of a device, procedure, process, technique, or science) reached at any particular time usually as a result of modern methods. As highlighted in Table 2-2, the key tasks were performed, and the type of research necessitated the completion of an extensive literature review.

The structure of the literature review and topics which required exploration were provided by a constructed plan. The researcher partook in preliminary studying, attaining an understanding of the original ideas, topics and key words regarding the research area. As a result, a working definition of the concept of OEM and supplier design and development outsourcing and the designing of a questionnaire, utilised in the field study, was created by the researcher.

Task 1.1 The good practice of product development outsourcing within supply chain, synthesized by an extensive literature review where each topic was researched separately.

As a result of the extensive literature review, the good practice of product development outsourcing within the supply chain will be established. The purpose of this task is to gain an understanding of the current practices of how OEMs and suppliers collaborate in product design and development outsourcing. In order to achieve this, it is important to ascertain the criteria used by the OEM to select and evaluate suppliers during product development outsourcing.

The following questions helped to perform the literature review

1. When does the OEM need to outsource its product design and development activities?
2. What are the criteria that should be used to select suitable suppliers that will carry out the outsourced activities in product design and development?
3. How to measure the design and development capabilities of the supplier?
4. How the OEM and supplier should communicate to ensure the right development of a product?

Task 1.2 The evolving challenges of product development within supply chain captured via an extensive literature review. The challenges are *captured after reviewing previous product design and development outsourcing and gathering information on the areas of success and failure.*

Task 1.2 was carried out at a similar time with task 1.1, with the focus on identifying the challenges faced during product design and development outsourcing within the literature. An organised method to ascertain the literature was performed and is detailed in the literature review section. The author extended the study to account for the feasibility of involving suppliers early in the product development process (design and development phase). The outcome of these two tasks led to the identification of research gap. The researcher gained an understanding about the outsourcing processes between OEM and supplier in design and development.

2.3.2 Phase 2: Industrial field study

This was a practical phase as communication with the industry was required. A field study was carried out consisting of 5 face-to-face interviews as well as group workshops. The present-day practices of outsourcing between OEM and supplier were captured. A field study with updated questions was performed to provide the researcher with necessary resources to develop the supply chain design and development framework.

Task 2.1 Design a questionnaire that can help gain knowledge on the industrial perspective of the current practices of PD and SC.

The initial findings from tasks 1.1 and 1.2 provided a satisfactory foundation, nevertheless research expansion required an industrial field study. Task 2.1 focused on ascertaining and understanding of existing industrial outsourcing practices between OEM and supplier. Accomplishing the task required the development of a semi-structured questionnaire. Certain questions were produced by the author grounded by an analysis as well as understanding of the literature. As elaborated in section 2.2.2, there are several methods which can be utilised during interviews in order to capture the opinion of the respondents. Based on the aforementioned statement, a semi-structured questionnaire was produced, containing closed and open questions where the open questions were utilised to incite dialogue.

Task 2.2 Perform industrial field study including face to face interviews in order to gain knowledge on the industrial perspective of the current practices of PD and SC.

The field study will collect industrial opinions on outsourcing in product design and development. A number of activities were carried out including face-to-face interviews, using a semi-structured questionnaire which were developed in task 2.1. The findings from the field study were gathered with the aid of a spreadsheet application which aided in developing the findings. The complete findings from the field study, distributed among the companies who partook.

2.3.3 Phase 3: Product design and development framework within supply chain

The design and development framework phase focused on developing the design and development framework between OEM and supplier as well as each activity and process involved. The three tasks in this phase were performed by further liaising with the industry about their procedures, using the knowledge gathered in the previous two phases and performing workshops with the industry profesionals. The development of the framework was a frequentative process which necessitated frequent alterations and corrections. The essential components in the development process were provided by the theoretical knowledge and industrial advice.

Task 3.1Use the knowledge previously gathered to develop the framework to allow successful outsourcing of PD within SC. All the activities involved in OEM and supplier design and development have to be captured to ensure that the task is accomplished.

To realise the benefits of a more efficient and robust procedure that enables good PD outsourcing between OEM and supplier, a product design and development framework will be developed. The framework and its processes were frequently assessed by the industry professionals via workshops until the final agreed framework was achieved.

2.3.4 Phase 4: Verification

Phase 4 of the research methodology concentrated on validating the product design and development framework in a realistic case study. Due to the nature of the research and the resources available to the author, the case study was simulated using realistic data received from industrial experts. The framework was verified via the case study.

Task 4.1 Case study verification

A simulated case study was used to verify the design and development framework between OEM and supplier using realistic data. The study commenced by following the tasks in the framework in a step by step manner. The outcome of the simulated case showcased the magnitude of impact, the design and development framework can offer an organisation.

2.4 **Summary**

A description of the methodology utilised to carry out the research in order to achieve the aim and objectives have been illustrated in the preceding Sections. The discussion commenced with in-depth information about the types of research and paradigms currently used today.

The rationale for the chosen research strategy as well as methods of data collection was emphasised. Furthermore, a discussion about the research methodology adopted by the researcher as it relates to the research objectives. Four phases were elaborated on: state of the art, industrial field study, product design and development framework within supply chain and validation. The next chapter chronicles the literature review outcomes.

3 LITERATURE REVIEW

3.1 **Literature review map**

The information depicted in figure 3-1 is a map that illustrates the path taken to carry out the literature review.

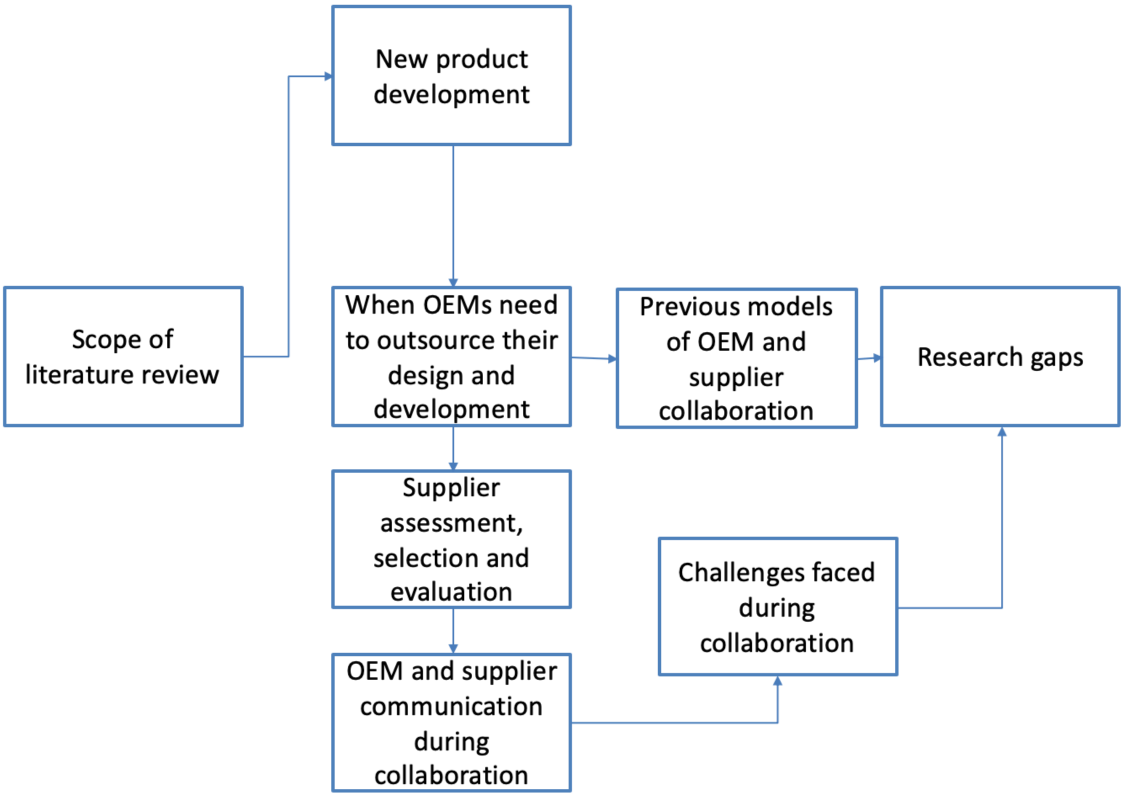

Figure 3-1 Literature review map

3.2 **Supply chain: An overview**

Supply chain is a term that was initiated in the early 80s, but recent times have seen it gain more notoriety. Academics since the early 1990s have made attempts to give structure to supply chain management.

Suppply Chain Management (SCM) is a network of manufacturing and distribution sites with a set of entities that include suppliers, logistics, service providers, manufacturer, distributors and resellers. A typical supply chain process involves raw materials purchasing, then conversion of the raw materials into intermediate and finished products, and finally the distribution of the finished products to customers. The chain is customarily categorised by a forward flow of materials and a backward flow of information (Beamon, 1998).

3.2.1 Definitions of Supply Chain Management

Supply chain management has had many definitions as it evolved over the years. The following are a few of the aforementioned definitions.

Table 3-1 Definitions of supply chain management

Reference	Definitions of supply chain and supply chain management
Westbrook and Scott, 1991	Supply chain management is a categorisation that links all parts of the supply and manufacture process from the raw materials at the commencement to the customer at the end
Lee and Billington, 1994	Supply chain management is the harmonisation of materials used for manufacturing, logistics, distribution and transport within an organisation
Farley, 1997	Supply chain management is a method of management that focuses on how organisations utilise their suppliers' processes, technology and information, in order to gain an advantage over competitors
Lambert et al., 1998	Supply chain management is a philosophy which is integrative and it is used to manage the entire stream of the distribution channel from supplier to final user
Lummus and Vokurka,1999	A supply chain encompasses all the activities involved in delivering a product from the raw materials to the customer. SCM coordinates all activities within a supply chain, into a seamless process
Lee, 2002	A supply chain is a set of procedures that initiates with the raw materials and ends with the final user, linking across the supplier-user industries
Ballou, 2007	SCM is the planning and management of all activities involved in procurement and sourcing, conversion as well as all logistics activities regarding the management of logistics
Habib, 2011	SCM is defined as the systemic, strategic coordination of traditional business functions and tactics across these business functions within a particular organisation

SCM is therefore a set of procedures that begins with the initial raw materials and ends with the final consumption of the finished product. It incorporates the planning and every activity involved in sourcing and purchasing, transformation, and all logistics management activities. It is the sequence that connects all aspects of a manufacturing process from raw materials to the end user. The processes it incorporates include suppliers, carriers, information systems providers, manufacturing, materials, and logistics. It is the definitive link between all parties involved in a manufacturing process. Figure 3-2 depicts the different levels of an automotive supply chain.

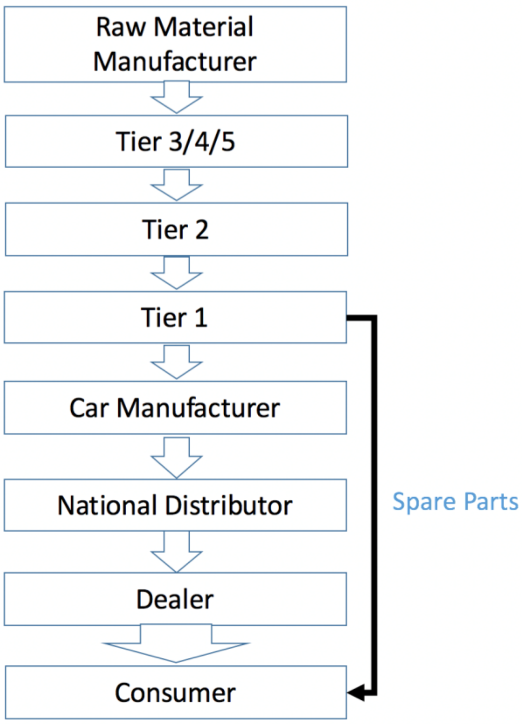

Figure 3-2 Supply chain levels (Wayne, 2015)

3.2.2 History of supply chain management

The word logistics mainly was considered to be a military expression until the 1950's (Ballou, 1978). It mainly consisted of the obtaining, maintaining and transporting of official military facilities, staff and resources (Heskett et al., 1973).

Before the 1950s, logistics was considered as dormant because during those years it was not considered to be a strategic function (Ballou, 1978). The initial transformation took place during the 1950s and as a result, the prominence of logistics increased quite considerably. This was partly due to the recognition of physical distribution management in manufacturing organisations as a separate entity (Heskett et al., 1964). The term supply chain was created in the 1980s by consultants in logistics (Oliver & Webber, 1992). The authors pointed out that supply chain should now be seen as an entity on its own and strategic decision making at the top level was required to manage the chain. Gripsrud, (2006) pointed out that the aforementioned perspective is shared with logisticians and marketing theorists.

In general, SCM has risen to become one of the most popular management set of procedures (La Londe et al., 1997) from the time when it was introduced in the early 1980s (Oliver and Webber, 1992). Several manufacturing journals, distribution journals, papers about marketing, transportation and integration have published numerous articles regarding SCM. The 1990s also saw a SCM evolution because of the growing global competition (Handfield., et al 1998)

Fernie and Clive (1995) made use of SCM in the NHS. The service industry later made use of that paper. Sampson (2000) looked into the duality of customer and supplier within service organisations as it related to SCM in the service industry. Supply chain application in the service industry were also investigated by Kathawala and Abdou (2003). Figure 3-3 shows the historical view of how SCM has transformed over the years.

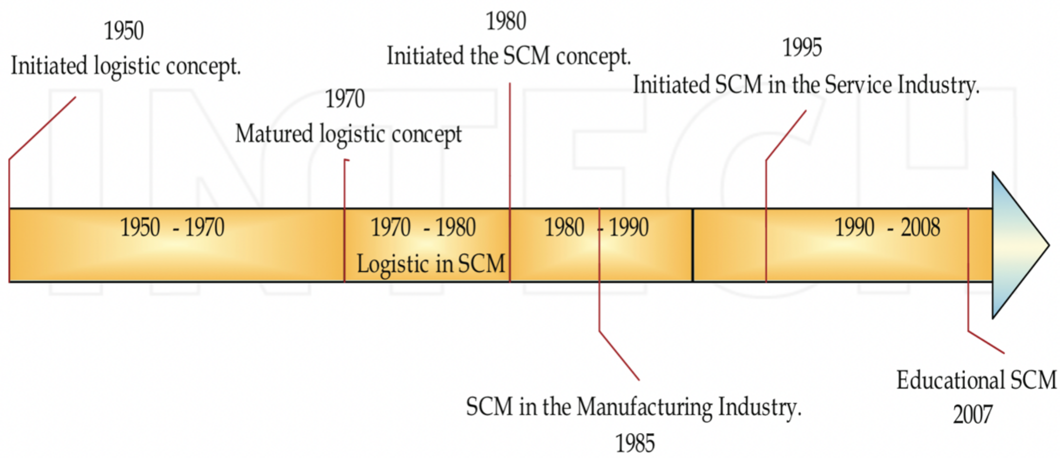

Figure 3-3 Historical view of supply chain management (Habib, 2011)

3.3 **New product development: An introduction**

The modern-day climate of globalization has had an immense effect on a vast number of organisations, ranging between the lowest sized companies and biggest international companies, in the development and manufacture of products. New Product Development (NPD) is an essential part of many manufacturing companies. It is a creative interdisciplinary activity that is used to guarantee that the company offers a wide assortment of products in order to meet the demands set by the customer (Krishnapillai & Zeid, 2006).

NPD encompasses several key processes that include but are not limited to specification of the product, engineering and design, planning for production, as well as manufacturing, assembly and acquisitions. The author created Figure 3-4 to elaborate on this by displaying certain key stages that occur during the lifecycle of a product. It is important to note that product design and engineering is a significant aspect in the lifecycle of a product, the designs serve as a basis for all the requirements of the product.

NPD cannot facilitate the creation of a successful product on its own but contributes to the formation of products which help organisations achieve success internationally (Kono & Lynn, 2007). Nevertheless, a company's decisions regarding new product development are strongly influenced by fluctuations within the world market as well as unceasing market demands. Any competitive organisation in the manufacturing sector who does not make the appropriate choices as early on in the process as the commencement stage of product development may experience a considerable rise in the entire life cycle cost of a product (McCarthy et al., 2006; et al., 1993).

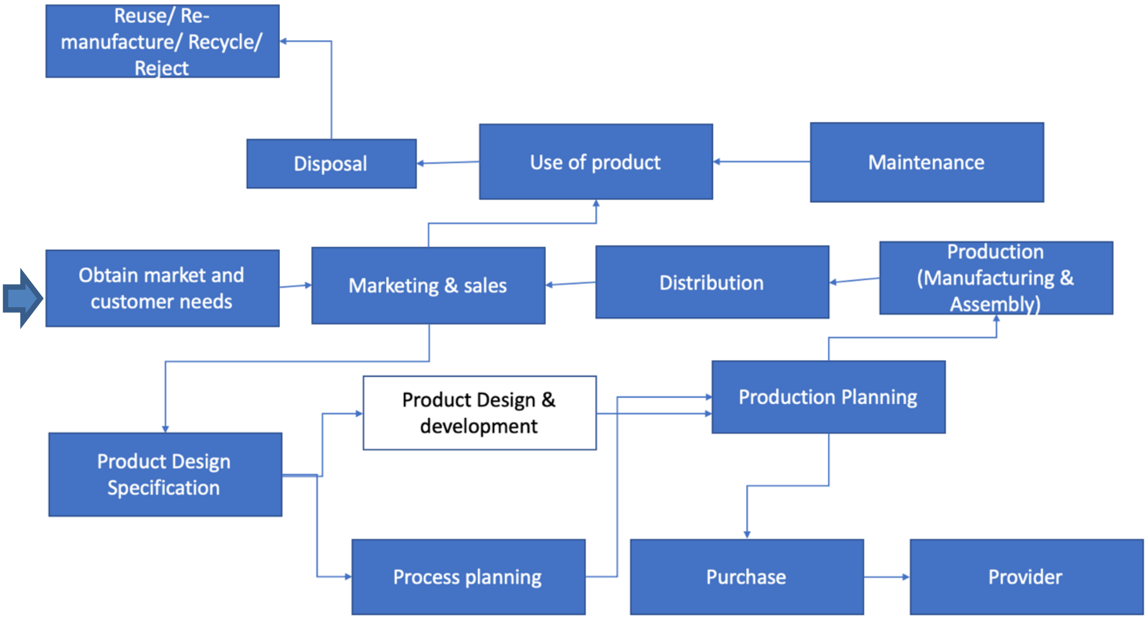

Figure 3-4 Key activities of product lifecycle (the author)

The processes involved in NPD are therefore very important. They have the ability to deliver unceasing support to organisations in the manufacturing sector, encompassing all areas, tools and procedures. Although, according to Liu, (2003), sustainable success can only be achieved if the core processes within the product development are determined and the relationship to the company's capability are defined. This risk is also reduced when the right decisions are made at the initial process in product development; the aforementioned decisions must be supported by a proper set of knowledge requirements. The gap between market conceptualization and the reality of actual production can also be bridged by the design engineers (Hong et al., 2005).

3.4 **When OEMs outsource design and development activities**

This section explains the reasons why an OEM may choose to outsource part or all of its design and development activities to an external supplier. When an OEM decides to make a decision regarding "make or buy", it is not confined to only manufacturing activities but also expanded to concept and/or product design activities of the product that is to be outsourced (Le Dain et al., 2008).

The decision of how suppliers should be involved has to be systematic and cross functional. These decisions are to be based on (1) the executive core capability and vision for the project, (2) the skills within the OEM's organisation, (3) the risks involved in the potential PD outsourcing, and finally (4) supplier market analysis (Wynstra & Pierick, 2000; Calvi & Le Dain, 2003; Echtelt, 2004).

As a result of an extensive literature review, some of most common and most important reasons for OEMs to outsource to suppliers have been highlighted in table 3-2.

Table 3-2 Reasons for OEM to outsource design and development activities to supplier

Reference \ Reason to outsource	Lack of skill and experience	Lack of tools and techniques	Reduce design and development cost	Reduce design cycle time	Market availability	Faster Launch
Ghadimi, et al,. 2017			x		x	x
Yen & Hung, 2017		x	x			
Parthiban, et al,. 2013	x		x		x	
Tavcar, et al., 2018	x	x			x	x
Nellore & Balachandra, 2001			x			x
Loechner & Jaikmal, 2010						x
Mohamad et al., 2015	x	x		x		
TOTAL	3	3	4	1	3	4

Table 3-2 was created in order to clearly show the most common reasons to outsource found in the literature, as well as the scholars who brought these reasons to light.

Lack of skill and experience: This reason to outsource mainly relates to the employees at the OEM's organisation. They may not possess the skills and experience and/or qualifications required to produce the desired product at the expected quality. Tavcar et al., (2018) surveyed eight automotive parts suppliers and found that suppliers were selected mainly because the employees at the supplier’s firm possessed valuable NPD technical knowledge which the OEM did not possess.

Lack of tools and technique: The OEM may choose to outsource its design and development activities if there is a lack of the latest CAD tools such as CATIA, CREO, or NX. Likewise, CAE tools such as ANSYS are also of vital importance during the design and development process. Also, any other tools that may be valuable in the design and development stage (Parthiban et al., 2013).

Reduce design and development cost: OEMs may require new skilled engineers, new facilities, new software and new prototyping techniques when designing a new product that may be unfamiliar (Yen & Hung, 2017). The aforementioned will significantly increase costs for the OEM. It is therefore a better option to outsource to suppliers who already have these items in place.

Reduce design cycle time: Competition in the market may cause the OEM to require suppliers who have processes in place with reduced design cycle times, therefore less time is spent on design and development activities (De Toni & Nassimbeni, 2001).

Market availability: The availability of suppliers in the market is quite important because it relates to all the other reasons to outsource. An OEM cannot outsource the design and development of a product if there are no suppliers available who are capable of meeting the OEM’s requirements (Tavcar et al., 2018; Parthiban et al., 2013).

Faster launch: Getting a product to market before the competition is very important to every OEM. This advantage can lead to superiority in the market (Nellore & Balachandra, 2001). OEMs therefore seek out suppliers that have the capability to speed up all the processes involved in design and development in order to design and develop products quickly enough to reach the market before competitors (Loechner & Jaikamal, 2010).

3.5 **Supplier assessment, selection and involvement**

The process of OEMs beginning a product development process with suppliers can be broken down into supplier assessment, selection and involvement. The first activity performed by the OEM is the assessment of suppliers who are currently available in the market. When this activity is complete, suppliers that are unsuitable are disqualified, thus leaving a smaller number of suppliers for the next phase (supplier selection). At the supplier selection phase, detailed analysis takes place in order to select the suppliers that are best suited to achieve the requirements of the OEM. Spekman, (1988) described the first two phases but did not detail the individual steps required to complete them. Several scholars have since developed on these findings, as well as providing information related to supplier involvement (Handfield et al., 1999; Pressey et al., 2007). Figure 3-5 shows the three main phases that are required for when suppliers are to be involved in an OEM's product development process.

Figure 3-5 Supplier assessment, selection and involvement (The author)

3.5.1 Supplier assessment in product design

Several studies have been performed to identify criteria that firms use to assess potential suppliers, some of these studies performed case studies with real world data (Parthiban et al., 2013; Handfield et al., 1999; Petersen et al., 2005; Zsidisin et al., 2004). These studies present criteria that OEMS use to assess available suppliers in the market before performing detailed supplier selection activities for potential suppliers. The OEM must also take into account, the technology selected, the product to be developed and the project itself. The aforementioned issues have a sizable impact on the number of potential suppliers (Melander, 2014). Figure 3-6 shows the individual activities within the supplier assessment process.

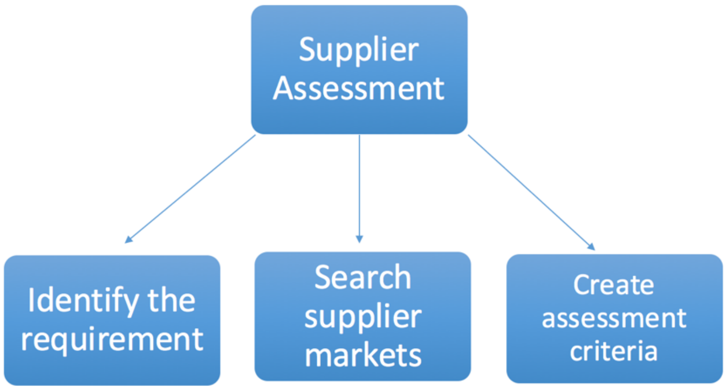

Figure 3-6 Supplier assessment stages (the author)

Identify the requirement: The first step an OEM must make when deciding on involving suppliers into their NPD design and development activities is to identify why a supplier is required. They may require suppliers because competition in the market requires a new break-through product (Parthiban et al., 2013; Tavcar et al., 2018), but the OEM does not possess the skill or knowlede to design and develop the product within a given time frame.

Search supplier markets: When the OEM has a clearer understanding of what is required from potential suplliers, the next phase is to search supplier markets for suppliers who are available. Petersen et al., (2005) and Handfield et al., (1999) noted that OEMs generally have a "bookshelf" of suppliers as well as current and new technologies. It is suggested that the OEM make use of this mechanism at this phase.

Create assessment criteria: Parthiban et al., (2013) and Ghadimi et al., (2017) stress the importance of having decision makers (DMs) use their expert judgement to help with the development of assessment criteria as well as prescreen potential suppliers in order to reduce the numbers of suppliers who pre-qualify for the detailed evaluation during the supplier selection phase.

Table 3-3 Supplier assessment criteria

Reference	Supplier commitment	Supplier growth potential	Technical competence	innovation & technical expertise	Business knowledge	Trust	Openness
Melander, 2014						X	
Yen & Hung, 2017						X	
Safa & Ismail, 2013						X	
Spekman, 1988	X	X			X	X	X
Bunduchi, 2013						X	X
Handfield et al., 1999			X	X			
Abdolshah, 2013	X	X	X	X	X		
Petersen et al., 2005	X	X	X	X	X		
TOTAL	3	3	3	3	3	5	2

The items in table 3-3 depict the assessment criteria that an OEM should consider when deciding on suppliers to involve in their NPD design and development activities.

Supplier commitment: Supplier commitment refers to the supplier's attitude or discernment towards their relationship with the OEM that is conveyed by certain actions such as information and knowledge sharing. A high level of commitment can have such results as improved functioning of the relationship between OEM and supplier, as well as create opportunities and increase performance within and outside the NPD project (Sjoerdsma & van Weele, 2015; Seppanen et al., 2007). Supplieir commitment is measured by OEM's assessment of the suppliers willingness to share information about their core processes, finances, man-power, technologies, and willingness to sign long-term contracts.

Technical competence: The OEM is required to determine if the supplier is competent enough to design and develop a product that meets the standards of the OEM (Handfield et al., 1999). The OEM assesses the competence of the supplier by evaluating the skill of the supplier engineers and designers, CAD/CAE facilities, prototyping facilities, etc.

Supplier growth potential: Based on the information provided to the OEM by the supplier such as manpower, qualification of supplier engineers, supplier's in-house technology capability etc. The OEM would be able to assess if the supplier is able to handle increased rate of development and if the supplier's technology roadmap allows for quick upgrades if the market demands (Spekman, 1988).

Innovation and technical expertise: The supplier's innovation and technical expertise is of great importance to the OEM because it determines the overall quality of the supplier's design and development ability (Handfield et al., 1999). The OEM assess this criterion with the information provided by the supplier, supplier performance history, and other research about the supplier.

Business knowledge: Suppliers business knowledge relates to the skills, experiences, capabilities and insight of the supplier. The aforementioned are created over time and they shape and affect all activities within the supplier's firm (Spekman, 1988). The OEM assesses this criterion by scrutinising the information provided to them by the supplier as well as the information found in the supplier's shared knowledge base.

Trust & openness: Trust is said to be one of the most important criteria when assessing suppliers (Melander, 2014; Yen & Hung, 2017; Spekman, 1988; Bunduchi, 2013; Handfield et al., 1999). Tust can be defined as the belief, atitude or expectation of the OEM concerning the probability that actions and outcomes of the supplier would be satisfactory (Bunduchi, 2013).

3.5.2 Supplier selection in product design and development

Supplier selection is the detailed analysis phase that takes place after potential suppliers have been assessed and the pool of suppliers has been narrowed down. The first stage involves creating selection criteria in order to assess potential suppliers. The selection criteria are created using nominal group technique (NGT) as suggested by Ghadimi et al., (2017) who also states that NGT is a formal group management technique which forces all parties involved to participate and therefore no person is allowed to dominate the proceedings. This allows the criteria selection to be unbiased.

The individual supplier selection criteria are calculated using AHP after initial values are provided by the DMs. When using AHP, the decision is first divided into a hierarchy of clearly understandable sub problems. Each sub problem is analysed individually. The hierarchy includes the goal of the decision, the evaluating criteria, alternate criteria, and the alternatives for reaching the goal (Jian, et al., 2018). When the analysis is complete, suppliers who qualify are selected for involvement in the OEM's NPD process and therefore go through the phases of supplier involvement. Figure 3-7 shows the different steps taken during the supplier selection process.

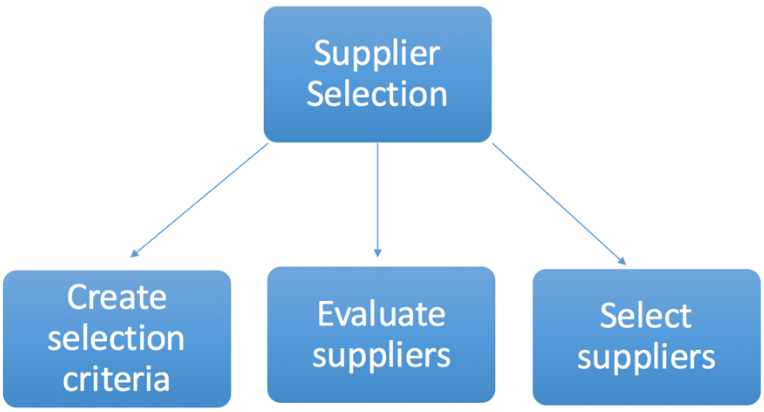

Figure 3-7 Supplier selection stages (the author)

Table 3-4 Supplier selection criteria

Reference \ Selection	Quality systems	Capability to handle abnormal quality	Warranty policies	Price performance value	Purchasing cost	Technology capability	Performance history	Capacity of supplier	Design cycle time	Supply risk	Trust
Melander et al., (2014)											X
Yan, (2011)										X	
Skilton & Dooley, (2010)										X	
Diestre & Rajagopalan, (2012)										X	
Yen & Hung ,(2017)								X			X
Safa & Ismail (2013)											X
Tavcar et al., (2018)	X										
Parthiban, et al., 2013					X						
Goren, (2018)	X				X	X		X	X		
Cao, (2011)				X							
Yenipazarli (2017)											X
Buyukozkan & Cifci (2011)	X										
Govindan et al., (2013)	X						X				
Ebrahimipour et al., (2015)			X								
Seth et al., (2017)	X		X	X		X	X	X			
Abdolshah, (2013)	X	X					X				
TOTAL	6	1	2	2	2	2	3	3	1	3	4

Table 3-4 depicts the criteria that an OEM considers when selecting suppliers for potential involvement in their design and development processes.

Quality systems: Quality systems refers to the suppliers' ability to ensure the quality of their process is controlled and to a high standard. Evidence of which is their possession of quality related certificates such as ISO9000, QS9000 etc. (Kannan et al., 2015).

Warranty policies: Ebrahimipour et al., (2015) stresses the importance of warranty polices as a means for the OEM to gain trust in the suppliers due to the risk and uncertainty that occurs during product design.

Price performance value: Price performance value refers to the relation between the value of the design and the cost. The aim of the OEM is to attain the best possible design quality at the lowest possible cost (Kannan et al., 2015).

Purchasing cost: The purchasing cost in product development within the supply chain includes the design and development cost as well as the warranty cost (Kannan et al., 2015). The importance of purchasing cost as a criterion for assessing suppliers has been mentioned by a plethora of scholars over the years (Ebrahimipour et al., 2015; Ghadimi et al., 2017; Goren , 2018; Abdolshah, 2013)

Technology capability: With new technologies emerging regularly, the supplier is required to be able to respond more quickly to OEM requirements as well as create more innovative designs. The OEM would therefore rather work with suppliers who are in possession of new technologies than old (Goren , 2018). Design capability, collaboration with research institutes, innovation and technology all come under technological capability (Parthiban et al., 2013).

Performance history: Seth et al., (2017) reviewed 9 criteria used to select and evaluate suppliers for involvement in the OEM's product development. It was found that performance history was of significant importance, thus supporting Dickson (1966) who came to the same conclusion. This is evidence that supplier performance history is of great importance as it gives the OEM insight on the behaviour and capabilities of a potential supplier before any involvement in the OEM's design and development is established. Govindan et al., (2013) measured supplier performcance based on a triple bottom line approach and also concluded that supplier performance history is of great importance.

Capacity of supplier: Capacity of the supplier relates to the ability of the supplier to handle the OEM's design and development needs at the required scale without compromising on the performance expected of them regarding product design and development (Cousins et al., 2011). The OEM must therefore take into consideration the supplier's total number of skilled design and development engineers and the supplier's facility capacity.

Design cycle time: Design cycle time can be defined as the time it takes to design and develop a new product from the design and development phase through to the testing and prototyping phase (Goren, 2018).

Supply risk: Supply risk is anything that can have a negative impact on the supply chain process such as supply disruptions, incompatible softer, misunderstanding of responsibilities and targets, etc (Skilton & Dooley, 2010).

Trust: Trust can be defined as the positive conviction, manner, or prospect of one party regarding the chance that the actions or consequences of the other party will be adequate. The underlying belief of one party that the other is credible as well as competent (Sjoerdsma & van Weele, 2015; Bunduchi, 2013; Rajendran , 2013).

3.5.3 Supplier Involvement in product design and development

After the potential suppliers have been evaluated during the supplier selection phase, the next phase entails the involvement of the suppliers who meet the requirements of the OEM into their PD process. Supplier involvement is broken down into three main parts; supplier contracts, then division of labour and finally continuous improvement. Figure 3-8 shows the activities that are performed during supplier involvement.

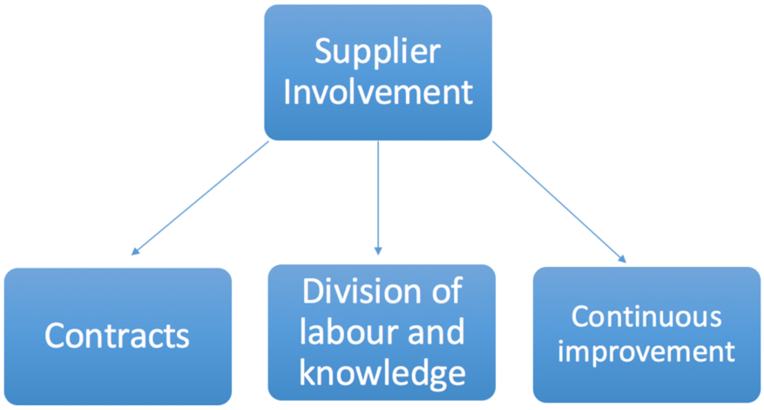

Figure 3-8 Supplier involvement (the author)

Contracts: Contracts have been seen by many scholars as a mechanism to build trust between OEM and supplier (Cousins et al., 2011; Bennett & Klug, 2012; Melander, 2014). Some examples of how a contract can build trust is by using none disclosure agreements (NDAs) and exclusivity contracts. On the other hand, Wang et al., (2011) state that over-detailed contracts may hinder knowledge exchange between OEM and supplier as well as give the suppliers less room to innovate. It is therefore suggested that the OEM issue long term contracts based on the suppliers' capabilities which were determined during the assessment and selection phases, but also leave room in the contract for suppliers to innovate.

Division of labour and knowledge: Studies from the past have shown that the main reason for OEMs to invovle suppliers in their NPD process is to take advantage of the supplier's technological expertise and knowledge during the design process, and that knowledge is created for both parties during the involvment of suppliers in product development (Le Dain et al., 2008; Lawson et al., 2011; Parthiban et al., 2013; Cousins et al., 2011; Squire et al., 2009; Farooq, 2018; Thomas & Obal , 2018). The OEM decides, at this stage, who will undertake the design and development activities based on the suppliers performance in the evaluation stages as well as the OEM's in-house capabilities. Nellore et al., (2001) and Kamath & Liker , (1994) discussed four types of relationships between OEM and supplier; partner, mature, child and contracted. Partners develop their own concepts to show the OEM. Mature suppliers are given specifications by the OEM. Child suppliers require detailed specifications with no room for innovation. Contracted suppliers supply standerdised items via catalogues to the OEM. Table 3-5 illustrates the different roles suppliers play in collaborative product development, based on the contract that is agreed upon after the supplier selection process.

Table 3-5 Supplier roles in product design and development (Nellore & Balachandra, 2001)

	Type of Supplier			
Requirements	**Partner**	**Mature**	**Child**	**Catalogue**
Length of Relationship	3-7 years	1-2 years	None required	None required
Product Specifications[3]	Develops systems independently of OEM requests and integrates them into the overall vehicle	Develops rough specification after critical input from OEM or generates critical specification himself	Supplier gets complete specifications or generates simple nut and bolt specifications himself	Order from catalogue
Involvement in the overall vehicle concept	Yes	No	No	No
Sub Supplier Selection and coordination	Own responsibility	Own responsibility with recommendations from OEM	Not applicable	Own responsibility
Technology leadership	Leader	Leader/follower	Process follower	Not applicable
Global presence	Mandatory	Mandatory/preferred	Not required	Not required
Decisions on cost	Preliminary costs decided up front with final costs decided at the end of the project	Target costs	Fixed price/inquiry/quotation	Fixed Price less discount
Market knowledge	Mandatory	Mandatory/preferred	No	No
Information Technology	EDI, CAD/CAM	EDI, CAD/CAM	EDI	EDI

Though many researchers discuss the various advantages of knowledge sharing between OEM and supplier (Cousins et al., (2011); Squire et al., 2009; Farooq, 2018; Yen & Hung, (2017); Soosay et al., (2008)), the majority do not explicitly explain the tangible knowledge that needs to be shared, nor do they clarify the mechanism that should be used for knowledge sharing activities. Thomas & Obal (2018); Cai et al., (2013); Kotabe et al., (2003) describe two different types of knowledge sharing, technical exchanges and technology transfer. Technical exchanges are described as simple small-scale explicit technical knowledge sharing within a specific project and involve relatively narrow and simple information resources. Whereas technology transfer consists of a set of realated techniques, methods and designs applicable to multiple projects, involving both tacit and explicit knowledge. Thomas & Obal (2018) concluded that technical exchanges have a greater effect in improving NPD performance than technology transfer because technology transfer requires long standing relationships between OEM and suppliers as well as more time and financial investment.

Cai et al., (2003) suggested there are two main mechanisms that facilitate knowledge sharing, namely trust and power. However, Farooq, (2018) proposed seven dimensions which can act as a facilitating mechanism to enhance the sharing of knowledge between OEM and supplier; supplier motivation, trust, organisational structure, organisational culture, management support, information & communication technology (ICT) and rewards systems.

Continous improvements: The results from the supplier assessment and supplier selection processes should serve as a basis for defining a continuous improvement strategy. The OEM must continuously evlaute suppliers as well as their NPD processes, in order to ensure that they remain competitive in the market.

A review of the literature has showed that a few scholars have different opinions on what constitutes the difference between design selection criteria (before involvement) and design performance criteria (during and after involement). Kannan, et al., (2015) and Govindan et al., (2013) grouped both selection and performance criteria together without formally noting the different time periods at which the distinctive activities take place.

It is suggested that the OEM continuously evaluate the suppliers performance after supplier involvment has begun. Suppliers performance during and after their involement in the product design and development processes of the OEM can be monitored using the criteria proposed by Le Dain, et al., (2011) and De Toni & Nassimbeni, (2001); suppliers identification of new technologies, assistance in developing product specification, assistance in simplification of the product, assistance in modularization activities, component selection, reliability of prototyping, communication about engineering changes, failure modes effects analysis (FMEA) activities, design for manufacturing (DFM) & design for assembley (DFA) actitivies and support.

Supplier development: Occasions may occur when the supplier possess a technology which is required by the OEM but does not have the necessary skills to reach an outcome which the OEM desires, the OEM therefore develops the supplier (Handfield et al., 1999). According to Melander, (2014), supplier development can be defined as any action taken by the OEM to make the capabilities and performance of the supplier meet the OEM's requirements. Modi & Mabert, (2007) discussed four main supplier development strategies. The strategies discussed are (1) competitive pressure where OEMs make suppliers compete against one another, (2) evaluation and certification systems where OEMs routinely evaluate supplier performance and provide feedback for performance improvement, (3) incentives where OEMs motivate suppliers by offering incentives such as the sharing of cost savings and (4) direct involvement where OEMs make capital and equipment investments in a supplier's operation. For example, Toyota typically owns 20-50% equity in their largest suppliers.

The next section detials the challenges faced during the outsourcing product development activities to suppliers.

3.6 Challenges faced during the outsourcing of OEMs' NPD to suppliers

Several challenges are faced when OEMs decide to outsource their design and development activities. The challenges are listed in table 3-6, followed by brief explanations of each challenge.

Table 3-6 Challenges involved in outsourcing activities between OEM and supplier

Reference \ Challenges of supplier integration	Lack of trust	Resistance to change	Large initial cost by OEM	Incompatible software and measurement units
Eisto et al., 2010	X	X		
Primo and Amundson 2002			X	
Wynstra et al., 2001				X
Handfield et al., 1999				X
Yen & Hung, 2017	X			
Cai et al., 2013	X			
TOTAL	3	1	1	2

Lack of trust: Trust can be defined as the positive conviction, manner, or prospect of one party regarding the chance that the actions or consequences of the other party will be adequate. The underlying belief of one party that the other is credible as well as competent (Sjoerdsma & van Weele, 2015; Bunduchi, 2013; Rajendran , 2013).

Resistance to change: Eisto et al., (2010) performed four case studies in the metal casting industry and found that resistance to change was one of the factors that challenged suppliers' involvement in NPD activities. The researchers found that the OEM designers were unwilling to allow the supplier designers engage in the design process, partly because the OEM's management were not prepared to relinquish control of the responsibilities pertaining to the design of the related components. The aforementioned situation meant that the OEM could not fully make use of the supplier's knowledge in the design and development of components.

Large initial cost for OEM: When OEMs decide to collaborate with suppliers, an effort must be made to alter their current NPD process in order to fit the new process which involves an external firm. These changes have the potential to be costly at the beginning and require a significant amount of manpower in order to ensure success (Primo & Amundson, 2002).

Incompatible software and measurement units: Le Dain & Merminod, (2014); stress the negative impact that having incompatible software can have on product development outsourcing. It is important that the OEM and supplier come to an agreement within the contract about the software that is to be used and what units. This will help both parties avoid delays during the outsourcing process.

3.7 **OEM and supplier communication during PD outsourcing**

Communication is very important in any NPD process. The most common methods of how OEMs and suppliers communicate, as found in the literature review, are depicted in table 3-7. The table was designed in order to show the preferred method of communication that past outsourcing projects have had.

Table 3-7 Communication between OEM and supplier during PD outsourcing

Communiation between OEM and supplier / Reference	Face to Face	Email	Telephone	Shared database	Resident engineer	Frequency of communication
Melander et al., (2014)	X	X	X			Weekly
Tavcar et al., (2018)		X		X		Weekly
Handoko et al., (2017)	X					Weekly
Soosay et al., (2008)				X		
TOTAL	2	2	1	2		

Face to face: Handoko et al., (2017) stressed the importance of having at least one contact person from the OEM at the supplier's firm and vice versa. These contact persons then go back to their respective firms and share the necessary knowledge with the engineers and designers.

Email: Melander et al., (2014) Surveyed the outsourcing of product development of a telecommunications OEM to their suppliers while working on a new component. The researchers noted that communication between OEM and supplier mainly took place via email and telephone between one development engineer at the OEM and one contact person at the supplier. The supplier's contact person then shares knowledge about technical issues to other development engineers within the organisation of the supplier. This situation is not ideal because a project cannot be successful based on tacit knowledge alone.

Telephone: In the same survey of Melander et al., (2014), the communication between the OEM and supplier was mostly carried out via weekly phone calls. During these phone calls, both parties shared technical information and presented problem reports.

Shared database: Tavcar et al., (2018) expresses the need for a shared database when engineers and designers from both the OEM and suppliers can share important knowledge related to the NPD project such as design drawings, CAD files, etc.

3.8 The importance of the criteria for selection and evaluation

The main goal of the supplier selection process is to pinpoint the suppliers who possess the maximum potential for achieving the needs of an OEM regularly and at a cost that is acceptable. Kahraman, et al., (2003) noted that the selection of suppliers is a expansive method for comparing suppliers by utilising a collective set of criteria and measures. The researchers also noted that the amount of detail used for the examination of potential suppliers could differ, depending on the needs of the firm.

In order for an OEM to determine the appropriate supplier, they must critic the ability of each supplier to regularly meet their needs in a cost-effective manner by making use of criteria and appropriate measures. In order to achieve this, the OEM develops criteria which are relevant to all suppliers currently being considered as well as account for the needs of the OEM and their technology and supply strategy (Kannan, et al., 2015). An OEM may struggle to translate their needs into criteria that is useful because their needs are commonly categorised qualitative impressions (Kahraman, et al., 2003), whereas according to Ghadimi, et al., (2017), criteria should be explicit requirements that can be evaluated in a quantitative manner. The OEM may create procedures during the process of criteria creation in order to safeguard the practicality of the use of the criteria.

Gathering information from the supplier is the step that proceeds creating the criteria. Information gathering has the ability to provide an awareness about the criteria used to evaluate suppliers but gathering of information frequently occurs while criteria are being created. This causes issues as information gathering without precise criteria development can lead to inessential work being performed by the OEM. There are several main categories to be considered when creating criteria to select suppliers. These are: Financial, managerial, technical and quality systems (Kahraman, et al., 2003; Le Dain, et al., 2011; Kannan, et al., 2015).

Financial

There are two aspects to finances regarding criteria development. Financial position and the actual cost of involving the supplier in an OEM's product design and development activities. Kahraman et al., (2003) state that an OEM should check to ensure that its potential suppliers are in a good financial position because financial strength can serve as a gauge of a supplier's stability. In terms of costs, Parthiban et al., (2013) states that there are several aspects of cost to consider as criteria for suppliers in an OEM's organisation such as purchasing cost and warranty costs.

Managerial

The support of the senior management, culture within the supplier organisation and the strategic orientation of the supplier are all aspects that need to be considered when creating criteria to invovle suppliers into an OEM's organisation (Melander, 2014). The aforementioned are important in order to ensure that a good relationship with the supplier as Kahraman et al., (2003) states that management stability is reached when there is good relaitonship between OEM and supplier.

Technical capability

Criteria related to the technical capability of the supplier are very important, more so in terms of design and development suppliers. Kahraman, et al., (2003) states that these criteria are important when an OEM's strategy involves new product development or when they need to gain access to the proprietary software of a supplier.

Quality systems

The criteria related to quality systems are required in order for the OEM to have confidence in the supplier regarding their processes's ability to improve as well as maintain delivery and quality (Kannan, et al., 2015). The criteria to be considered include control procedures, quality assurance, procedure for handling complaints, ISO 9000 standard and quality manuals.

3.9 Identification of criteria from literature

Throughout the research journey, several criteria were discovered that focus on supplier selection and supplier evaluation. The supplier selection and evaluation criteria are depicted in table 3-8. The selection criteria have a blue background while the evaluation criteria have a yellow background.

Table 3-8 Selection and Evaluation criteria

Reference \ Criteria	Quality systems	Capability to handle abnormal quality	Warranty policies	Price performance value	Purchasing cost	Technology capability	Performance history	Capacity of supplier	Design cycle time	Supply risk	Trust	product quality	communication systems	amount of past buiness	financial position	management and organisation	resiprocal arrangements	flexibility	Tools and equipment	General reputation	intallectual property	response speed	Identification of new technologies	assistance in developing product specification	assistance in simplification of product	assistance in modularization activities	component selection	reliability of prototyping	communication about engineering changes	failure mode effects analysis	Support in DFM activties	Support in DFA activities	Collaboration attitude	after sales service	Innovation
Melander et al., (2014)											x																								
Cousins et al., (2011)								x		x																									
Skilton & Dooley, (2010)										x																									
Diestre & Rajagopalan, (2012)										x																									
Yen & Hung ,(2017)								x			x																								
Safa & Ismail (2013)											x																								
Tavcar et al., (2018)	x																																		
Parthiban, et al., 2013					x																														
Goren, (2018)	x				x	x		x	x																										
Cao, (2011)				x																															
Yenipazarli (2017)											x																								
Le Dain et al., (2011)																					x	x	x	x	x	x	x	x	x	x	x	x			x
De Toni & Nassimbeni, (2001)																					x	x	x	x	x	x	x	x	x	x	x	x			x
Ebrahimipour et al., (2015)			x																																
Abdolshah, (2013)	x	x					x					x																							
Handfield, (1999)													x																						
Dickson, (1966)			x		x		x					x	x	x	x	x	x		x	x													x	x	
Wind and Robinson (1968)				x		x						x		x			x			x															
Lehmann and O'Shaughnessy, (1974)			x		x	x						x		x	x					x														x	
Perreault and Russ (1976)					x							x				x	x																		
Abratt (1986)																				x														x	
Billesbach et al. (1991)					x							x																							
Weber et al., (1991)					x	x	x					x	x	x	x	x	x		x	x													x	x	
Stavropolous, (2000)					x							x																							
Teeravaraprug, (2008)					x							x																							
Sanayei et al., (2008)																x		x		x															
Peng, (2012)					x							x							x															x	
Tektas and Aytekin, (2013)						x						x	x																						
Buyukozkan et al., (2011)					x							x																						x	
Mehralian et al., (2012)					x											x			x																
Teng and Jaramillo, (2005)					x	x						x						x		x															
Zeydan et al., (2011)			x		x	x						x			x			x	x	x													x	x	
Tan and Kannan, (2006)					x	x						x	x		x			x																	
Katsikeas et al., (2004)			x		x	x						x	x					x		x														x	
Chan and Kumar, (2007)						x						x	x		x			x		x															
Kirytopoulos (2008)					x							x			x																				
Ordoobadi, (2009)					x									x																				x	
Wang, (2010)					x									x	x																				
Lin et al., (2011)					x							x		x																					
L. M. Ellram (1990)			x			x	x							x	x	x																	x		
Buyukozkan & Cifci (2011)	x																																		
Aloini et al., 2016																								x	x	x	x			x	x	x			
Mohamad et al., 2015																															x	x			
Govindan et al., (2013)	x						x																												
TOTAL	5	1	6	2	20	11	5	2	1	3	4	18	6	8	9	6	4	6	5	10	2	2	2	3	3	3	3	2	2	3	3	2	4	9	2

3.10 **The meaning of each criteria**

The following paragraphs show the definition of each criterion listed in table 3-9.

Quality systems: Ensure high quality control on the product and provide the quality related certificates such as ISO9000, QS9000 etc. The aforementioned quality systems may be chosen to assess the quality of a supplier's organisation, but they do not appropriately determine the quality of a product (Abdolshah, 2013). An ISO registration does not always mean the following: improved quality of product, fulfilment of customer needs, better quality than that of companies which are not registered and good productivity, responsiveness and workforce development (Goren, 2018). Moreover, complete quality systems that are shaped by ISO standards have some amount of merit, but the best quality is not attained by a company using this alone (Tavcar et al., 2018).

Capability to handle abnormal quality: Capability to fulfil the abnormal quality specification of the customer without compromising the existing product price. This capability is qualitative and very important but cannot ensure the quality of a product. The competitive climate nowadays has resulted in new approaches requiring no defects and rely on zero reject rates. Most companies now focus on low eject rates rather than focus on issues relating to abnormal quality such as the handling of the product. Nevertheless, a supplier may possess poor quality products but have good methods for handling products of abnormal quality (Abdolshah, 2013).

Warranty policies: A warranty can be described as a contractual commitment that relates to the sale of a product by a supplier. Product performance is guaranteed by this contract. The warranty ensures a product is repaired or replaced for free or for a reasonable price following a product failure. Existence of warranties and claims policies are provided by suppliers or agreements between the OEM and supplier for faulty products (Ebrahimipour, et al., 2015). According to Murthy et al., (2004), a study was carried out about the classification of 15 types of warranties came to a conclusion that warranties play an crucial role when dealing with complex products where the buyer cannot evaluate the performance of the product before the purchase is made due to lack of knowledge or resources. In the case of selecting suppliers for product design and development activities, warranty policies are important because the products are often very complex, and it also enables the supplier to gain more trust in the OEM.

Price performance value: Price performance value relates to the relation between the value of the design and the cost. The value here relates to the value of the product from a customer's perspective rather than the historical cost of the product or service (Cao, 2011).

Purchasing cost: The cost of production that governs the final cost of the product and includes processing cost and maintenance cost. Lower product price without compromising on the quality which includes warranty cost, processing cost etc. Supplier selection traditionally focused mainly on purchasing cost for decision making (Dickson, 1966). Following an extensive review on supplier evaluation methods, Weber et al., (1991) concluded that purchasing cost was the most important factor.

Technology capability: Every organisation has within it a vital interdependence between activities such as technology, innovation and other activities. Technology gains higher priority during strategic planning. The degree of technological capability varies from organisation to organisation. Technology capability includes to the following factors: design capability, innovation, technology, collaboration with research institutes, the team's ability to quickly respond to product research and development demands and so on (Weber et al., 1991).

Performance history: OEMs look at supplier's previous design and development work in order to predict how they would perform in a potential PD outsourcing project. Dickson (1966) performed a survey in order to ascertain the criteria that should be considered for supplier selection. Upon reviewing 23 criteria, it was found that the three most significant criteria were quality, delivery and performance history. Moreover, Weber et al., (1991) reviewed 74 papers published since Dickson's paper and found that cost was the most important criteria but closely followed by quality and performance history. This therefore illustrates the importance of performance history when selecting suppliers for a potential involvement in an OEM's product design and development activities.

Capacity of supplier: The supplier's ability to process the design and development requirements of the OEM at the desired scale without compromising on product development performance (Cousins et al., 2011). With interconnected design and development activities in supply chain nowadays, a large amount of

OEMs now seek external suppliers to design their products. Therefore when an OEM considers the design and development of a product, they not only consider their internal capacity but the external capacity of their suppliers as well (Ding, et al., 2007). Any problems that arise as a result of incorrect evaluation of supplier capacity can result in scheduling issues which can have a significant negative impact on the costs that the OEM will incur throughout the process (Yen & Hung, 2017).

Design cycle time: The time it takes to design and develop a new product from the design and development phase to the testing and prototyping phase (Goren, 2018). The design cycle time is important when considering suppliers to be involved in design and development activities because the supplier's design cycle time can have a great impact on the delivery of the finished product, therefore impacting the OEM's ability to fulfil customer demands.

Supply risk: Anything that can have a negative impact on the supply chain process such as incompatible software, misunderstanding of responsibilities and targets etc (Skilton & Dooley, 2010). Supply risk can be evaluated by addressing quality issues, reducing disruption likelihood and improving processes (Zsidisin et al., 2004). An OEM looking to involve suppppliers in their design and development process would ideally require a situation where supply risk is a low as possible.

Trust: The positive conviction, manner, or prospect of one party regarding the chance that the actions or consequences of the other party will be adequate. The underlying belief of one party that the other is credible as well as competent (Sjoerdsma & van Weele, 2015; Bunduchi, 2013; Rajendra, 2013). Having trust in a potential supplier means the OEM does not lose time by checking that all the information provided by the supplier is accurate. This time saved can speed up the entire process of product design and development.

Product quality: Final deliverable specifications compared to the required ones (Weber et al., 1991). Product quality has been defined by Abdolshah (2013) as the capability of products and services to meet or exceed customer's expectations, and should not be viewed as a special feather, rather an essential part of a product or service. A higher product quality is important to the OEM because it ensures that they fulfil customer expectations as well as ensuring they are able to price the products higher therefore increasing their gross income.

Communications systems: Supplier's processes or ways of communication to transfer documents and the deliverables required, fundamental as design and development services concern technical information (communication systems compatible throughout the whole supply chain) (Weber et al., 1991). Communication with suppliers is a very important part of the design and development process. Suppliers need to be made aware of engineering changes during the design and development process, therefore it is important for the OEM to set out clear methods of communication at the start of the process of involving suppliers in their product design and development process. Ensuring that the suppliers have the right communication tools and methods will help build a positive relation between OEM and supplier as well as ensuring that their mutual long-term goals are achievable (Handfield et al., 1999).

Amount of past business: The total number of past design and development projects the supplier has undertaken. According to Wasti & Liker , (1999), the amount of successful past business of the supplier gives the OEM an indication of the supplier's behavioral tendencies and reduces the requirement of the OEM to constantly monitor the behavior of the supplier. In terms of supplier involvement in design and development outsourcing, a supplier's amount of successful past business means that the OEM may feel more comfortable giving the supplier more responsibility a dn involving the supplier earlier in the process.

After sales service: All the help and services provided to the OEM by the supplier after the outsourcing project is over. Suppliers continuously improve the services they provide in order to withstand the existing scenario of strategic business with OEMs. For better opportunities to stay ahead of competitors, suppliers place after sales services as a criterion of significance (Parthiban et al., 2013). After sales services refers to the technical support, sale representatives' competence, rate of delivery in time, accuracy of order processing, degree of information modernised, rate of in time delivery, and manner of service

(Ordoobadi, 2009). Several researchers have suggested that after sales service is an important criterion when selecting suppliers for involvement in an OEM's product development process (Dickson 1966; Weber et al., 1991; Peng 2012).

Financial position: A supplier's financial situation has a great impact on their ability to successfully carry out design and development activities. A heavily financially leveraged supplier would be too eager to seek a new contract with a potential OEM and my therefore be dishonest about their capabilities (Zeydan et al., 2011). An OEM should always check a supplier's financial situation as it determines how the partnership will progress.

Management and organisation: The top management and organisational culture at the supplier needs to be compatible with the OEM's. The upper management of the supplier strongly influence their subordinates therefore the overall attitude of the design and development engineers can be affected by their superiors' attitude towards their involvement in the OEM's design and development activities (Dickson 1966; Weber et al., 1991).

Reciprocal arrangements: The agreement that the supplier and OEM is fully aware of each of their responsibilities throughout the process. Kamath & Liker (1994) addressed the different types of relationship agreements that are possible between OEM and supplier. The supplier's responsibility in design and development activities varies depending on the type of relationship agreed upon at the start of the agreement. The relationships are contractual, child, mature and partner.

Flexibility: A supplier's flexibility within a supply chain can be considered as a tool utilised to handle environmental uncertainties. Suppliers who are flexible are efficient at processing other jobs alongside the job they are the primary supplier for (Chan & Kumar 2007). Where there are many suppliers to choose from, flexibility can be used to distinguish suppliers from one another by looking at their operating characteristics which determines the lead time it takes for each supplier to perform the same operation (Chan et al., 2009).

Innovation: Suppliers ability to introduce new ideas, components and processes. Supplier innovation relates to the leveraging of suppliers' innovation performance. When managed properly, supplier innovation can have many advantages such as shorter time to market, fresh ideas and higher margins. All of the aforementioned can result in the growth of the OEM's organisation (Le Dain et al., 2011).

Intellectual property: A supplier's intellectual property is a classification of property that comprises of creations by the supplier which are tangible. There are several types of intellectual property which a supplier could possess such as patents, trademarks and trade secrets (De Toni & Nassimbeni 2001). An OEM may find the possession of a supplier's trade secrets essential to ensure they gain an advantage over their competitors.

Response speed: The supplier's ability to respond quickly to meet any change required in the design and development of outsourced components (Le Dain et al., 2011). A supplier who has a quick response speed is able to gain the confidence of the supplier because the industry moves quickly and responding quickly puts the OEM in an advantageous position.

Identification of new technologies: The suppliers' ability to introduce new technologies to the OEM that the OEM was previously unaware of or is not in possession of. The aforementioned new technology has the potential the transform the OEM and also has a great impact on the OEM's market position (Le Dain et al., 2011).

Assistance in developing product specification: The suppliers' participation in working with the OEM to develop product specifications that meet the demands of the market (Le Dain et al., 2011).

Assistance in simplification of product: The suppliers' participation in aiding the OEM to reduce the complexities of products or components. OEMs are currently in need of faster product launches or new versions of current products. This means that the ability to quickly render products in an efficient manner, is essential. When a product has a large number of components, the structure and the process of the product need simplification, limiting the number of components. When a product design is simplified, several advantages can be realised. These advantages include cost reduction, quality improvements and shorter lead times. The supplier’s contribution to this can be highly advantageous to the OEM (De Toni & Nassimbeni, 2001).

Assistance in modularisation activities: The suppliers’ participation in aiding the OEM to reduce the complexities of a system. Modularisation allows for differentiated products to be attained at the same time as the reduction in design and development costs. A supplier’s contribution can be greatly realised when a product’s modular composition necessitates modifications in a new product’s design (De Toni & Nassimbeni, 2001).

Component selection: Suppliers involvement in selecting the most efficient components to be part of a product. Parts are more readily available when standard components are used. The result of this is a reduction in lead-time and inventory costs. Standard component designs can be automated using tools such as CAD which have elements stored within the supplier’s system and can be made available to the OEM in order to be added to the design of a product. The supplier may recommend standardised solutions as this allows the design team to work faster and make the process more economical (Aloini et al., 2016).

Reliability of prototyping: The frequency of the supplier’s prototypes meeting the required specifications. The reliability of the prototypes is of great importance as it allows the OEM evaluate the suppliers performance after the supplier has been selected (De Toni & Nassimbeni, 2001).

Communication about engineering changes: How quickly and efficiently the supplier communicates with the OEM about changes to the product, component or process.

Failure mode effects analysis capability (FMEA): FMEA techniques aid the design and development team in studying and causes and effects related to the failure of a given product. FMEA allows designer to develop a product that will withstand a range of conditions because it specifies the conditions that a product will experience and tests how it reacts to those conditions. Suppliers who have higher knowledge regarding components can suggest solutions at a lower cost to problems revealed under these conditions (Le Dain et al., 2011).

Support Design for manufacture (DFM)/ Design for assembly (DFA) activities: Making use of DFM and DFA techniques have the ability to aid suppliers in developing a product at a competitive price as the costs of manufacture and production are taken into account. If an issue arises at the DFM phase and is solved, the solution can be advantageous to the entire process (Mohamad et al., 2015). Suppliers need to take advantage of the opportunity to work with an OEM in order to improve their technology capabilities. If a supplier therefore has very good in-house technologies, they are more attractive to OEMs and have a higher chance of being selected for involvement in the OEM's design and development activities (De Toni & Nassimbeni, 2001).

Collaboration attitude: A supplier's collaboration attitude is the cooperative tendency or external focus entrenched in a supplier's company. A supplier may be in possession of innovative proficiencies that may not be put to good use if there is no willingness to collaborate (Dickson, 1966; Weber et al., 1991).

Tools and equipment: The design and development tools currently present within the supplier's facilities. The tools and equipment used by the supplier at the early stages of design and development have a significant impact on the quality of the final product. The OEM there has to be careful to select a supplier whose tools and equipment are not only adequate but are also in line with goals set by the OEM (Peng, 2012; Zeydan et al., 2011).

General reputation: Supplier's general reputation related to design and development activities. This reputation is derived from the suppliers past successes in design and development as well as how the supplier's organisation conducted themselves during previous projects (Dickson, 1966; Abratt, 1986; Chan & Kumar, 2007).

The diverse range of criteria for supplier selection and evaluation have been presented in this section and explained in some detail. The next section will deliver more information about the industrial perspective of the product design and development outsourcing. This will provide a better understanding of how the criteria are used in the industry.

3.11 Mathematical tools used to calculate supplier performance against criteria

Following the information provided in section 4.1 about the importance of criteria and how criteria are categorised into groups. It becomes necessary to investigate the methods found in the literature relating to how the aforementioned criteria are calculated in order to rank potential suppliers in order to select the most qualified.

There is a plethora of methods found in the literature that can be used as supplier rating systems in order to select the most adequate supplier to be involved in the OEM's product design and development activities. The mathematical methods are commonly known as integrated MCDM approaches. Amongst the list of methods, the most commonly used are analytical hierarchy process (AHP), data envelopment analysis (DEA), technique for order of preference by similarity to ideal solution (TOPSIS) and analytic network process (ANP). According to Kolios, et al., (2016), MCDM was initiated by Saaty with the intent to evaluate priorities.

Table 3-9 Supplier rating methods for supplier selection

Reference \ Method	Analytical hierarchy process	Technique for order of preference by similarity to ideal solution	Analytical network process	Data envelopment analysis
Govindan, et al., 2013		X		
Yu and Su, 2017				X
Ozgen, et al., 2008	X			
Parthiban, et al., 2013				X
Lee, et al., 2009	X			
Shaw, et al., 2013	X			
Azadnia, et al., 2015	X			
Kumar, et al., 2014				X
Duo, et al 2014			X	
Mafakheri, et al., 2011	X			
Buyukozkan and Cifci 2011			X	
Jain, et al., 2016	X	X		

The information illustrated in table 3-9 shows the different methods for supplier rating, along with the authors who made use of them during a case study. Some authors made use of more than one mathematical method within a single case study.

Govindan, et al., (2013), used TOPSIS alone to rank a group of four suppliers in a triple bottom line approach (economic, environmental and social) and was able to recommend that the highest ranked supplier be chosen for selection. Jian et al., 2018 used two separate mathematical methods in a single case study, to rank automotive headlamp suppliers. AHP and TOPSIS were both used to rank the same set of suppliers in the case study. The results showed that AHP was more robust and was therefore chosen for the final ranking of the suppliers.

Parthiban, et al., 2013 used DEA to compare 20 automotive suppliers. The final results showed that three suppliers equally received the highest efficiency score.

Even though the authors gave each supplier a rank of 1-3, it is clear that DEA is not the best method to rank suppliers as the authors were unable to point out one single supplier as the highest ranking.

Based on some of the information provided in the preceding paragraphs, it is clear that AHP is a very robust method for ranking suppliers. Furthermore, as illustrated in table 3-9, AHP is the most popular method. It must be stated that other methods are quite popular as well but AHP appears to be more commonly used in the most recent literature. For that reason, further details about AHP will be illustrated in section 3.11.1.

3.11.1 Analytical hierarchy process as a method for ranking suppliers

Analytical hierarchy process is a mathematical method that OEMs can use to rank and therefore select suppliers for participation in product design and development.

AHP can be considered as a wide-ranging concept of measurement, utilised to develop ratio scales from both distinct and continuous comparisons. The aforementioned comparisons may be taken from a scale that mirrors the strength of preference and feelings or tangible measurements (Saaty, 1987). The AHP is able to produce a weight for each criterion being used, based on the pairwise comparison by the decision maker. The more important criterion receives higher weights. The AHP then allocates a score to each criterion based on the pairwise comparison made by the decision maker of the choices that are based on the criterion. The AHP then conglomerates the weights of each criterion and the scores for each option, therefore defining a general score and ranking for each of the options. The general score for each option is a weighted total of the scores it acquired in relation to all the criteria involved (Saaty, 1980). The flow chart in figure 3-9 better illustrates the aforementioned activities.

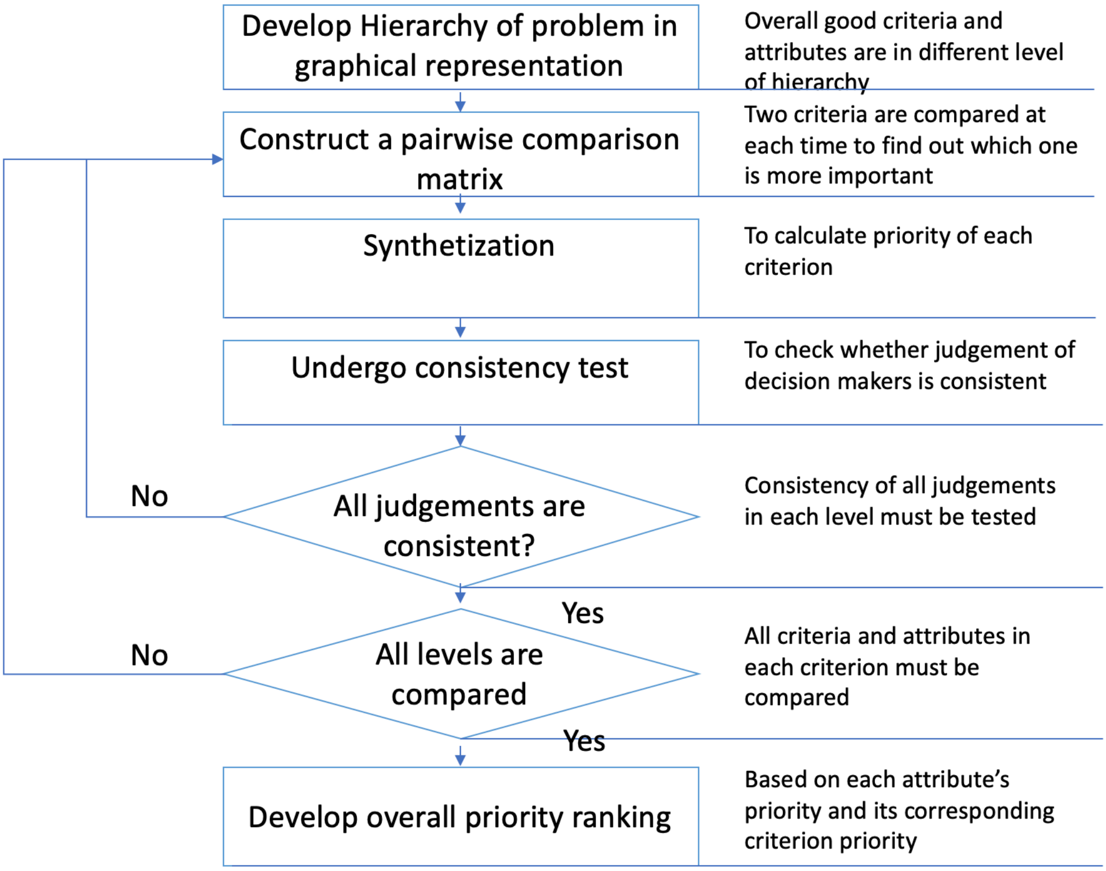

Figure 3-9 AHP flow chart (Saaty, 1980)

The AHP also has in place, mechanisms to address the inconsistences in the choices of the decision makers. The AHP method tackles this inconsistency by providing the assessment measurement inconsistency. The assessment results become more inconsistent as the value on the consistency ratio rises.

The formula in equation 3-1 can be used to calculate the consistency index (CI):

Equation 3-1 Consistency index equation

$$CI = \frac{maks.\ eigenvalue - n}{n-1}$$

$$maks.eigenvalue = \sum_i wi.ci$$

The consistency ratio (CR) is to be calculated, following the CI. This is calculated using the formula in equation 3-2:

Equation 3-2 Consistency ratio equation

$$CR = \frac{CI}{RI}$$

Table 3-10 depicts a random consistency index (RI).

Table 3-10 Random consistency index (Saaty, 1987)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The AHP method would no longer be useful if the consistency ratio is greater than or equal to 10% (Saaty, 1987). The information depicted in Table 3-10 was developed by Saaty, (1987) and is used as a template to calculate the consistency of each criterion as it compares to another within a given group of criteria. The letter "N" refers to the total number of criteria being compared, while "RI" refers to the inconsistency permitted for each value of "N".

It can be concluded that AHP is a relatively easy mathematical method to use and understand. This method produces accurate results; therefore, an OEM can trust that this method will be of a greater advantage than some of the other popular methods in the literature. It must be noted that considerations have been made regarding OEM's currently using a mathematical tool which they not only prefer but are already accustomed to. For this reason, even though the design and development framework suggest the OEM use AHP, the framework is designed in such a way that other mathematical tools can be used.

3.12 Previous models for OEM and supplier PD outsourcing

There are several models that have been found in the literature that act as a guideline for OEM and supplier PD outsourcing.

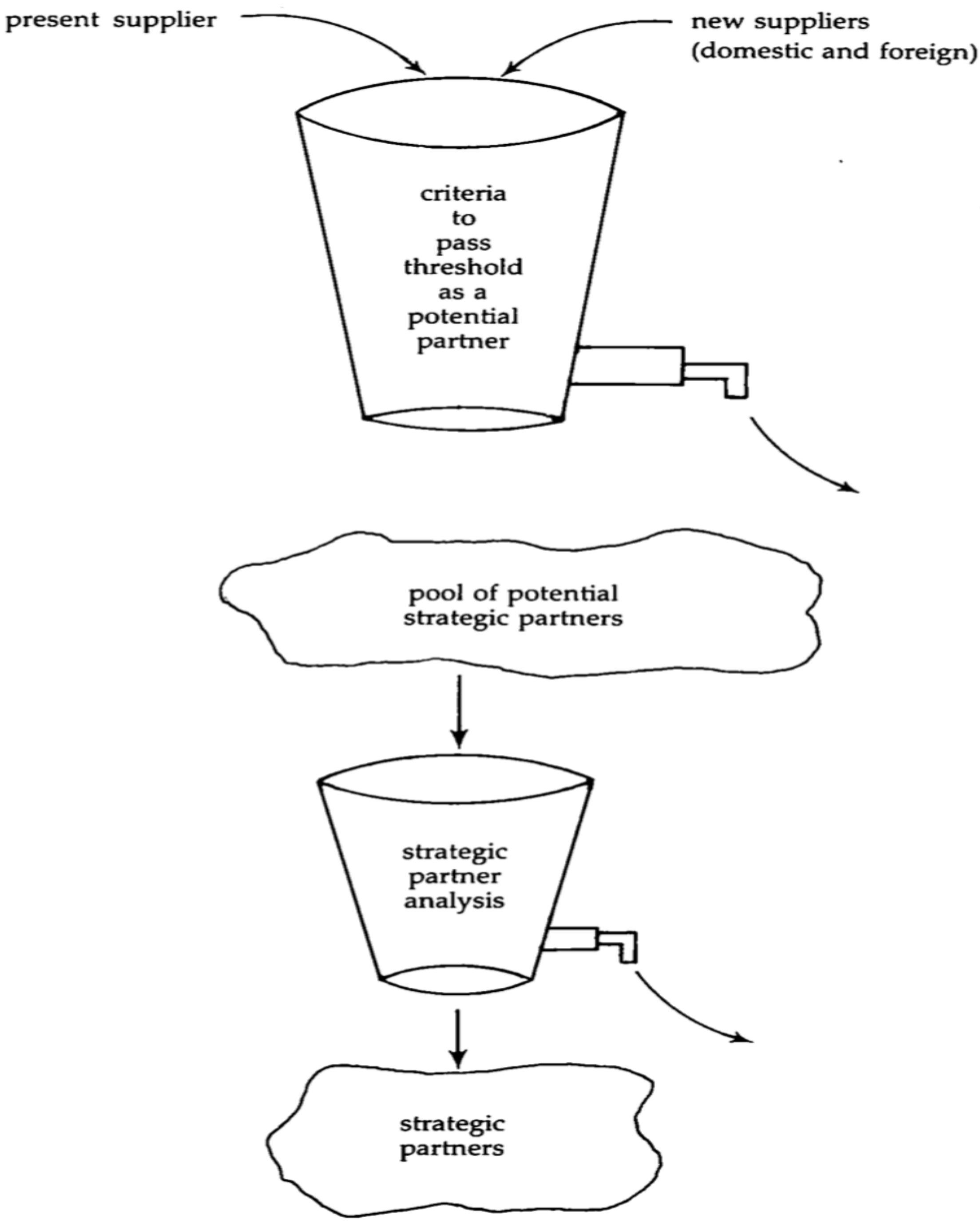

Figure 3-10 Selecting a strategic partner (Spekman, 1988)

Figure 3-10 illustrates the process model of Spekman (1988) regarding supplier selection for OEMs. The process model suggests that there are two main stages to a partnership between OEM and supplier. The first stage follows tradition methods of selecting suppliers by evaluating their performance whereas the second stage focuses on the selection of strategic partners from a smaller pool of suppliers who made it past the first stage. The author claims that the positive effect of such a process results in the establishment of a threshold performance level in which potential suppliers will not be considered for potential strategic partnership if they are not above that threshold.

The supplier evaluation process within this process model is based on 10 main questions, they are: (1) how has the supplier demonstrated commitment? (2) How early in the design stage should the supplier be brought in? (3) Is the supplier aware of the level of commitment required to achieve the set goals? (4) Does the supplier have growth potential? (5) Is the supplier able to provide technical support? (6) Does the supplier demonstrate teamwork in solving problems? (7) Are the top management within the supplier's organisation committed to the potential partnership? (8) How much planning for the future is the supplier willing to share? (9) How well does the supplier know the OEM's business? (10) What does the supplier demand from the OEM?

It is clear from the list of 10 questions that the supplier selection process within the process model of Spekman (1988) is limited in two ways; the total number of criteria and the detail in which the criteria are used to evaluate the suppliers for selection. For example, the first question states "how has the supplier demonstrated commitment? Without making use of mathematical models and a structured system to calculate the value of supplier commitment, it is difficult to compare one supplier's commitment to another. Moreover, the process model does not contain nearly enough criteria that would provide an OEM with enough confidence in selecting a supplier for potential involvement in the OEMs product development process. There are several criteria that could be added to make this process model more robust. An example is the criterion of the capacity of the supplier. Without knowing a supplier's capacity, it is difficult to ascertain the volume of work and responsibility that should be given to the supplier.

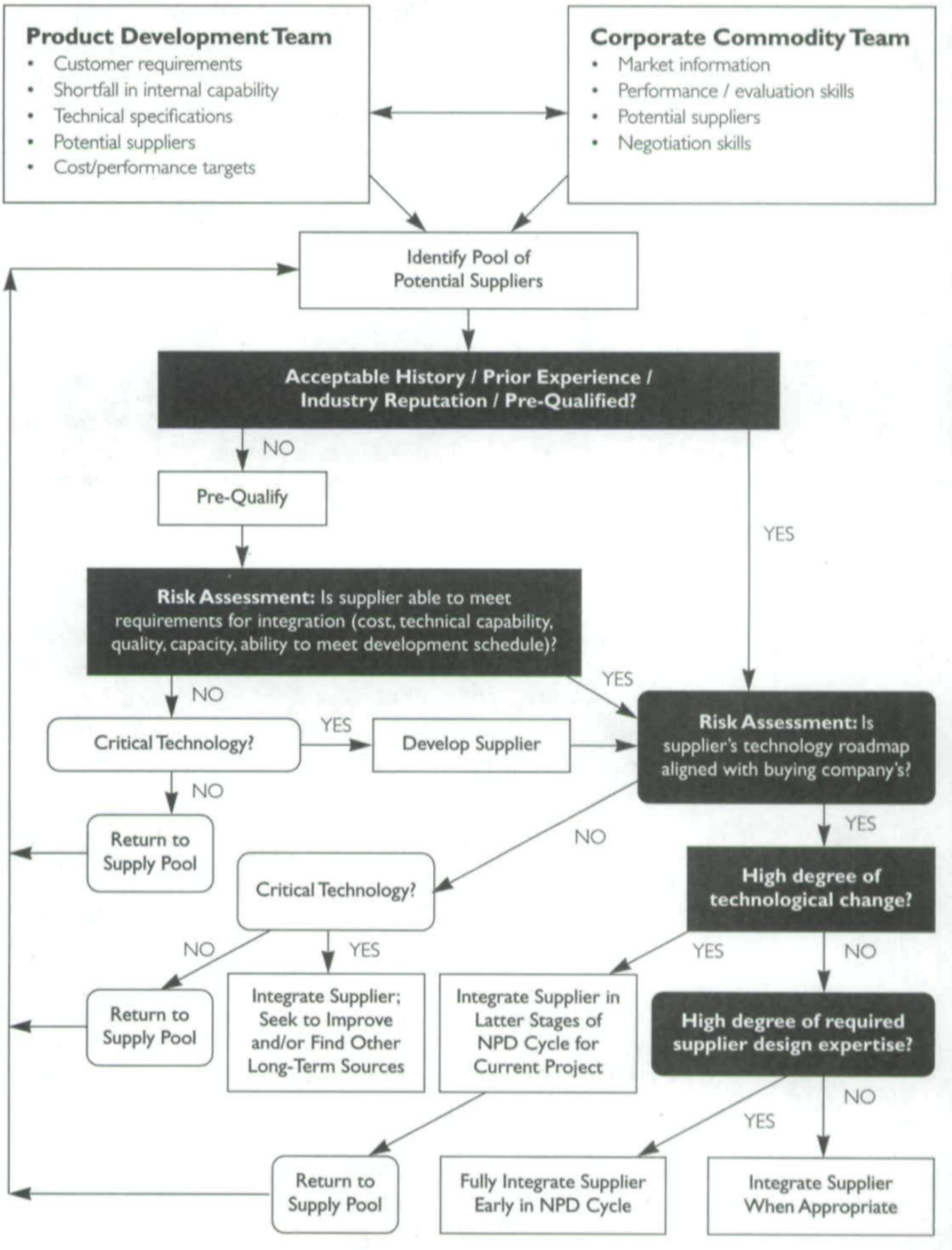

Figure 3-11 Process model for supplier integration into product development (Handfield et al., 1999)

The framework developed by Handfield et al., (1999) builds on the framework of Spekman (1988) and entails a two-stage process for supplier selection. In this framework, after the initial pool of potential suppliers is identified, the first stage of supplier selection takes place. Following this process, the suppliers who qualify for the next stage are then evaluated for a potential partnership. After this, further risk assessments take place to further ensure that the suppliers chosen are the appropriate suppliers for the job.

The first set of criteria at the first stage of supplier selection in this two-stage process model are namely: Acceptable history, prior experience, industry reputation and pre-qualification. For the second stage of supplier selection, the criteria are: Cost, technical capability, quality, capacity and the ability to meet development schedule. This process model also includes supplier development, critical technology possession of the supplier and what stage within the product development process should the supplier be involved in. the aforementioned aspects were not present in the Spekman (1988) process model.

It is clear to see that the process model of Handfield et al., (1999) built upon the findings in the process model of Spekman (1988) due to it having similar process but with more details and procedures. The criteria in this process model also do not go into enough detail on how to calculate them, therefore resulting in difficulties when tasks with comparing one supplier against another. The process model provides information about when a supplier should be involved in an OEM's product development process but does not provide information regarding the proceeding activities after selection.

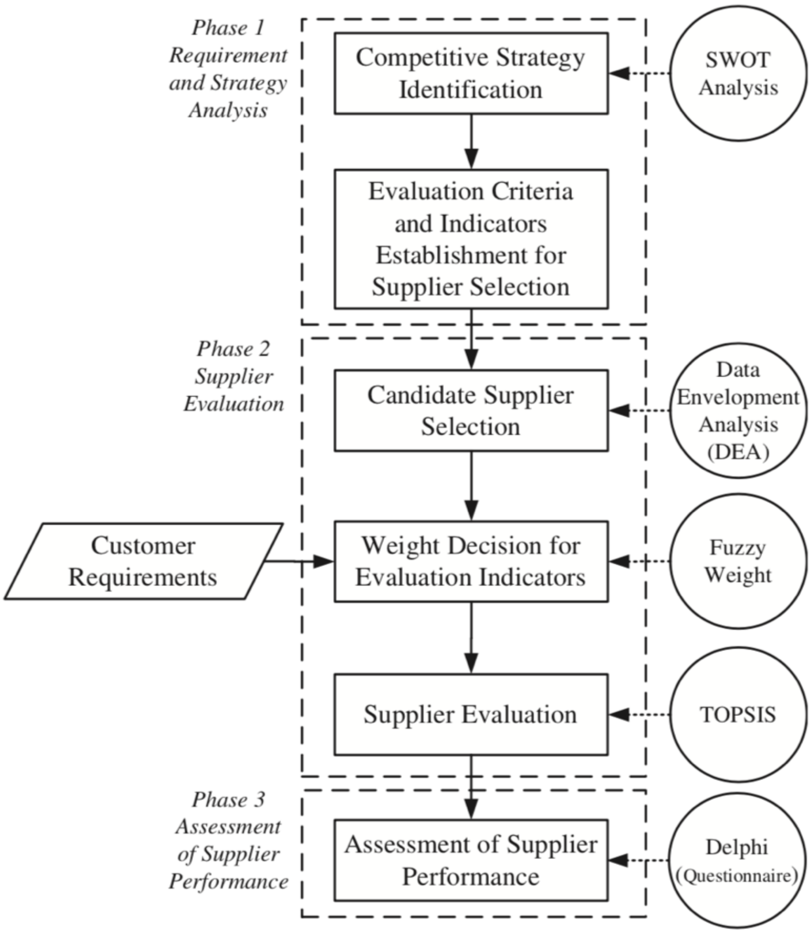

Figure 3-12 Supplier selection and evaluation process model (Chen, 2011)

Chen (2011) developed a process model seen in figure 3-12, using multiple mathematical tools to assess and evaluate suppliers for selection into OEMs PD processes. The process model is divided into three distinct phases. Phase 1 is the requirement and strategy analysis, phase 2 is supplier selection and evaluation and finally phase 3 is titled assessment of supplier performance.

During the first phase SWOT analysis is utilised to define the requirement and strategy of the OEM. The supplier evaluation criteria are then established as well as indicators for supplier selection. In phase 2, DEA is used to simplify the supplier selection process and eliminate the suppliers who do not qualify, based on the requirements set out by the OEM. In phase 3, a questionnaire is designed to assess the performance of suppliers.

The process model of Chen (2011) is more modern than the process models of Spekman (1988) and Handfield (1999), this is evident partly by the more focused use of mathematical methods to select and evaluate suppliers. This use of mathematical methods provides higher accuracy than the process models that preceded it in the selection and evaluation processes. Though the process model of Chen (2011) is more accurate than the model of Handfield et al., (1999), it less robust as it has significantly less activities. One of the activities not present in this process model is supplier development. Supplier development is an important aspect of the supplier selection process and Kahkonen, et al., (2015) noted that supplier development has a positive influence on the performance of the entire supply chain process because it enhances the relationship between OEM and supplier.

The process model includes supplier performance evaluation in its final phase. This is another activity that is present in this process model but not in the process models of Handfield et al., (1999) and Spekman (1988). Although supplier performance evaluation is present, this process model does not include enough detail about supplier performance evaluation process after the supplier has been selected. It is important for a process model such as this to have individual activities within the supplier performance evaluation phase, so OEMs can have a clear understanding of the exact activities that need to be performed in order to achieve optimal performance from the supplier.

Figure 3-13 Supplier evaluation and selection process (Abdolshah, 2013)

The process model of Abdolshah (2013) depicted in figure 3-13 commences in a similar manner to the process models depicted in figures 3-12 and 3-11. This initial activity is the identification of purchasing and sourcing, explained in the paper as the requirement. The next activity is to determine the purchasing strategy. This is the logical next step when compared to other process models. The third activity requires the OEM to identify potential suppliers as this is important when considering the involvement of suppliers into an OEM's product development process. One key point to note in the fourth activity is the first cut which reducing the number of suppliers in the pool. This is a common trend as it appears in the process models of Spekman (1988), Handfield et al., (1999), and Chen (2011). Reducing the number of suppliers from the initial larger number helps the OEM to focus more resources on evaluating the suppliers who have a greater chance of being selected to be involved in the OEM's product development process. In this case, the author did not specify what method is to be used to reduce the number of suppliers unlike Chen (2011) who used DEA analysis for this process. The next activity involves determining the criteria for supplier evaluation and selection. This activity is necessary is it is present in all other process models reviewed. The final activity in this process model is the decision-making process regarding supplier selection. The suppliers are chosen at the end of this process model.

The process model ends with the selection of suppliers therefore no activities occur after supplier selection. The process model would be more comprehensive if it included supplier evaluation activities after the supplier selection process. In the real world, OEM’s proceed to evaluate supplier performance after selection. This is not only logical but has been stated by Chen (2011) and Le Dain (2011). Furthermore, this process model does not include certain activities such as supplier development, requesting a prototype from the supplier and even though criteria were used, the criteria were not weighted and compared against one another.

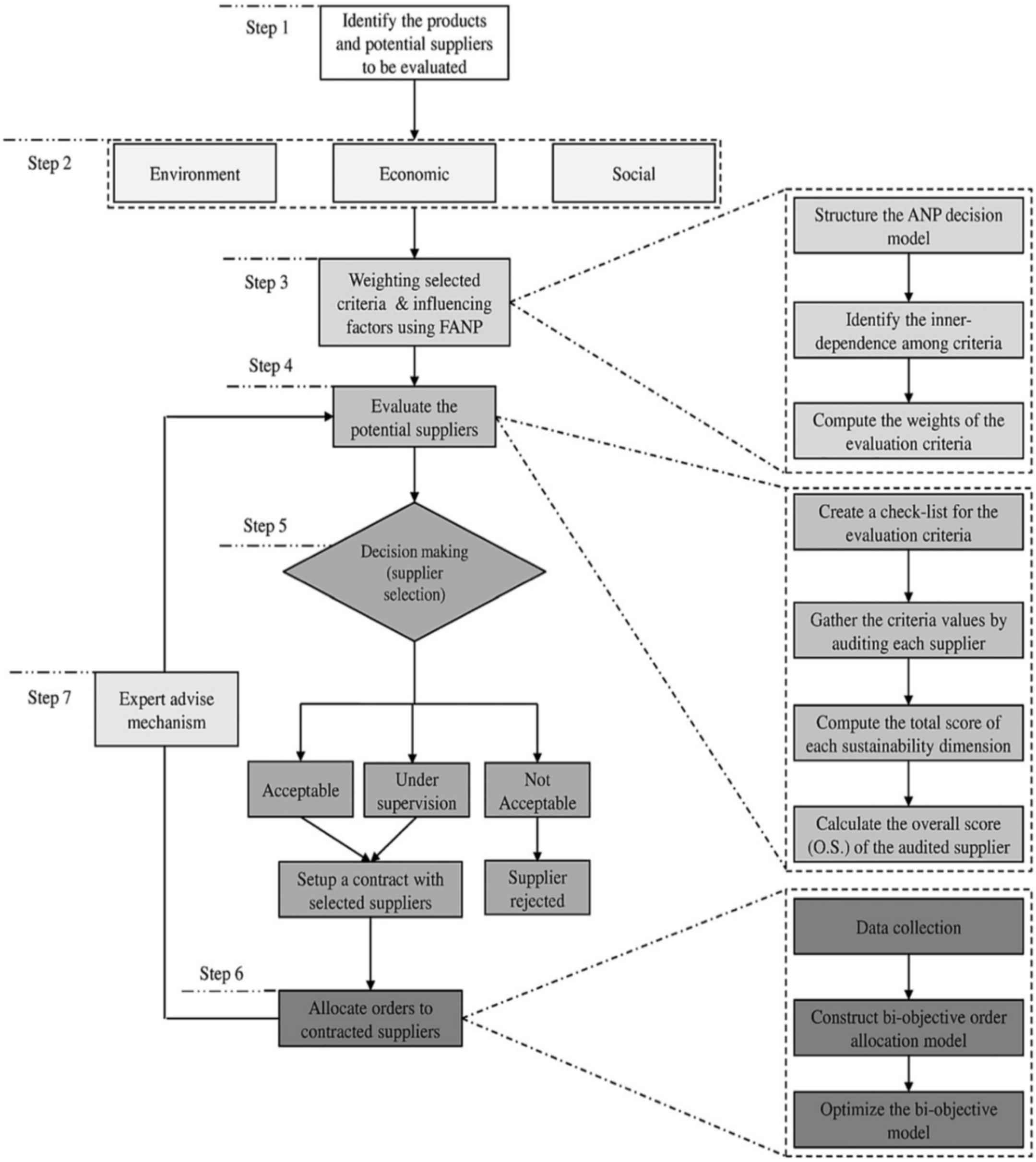

Figure 3-14 Supplier selection and order allocation framework (Ghadimi et al., 2017)

Figure 3-14 depicts the framework developed by Ghadimi et al., (2017). Like the previously mentioned process models, the first step of this framework involves the identification of the product/requirement. On the other hand, contrary to the process models of Abdolshah (2013), Chen (2011) and Handfield et al., (1999) who all separated the activity of requirement identification from supplier identification. It would be more beneficial to the OEM if the identification of the requirement is separated from the identification of suppliers. This allows the OEM focus more on having the best possible understanding to the requirement. A tool that may assist the OEM in determining the requirement is SWOT analysis which was used by Chen (2011) but not used by Ghadimi et al., (2017).

Step 2 in the Ghadimi et al., (2017) framework relates to the selection of criteria by DMs. NGT was used in order to ensure the selection of criteria is unbiased. The selected criteria are then weighed against one another in step 3. The use of weighed criteria allowed for the selection calculations to be more precise because the weights capture the expert opinion of the DMs. The performance score for each supplier is attained in step 4 and the decision-making process takes place in step 5, based on the supplier scores in step 4. Following step 5, it can be seen that there are three options with regards to how a supplier is selected (acceptable, under supervision and not acceptable), this further buttresses the idea that supplier selection is not only a yes or no decision as mentioned by Kahkonen et al., (2015) and Handfield et al., (1999). This framework, however, does not make note of supplier development, instead provides two options for selecting suppliers which are *acceptable* or *under supervision*. Step 7 can be considered as a continuous improvement mechanism, where the OEM continuously re-evaluates contracted suppliers to ensure supplier performance is always optimal. The framework also does not include a two-stage supplier selection process where supplier assessment occurs in order to reduce the total number of suppliers for the supplier selection process.

3.13 **Research Gaps**

1. There is a difference of opinion on what constitutes as assessment criteria, selection criteria and supplier evaluation criteria in product design and development.

2. Previous PD models have been unable to fully tackle the evolving challenges that still plague OEM and supplier during the process of outsourcing design and development in new product development.

3. There is no clear and comprehensive framework to assess, select and evaluate suppliers during the process of outsourcing product design and

development within the supply chain.

3.14 **Summary**

This chapter has offered an extensive review of the scientific literature in the region of product design and development within the supply chain. The definitions and history of SCM were discussed in order to provide a foundational background for product design and development within the supply chain. An overview of new product development was also presented, showing the current practices of product development.

The reasons for an OEM to outsource their design and development activities to external suppliers was presented. This was presented and the reasons discussed in some detail. The process of design and development outsourcing was detailed and broken down into the supplier assessment, supplier selection and supplier performance evaluation. There was very little research regarding supplier assessment as most scholars focus mainly on the supplier selection process alone.

Previous OEM and supplier product development process models were discussed in detail. It was found that some process models possessed activities that were not present in others but none of the process models possessed a complete set of activities that begin with supplier assessment and end with supplier evaluation.

Finally, the author presented a number of research gaps found within the area of product design and development outsourcing. The proceeding chapter presents the industrial perspective of product design and development with an analysis of the most significant questionnaire responses.

4 INDUSTRIAL PERSPECTIVE OF PRODUCT DESIGN AND DEVELOPMENT

4.1 Introduction

This section shows the current industrial practices and perspectives on product design and development outsourcing. The information about the industrial practices were captured as a result of the field study. Section 4.2 explains the method used to carry out the field study as well as selected numerical information relating to the interviewees. The basis for the design of the questionnaire was related to important research regions of section 4.3. Section 4.4 contains samples of the data analysed from the field study. Chapter 4 concludes with 4.6 where a chapter summary is presented.

4.2 Industrial field study approach

Following the completion of the extensive literature review as well as the identification of gaps in the research in chapter 3, it becomes necessary to conduct an industrial field study to attain an insight into the current practices of organisations as well as become more conscience of the industrial dynamics within them. The goals of the field study were to gain familiarisation with current product design and development outsourcing practices, capture the perspective of product design and development outsourcing and engage with the industry in order to construct the product design and development design and development framework. The field study largely outlines a few activities carried out, including face-to-face interviews using a semi-structured questionnaire, site visits, discussions with designers and engineers, and the collection of data linked to the current design and development outsourcing practices.

The industry interactions while conducting this study are illustrated in table 4-3. The interactions commenced with initial industrial pre visits. The subsequent progression of the research led to the full case study being undertaken with the use of semi-structured questionnaires as well as other interactions with a number of engineering organisations from different sectors, as highlighted in table 4-3.

Five interviews were carried out in a face-to-face format. The professionals interviewed involved largely manufacturing engineers as well as designers. 60% of the participants have held their position for at least 5 years, 40% had 10 years of experience or more. The results show that the field study respondents were diverse with varying skill sets, therefore ensuring the authentic nature of the study. The next section shows questionnaire design based on important areas of inquest.

Table 4-1 Respondents who participated in the field study and their organisations

No	Company	Sector	Position	Years of experience
1	Technip UK Ltd	Engineering and Project management	QHSES Programs Manager	10+
2	Collins Aerospace	Aerospace and Defence	Head of Operations	10+
3	Siemens	Engineering Infrastructure	Data and Design Engineer	5+
4	Collins Aerospace	Aerospace and Defence	Materials Manager	5+
5	JLR	Automotive Engineering	Systems and Commodity Engineer	5+

The sample size of 5 interviewees was considered to be appropriate because several informal discussions were had with other members of industry and it became clear that there are certain patterns in engineering design and development that most organisations follow. Furthermore, it was important to have two interviewees from the same organisation because of the value that was gained from discovering how different business units operate with different processes within the same organisation. Furthermore, the respondents represent four distinct engineering sectors.

4.3 **Design of Questionnaire**

In order to comprehend the current design and development outsourcing practices OEMs and suppliers engage in, a semi-structured questionnaire was designed. This was based on the inquest of the findings from the literature review, as listed:

1. The decision-making strategy (chapter 3, section 3.4)
2. Supplier assessment and selection (chapter 3, sections 3.5.1 and 3.5.2)

The discussion that follows represents how the 5 important questions were developed. The basis of the questions as they are related to the literature is discussed. A discussion is also had about the purpose of each question as well as the anticipated projection of result visualisation. The questionnaire can be found in Appendix A. 1, the following section depicts a sample of the analysis of the results.

Inquest 1: When does the OEM need to outsource its product design and development activities, who are the people involved and what procedures are followed?

Chapter 3 initiated with a detailed discussion of supply chain management, including an overview, definitions and history. The chapter moved on to a discussion about the outsourcing process, initiating with the reasons OEMs decide to outsource their design and development activities as discussed in section 3.3. The following questions were produced to give an opportunity to grasp the industrial version of the information in the literature.

(1) Which of the following are important drivers for your company to outsource the design and development activities?
(2) Which of the following make a good representation of the responsibilities involved in design and development activities?

The reason Question 1 was produced is for the identification of the reasons that require the OEM to outsource design and development activities as well as the importance of each reason. A list of reasons to outsource was presented to the respondents as they were asked to indicate the level of importance associated to each criterion, illustrated in figure 4-1. The main reason the question was design in this format was to grasp the criteria used by OEMs as well as how important they believe each criterion is with regards to outsourcing their design and development processes. If there is a reason to outsource not used by the interviewee, the corresponding boxes related to importance are left blank.

Which of the following are important reasons for your company to outsource the product development?

Reasons to outsource design and development	**Importance**				
	Very low	*Low*	*Normal*	*High*	*Very high*
1. Reduce design and development cost					
2. Reduce design cycle time					
3. Faster product launch					
4. Lack of skills or experience (knowledge)					
5. Market availability					
6. Lack of tools or techniques (in-house capability)					
7. High operational and financial risks					
8. Others:					

Figure 4-1 Question 1 relating to the reason OEMs outsource their design and development activities

Question 2 builds upon the literature findings and seeks to identify the responsibilities of each party at the initial phase of the outsourcing project. The questions aim to ascertain who is responsible for outsourcing the design and development as well as the skills of the people involved. The layout of the questions is not dissimilar to question 1 where a list is offered that contains information found in the literature review, and respondents are requested to choose the most suitable answer that is the closest to their current practices. Only one answer can be chosen from the list.

Is there a technical leader who is responsible for the entire development of a product from concept to launch? How effective do you find this leadership? (Select one)

Options	
❑	1. There is neither a technical leader nor a project leader, who has the responsibility for the entire PD of a product.
❑	2. A project leader (non-technical) has responsibility for the entire development of a product.
❑	3. A project leader (non-technical) has responsibility for the entire development of a product while an engineer or a group of engineers share some responsibility.
❑	4. A single chief engineer has the technical responsibility and competence for the entire development of a product.
❑	5. A single chief engineer has the technical and management responsibility as well as the competence for the entire development of a product.

Figure 4-2 Question 2 relating to the responsibilities within the OEM organisation

Inquest 2: The criteria used to assess and select suppliers for outsourcing in product design and development.

After identifying the OEM's reasons to outsource and the team of employees involved in the decision making, the details of the outsourcing process was further explored revealing the processes involved in assessing and selecting suppliers for outsourcing product design and development. The details of this are provided in Chapter 3, Sections 3.5.1 and 3.5.2. The second enquiry seeks to identify the criteria used to assess and select suppliers from an industrial perspective; therefore, two questions were populated.

(3) What criteria do you use to assess product design and development suppliers?

(4) What criteria do you use to select product design and development suppliers?

Based on the review of the assessment criteria in Chapter 3, section 3.5.1, the criteria were only mentioned by small number of authors when compared to the mentions of supplier selection criteria by authors. This meant that it was important to find out if the industry makes use of these criteria. Table 3-3 in Chapter 3 depicts the list of supplier assessment criteria found in the literature, as well as the authors who stated them. The question shown in figure 4-3 gave the interviewees the option to select the criteria they use as well as select the importance of each criterion when assessing design and development suppliers. The importance of each criterion is critical as it allows for an AHP matrix to be developed, ranking each criterion and thereby giving a weight to each criterion for supplier assessment. Any criteria that are on the list but not used in the interviewee's organisation are left blank.

What criteria do you use to assess product design and development suppliers?

Assessment criteria		IMPORTANCE				
❑	1. Supplier commitment	❑ 1	❑2	❑3	❑4	❑5
❑	2. Supplier growth potential	❑ 1	❑2	❑3	❑4	❑5
❑	3. Technical competence	❑ 1	❑2	❑3	❑4	❑5
❑	4. Innovation and technical expertise	❑ 1	❑2	❑3	❑4	❑5
❑	5. Business knowledge	❑ 1	❑2	❑3	❑4	❑5
❑	6. Trust	❑ 1	❑2	❑3	❑4	❑5
❑	7. Openness	❑ 1	❑2	❑3	❑4	❑5
❑	8. Flexibility to align their process with my processes	❑ 1	❑2	❑3	❑4	❑5
❑	9. Other	❑1	❑2	❑3	❑4	❑5

Figure 4-3 Question 3 relating to assessment criteria

Question 4 seeks to find out the criteria used to select suppliers from a smaller more competitive pool of suppliers, after several suppliers have been disqualified due to the lack of meeting the capability requirement of the OEM. The supplier selection process is a more detailed process and determines the suppliers who will partake in the product design and development activities alongside the OEM.

What criteria do you use to select product design and development suppliers?

	Selection criteria		IMPORTANCE				
❑	1. Warranty Policies		❑ 1	❑2	❑3	❑4	❑5
❑	2. Design cycle time		❑ 1	❑2	❑3	❑4	❑5
❑	3. Price performance value		❑ 1	❑2	❑3	❑4	❑5
❑	4. Capacity of supplier		❑ 1	❑2	❑3	❑4	❑5
❑	5. Capability to handle abnormal quality		❑ 1	❑2	❑3	❑4	❑5
❑	6. Purchasing cost		❑ 1	❑2	❑3	❑4	❑5
❑	7. Quality systems		❑ 1	❑2	❑3	❑4	❑5
❑	8. Flexibility to align their process with your processes		❑ 1	❑2	❑3	❑4	❑5
❑	9. Technology capability		❑ 1	❑2	❑3	❑4	❑5
❑	10. Performance history		❑ 1	❑2	❑3	❑4	❑5
❑	11. Supply risk		❑ 1	❑2	❑3	❑4	❑5
❑	12. Other		❑ 1	❑2	❑3	❑4	❑5

Figure 4-4 Question 4 relating to supplier selection

4.4 Field study results and industrial opinion on product design and development outsourcing

This section consists of a discussion which has two parts, the former depicts a sample of the data analysis and the latter dedicated to the industrial opinions on design and development outsourcing.

4.4.1 Analysis of field study data

This section presents a graphical illustration sample of the analysed data from the field study. The enquiry areas in section 4.4.3 served as the basis of the analysed data.

Sample 1: Which of the following are important reasons for your company to outsource design and development?

When an OEM starts to consider outsourcing their design and development activities, it is important for first determine the reason why the outsourcing would be beneficial to the organisation. The design of the question gave the interviewees choices from a list of possible reasons to outsource. The interviewees were given the opportunity to add any reasons to outsource that were not on the list. The reasons to outsource were also given put on a scale of importance from 1-5 then the average importance was taken from each interviewee and then averaged and converted into percentages depicted on the Y axis. This was necessary as it allows the interviewees to show the impact that each reason to outsource has on their organisation.

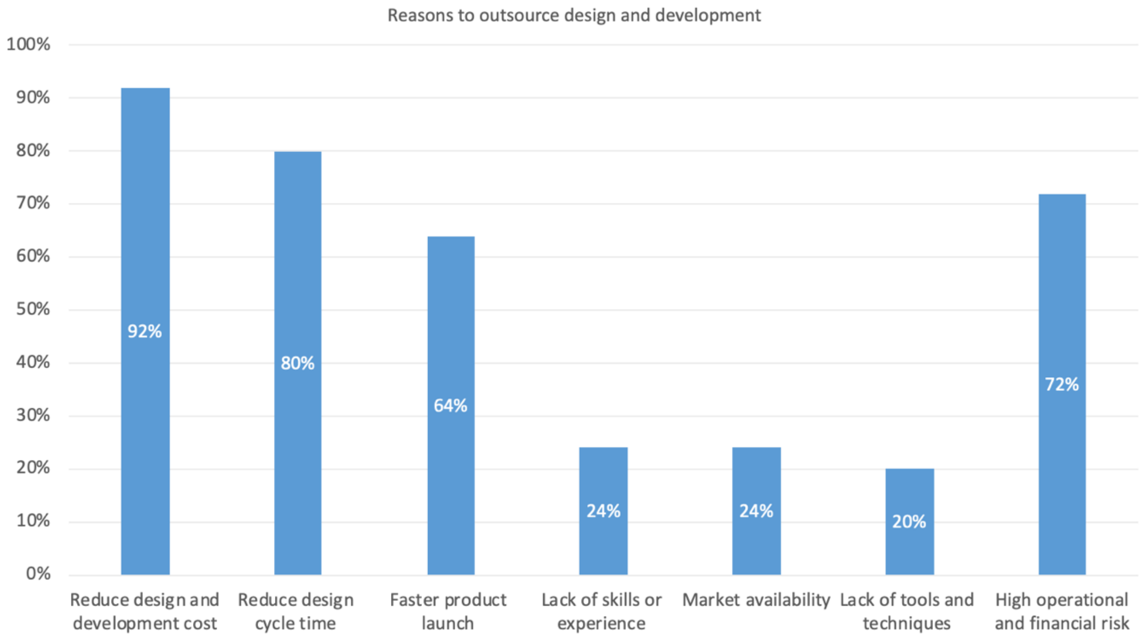

Figure 4-5 Results showing the importance of each reason to outsource

From the results shown in figure 4-5, it is clear that majority of the interviewees considered “reduce design and development cost” as the most important reason to outsource. This coincides with Yen & Hung, (2017) who state that reducing design and development cost is the most important reason for an OEM to outsource to suppliers when developing a new or unfamiliar product. This is because the OEM weighs the cost of making changes to their facilities and processes against paying suppliers who are already skilled at those processes and decide that involving suppliers is cheaper in that instance. Ghadimi et al., (2017) stated that cost cutting was tradition the most important reason to outsource in the past but recent times have seen a move from cost cutting to faster product launch as the main reason for OEMs to outsource their design and development activities to suppliers. Design cycle time resulted as the second most important reason to outsource. This result is not surprising as it can be seen as correlating with the statement of Ghadimi et al., (2017) regarding faster product launch. This is due to the relation between design cycle time and the launch of the product, having a faster design cycle time logically increases the chances that a product can be launched faster than if the design cycle time was longer.

The interviewees also placed high importance on outsourcing to reduce operational and financial risk. During the interviews, discussions were had around the topic and reducing operation and financial risk was deemed important especially in scenarios where the OEM was entering a new market and was unsure about product performance. Yao et al., (2010) stated that OEMs would typically enter into a gain-sharing contract with suppliers in order to mitigate financial and operational risk.

Lack of skill, lack of tools and technique and market availability scored the lowest in importance even though the literature review resulted in three papers mentioning each of the three reasons as very important reasons to outsource. Mohamad et al., (2015) suggested that OEMs involve suppliers into their product development process because they lack the skills which the supplier possesses and want to also secure access to the supplier's technology and core competences.

In conclusion, it is clear to see that the reason to outsource is very important in any OEM organisation. When OEMs have a clear understanding of their reasons to outsource, they are more likely to select the appropriate suppliers. There are several reasons to outsource which have varying levels of importance. The results show that even though some reasons score higher than other, the reason to outsource will always depend on the organisation and the project that is being outsourced.

Sample 2: Is there a technical leader who is responsible for the entire development of a product from concept to launch?

When an OEM is to embark on a new project, it is important to establish leadership at the early stages of the project. This ensures that the people involved have an understanding about the authorities involved in the project. The question gave interviewees the five option where only one answer could be selected. The individual option chosen by each interviewee was collected and averaged. The average was converted into percentages which are depicted on the Y axis. The selected answer would be the one that most closely relates to the current practices within their organisation.

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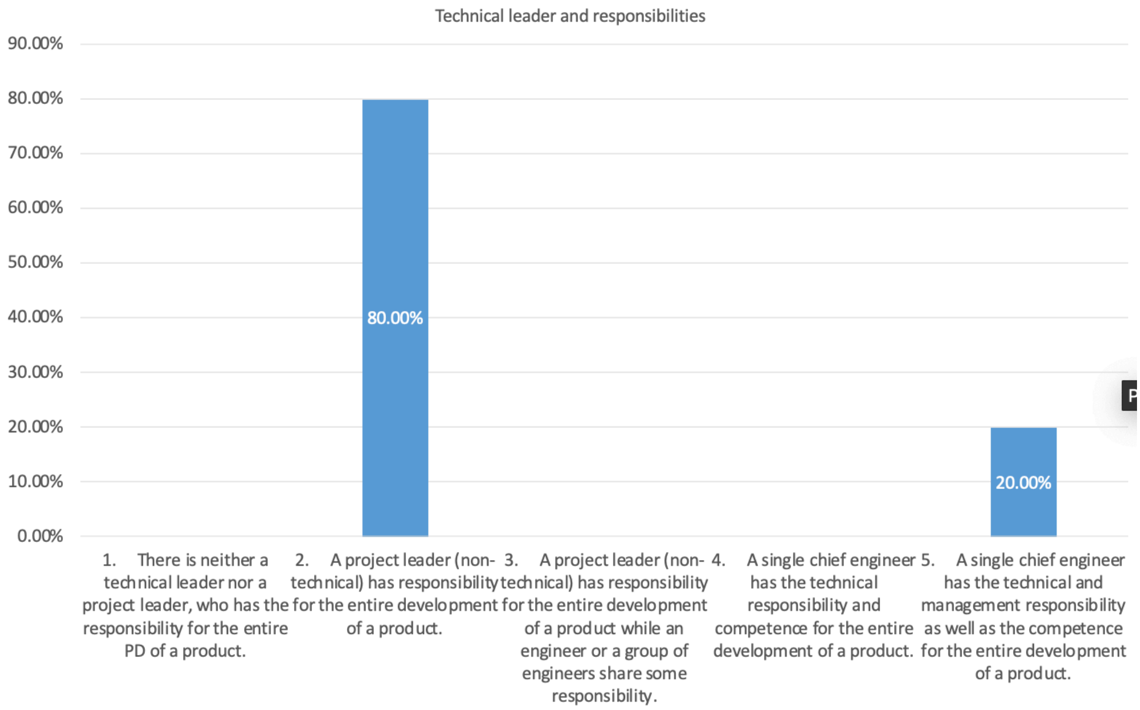


Figure 4-6 Results showing the responsibilities of a technical leader

The results in figure 4-6 are quite clear in noting that the majority of interviewees chose the second option which states that whenever there is a project, a project leader is assigned who is non-technical and is responsible for the entire development of the product. This shows that it is more important for a project lead to have more managerial skills than technical skills because the subordinates who are engineers and designers possess the technical skills required. The only other option chosen by interviewees was the option relating to a chief engineer who has the technical and management responsibility as well as the competence for the entire development of a product. It is interesting to note that this option is significantly less than the first option. This suggests that even though there are some organisations who have technical chief engineers lead product development projects, it is more common to have a non-technical project leader. None of the previous process models reviewed in Section 3.12 mentioned a project lead of any kind. Nevertheless, having a project lead is very important to every project and therefore a framework that relates to product development. The interviewees pointed out that every project undertaken by their organisations always appointed a lead.

In conclusion, it is evident that a leader is required in every product development project. The previous process models reviewed did not discuss the involvement of a project leader or what role the leader would play, nor were the leaders qualifications discussed. Parthiban et al., (2013) on the other hand, discussed decision-makers who assume control during a project and can be seen as project leaders. Even though the decision-makers were mentioned, very little detail was provided regarding their exact role or experience. This makes it clear that a more robust framework is required that includes the involvement of a project leader who is skilled enough to delegates tasks in a manner that ensures optimal performance from both the OEM and suppliers.

Sample 3: What criteria do you use to assess product design and development suppliers?

Selection of the right suppliers is an integral part of the outsourcing process between OEM and supplier. Design and development engineers utilise assessment criteria in order to narrow the field of suppliers down before the supplier selection activities. The question's design obligated the interviewee to select the assessment criteria utilised by their organisation, as well as the importance of each criteria. The importance rating for each criterion was divided into five levels. The importance of each criteria was rated from 1-5. The least important was rated as 1 while the most important was rated as 5. An average was created following the amalgamation of the results.

Figure 4-7 Results showing the importance of each assessment criterion

The results in figure 4-7 are quite interesting as they show that there are a few criteria which are considered to be extremely important. It is important to firstly note that all the criteria from the literature review are being used by all respondents, this corroborates the findings of the literature review. The Y axis depicts the respondent's opinion on the importance of each criterion. The importance of each criterion was provided by the respondents then averaged and converted into a percentage of the total possible score. Business knowledge, trust and technical competence appear to be the most important criteria according the field study results. Conversely, supplier growth potential was seen as the least important assessment criteria from this list. Interviewees noted that the growth potential of the supplier is not of great importance as OEMs generally have different suppliers for different products and projects. These aforementioned suppliers possess different skill levels as well as capacity, therefore the growth of one particular supplier is not unimportant, but less important when compared to the other criteria shown in figure 4-7. Supplier commitment is of great importance, especially during supplier assessment activities. The importance of supplier commitment stems from the desire of the OEM to know that the upper management within the supplier are essentially willing to participate in the outsourcing of product design and development with the OEM. The aforementioned information is important towards the beginning of the process of choosing suppliers as a later discovery of a supplier’s lack of commitment means the OEM may have already lost valuable time and resources before having to return to the beginning of the process. Due to the scarcity of information regarding the supplier assessment process in the literature, there are no surveys carried out that suggest the importance of each assessment criteria.

A conclusion can be drawn from the aforementioned results that the use of assessment criteria is an important method for assessing suppliers before the more resource intensive supplier selection process. This therefore emphasises the opportunity to have a comprehensive method for assessing suppliers which is simple and easy to follow. This is a contrast from the common methodology today where numerous unique criteria are developed for individual potential suppliers.

Sample 4: What criteria do you use to select product design and development suppliers?

When the field of suppliers is narrowed down to a smaller more competitive field, supplier selection activities take place in order to select the suppliers who will be integrated into the OEMs product design and development processes. The design of the question is similar to the design of the question in sample 1 where the interviewee is given the option to select the selection criteria they currently use in their organisation, as well as rate the importance of each criterion. Ratings of 1-5 were provided for each criterion and the interviewees were given the option to select how important each criterion was from that range. The most important criteria were given a 5 rating while the least important were given a 1 rating. The results were gathered, and an average was produced.

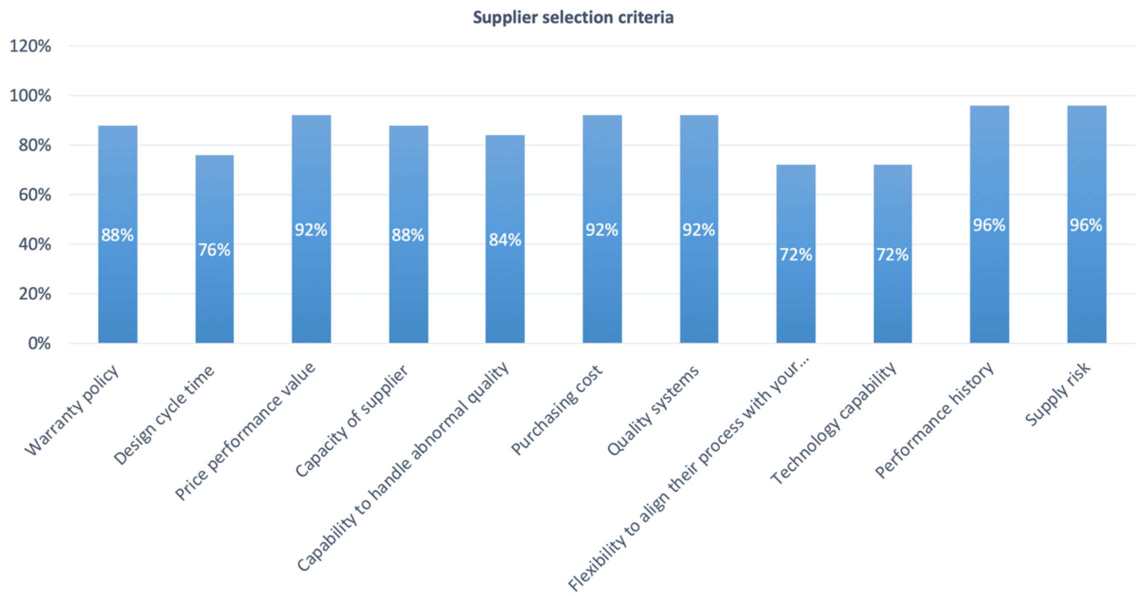


Figure 4-8 Results showing the importance of each supplier selection criterion

The results in figure 4-8 are more diverse than the supplier assessment results depicted in figure 4-7. Both supplier performance history and supply risk were rated as the most important criteria by the interviewees. The aforementioned criteria scoring the highest is not surprising because all interviewees stated that a supplier's performance history is a strong indicator of their future performance. This somewhat corroborates the findings from the literature as Abdolshah, (2013) ranked 23 criteria and found performance history to be the third most important. Wasti & Liker (1999) did not rank performance history but noted that it provides the OEM with a strong indication of the behavioural tendencies of the supplier and has a very strong positive effect on supplier's involvement in product design. The supply risk is also notable because it can be concluded that supply risk shares a relationship with performance history. If the supplier has previously had issues such as delivery failure, price increase, inadequate quality of the design, etc. these past issues increase the supply risk for future outsourcing projects within product design and development. Based on the research, it was surprising to note that design cycle time scored lower than almost all the other criteria. Respondents noted that even though design cycle time is important, it would be preferred if some extra time was spent in ensuring the right design is completed to the highest standards. Liker et al., (1998) suggested design cycle time is very important as it affects the speed of the entire product development process which would give the OEM an advantage over competitors if their products reach the market faster. The aforementioned statement by Liker et al., (1998) contradicts the field study findings which ranked design cycle time rather low when compared to other criteria. The ranking of design cycle time differing from the literature could be due to the market now focusing more on higher quality products than speed to market. Goren (2018) noted that companies now gain a lager benefit from higher quality product which helps in customer acquisition and retention than a lesser product which was launched faster.

Warranty policy relates to the quality of the design produced by the supplier because a longer policy denotes the supplier is confident in their design and therefore the design is of good quality. Ebrahimipour et al., (2015) suggested that warranties are of great importance to the OEM but it does not determine the supplier who is chosen because all suppliers have some warranty policy in place.

The lowest scoring criteria are the flexibility of the supplier's processes and technology capability. The respondents noted that suppliers' process flexibility is not amongst the most important criteria because part of the reason they outsource is to make use of the processes of the supplier as opposed to their in-house processes.

In summary, the impression taken from the interviewees suggests that there is a lack of a well-defined criteria template of which to use to select suppliers for multiple projects. Nevertheless, when presented with a list of criteria, respondents were immediately able to realise the benefits of using such a technique. During an interview with an engineer, it was noted that even though they do have methods for selecting suppliers, none were as comprehensive and efficient as they would like.

Sample 5: What challenges do you face when integrating suppliers into your product design and development process?

Outsourcing design and development to suppliers comes with great benefits. However, there are also some drawbacks which have plagued the process. The question's design obligated the interviewees to select from a list of 10 challenges that they have faced in their past product design and development outsourcing projects. They were also encouraged to indicate the impact that each selected challenge had on the outcome of the outsourcing project. The impact rating for each challenge was divided into five levels. And the possible ratings were 1-5. A rating of 1 meant that the challenge had lowest impact on the overall progress of the outsourcing project while a rating of 5 meant the challenge had a massive impact on the project. The impact of each challenge chosen by the interviewees was collected and averaged. The averages were then converted into percentages which are depicted on the Y axis of figure 4-9.

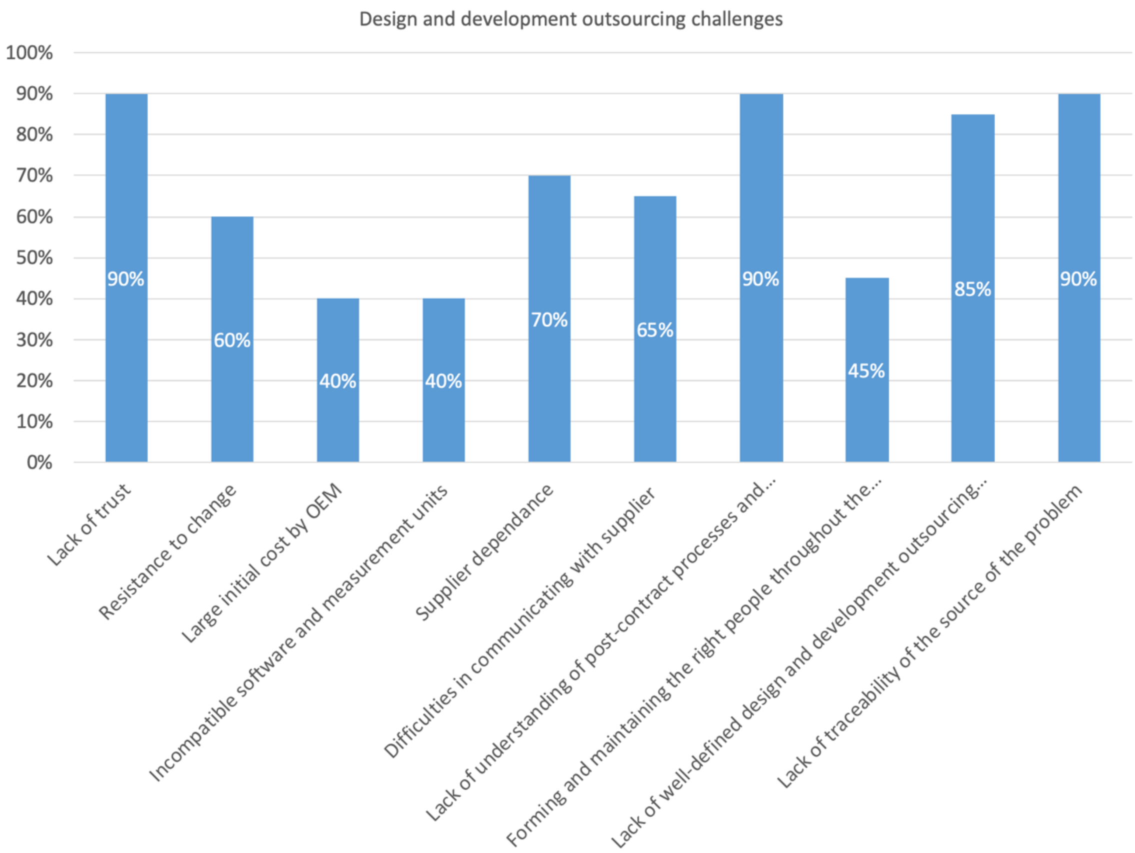


Figure 4-9 Results showing the impact of each challenge faced during design and development outsourcing

The results depicted in figure 4-9 show that there are three challenges which pose the largest impact on the design and development outsourcing process. The aforementioned challenges are lack of trust, lack of understanding of post contract processes and activities as well as lack of traceability of the source of the problem. The latter two challenges were said to cause severe delay, according to the respondents. Bunduchi (2013) suggested that lack of trust is the most impactful challenge faced by OEMs and supppliers when working together and trust plays an absolute vital role when OEMs outsource to suppliers. This statement was confirmed by the respondents as it scored the highest , along with lack of traceability of the source of a problem and lack of understanding of the post-contract processes and responsibilities. Lack of well defined guidelines for outsourcing product design and development was the challenge which was ranked and second most impactful, according to the respondents. The aforementionend is an interesting result as this criterion was not found in the literature but only realised during informal discussions with the industry proffesionals. This further justifies the need to have a comprehensive framework which guides the activities that take place during product design and development outsourcing. Difficulties in communicating with suppliers, supplier dependence and resistance to change all ranked quite high in terms of impact. All respondents noted that supplier dependece is something that they all worry about as it could lead to increased costs and other delays in the product design and development process. Large initial cost by the OEM and incompatible software ranked the lowest because respondents stated that the cost is a factor that they expect when making a decision to outsource and competition between suppliers means that suppliers are generally trying to cost less in order to seem more attractive. This is contrary to the findings of Primo & Amundson (2002) who found that the initial cost was a highly impactful challenge to OEMs.

Overall it can be concluded that there are a wide variety of challenges that need to be mitigated in order to improve the efficiency of product design and development outsourcing projects. Some challenges have a greater impact than others, but all challenges need to be addressed. The respondents generally welcomed a comprehensive framework which possesses the ability to tackle the challenges head on.

4.4.2 Industrial opinions on product design and development outsourcing

The previous section presented the results from the first part of the questionnaire. In this section, the results from the open-ended questions are discussed as well as the denotations of the received responses.

Sample 1: Could you briefly explain your company's strategy of product design and development outsourcing?

> Our company performs most of its R&D in-house, either in the UK or at the global engineering centres in Poland and India. Our company also owns these subsidiaries.
>
> The outsourcing outside the group is more prevalent in the manufacturing phase of product development.
>
> Looking at outsourcing from one business unit to another, we work collaboratively with our global engineering centres through our gated processes of UPI – UTC Product Introduction.
>
> The UPI goes from a P0 – P5
> *Proposal*
> *Preliminary Design*
> *Detailed Design*
> *Verification & Validation*
> *Production & Support*
>
> The Key elements to this are in stages below:
> *Requirements management*
> *Risk management*
> *Technology, Production, Service Readiness*
> *Part Families and Re-use (Head of operations strategy, Aerospace and defence)*

> Due to the specialised nature of our company's scope of supply in the subsea oil and gas sector, we do most of our product development in-house. Outsourcing is limited to specialised items or materials within a very limited scope and using trusted suppliers. *(QHSES programs manager, Engineering and project management)*

A deduction can be made that every organisation not only already has their outsourcing strategies in place but also outsource different parts of their product development process. The respondents also confirmed that outsourcing takes place between one business unit and another, within the same organisation, as mentioned in the literature review in Chapter 3. All respondents confirmed that their companies perform the majority of their product development in house and only outsource a small percentage. It was also found that trusting suppliers is very important and therefore a more robust method of selecting and evaluating suppliers was welcomed by all respondents.

Sample 2: What do you think is the criteria difference between supplier selection and supplier performance evaluation?

> Supplier performance evaluation as it states measures the performance of a supplier through set KPIs – these KPIs are defined in agreement with the OEM.
>
> In the case of product development, there are milestones associated with performance. i.e deliver a product or prototype design by a certain date to a cost and a defined scope, if the supplier reneges on those terms then an evaluation is necessary. The ultimate difference between supplier selection and performance evaluation is the yardstick used to select the supplier.
>
> The supplier selection matrix or decision tree will dictate if a supplier meets the specification for engagement, i.e. are the NADCAP or ISO 9001 certified? In essence, the criteria for selection already defined by the OEM and specification of work will determine the selection. *(Head of operations strategy, Aerospace and defence)*

> Supplier selection is speculative in the sense that we use known characteristics such as past performance to predict future performance and the ability to deliver while performance evaluation is a lagging indication of delivery against set and agreed criteria. We have developed a selection process which incorporates performance criteria and use technical risk assessment tools (e.g. PFMECA) in the selection and management process. *(QHSES programs manager, Engineering and project management)*

It was interesting to see the different ideas each interviewee had about supplier selection and supplier performance evaluation. A number of interviewees mentioned that supplier performance evaluation only takes place when the supplier reneges on the terms of their contract. The aforementioned statement can be seen as a justification for the design and development framework as it suggests the supplier's performance is evaluated on every project, regardless of contract fulfilment. This is suggested in order to ensure that the OEM always receives the best possible performance from the supplier as well as ensuring that the supplier is still up to the task. Doing this will ensure the OEM always has a competitive advantage and does not have to wait for an error to occur in order to search for improvements.

4.5 **Major outcomes from field study**

The major outcomes from the field study can be described as follows:

- Criteria are always used when selecting suppliers, but the importance of each criterion is always dependant on the particular project suppliers are being selected for, and the overall focus of the OEM.
- Many challenges are still faced when OEMs decide to outsource their design and development activities. Trust in the supplier and communication with the supplier at the right time, using the right method, is still a factor that needs improvement.
- There is no common method of outsourcing that is utilised between different organisations and different sectors such as automotive, aerospace or oil and gas. This gives room for a framework that encompasses the activities of product design and development outsourcing but is also malleable in order for different sectors to utilise it in different ways.

4.6 **Summary**

The current industrial methods for outsourcing have been presented in this chapter. The chapter commenced with an explanation of the approach utilised for the field study and provided the details of the companies who took part in the field study. Following this, details about the development of the questionnaire was described before a sample of the results and industrial opinion on product design and development were analysed. The next chapter describes the development of the design and development framework by utilising the findings from the literature review as well as the industrial field study.

5 OEM AND SUPPLIER DESIGN AND DEVELOPMENT FRAMEWORK

5.1 Introduction

One of the objectives regarding this research is the development of a design and development framework between OEM and supplier during product development which encompasses the activities involved in assessing, selecting and evaluating suppliers in product development design and development. Information about the method used to complete this objective can be found in Section 5.2, a thorough account of the OEM and supplier design and development framework is conferred in section 5.3. This chapter's summary is presented in 5.4

5.2 Development of the design and development framework between OEM and supplier

The process of developing of the design and development framework between OEM and supplier was achieved using the logical sequence depicted in figure 5-1.

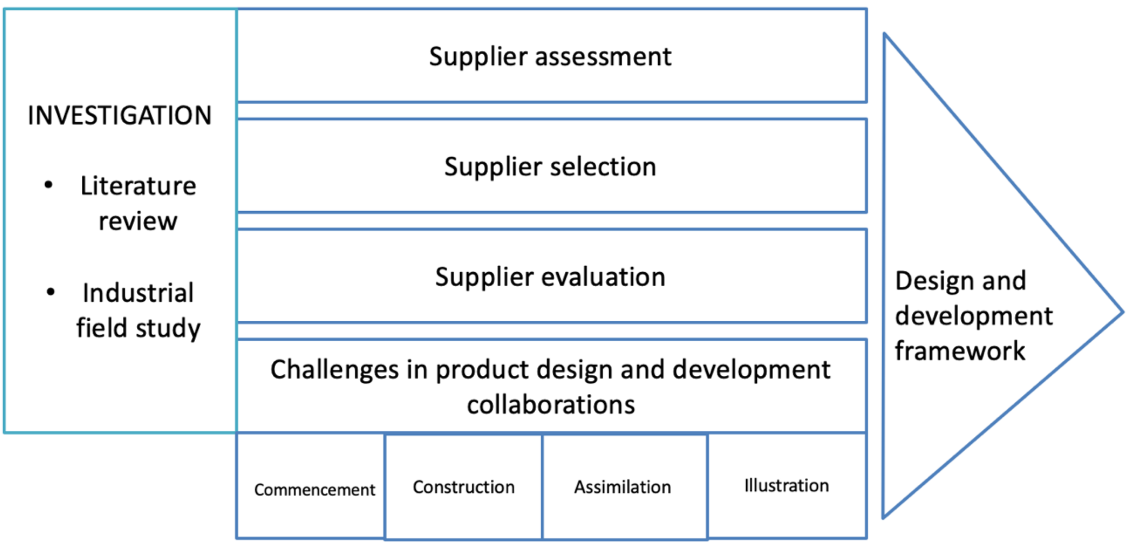


Figure 5-1 OEM and supplier design and development framework development process

The procedures for supplier assessment, selection and evaluation which were discovered as a result of the extensive literature review in Chapter 3, as well as industrial field study in Chapter 4, section 4.5 do not offer sufficient resources to the designer in achieving an OEM and supplier framework plan. Consequently, the necessity arose to cultivate a comprehensive design and development framework that would encapsulate the supplier selection process as well as the procedures performed to evaluate supplier performance after selection. The framework development was categorised into four distinct stages, seen in figure 5-8 and as a consequence of the development, the OEM and supplier design and development framework was developed. A description of the stages involved in developing the design and development framework is presented below:

Stage 1: Commencement

At the commencement of this research, the following questions were posed: (1) when does the OEM need to outsource its design and development activities? (2) What are the criteria that should be used to select suitable suppliers that will carry out the outsourced activities in product design and development? (3) How are the design and development capabilities of the supplier measured? And (4) what way should the OEM and supplier communicate to ensure the right development of a product?

The intent of this research is the designing and development of a framework capable of managing the activities involved in assessing, selecting and evaluating suppliers during the product development processes. The intended target audience are OEMs that currently have suppliers involved in their design and development processes or wish to involve suppliers in the future. The functional range of the design and development framework involves the following: (1) the provision of the appropriate criteria for supplier assessment, selection and evaluation, (2) mitigating the evolving challenges that occur during typical outsourcing projects between OEM and supplier (3) provide well-defined instructions about the responsibilities as well as activities required to successfully collaborate in product design and development.

Stage 2: Construction

Detailed studies and the conduction of workshops with partners broadly influenced the construction stage. The main focus of the construction aspect was to ascertain and put together the parts that makeup the framework as well as the ideal techniques to arrange it. The conclusion that the design and development framework would be categorised into consecutive phases was reached at the construction stage after careful deliberation and feedback from the industry professionals. It was also concluded that there would be five activities in each phase, making it easier for the OEMs who use the design and development framework to separate the procedures and complete them in a specific achievable order. Flexibility served as the main driver for the conclusion as it would entail the activities before and after selection. The activities before selection guarantee that the supplier is capable before selection and the activities after selection would ensure the suppliers continue to perform at a high standard and do not require replacement. A discussion of the framework contents is depicted in section 5.3.

Stage 3: Assimilation

The assimilation aspect of the framework development process focused on integrating the contents as well as attaining an equilibrium. Consistency was ensured for the phase transitions and redundant activities taken out. Additionally, the framework's contents were reviewed meticulously to ensure sufficient availability of information.

Stage 4: Illustration

The identification of the best approach to represent the framework was performed at the illustration stage. This was carried out to ensure the design and development framework would adhere to the need of the intended audience.

5.3 Previous design and development framework

This section presents some detail about the previous design and development frameworks that were created before the final version. The first version is called the conceptual framework and was developed before the literature review was completed and before any interaction with professionals from the industry. The layout and information displayed represents the preliminary findings from the literature review.

The second framework builds upon the conceptual framework and is titled the initial design and development framework. This framework is a result of further literature review as well as discussions with members of the industry. It adds steps and extra activities, making it more robust than the conceptual framework.

The penultimate version of the framework titled the second design and development framework had similar steps and activities with the initial framework but upon having exchanges with the members of industry, it was decided that the framework be divided into 3 phases. After several discussions and workshops with the industry, it was decided that 3 phases would be flexible and cover pre and post activities related to supplier selection in design and development. Pre-selection activities would ensure that the best possible suppliers are selected, and post-selection activities would ensure that the selected suppliers are encouraged to always perform at an optimal level.

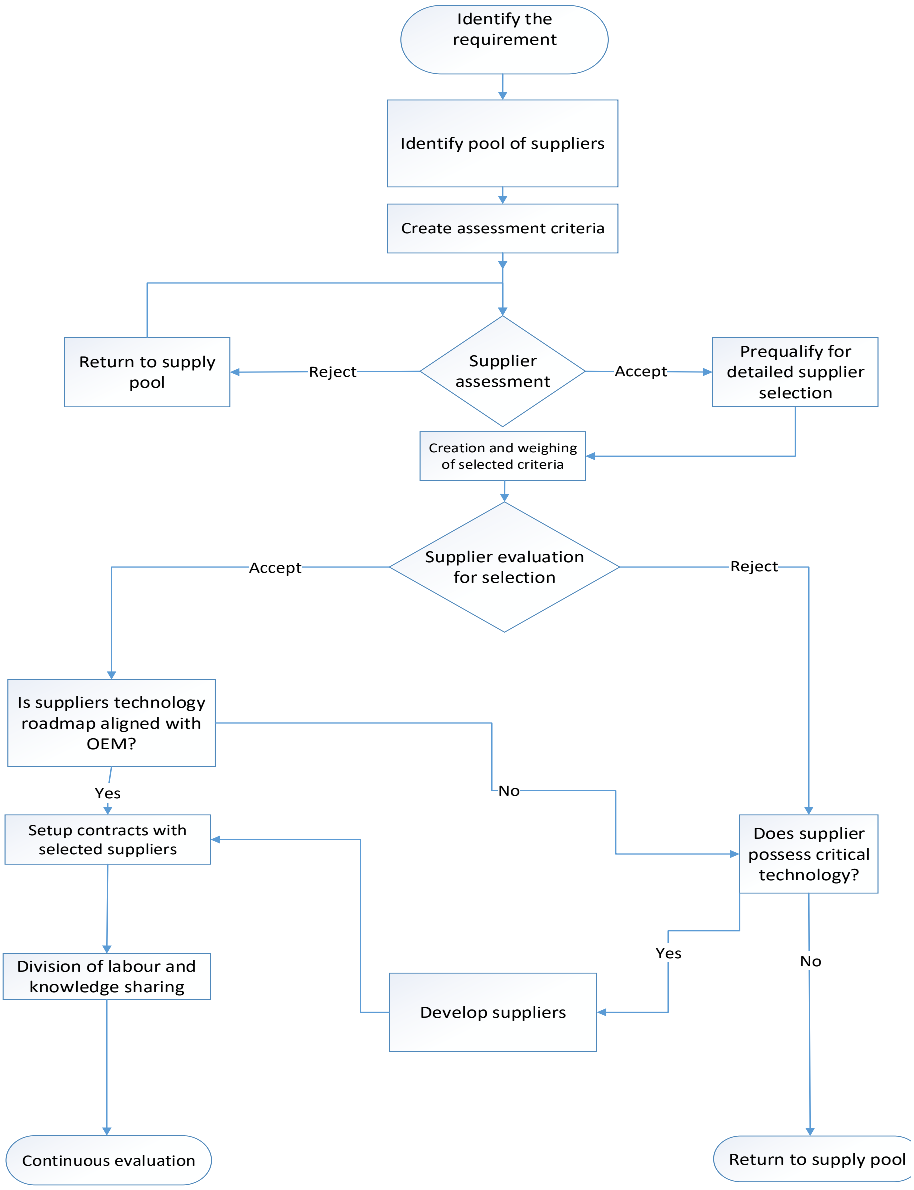


Figure 5-2 Conceptual design and development framework

The framework depicted in figure 5-2 shows the conceptual framework which was developed while the literature review was being carried out and before interactions with members of the industry via industrial field study. The framework in figure 5-2 is based on the supply chain models of Handfield et al., (1999); Ghadimi et al., (2017); Chen, (2011); Abdolshah, (2013); Spekman, (1988). The five models revealed that there was a common trend amongst them in the initial stage. This common trend is that the initial stage starts with identification, Handfield et al., (1999) and Ghadimi et al., (2017) initiate their frameworks with the identification of potential suppliers. However, Abdaolshah, (2013) and Chen

(2011) initiated their frameworks with the identification of the requirements/ products. The author decided to initiate the framework in figure 5-2 with the identification of the requirements because this activity logically occurs before any suppliers are to be considered. The next activity in the conceptual design and development framework is the identification of suppliers from a pool. All five process models make reference to this because it is an essential step when involving suppliers into an OEM’s product design and development process.

Following the identification of the pool of potential suppliers, the OEM is then required to begin a process that reduces the number of suppliers into a smaller, more competitive pool. The model of Handfield et al., (1999) talks about evaluating suppliers based on certain criteria but does not formally name this process whereas the models from Ghadimi et al., (2017) and Chen, (2011) mention the creation of criteria to be used for supplier evaluation at this stage as well as the weighing of each criteria against one another in order to determine which is the most important in each product development process. The framework of Abdolshah, (2013) mentions the process of reducing the number of suppliers to a smaller, more competitive pool as well. Spekman, (1988) used a two-stage process model where the first stage involves narrowing down the initial pool of suppliers before the next stage where suppliers are chosen as strategic partners. From the aforementioned process models, Spekman, (1988) and Handfield et al., (1999) both have a process model that involves narrowing down and initial pool of suppliers to a smaller pool before the final suppliers are chosen and Ghadimi et al., (2017), Chen, (2011) and Abdolshah, (2013) make reference to the use of weighted criteria to select suppliers, albeit only referring to one selection process.

Judging from this, the author decided to create the design and development framework to include processes where an initial pool of suppliers is assessed before leaving a smaller, more competitive pool of suppliers to go through a selection process. Based on the aforementioned use of weighted criteria for supplier selection, it was decided that the assessment criteria be weighted as well when used in the design and development framework. This addition makes the framework more robust than models of the past.

When suppliers successfully progress through the supplier assessment process, the smaller group of suppliers then undergoes a more detailed supplier selection process. The selection criteria are also weighed against one another in order to determine which criterion should carry the most weight. This weight is taken into consideration throughout the supplier selection process. All five models referenced a supplier selection process, however only Handfield et al., (1999) and Ghadimi et al., (2017) provide information regarding what the OEM should do if the supplier does not necessarily meet all the requirements provided by the OEM. Both authors recommend that suppliers who do not meet the requirement but possess critical technology needed by the OEM, should be developed before they are provided with contracts to work with the OEM. The author adapted this process into the design and development framework as it would allow the OEM to ensure they select the best possible suppliers for the job at hand.

The decision to add the activity called division of labour and knowledge sharing was made based on the information depicted in table 3-5 in Chapter 3 by Nellore & Balachandra, (2001) that details the different responsibilities a supplier may have when involved in the product development process of an OEM. The decision was also made because Handfield et al., (1999) and Ghadimi et al., (2017) emphasise the need to develop certain suppliers who do not meet the requirement but is selected due to the possession of critical technology. This means that suppliers are somethimes selected when they do not possess all the qualities that the OEM requires of them. This means that there should be a system within the framework that gives the supppliers higher or lower responsibilities based on their capabilities as well as what the OEM requires of them.

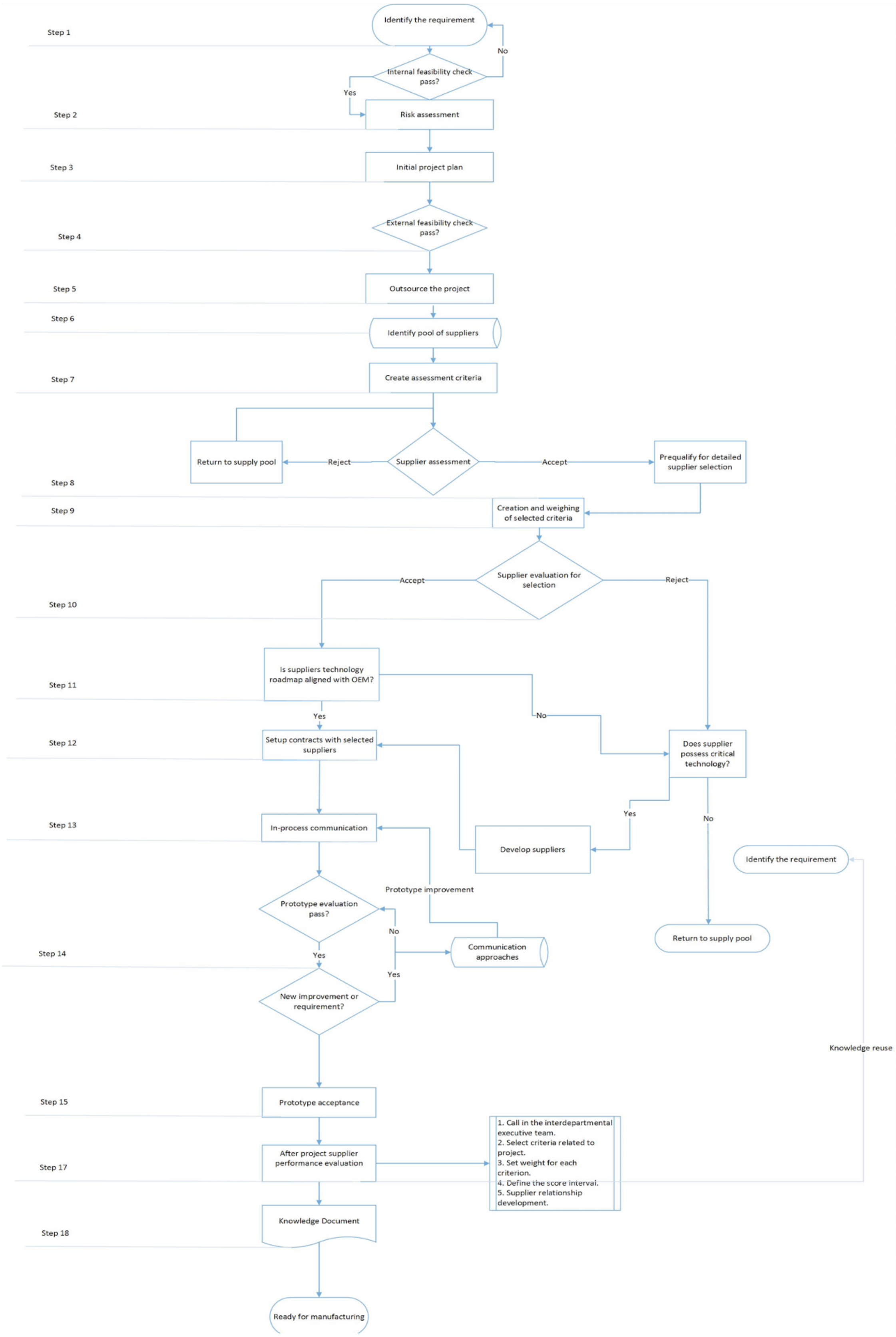


Figure 5-3 Initial design and development framework

Following the conceptual framework presented in table 5-2, more information was attained from the literature as well as new information derived from members of industry. The aforementioned activities led to the development of the initial framework depicted in figure 5-3. The initial framework depicted in figure 5-3 is more robust than the conceptual framework in figure 5-2 in several ways. One of the main differences is the addition of a steps as the industry professionals suggested this would make it easier for potential OEMs to carry out the activities within the framework and document their progress. Other changes include the internal and external feasibility checks, checking that OEM and supplier road maps are aligned and the inclusion of the OEM requesting prototypes from suppliers. The details of the steps and activities included in the initial design and development framework are detailed below:

Step 1

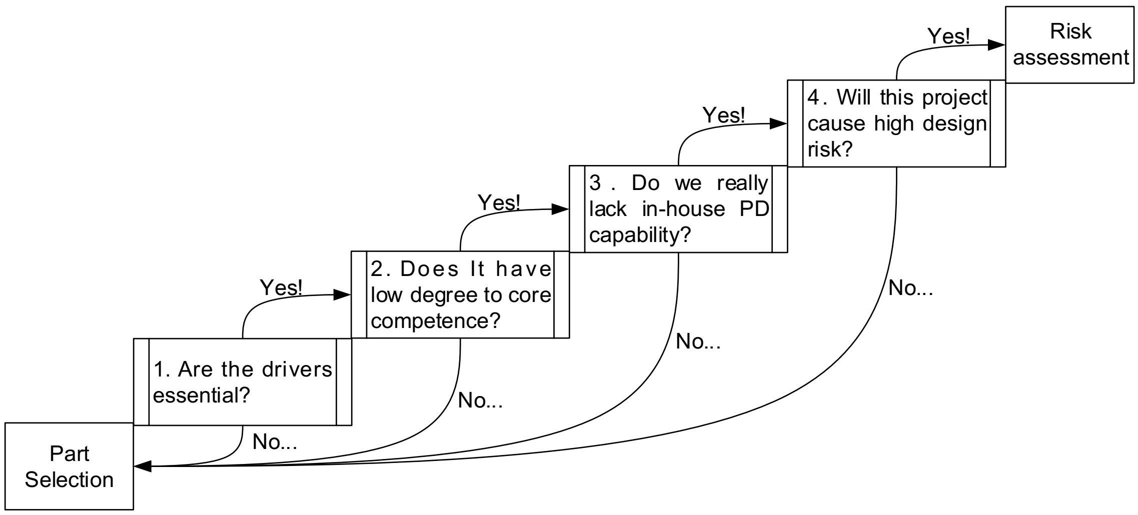
Activity 1: Members of the OEM discuss what product is to be outsourced and what benefits it could bring.

Activity 2: The OEM performs SWOT analysis to aid the decision of outsourcing a product or process.

Step 2

Activity 1: Check the feasibility of the project by having the critical elements reviewed. Four critical elements using a go/ no go model can be used.

Figure 5-4 Quick judgement model



Activity 2: Analyse the potential risks that may influence the product development outsourcing process as a last module of the feasibility check step. The risks can be analysed using failure modes effects analysis (FMEA). FMEA is recommended because it is a highly structured, systematic failure analysis technique (Ashley, 2010).

<u>Step 3</u>

Activity 1: Release initial project information such as detailed information about the product and the project.

Activity 2: Estimate the initial specification, timetable and budget.

<u>Step 4</u>

Activity 1: Check that the requirements can be aligned with potential suppliers.

Activity 2: expert judgement is made to ensure that a potential design and development outsourcing project is feasible. If it is not feasible then return to initial project plan. If it is feasible, then progress to step 5.

<u>Step 5</u>

Activity 1: Based on positive results from the external feasibility check, the decision to outsource the design and development of the project is made.

Step 6

Activity 1: Consult the company's internal supplier database to locate current suppliers and potential new suppliers who are suspected to be able to achieve the requirement.

Activity 2: New suppliers can be found through various methods such as peer investigation, colleague introduction and various other external databases.

Step 7

Activity 1: Create assessment criteria which are not only specific to the project at hand because potential suppliers who are successful may be used in future projects.

Step 8

Activity 1: Collect information about potential suppliers by communicating with the suppliers via phone calls, tele conference and email. Other information regarding the supplier can also be found online and via supplier both internal and external supplier databases.

Activity 2: Use AHP to calculate and rank suppliers based on information previously gathered as well as the assessment criteria created in step 7, activity 1.

Activity 3: Suppliers who rank the highest are prequalified for the next step which is the detailed supplier selection. Suppliers who rank the lowest are disqualified, therefore narrowing the pool of suppliers who are evaluated in the more resource intensive supplier selection step.

Step 9

Activity 1: Create supplier selection criteria that is not based only on the project at hand because potential suppliers may be used in future projects.

Activity 2: Based on expert judgement and customer requirements as well as AHP calculations and ranking, supplier selection criteria are calculated and weighed against each other, allowing the OEM to quickly see which criteria are the most important.

<u>Step 10</u>

Activity 1: The now smaller pool of suppliers undergoes detailed supplier evaluation based on the weighted criteria and information provided.

Activity 2: Communication during this step is carried out via face-to-face meetings, teleconference, OEM plenipotentiary in supplier's facility, supplier team in OEM's facility and email.

<u>Step 11</u>

Activity 1: After the detailed supplier selection, suppliers who ranked the highest against the weighted criteria move to the next step where the OEM decides which suppliers should be given contacts.

Activity 2: Suppliers who are deemed acceptable are given contracts.

Activity 3: Suppliers who ranked well but do not meet the specific requirements of the OEM are checked to see if they possess critical technology that the OEM needs. If they do possess this critical technology, the supplier is then developed by the OEM in order to ensure they meet the requirements. Suppliers who do not possess critical technology are return to the pool of suppliers.

<u>Step 12</u>

Activity 1: Suppliers at this step are given contracts which include product specification, timetable, budget, intellectual property policy, confidential issues, rights and obligations and agreed communication approaches.

Activity 2: Three types of contract forms can be offered to the supplier, depending on the type of relationship agreed upon with the OEM. The three types of contract forms are, fixed-price (fixed all-inclusive fees for predetermined services), Cost-plus (cost rise when additional events occur) and gain sharing (OEMs share cost saving s or cost overruns with suppliers).

Step 13 and 14

Activity 1: Communicate with suppliers at set points during the process via telephone, email, teleconference, face-to-face, OEM plenipotentiary in supplier's facility, and shared database.

Activity 2: The main communication should take place during the prototype testing and acceptance stages.

Activity 3: Ensure specification completeness and contract fulfilment by going through the steps that form the prototype improving loop in which multiple acceptance inspections could develop prototype performance.

Activity 4: Further communication contraposing specific problems will be arranged through different communication approaches.

Step 15

Activity 1: Prototype acceptance is a halt to the product development process. The technical work of the supplier stops at this stage, but the contract is still valid due to after-project work.

Step 16

Activity 1: Supplier performance evaluation criteria are generated, weighted and then used to evaluate suppliers based on their performance during the product development process.

Activity 2: Suppliers are informed about their performance and made aware of any areas in which improvement is required.

Step 17

Activity 1: A knowledge document resource is created which encompasses all the knowledge gained from both the project and the supplier, as well as the knowledge shared throughout the entire project. This knowledge is stored in a database for future reuse.

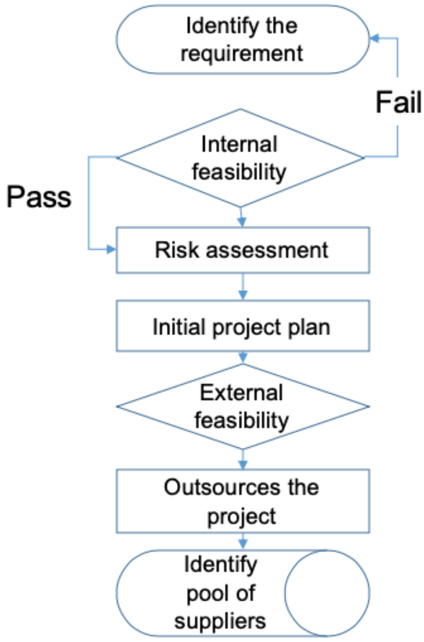


Figure 5-5 Second design and development framework phase 1: Decision making

The first phase of the second design and development framework is displayed in figure 5-5. The phase is titled decision making as it encompasses the decision-making activities to be undertaken by the OEM when deciding on involving suppliers into their design and development process.

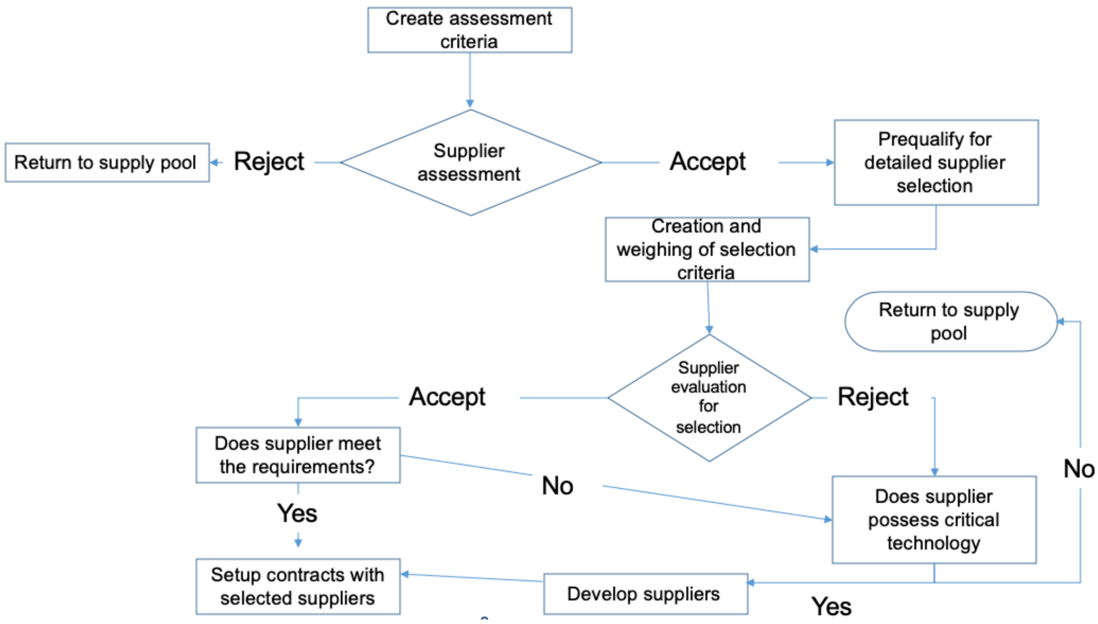


Figure 5-6 Second design and development framework phase 2: Supplier assessment and selection

The second phase of the second design and development framework is titled supplier assessment and selection and depicted in figure 5-6. During this phase, the original pool of suppliers is assessed and reduced down to a smaller pool of suppliers who then undergo supplier selection activities by the OEM.

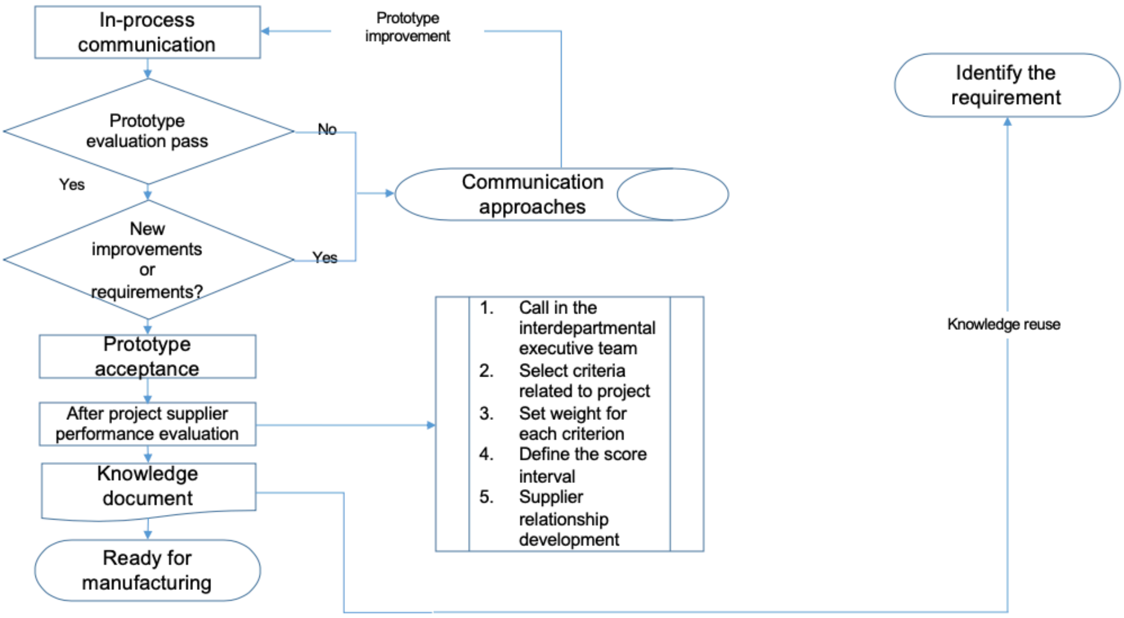


Figure 5-7 Second design and development framework phase 3: supplier management and evaluation

The final phase of the second design and development framework is titled supplier management and evaluation and shown in figure 5-7. This phase takes place after prospective suppliers have been selected and tasked with developing a prototype in order to demonstrate their capabilities. In this phase, the suppliers' design and development capability will be tested by OEM to ensure that a smooth partnership can be obtained going forward.

5.4 Design and development framework between OEM and supplier: An overview

This section presents the design and development framework between OEM and supplier as well as a description of its contents, as shown in figure 5-8. When a supplier is selected, it is necessary to manage the relationship between OEM and supplier. The OEM is also required to evaluate the performance of the supplier. For this reason, the framework has the following phases; (1) decision making, (2) supplier assessment and selection as well as (3) supplier evaluation and management. These aforementioned phases were built upon the similarly titled phases of the second design and development framework. The design and development framework depicted in figure 5-8 has more detail in each phase and each activity within the phases. The layout of the framework was changed as a result of feedback from the industry professionals as the new layout means the framework is easier and more straightforward to follow. This allows the OEM to fully understand how to properly implement the design and development framework.

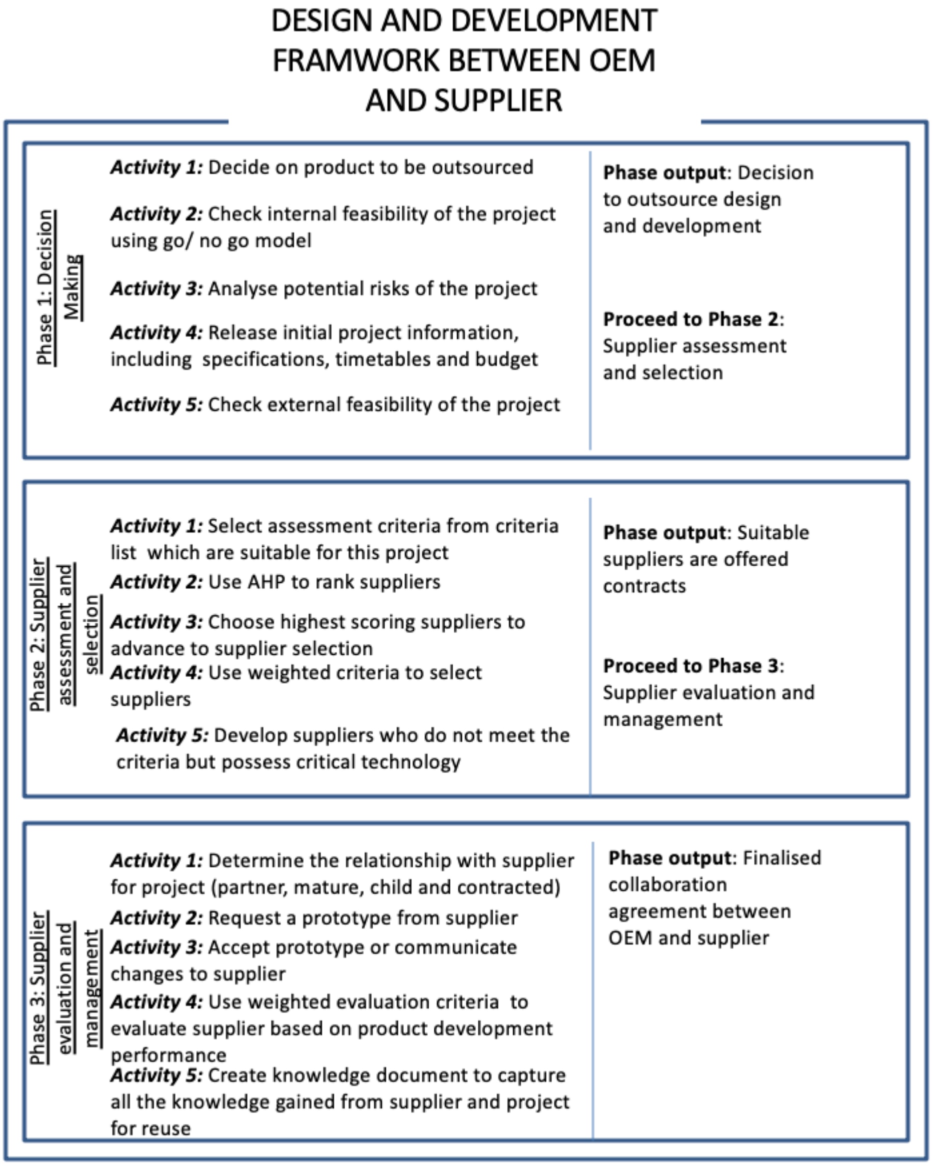


Figure 5-8 Design and development framework between OEM and supplier

5.4.1 Design and development framework between OEM and supplier Phase 1: Decision making

The first phase of the design and development framework between OEM and supplier is 'decision making', it aims to aid the decision of whether a product's design and development activities are to be outsourced or carried out in-house. In order to reach this decision, certain activities must take place. Firstly, the decision must be made on what product's design and development activities require outsourcing. To achieve this, the strengths and weaknesses of the organisation need to be addressed. The second activity requires checking the feasibility of the decision that was reached in the first activity. The third activity requires the investigation of the potential risks to the project before the initial project information is determined and released. Finally, the external feasibility of the project is determined before the decision can be made to outsource design and development activities. The following are details of the five activities in Phase 1.

Activity 1.1: Perform SWOT analysis

In Activity 1, the OEM is suggested to define the requirement in a way that could be communicated with the suppliers. The requirement is defined in order to fulfil a need from the market. The OEM is aware of market needs as a result of the marketing team within the OEM performing market research and delivering the results to the product design and development team. The information received from the marketing team is then converted into requirements. When the OEM is aware of the requirements, the team headed by the project leader are advised to utilise a SWOT analysis. A project leader is assigned to head the team because the results from the field study overwhelmingly supports this appointment. The SWOT analysis is suggested by Parthiban et al., (2013) and Ghadimi et al., (2017) because it allows the designers understand their internal strengths and weaknesses of their design and development ability in terms of capacity and capability while also realising their external opportunities that may be gained from potential suppliers as well as threats that an outsourced project may pose. An example of SWOT analysis is depicted in figure 5-9.

	Helpful	Harmful
Internal (In-house performance)	**S**trengths (How can we use each strength?)	**W**eaknesses (How can we stop each weakness?)
External (Outsource performance)	**O**pportunities (How can we exploit each opportunity?)	**T**hreats (How can we defend against each threat?)

Figure 5-9 SWOT analysis example

Activity 1.2: Check internal feasibility of the project

Following the decision made in Activity 1, a team headed by the project leader are required to perform internal feasibility checks by reviewing the critical elements of the product design and development process that would be required to build the component. The feasibility check is to be carried out using a template which includes four important elements set as questions to aid quick judgement. The author developed a go/no-go model based on this; the model can be seen in figure 5-10. The go/ no-go model is based on a set of questions designed in the form of steps. When a question is asked, and the answer is yes, the team led by the project leader advance to the next question. If a no answer is received, regardless of what question number the team is on, the procedure is to revert back to the first step which is “part selection” in this case. The template would also include other factors determined by company policy. A template is used because it ensures uniformity between different product design and development processes. This provides product designers with the ability to easily refer to other projects to gain information about the feasibility checks of previous projects. After the feasibility check is passed, the project leader works with a team to develop a concept which will be provided to the supplier in Phase 3, Activity 3.1. The respondents of the questionnaire noted that the project leader is the person appointed by the OEM to oversee all design and development outsourcing activities.

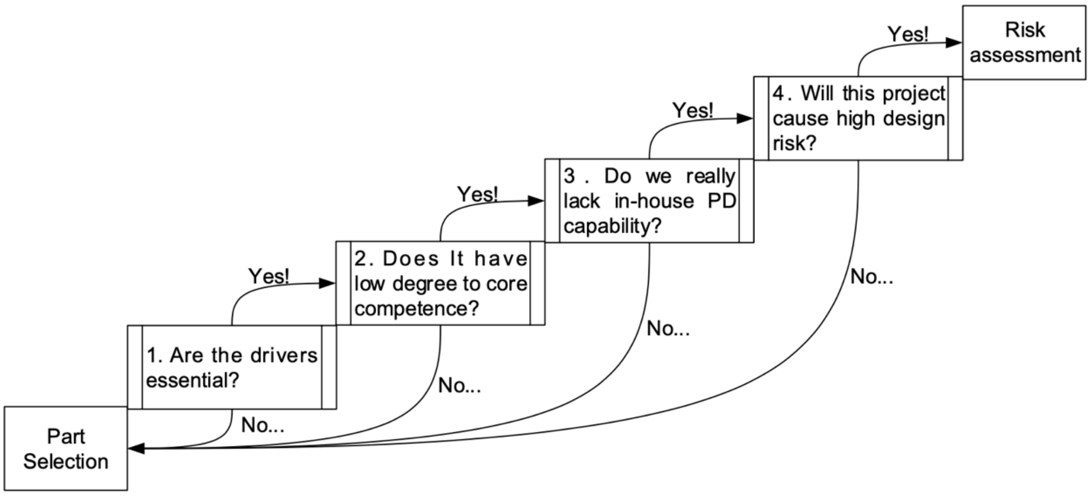


Figure 5-10 Quick judgement model

Activity 1.3: Analyse potential risks of the project

The third activity requires the analysis of any possible action that may hinder the process of outsourcing product design and development. The project leader may use FMEA for the risk assessment activities. The FMEA process is used to analyse the risks of the product based on the concept that was developed in Activity 1.2. FMEA is recommended by Nassimbeni, (2001); Ashley (2010) and Le Dain, et al., (2011) as it is a greatly structured and systematic technique for failure analysis. Furthermore, using these methods could help detect potential failure modes based on two methods; (1) previous experience with similar processes and products and (2) common physics of failure logic.

Activity 1.4: Create initial project plan

The integrated product technical lead should work with a team following the conclusion of the risk assessment, to create and release an initial project plan. The project plan should contain the initial project information such as project specifications, timetables and budgets.

Activity 1.5: Check external feasibility of the project

After the initial project plan has been created, the OEM at this stage has performed all the internal checks in order to reach the conclusion that outsourcing the design and development activities for the project is achievable. This activity therefore requires the alignment of specifications to suppliers. A document is issued which details the exact capability the supplier is required to possess in order to be considered for a potential partnership. A check is required to determine if potential external suppliers are capable of achieving the desired outcome at the technical level required. At the end of this activity, the OEM knows the exact capability potential suppliers are required to possess. Therefore, the decision to outsource the design and development activities is made and the OEM can commence Phase 2 by searching for suppliers with the capabilities determined in Phase 1, Activity 5.

5.4.2 Design and development framework between OEM and supplier Phase 2: Supplier assessment and supplier selection

The most analytic part of the framework is Phase 2 the suppliers who will collaborate in the product design and development activities are selected in this phase. The suppliers who are selected during this phase will carry out the activities finalised in Phase 1. The key activities in this phase are supplier assessment and supplier selection.

Activity 2.1: Search for suitable suppliers

It is recommended that the OEM search for suitable suppliers as the first task in this activity. The search should include current suppliers as well as potential suppliers. Suppliers can be located via the company's internal supplier database, peer investigation, colleague introduction, internet search and other external databases. When a list of ideal suppliers is populated, the OEM can passage on to activity 2 where supplier assessment takes place.

Activity 2.2: Use weighted assessment criteria

The OEM, with regards to the assessment criteria, is to use a mathematical tool to weigh each criterion in order to determine their rank, therefore distinguishing the more important criteria from the less important criteria. Members of the OEM's organisation are to brainstorm about each criterion in order to determine which is more important and which is less important. Each criterion therefore has a weight at the end of this activity. The aim of this activity is to narrow down the pool of suppliers to a smaller and more competitive pool for the detailed supplier selection process. The process for narrowing down the pool of suppliers is different for each OEM. This process allows the OEM to apply a numerical value to each supplier so a supplier who does not meet the cut-off number set by the OEM can be easily eliminated from the pool. Table 5-1 illustrates an example of a list of suppliers' assessment criteria ranked using AHP.

Table 5-1 Example of AHP ranking of suppliers' assessment criteria

	Behaviour		Performance			Risk			
Criteria / Supplier	Supplier commitment	Supplier growth potential	Technical competence	innovation & technical expertise	Business knowledge	Trust	Openness	Flexibility to align their processes with my processes	Average
Supplier 1	8	9	7	7	6	7	8	7	6.984
Supplier 2	8	8	7	7	7	7	6	8	6.828
Supplier 3	8	7	8	7	7	6	7	7	6.748
Supplier 4	8	8	6	7	7	7	7	8	6.686
Supplier 5	7	8	7	8	6	7	7	8	6.636
Supplier 6	7	8	7	7	7	7	7	8	6.606
Supplier 7	7	8	8	6	6	6	7	7	6.508
Supplier 8	8	7	6	7	8	7	7	6	6.496
Supplier 9	7	7	6	7	7	7	6	7	6.158
Supplier 10	7	7	6	7	7	6	6	7	6.134

Activity 2.3: Use weighted design capability selection criteria to select suppliers

Following the procedures performed in Activity 2.2, the field of suppliers has already been narrowed down to a more competitive field when Activity 2.3 commences. The OEM is then required to align the product requirements to each selection criterion in order to determine the weight of each criterion. The suppliers are then ranked based on their performance against the weighted selection criteria, using a mathematical method. The suppliers who rank the highest are to be selected for involvement in product design and development while suppliers who do not meet the requirements are either not accepted or developed. Table 5-2 shows an example of suppliers who have been ranked based on selection criteria.

Table 5-2 Example of suppliers ranked via selection criteria

Supplier \ Criteria	Quality systems	Capability to handle abnormal quality	Warranty policy	Price performance value	Purchasing cost	Technology capability	Performance history	Capacity of supplier	Design cycle time	Supply risk	Trust	Average
Supplier 1	8	9	8	8	9	8	9	9	9	7	8	8.36
Supplier 2	6	7	8	8	7	5	6	7	8	7	9	7.09
Supplier 3	5	4	6	4	5	6	7	4	3	6	4	4.9

Activity 2.4: Develop suppliers who do not meet the criteria but possess critical technology

Following the previous activity, suppliers who do not meet the requirements but possess critical technology should be developed by the OEM. Supplier development should occur to ensure the supplier meets the required criteria set by the OEM while also ensuring the OEM possess the supplier's critical technology which would provide an advantage over competitors. The OEM may choose to utilise one or more of the four supplier development strategies discussed in section 3.5.3.

Activity 2.5: Determine the relationship to be had with suppliers for the project

The first task in this activity is to determine the relationship between the OEM and supplier during the product design and development activities. The four options are partner, mature, child and contracted as depicted in Table 5-3. The relationship agreed upon by both parties should largely rely upon the performance of the supplier during the process of supplier selection. The relationship is therefore determined by the supplier's capability.

When the relationship going forward is agreed upon, this information is included in the contract along with other information such as product specification, agreed duration of the design and development project, cost of the project, information about proprietary property, confidentiality agreements, rights and responsibilities and agreed communication approaches and frequency. The three types of contracts that should be considered are fixed price (fixed all-inclusive fees for predetermined services), cost-plus (cost rises when additional events occur) and gain sharing (OEM shares cost saving or cost overruns with suppliers).

Table 5-3 Supplier roles in product development (Kamath & Liker, 1994)

	Contractual	Child	Mature	Partner
Design Responsibility	Client	Joint	Supplier	Supplier
Product Complexity	Simple Parts	Simple Assembly	Complex Assembly	Subsystem
Specifications Provided	Complete Design	Detailed Specifications	Critical Specifications	Concept
Supplier's Influence on Specifications	None	Present Capabilities	Negotiate	Collaborate
Stage of Supplier's Involvement	Prototyping	Post-concept	Concept	Pre-concept
Component-testing Responsibility	Minor	Moderate	Major	Complete
Supplier's Technological Capability	Low	Medium	High	Autonomous

5.4.3 Design and development framework between OEM and supplier Phase 3: Supplier evaluation and management

Following the outcome of Phase 1 where the OEM and supplier have agreed on terms and signed contracts, the OEM now should evaluate the supplier's product development performance. In order to do so, it is suggested that the OEM request a design from the supplier and then evaluate the performance of the supplier following the product design and development activities.

Activity 3.1: Request a design from supplier

The OEM is suggested to request a design from the supplier. At the commencement of this activity, the OEM has previously decided on the product specification as well as performed both internal and external feasibility checks, as detailed in section 5.4.1. The aforementioned activities are performed to ensure the design and development outsourcing of the product is achievable and may be carried out by suppliers, before arriving at this activity. The product's key value attributes have also been matched to the criteria for supplier selection and used as a basis to weigh each criterion, an example of the key value attributes of a brake pedal box design ranked using AHP is depicted in table 5-4. This ensures that the selected supplier is capable of performing the desired design and development activities. The OEM provides the supplier with the concept design as well as design constraints while the supplier is responsible for developing the specification as well as detailed design and development. Depending on the relationship agreed on between the OEM and supplier within the contract, the supplier carries out design and development activities using CAD/CAE tools during activity 3.1. After the design and development activities have taken place, the supplier delivers the design to the OEM along with the engineering and tools data as well as the prototype and testing data.

Table 5-4 Key value attributes of brake pedal box ranked via AHP

	Feeling	Stiffness	Safety	Manufacturability	Weight	Aesthetics	Packaging	Ergonomics	Durability	Cost	AHP Priority
Feeling	1	0.33	0.14	1	3	7	1	1	0.14	0.33	7%
Stiffness	3	1	1	3	3	9	3	3	1	3	14%
Safety	7	1	1	7	3	9	3	3	3	9	22%
Manufacturability	1	0.33	0.14	1	3	3	1	1	0.33	1	6%
Weight	0.33	0.33	0.33	0.33	1	3	0.33	0.33	0.14	0.14	3%
Aesthetics	0.14	0.11	0.11	0.33	0.33	1	0.33	0.14	0.11	0.14	1%
Packaging	1	1	0.33	1	3	3	1	1	0.33	0.33	6%
Ergonomics	1	0.33	0.33	3	3	7	1	1	0.33	1	8%
Durability	7	1	0.33	7	7	9	3	3	1	3	19%
Cost	3	3	0.11	7	7	7	0.33	1	0.33	1	14%

Activity 3.2: Accept design or communicate changes

The second activity involves the acceptance or rejection of the design and should be performed by the OEM to ensure the product specification was met and the contract fulfilled by going through steps that form the loop of prototype improvement where the prototype may benefit from several reviews before final approval. The OEM is required to inspect the prototyping and testing data received from the supplier. If the results meet the OEM’s standards, the design is checked in order to determine if it could benefit from further improvements. If it is concluded that no further improvements are required, the design is accepted. However, if further improvements are required, the OEM communicates to the supplier via one of the communication methods agreed upon within the contract about the engineering changes required. The aforementioned scenario reverts the process back to the design and development activities carried out by the supplier in order to adhere to the changes requested. The same sequence occurs if the OEM inspects the prototyping and testing data and is not satisfied with the design. The OEM communicates engineering changes to the supplier and improvements are carried out to ensure the design meets the specification.

Activity 3.3: Use weighted evaluation criteria to evaluate supplier based on product development performance

Activity 3.2 required the supplier to perform design and development activities in order to deliver a design that meets the requirements of the OEM. In Activity 3.3 the OEM is required to utilise mathematical tools in order to weigh the evaluation criteria shown in Chapter 3, Table 3-8. Each criterion should be weighed according to their level of importance regarding the specific project. When the criteria are weighted, the OEM's is then required to evaluate the supplier's performance based on the weight of each criterion. The OEM then performs supplier management activities including the sharing the supplier's performance information with the supplier via the agreed communication methods as well as areas of required improvements. The following activities should take place after the supplier completes the requested product design and development procedures.

1. Call in the interdepartmental executive team
2. Select project related evaluation criteria
3. Calculate the weight of each criterion
4. Develop relationship with supplier

Activity 3.4: Create knowledge document

The final activity within the final phase of the design and development framework between OEM and supplier is the creation of a document containing all the knowledge gained from the project as well as the knowledge gained from the supplier during the project. The knowledge should include knowledge about tools and methods as well as test data knowledge. This knowledge from the project should be stored in a knowledge database where it can be reused on future projects.

6 CASE STUDY VERIFICATION

6.1 Introduction

The validation for the design and development framework in Chapter 5, is discussed in this chapter. The validation of the design and development framework was achieved via a simulated case study. The chapter has been organised into five sections, after the introduction depicted in section 6.1, the case study plan is shown in section 6.2. Details of the case study and theoretical background are described in section 6.3. In section 6.4 the implementation of the product design and development framework with the case study to achieve a more efficient collaborative partnership between OEM and supplier is discussed. The chapter concludes with a chapter summary in section 6.5.

6.2 Case study plan

The author of this research devised a case study strategy consisting of four phases, as shown in Table 6-1. Preliminary planning took place in the first phase. In this phase the case study type as well as the important information required to successfully complete the case study were recognized. Phase two focused on data collection such as interviews and workshops. Phase three was concerned with the analysis of the data received in phase two. The implementation of the design and development framework was achieved in phase four.

Table 6-1 Phases in case study plan

1. Planning
Brainstorming about case study topics
Identifying the information that is required and the source
Identify review material
Create a list of potential designers/engineers to be surveyed/interviewed
Confirm that the national and international ethics standards are followed by the research

2. Data collection
Collect all documents relevant to the case study
Devise workshops and interviews with designers and engineers
3. Data analysis
Evaluate interview data
Evaluate materials relevant to the research
4. Implement design and development framework
Apply the framework by going through the phases
Generate a more efficient design and development environment between OEM and supplier

6.3 **Verification through case study**

A case study with a simulated electric reader company which outsources design and development activities was simulated. The study initiated with ascertaining a potential case study which would allow the author to exercise the design and development framework, as a consequence the design and development outsourcing activities within the firm was selected. All phases and activities during this case study are performed based on assumptions of what a real-world company would utilise. This is done as a test run to showcase the benefits of the design and development framework.

6.3.1 Theoretical background of entree control systems

Several organisations around the world make use of a form of entree control in order to constrain entry into a building or other restricted area. The main aim of an entree control reader is the identification of people who attempt entry to the building or area using the device.

Figure 6-1 depicts a standard collection of devices which operate in tandem to form a system. Entry into a building using the device would require the device to recognise the credentials of the person attempting to gain access. This is different from the conventional physical key.

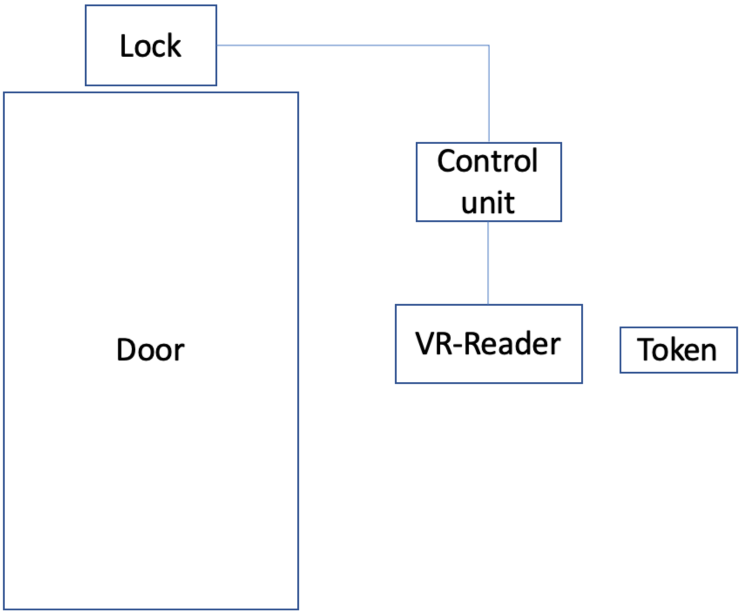


Figure 6-1 System of devices that make up the system of entree control

When entree is required, the token makes contact with the reader device. When a reader detects a signal from a token, it receives the credential information contained within the token and sends it to the control unit. At this stage signal analysis takes place, allowing the device to decide on whether to provide entree or not. If the signal is valid (the credentials are approved), the door will open. If the aforementioned signal is not approved, entree will be denied.

6.3.2 Description of selected case study

A simulated company called Locksmith offers several advantages for control in buildings. The typical uses of their products include environments such as swimming pools, schools, SME companies and gyms. The marketing department have recently informed the product development team about a new opportunity to develop a product called “VR-Reader”. Lack of suitable capacity has led the company to consider performing a study regarding outsourcing the design and development processes of the VR-Reader and carryout manufacturing and assembly processes within their in-house facilities.

6.3.3 Implementation of the design and development framework

In this section the design and development framework is implemented in a step by step manner, elaborated in section 5.4, in order to produce an improved version of the VR-Reader.

6.3.4 Phase 1: Decision making

The implementation of the design and development framework between OEM and supplier for the application of the VR-Reader commenced with the decision-making phase.

Activity 1.1: Perform SWOT analysis

The marketing team within the OEM has recently informed the product design and development department about a new opportunity in the market regarding a new VR-Reader. The OEM then converted the information received from the marketing team into requirements. The requirements would help aid the decision of designing and developing the VR-Reader in-house or outsourcing the design. The following are brief descriptions of the requirements for the VR-Reader.

Table 6-2 Anti-Vandalism device requirements

Possible damage	Requirements
Pressure resistance	≥5.2 MPa
Removal resistance	Difficult to grab and resistant screws
Fire resistance	≥95ºC for 45 seconds
Corrosion resistance	Resistance to water, weak alkalis and acids and alcohol
Water intrusion	Waterproof

The OEM brainstormed about the requirements and concluded that the device should be resistant to 5.2 MPa pressure of impact, 95ºC temperature resistance for 45 seconds, resistant to water, alcohol, and less potent acids and alkalis. The information provided in table 6-2 was provided by experts from the industry and the author, after numerous workshops.

The product design and development department at the OEM performed a SWOT analysis based on the requirements of the new product. The results from the SWOT analysis showed that the OEM did not have the capability to carry out the design and development activities of the VR-Reader.

Based on the requirements, the OEM performed a SWOT analysis as depicted in table 6-5.

Table 6-3 SWOT analysis for VR-Reader

Strengths	Weaknesses
• *Expertise* • *Project management* • *Procurement and supplier management* • *Reputation* • *Engineers and designers*	• *Design cycle time* • *Capacity* • *Tools and technique*
Opportunities	**Threats**
• *Enter new market* • *Reduce risk*	• *New competitor* • *Increasing supplier costs* • *Possible bankruptcy of supplier*

Activity 1.2: Check internal feasibility of the project

Following the realisation of the OEM in activity 1.1 that they did not have the capacity to carry out the design and development activities of the VR-Reader, the OEM proceeded to perform internal feasibility checks of the product. The feasibility checks were performed by reviewing the critical elements of the product design and development activities required to build the product. Following the template, the feasibility check was passed. Therefore, the project leader worked with a team to develop a concept of the VR-Reader that is to be outsourced to suppliers. The model for quick judgement in figure 6-2 was able to aid their decision making.

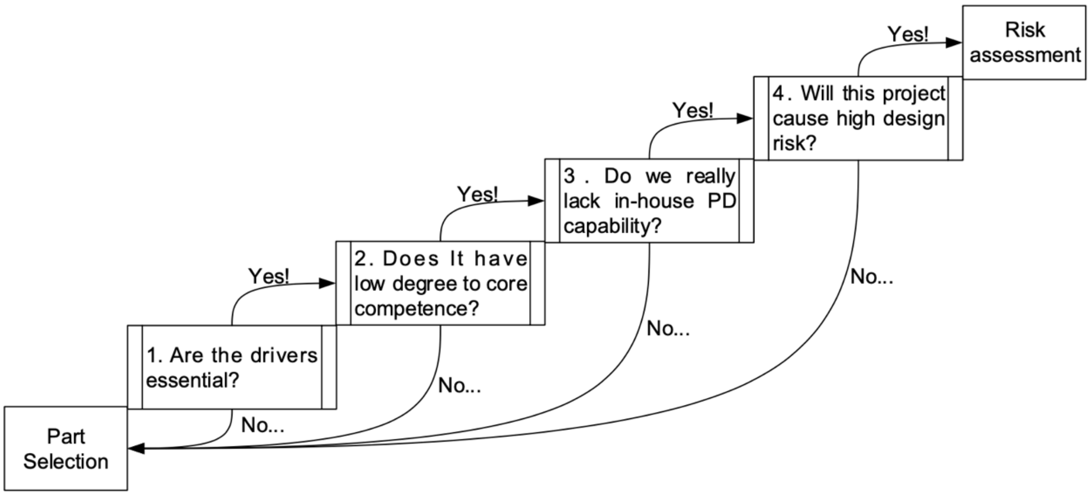


Figure 6-2 Model for quick judgment

Activity 1.3: Analyse potential risks of the project

The project leader, as suggested by the field study interviewees, works with the product design and development team. They performed risk analysis on the concept of the VR-Reader that was developed in Activity 1.2. The template used for the risk analysis included information from previous projects as well as the common physics of failure. At the end of Activity 1.3, the product design and development team is aware of potential failures that could pose a threat on the design and development of the VR-Reader.

Activity 1.4: Create initial project plan

The project leader worked with a team to create a project plan after the risk assessment activities in Activity 1.3 were concluded. The project plan included the initial project information such as project specification, timetables and budgets.

Table 6-4 Design and development cost assumptions for outsourcing mechanical components

Supplier staff member	Cost per hour in £	Hours required	Cost per member in £
Project manager	125	280	35000
Senior Mechanical Engineer	80	220	17600
CAE operator	92	350	32200
Design Engineer	85	210	17850
CAD operator	45	350	15750
Administrative	37	140	5180
Final personnel cost in £			123580

Table 6-5 Design and development cost assumptions of outsourcing electrical and software components

Supplier staff member	Cost per hour in £	Hours required	Cost per member in £
Project Manager	122	220	26840
Senior Electronic Engineer	105	210	22050
Software Engineer	75	245	18375
CAE Operator	70	320	22400
Design Engineer	72	250	18000
CAD Operator	45	300	13500
Administrative	42	130	5460
Software License			50000
Final Personnel Cost			176625

The costs are based on a timetable of two months because the team at the OEM concluded that this project will take two months to complete.

Activity 1.5: Check external feasibility of the project

The project leader worked with a team to create a document which contains the exact capabilities that potential suppliers must possess in order to be considered as candidates for the product design and development outsourcing of the VR-

Reader. The aforementioned document is stored in the internal database and available to members of the product development team involved in this project. The team utilised knowledge from previous projects to conclude that suppliers potentially are capable to carry out certain required design and development activities. The decision was therefore made to outsource the design and development activities. This meant the team had to begin the search for potential suppliers.

6.3.5 Phase 2: Supplier assessment and selection

Activity 2.1: Search for suitable suppliers

The product design and development team searched their internal supplier database as well as the internet for potential suppliers. Ten suppliers were compared. All the suppliers involved are experts in the field of design, development and manufacturing.

Activity 2.2: Use weighted assessment criteria

Following the outcome of activity 2.1, the design and development team at the OEM now have a list of potential suppliers to outsource the design and development of the VR-Reader. This activity required them to assess the potential suppliers by selecting the most applicable assessment criteria from the list in Chapter 3, table 3-3. When the criteria were selected, the team at the OEM would normally weigh each criterion by brainstorming, in order to rank the criteria in order of importance. In this case, the criteria are ranked based on feedback from experts in the industry, following the field study. The ranked assessment criteria are listed in table 6-6.

Table 6-6 AHP ranking of assessment criteria

	Supplier commitment	Supplier growth potential	Technical competence	innovation & technical expertise	Business knowledge	Trust	Openness	Flexibility to align their processes with my processes	AHP priority
Supplier commitment	1,00	4,00	0,33	0,33	0,33	0,33	0,33	0,5	5.90%
Supplier growth potential	0,25	1,00	0,17	0,17	0,17	0,17	0,17	0,17	2.40%
Technical competence	3,00	6,00	1,00	1,00	1,00	1,00	1,00	2,00	16.40%
Innovation & technical expertise	3,00	6,00	1,00	1,00	1,00	1,00	1,00	2,00	16.40%
Busiiness knowledge	3,00	6,00	1,00	1,00	1,00	1,00	1,00	2,00	16.40%
Trust	3,00	6,00	1,00	1,00	1,00	1,00	1,00	2,00	16.40%
Openness	3,00	6,00	1,00	1,00	1,00	1,00	1,00	2,00	16.40%
Flexibility to align their processes with my processess	2,00	6,00	0,5	0,5	0,5	0,5	0,5	1,00	9.50%
TOTAL									100%

Based on the results of the AHP calculations of the assessment criteria in table 6-6, a list ranking each criterion based on AHP priority was developed and is depicted in table 6-7. The AHP rankings in table 6-6 are calculated based on the weight of each criterion provided by the experts in the industry and used here to simulate a scenario where an OEM would use these criteria to assess potential suppliers.

Table 6-7 AHP ranking of assessment criteria

Assessment criteria	AHP priority
Technical competence	16.4%
Innovation & technical expertise	16.4%
Business knowledge	16.4%
Trust	16.4%
Openness	16.4%
Flexibility to align their processes with my processes	9.5%
Supplier commitment	5.9%

Supplier growth potential	2.4%

Based on the ranking of each criterion, the team was able to measure and rate each supplier by scoring them against the weighted assessment criteria. The result of this is listed in table 6-8.

Table 6-8 Suppliers' overall score based on AHP ranking of assessment criteria

Supplier \ Criteria	Supplier commitment	Supplier growth potential	Technical competence	innovation & technical expertise	Business knowledge	Trust	Openness	Flexibility to align their processes with my processes	Average
Supplier 1	8	9	7	7	6	7	8	7	6.984
Supplier 2	8	8	7	7	7	7	6	8	6.828
Supplier 3	8	7	8	7	7	6	7	7	6.748
Supplier 4	8	8	6	7	7	7	7	8	6.686
Supplier 5	7	8	7	8	6	7	7	8	6.636
Supplier 6	7	8	7	7	7	7	7	8	6.606
Supplier 7	7	8	8	6	6	6	7	7	6.508
Supplier 8	8	7	6	7	8	7	7	6	6.496
Supplier 9	7	7	6	7	7	7	6	7	6.158
Supplier 10	7	7	6	7	7	6	6	7	6.134

The OEM then selected the three highest scoring suppliers to participate in the more detail supplier selection process.

Activity 2.3: Use weighted design capability selection criteria to select suppliers

At the commencement of activity 2.3, the field of potential suppliers has been narrowed down by utilising the supplier assessment procedures in activity 2.2. The OEM first determined the rank of each criterion via brainstorming sessions. The list of AHP ranked supplier design and development selection criteria is displayed in table 6-9, table 6-10 shows the same criteria but arranged in order of importance.

Table 6-9 AHP ranking of supplier design and development capability criteria

	Quality systems	Capacity to handle abnormal quality	Warranty policy	Price performance value	Purchasing cost	Technology capability	performance history	capacity of supplier	Design cycle time	Supply risk	Trust	AHP priority
Quality systems	1	2	3	1	1	6	1	3	4	1	1	13.10%
Capacity to handle abnormal quality	0.5	1	2	0.5	0.5	3	0.5	2	3	0.5	0.5	7.20%
Warranty policy	0.33	0.5	1	0.33	0.33	3	0.25	1	2	0.25	0.25	4.40%
Price performance value	1	2	3	1	1	5	1	3	4	1	1	12.90%
Purchasing cost	1	2	3	1	1	5	1	3	4	1	1	12.90%
Technology capability	0.17	0.33	0.33	0.2	0.2	1	0.2	0.33	0.5	0.2	0.2	2.20%
Performance history	1	2	4	1	1	5	1	3	4	1	1	13.20%
capacity of supplier	0.33	0.5	1	0.33	0.33	3	0.33	1	2	0.33	0.33	4.70%
Design cycle time	0.25	0.33	0.5	0.25	0.25	2	0.25	0.5	1	0.25	0.25	3.10%
Supply risk	1	2	4	1	1	5	1	3	4	1	1	13.20%
Trust	1	2	4	1	1	5	1	3	4	1	1	13.20%
TOTAL												100%

Table 6-10 Listed AHP ranking of supplier design and development capability criteria

Selection criteria	AHP priority
Performance history	13.2%
Supply risk	13.2%
Trust	13.2%
Quality systems	13.1%
Purchasing cost	12.9%
Price performance value	12.9%
Capability to handle abnormal quality	7.2%
Capacity of supplier	4.7%
Warranty policy	4.4%
Design cycle time	3.1%
Technology capability	2.2%

The weights of each criterion were provided by field study interviewees and AHP was used to calculate how each criterion compared against one another. The suppliers who advanced from the supplier assessment process are then ranked using the weighted supplier design and development selection criteria. The results of the supplier AHP ranking is depicted in table 6-11.

Table 6-11 Suppliers' overall design and development capability score, ranked using AHP

Supplier \ Criteria	Quality systems	Capability to handle abnormal quality	Warranty policy	Price performance value	Purchasing cost	Technology capability	Performance history	Capacity of supplier	Design cycle time	Supply risk	Trust	Average
Supplier 1	8	9	8	8	9	8	9	9	9	7	8	8.36
Supplier 2	6	7	8	8	7	5	6	7	8	7	9	7.09
Supplier 3	5	4	6	4	5	6	7	4	3	6	4	4.9

Based on the results of the design and development capability of each supplier, Supplier 1 was selected as the supplier to carry out the design and development outsourcing for the VR-Reader.

Activity 2.4: Develop suppliers who do not meet the criteria but possess critical technology

After the conclusion of activity 2.3, the OEM selected Supplier 1 because this supplier secured the highest overall score based on the criteria chosen by the OEM to score the suppliers. Supplier 2 did not score as high as Supplier 1 but possessed critical technology, therefore the OEM decided to develop the supplier.

Activity 2.5: Determine the relationship to be had with supplier for the project

The supplier chosen to carry out the design and development of the VR-Reader was chosen in activity 2.3. Supplier 1 proved to be capable because they possessed broad experience with products that are similar to the VR-Reader and their team was large enough, therefore having the capacity which the OEM concluded was lacking within their organisation in Activity 1.1. Supplier 1 were also in possession of the software required to develop the electronic project and prototype it, as well as the facilities in place to manufacture the product if requested. The aforementioned statements meant that Supplier 1 was requested to have a partner relationship with the OEM as described in Chapter 5, table 5-3.

6.3.6 Phase 3: Supplier evaluation and management

Activity 3.1: Request a design from supplier

Given that the OEM and supplier have agreed on the type of relation to be had for the outsourcing of the VR-Reader in activity 2.5, the project leader then formally requested a design from the supplier. In order to ensure the supplier delivers the desired product, the key value attributes of the VR-reader as well as tolerances and materials to use were provided to the supplier by the OEM. The following figures show the different views of the design created by the suppliers. The dimensions of the device are measured in millimetre (mm) units.

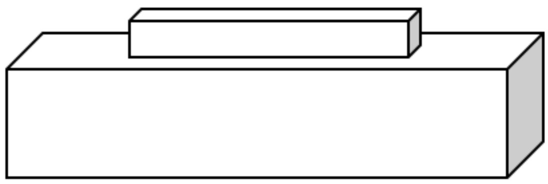


Figure 6-3 Side view of new design

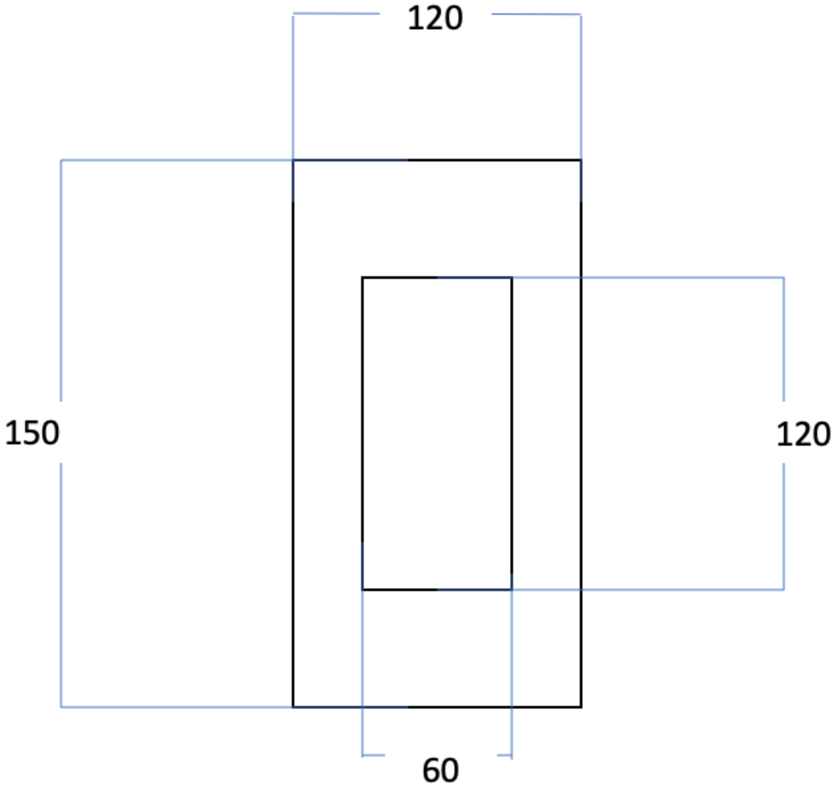


Figure 6-4 Model view of new design with dimensions

Activity 3.2: Accept design or communicate changes

In Activity 3.2, Supplier 1 has received all the information required in order to design and develop the part. They therefore designed the part using a CAD tool called OpenCAD. The suppliers then transformed the design into a prototype for testing. The suppliers performed tests using the thresholds provided to them by the OEM in activity 3.1. The suppliers then delivered the design along with the prototyping and testing data to the OEM for validation. The OEM accepted the design because it met the requirements set in activity 1.4.

Activity 3.3: Use weighted evaluation criteria to evaluate supplier based on product design and development performance.

In activity 3.2, Supplier 1 was given the task of designing and developing the VR-Reader by the OEM. Supplier 1 completed this task by designing a CAD part and then performing stress analysis on the part. The next step involved developing a physical prototype and then testing the prototype to ensure it met the standards required by the OEM. After the design and development activities were concluded and the testing and validation data returned to the OEM, the OEM selected criteria from the table in Chapter 3, Table 3-8 to evaluate the supplier's performance during the product development activities. The supplier's performance was evaluated using the weighted evaluation criteria depicted in table 6-12.

Table 6-12 AHP ranking of supplier evaluation criteria

	Innovation	intallectual property	response speed	Identification of new technologies	Assistance in developing product	Assistance in modularization activities	Component selection	Reliability of prototyping	Communication about engineering changes	
Innovation	1	0.33	0.14	1	3	7	1	1	0.14	7%
Intellectual property	3	1	1	3	3	9	3	3	1	14%
Response speed	7	1	1	7	3	9	3	3	3	22%
Identification of new technologies	1	0.33	0.14	1	3	3	1	1	0.33	6%
Assistance in developing product specification	0.33	0.33	0.33	0.33	1	3	0.33	0.33	0.14	3%
Assitance in modulirization activities	0.14	0.11	0.11	0.33	0.33	1	0.33	0.14	0.11	1%
Component selection	1	1	0.33	1	3	3	1	1	0.33	6%
Reliability of prototyping	1	0.33	0.33	3	3	7	1	1	0.33	8%
Communication about engineering changes	7	1	0.33	7	7	9	3	3	1	19%

After the evaluation of the supplier's product design and development capabilities have been completed, the OEM communicates to the supplier about areas of improvement for subsequent projects.

Activity 3.4: Create knowledge document

The final activity required the OEM to create a knowledge document which included all the knowledge gained from the project as well as the knowledge gained from the supplier during the project. This includes knowledge about the tools and methods, as well as test data. The knowledge is then stored in a database in order to make it available for future projects.

7 DISCUSSION, CONCLUSIONS AND FUTURE WORK

7.1 Introduction

In order to have a good design and development framework to outsource product design and development, there is a need for a process, this process needs to have different activities. One of these activities is to have criteria to assess, select and evaluate suppliers. The literature talks about different aspects of outsourcing activities, mainly in manufacturing processes but very few of them talk about outsourcing product design and development. In addition, there is some literature that mentions criteria but do not provide a comprehensive study about criteria. This PhD research has provided a study about the process of outsourcing product design and development, as well as providing a list of good criteria to select and evaluate suppliers. This work has been confirmed through good industrial field study and a simulated case study.

This research aimed to develop a novel product design and development framework to enhance the process of outsourcing design and development. The achievement of this was accomplished via procedural investigation that was divided into three separate phases. The initial phase was formed from a basis of exploration, which had the intent to ascertain the current practices in product design and development outsourcing as well as the necessity to implement a new design and development framework. The second phase entailed the performing of an industrial field study in order to identify the current process of outsourcing product design and development as well as the industrial opinions of these processes. The third phase included the integrating of the findings in the development of the outsourcing design and development framework between OEM and supplier. A simulation of an industrial case study enabled the author to exhibit the application of the design and development framework as discussed in Chapter 6.

This chapter makes use of the following format:

Section 7.1 is an introduction of the chapter, while section 7.2 is a discussion of the research findings. Section 7.3 depicts the contribution this research has made to the knowledge while section 7.4 shows the research limitations. The conclusions of the research and shown in section 7.5 and finally the future work is shown is section 7.6.

7.2 **Discussion**

This section was developed largely for a discussion about the research findings on the simulated case study that was performed. The case study will be summarised, and key findings are emphasized.

In order to develop a design and development framework, steps were required to be taken in so as to understand the processes involved in starting the entire process. A literature review around the topic showed that the use of criteria allowed OEMs to assess and select potential suppliers, although the supplier assessment process and criteria were scares in the research. This meant that the field study was the avenue to confirm that not only is the supplier assessment process a reality, but it is also vital to the overall product design and development outsourcing process. The selection criteria, however, was more prevalent in the research. Even though a plethora of research has covered supplier selection and selection criteria, the majority of this research was focused on manufacturing outsourcing as opposed to design and development outsourcing. Furthermore, it was found that there needed to be a clarification of design and development outsourcing criteria for supplier selection and supplier performance evaluation as these are two separate processes entirely. The combination of supplier selection and supplier performance evaluation criteria as they are found in the literature is depicted in Chapter 3, Table 3-8. However, when separated into their respective categories, it makes the understanding of each criteria and its position in the outsourcing process clearer. This is depicted in Chapter 3, Sections 3.4.2 and 3.4.2 respectively.

An analysis of the literature also produced information about the communication methods between OEM and supplier during design and development outsourcing. Communication methods were discovered as well as a limited amount of information regarding communication frequencies. The field study that was performed, helped confirm the communication methods discovered in the literature as well as the frequency of communication. Every respondent in the field study stated that communication frequency is never set or agreed upon within the contract. Rather, the communication frequency is solely based on the type of project and the relationship with the supplier. This meant that the design and development framework could not include any suggestions about frequency of communication between OEM and supplier.

During the course of the research, a number of challenges faced during product development outsourcing were captured via an extensive literature review and industrial field study. It was therefore important for the design and development framework depicted in Chapter 5, Figure 5-2 to be able to mitigate the challenges faced. This would ensure an outcome of a more efficient product design and development outsourcing process. In total there were 9 challenges captured from various articles and theses. Each of the challenges were not only supported by reliable literature but also confirmed during the field study. During the interviews, the challenges were either confirmed or a slight variation of the challenge already on the list was mentioned. These findings were utilised as a basis to demonstrate the ability of the design and development framework to mitigate them. The following are a list of challenges and how the design and development framework mitigates each one:

1. Lack of trust: Lack of trust can be mitigated by following the design and development framework in Chapter 5, Figure 5-8 and exercising Activities 2.2 and 2.3 where the OEM can make use of the criteria found in Chapter 3, Tables 3-3 and 3-4. These criteria help build trust, therefore the OEM can trust the supplier who can be successfully progressed through both the supplier assessment and supplier selection processes.
2. Resistance to change: This challenge can be mitigated by exercising activity 2.5 in the design and development framework where the OEM and supplier determine the responsibilities of each party before signing the contract.
3. Large initial cost by OEM: There are two criteria directly related namely, price performance value and purchasing cost. These criteria are to be

used in the supplier selection process if cost is a factor. Furthermore, there are three types of contracts suggested by the framework (fixed-price, cost-plus and gainsharing). The OEM can select the contract type that can be financial accommodated.

4. Incompatible software and measurement units: As part of the technology capability criterion as well as the tools and equipment criterion in Chapter 4, Table 4-3 the OEM is able to determine the software and measurement units used by the supplier earlier in the process of supplier selection.
5. Difficulties in communicating with the supplier: In activity 2.5, the framework suggests that the OEM and supplier agree upon the communication methods going forward. This, along with the agreed responsibilities, rights and obligations will ensure that the supplier communicates adequately with the OEM.
6. Lack of understanding of post-contract processes and activities: In activity 2.5 of the design and development framework, the OEM and supplier are suggested to agree on their individual responsibilities and roles, therefore each party understand the processes and activities they are responsible for.
7. Forming and maintaining the right people throughout the outsourcing process: There are several checks that the OEM is suggested to perform by utilising the criteria list in Chapter 4, Table 4-3. Criteria such as performance history, management and organisation and general reputation can be used to ensure the right people are selected throughout the process.
8. Lack of well-defined design and development outsourcing guidelines: The entire design and development framework in Chapter 5, Figure 5-8 serves as a guideline for outsourcing design and development. Therefore, the use of the design and development framework will ensure a successful outsourcing process is achieved.
9. Lack of traceability of the source of a problem: This challenge occurs when individuals involved in the outsourcing project do not fully

understand their roles and responsibilities. It is therefore difficult to trace the source of a problem if it is unknown where the problem stems from. Using the design and development framework, specifically activity 2.5 where each party is aware of their individual responsibilities. When an issue arises, the source can be detected by knowing the individual whose responsibility it is to perform that task.

7.2.1 Discussion of the results of the Locksmith case study

This case study was simulated using realistic data based on a company named Locksmith. The company was selected due to its incessant production of products with high innovation. These products add customer value as well as a range of other services. The case was developed in order to create a new design for the "VR-Reader" which could achieve the characteristics of vandal resistance where the new design and development is done by suppliers. This meant the VR-Reader required resistance to several types of possible damages such as; removal by hand, fire damage, liquid damage, stone damage and impact from a foreign object. The VR-Reader also required the ability to capture a plethora of credentials as well as easy maintenance and installation.

The choice to implement the design and development framework helped the company in smoothening their outsourcing process as well as gain confidence in the new product as it was design to specification. A number of outcomes were derived from the Locksmith case study:

1. The company was able to utilise the framework in order to make the decision on whether to outsource the design and development of the VR-Reader to suppliers.
2. Each phase is characterised into systematized step by step activities in order to produce a smooth flow during the process of product design and development outsourcing.
3. The process of first assessing suppliers before the selection process ensured that the right supplier was selected to carry out the required design and development activities.

4. The evaluation of the supplier's performance after the product design and development activities took place ensures that there are always continuous improvements, therefore the OEM can continue to remain a market leader.
5. The framework was very easy to follow because all the activities are explained clearly and in a logical manner.
6. The implementation of the framework produced the expected results as the simulated suppliers were able to meet the requirements of the OEM after the simulated OEM followed the steps of the framework.

7.3 **Contribution to the knowledge**

The intellectual contribution the researcher has made to date are:

1. The developed framework provides a clear understanding of what constitutes as assessment criteria, selection criteria and evaluation criteria in product design and development within the supply chain.
2. The framework mitigates the evolving challenges faced by OEM and suppliers when they work together in product design and development.
3. The developed framework is novel as it is the only framework that encompasses all the activities involved in assessing, selecting and evaluating suppliers throughout the design and development process.

7.4 **Limitations**

During the course of any research, it is not uncommon for the researcher to experience research limitations. Likewise, this research also experienced certain limitations as explained below:

1. **Scope of the research**

   The research scope was based on the development of a design and development framework between OEM and supplier illustrated in figure 5-8. Furthermore, the researched focused mainly on the outsourcing of product design and development. In order to fully obtain the tangible benefits of the design and development framework, it would require utilisation in several other scenarios that are detailed in table 5-3.

2. **Research approach**

   Given that the nature of this research is qualitative, there are therefore certain unavoidable biases that are associated with it. The author however took certain precautions in order to mitigate the negative effects of bias. The aforementioned was achieved via the adoption of the triangulation approach involving literature reviews, involvement with industrials experts and case study validation. The results were then amalgamated and analysed in order to arrive at trustworthy conclusions.

3. **Time limitation**

   Limitations of time is always a concern when carrying out a PhD research. The time spent performing field studies and other engagement with industrial experts is quite short due to the busy schedules of the industrial experts.

7.5 **Conclusions**

The academic proposal presented by this research suggested that through the use of a well-structured framework, OEMs can successfully outsource their product design and development activities in a more efficient manner than before. Several scholars have made similar claims but were unable to develop a fully comprehensive answer that mainly focuses on the design and development aspect of product development, as opposed to the manufacturing. A structured research was therefore required in order to demonstrate how suppliers should be assessed, selected, and evaluated during product design and development outsourcing. The following conclusions were reached following the completion of this research:

1. Design and development outsourcing is constantly progressing in order to tackle several challenges experienced worldwide to produce better, more competitive and cheaper products. There is therefore a necessity to adopt a design and development framework.

2. The significance of criteria for assessing, selecting and evaluating suppliers have been mentioned by scholars but there is still a dearth of adequate research regarding the design and development activities of product development.
3. The design and development framework includes several distinctive aspects that deliver an easy to follow and efficient method of facilitating the design and development activities between OEM and supplier from the commencement of the process to the end.
4. The design and development framework exhibited with a simulated case study, mitigates many of the challenges faced in product design and development outsourcing.
5. The design and development framework is flexible and therefore it can be utilised in a wide range of industries and sectors.

7.6 **Future work**

Opportunities to further the research based on the research findings, are as follows:

The existing framework utilises a static graphical representation. This static representation limits its capability therefore it would benefit from being implemented into a media-based application which would allow for more customisable solutions.

1. The scenario presented in this framework is a partner scenario, based on the information provided in table 5-3. There is still a need to explore the child, mature and contracted scenarios of the relationship between OEM and supplier during product design and development outsourcing.
2. This research could also benefit from exploring lean design principles as well as enablers such as set based concurrent engineering (SBCE). The OEM and supplier can design and develop product in a lean environment, depending the relationship agreed between both parties.

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