Tampere University

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DEFINITION OF A MODEL FOR CONTINUOUS EVALUATION OF SUPPLIER PERFORMANCE

Case study from the automotive battery industry

Master of Science Thesis
Faculty of Engineering and Natural Sciences
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ABSTRACT

Nicolò Mercuriati: Definition of a Model for Continuous Evaluation of Supplier Performance: Case Study from the Automotive Battery Industry
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As in modern business world purchasing is increasingly perceived as a strategic function, firms are called to further develop their vendor management system (VMS). The extant literature highly testifies this trend, with a plethora of studies conducted on different purchasing processes in different industries. Surprisingly enough, the highly regulated automotive industry seems to have received less attention from scholars. In the last decades, industry standards played a crucial role in assisting automotive companies to achieve high levels of quality, efficiency, and risk mitigation. However, a radical transformation shaped by new trends such as autonomous cars, urban mobility, emerging markets, connectivity, and electrification is currently changing the automotive industry at a fast pace. In this context, the application of well-stablished industry standards poses additional challenges to companies operating in such evolving context.

The goal of this study was to investigate the relevant criteria adopted by manufacturing companies to evaluate the performance of current suppliers in the context of the rapidly growing automotive lithium-ion battery (LIB) industry. This study also unveiled the relative importance of the different performance criteria by examining the weights given to each criterion placed in a linear weighting model. The identified criteria were then used to design a performance evaluation system that could have been adopted by the case company that collaborated in this research.

This study was executed as a case study in collaboration with a case company operating in the fast-paced automotive LIB industry. To gather data, an extensive literature review including the automotive quality management standard IATF 16949:2016 was carried out. In addition, information from selected senior professionals within the case company was retrieved by conducting questionnaire surveys and semi-structured interviews.

The empirical findings of this study unveiled that quality, delivery and service, price/cost, and sustainability are the most relevant metrics for evaluating the performance of active suppliers in the automotive LIB industry. Furthermore, this study confirms the primary importance of quality and price/cost metrics, while it finds that the delivery and service performance of suppliers are less relevant than their performance in safety and sustainability. These findings underpin the well documented increasing importance of corporate social responsibility (CSR) as a key metric in purchasing and supply management (PSM), especially for supplier selection, supplier monitoring, and supplier development. This thesis also provided a framework to be used for the development of vendor ratings, as well as it defined a roadmap for the implementation of a system to evaluate the performance of suppliers. In particular, the developed vendor ratings were defined by applying the linear weighting model and the analytic hierarchy process (AHP).

Even though the defined roadmap could not be implemented within the scope of this study, its definition resulted to be particularly important for the case company, as it highlighted recommended short-term and long-term actions which were presented and discussed with the representatives of the company. Furthermore, the defined roadmap can be beneficial for the case company to meet the stringent requirements of IATF 16949:2016. Overall, the vendor ratings defined in this study offer interesting insights for future deployment and development of the supplier performance measurement.

Keywords: Supplier Performance Evaluation, Supplier Monitoring, Vendor Rating, Analytic Hierarchy Process, Automotive Industry, IATF 16949:2016.

PREFACE

During my studies, I have learned that dedication and motivation are the true keys to achieve outstanding results despite the challenges that one may encounter during his professional and personal life. I firmly believe that learning is a perpetual process which requires involvement and commitment. In this respect, the last two years at Tampere University represent the most authentic learning experience in my life so far.

I would like to thank professor Jussi Heikkilä for his precious suggestions and for taking the supervision of this project. I am also deeply grateful to senior research fellow Aki Jääskeläinen for guiding my work throughout this thesis. I would like to express my special gratitude to my work colleagues and the management team of the case company, which gave me the opportunity to carry out this project and to combine work and studies during the entire course of the Master's Programme at Tampere University.

This thesis has also been written in one of the most difficult times of my life. Started in April 2020, this research was executed in a moment in which the world was facing the tremendous consequences of the outbreak of the coronavirus disease 2019 (COVID-19), which created a global health crisis that has been lasting for almost an entire year. Under these circumstances, to keep up with the commitment required both by a demanding job and intense academic studies could not have been more difficult.

I deeply thank my parents, my brother, and my friends whom, despite the distance that divides us, have never stopped to support me even in the most difficult moments. Most of all, I want to express my deepest gratitude to Saana, who shared with me these years of intense work and study. I thank Saana for the wonderful years we have been living together so far, for always supporting me in pursuing my ambitions, and for helping me to see the world from a different and more positive perspective. Without Saana, my parents, my brother, and my friends, this journey would have been truly burdensome.

Tampere, 8 November 2020

Nicolò Mercuriati

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LIST OF SYMBOLS AND ABBREVIATIONS

n	Number of Criteria in the Pairwise Comparison Matrix
ρ_i	Comparative Weight (where i = 1 to n)
ρ_{AVG}	Comparative Average Weight
λ	Eigenvalue
λ_{max}	Maximum Eigenvalue
σ	Standard Deviation
ω	Score of Pairwise Comparative Analysis

AHP	Analytic Hierarchy Process
ANP	Analytical Network Process
BEV	Battery Electric Vehicle
BOM	Bill of Material
CI	Consistency Index
CSR	Corporate Social Responsibility
CV	Coefficient of Variation
DCV	Dynamic Capabilities View
ESS	Energy Storage System
EV	Electric Vehicle
FAHP	Fuzzy Analytic Hierarchy Process
IATF	International Automotive Task Force
ICT	Information and Communication Technology
IP	Interviewed Person
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LIB	Lithium-ion Battery
OEM	Original Equipment Manufacturer
PPAP	Production Part Approval Process
PSM	Purchasing and Supply Management
QMS	Quality Management System
R&D	Research and Development
RI	Random Index
SLR	Systematic Literature Research
VMS	Vendor Management System

1. INTRODUCTION

1.1 Research background

The importance of purchasing and supply management (PSM) in the contemporary business world is unquestioned. Several studies indicate that in average the purchasing expenditure of a modern manufacturing company accounts for 60% to 70% of the yearly revenue (Ellram, 1996; Heberling et al., 1992; cited in Zsidisin et al., 2003). In the automotive sector, this figure is increased by multiple factors such as supply-base reduction policies, modularization, the greater demand of supplier capabilities and the consequent handover of roles such as design, testing, and final assembly from the carmakers to their suppliers (Oh and Rhee, 2008). Academic research also suggests that PSM practices can support organizations in creating customer value (Jääskeläinen and Heikkilä, 2019) which can provide sustained competitive advantage (Barney, 1991). On the one hand, purchased goods and services typically account for 50% to 90% of the cost of sales of a company (Emiliani, 2010). On the other hand, outsourcing can reduce operational costs by 15% to 20% (Olson, 2010). Consequently, the PSM function is increasingly under pressure for providing additional value (Ah et al., 2018).

Practitioners and scholars have largely described the effects of the relationship between buying companies and their suppliers, which over the time have evolved from adversarial to collaborative (Graca et al., 2015). Some of the advantages of this evolution are improved quality, cost, and cooperation, risk reduction, knowledge acquisition, new product development, and financial performances (Pardo et al., 2011). Consequently, companies are increasingly called to improve the management of the multiple relationships within their supply base. In this respect, to regularly evaluate the performance of active suppliers through a vendor rating enhances the effective management of supplier relationships and allows the buying organization to identify and to undertake actions such as penalties, rewards, and improvement plans towards its suppliers (Santos et al., 2019). Supply contracts can last several years, therefore monitoring to the performance of suppliers during the duration of the contract brings several advantages to the buying organization (Beil, 2011).

In general, measurement processes are often affected by an insufficiently clear definition of the objects that are meant to be measured (Tangen, 2005). In this respect, in the

context of PSM, several studies focused on the definition of criteria for the evaluation of supplier performance (Maestrini et al., 2018). Over time, the focus of the academic research has shifted from common evaluation criteria such as quality, service or delivery, and price (Simpson et al., 2002), to embrace measures related to corporate social responsibility (CSR) (Reuter et al., 2010) such as environmental factors (Vanalle and Santos, 2013; Zimmer et al., 2015), social risks (Zimmer et al., 2017), and financial performance (Itzkowitz, 2015). Interestingly, despite the profuse literature on this subject, there is scarcity of studies in the context of the highly regulated automotive industry. In this context, some studies have been carried out from the perspective of the carmakers, but the analyses from the perspective of the first-tier manufacturer-supplier relationship are rare.

To tackle the oil dependency and its negative environmental impact, the automotive industry is currently going through radical transformations shaped by multiple trends such as autonomous cars, urban mobility, emerging markets, connectivity, and electrification (McKinsey, 2016). The overall sales of battery electric vehicles (BEVs) are estimated to account for about 3% of the global car sales in 2020, registering a 40% year-to-year increase (IEA, 2020). Consequently, following the strategies of carmakers, battery-cell suppliers are called to rapidly ramp-up their capacities (Gersdorf et al., 2020). This fast-paced transformation does not come without challenges. Several factors in the electric vehicle (EV) sector need investigations as some technologies are immature and business models are rapidly changing (Kalaitzi et al., 2019). In the effort to contribute to the scarce existing studies on this subject, the focus of this research is placed on the definition of a model for continuously evaluating supplier performance in the context of the automotive lithium-ion battery (LIB) industry.

1.2 Research context

The case company of this Master's Thesis manufactures LIBs and complete battery systems. The case company has clearly identified the automotive market as the main market for its LIBs. In the automotive industry, most of the products are engineered and manufactured by suppliers due to their high involvement during the development activities of the vehicle (Neumann et al., 2013). The automotive industry is also highly regulated. In this respect, in 2016 the International Automotive Task Force (IATF), released the standard IATF 16949:2016, which is a sector-owned document (Reid, 2017).

To tackle the stringent requirements of the automotive market, the case company is called to develop a clear roadmap to obtain the certification to IATF 16949:2016. As Chairini and Vagnoni (2020) point out, each company which is intended to achieve IATF

certification must implement the several requirements of the standard documenting several processes which are assessed through an independent body accredited by IATF.

To support the case company to achieve its target, this thesis aims to define a model for the periodic evaluation of the performance of current suppliers in compliance to the requirements of IATF 16949:2016 standard. Specifically, to be compliant to IATF requirements, the evaluation of supplier performance must be based at least on the following indicators:

1. Product conformity to requirements
2. Original equipment manufacturer (OEM) disruptions at its receiving plant
3. Delivery schedule performance
4. Occurrence of premium freights.

The case company is divided in two business lines, namely LIB Cells and Battery Systems. The main products of the two business lines are illustrated in Figure 1.

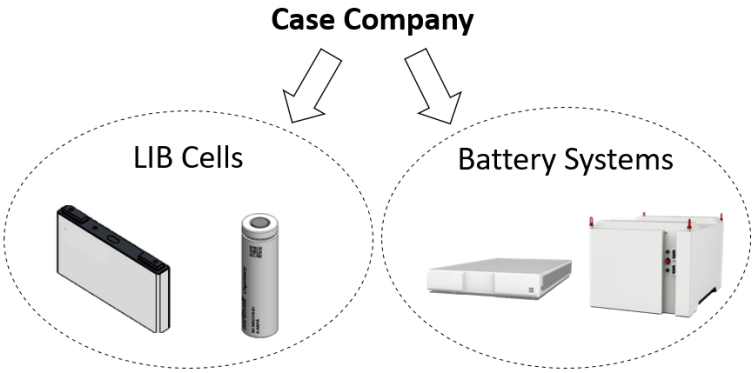

Figure 1. *Business lines and product portfolio overview of the case company.*

As the figure shows, one business line, named LIB Cells, is dedicated to the design, development, and production of LIBs. The other business line, named Battery Systems, is dedicated to the design, development, and production of complete battery systems which include energy storage systems (ESSs) and battery packs. The processes within the two business lines have different characteristics due to the different product applications and target markets.

This thesis focuses on the purchase operations of LIB Cells, as the products of this business line target directly the automotive market. The case company has planned to achieve the certification of this business line to IATF 16949:2016 by the next few years. This target will be achieved by defining a detailed roadmap, including a time plan and specific milestones for executing and controlling the whole certification project.

1.3 Objectives and research questions

There are two objectives in this thesis. First, this thesis identifies the main metrics to be used for regularly evaluating the performance of current suppliers in the context of the LIB automotive industry. Second, this thesis investigates the relative importance of the identified different criteria for regularly evaluating the performance of current suppliers in the context of the case company. More specifically, two research questions are addressed:

1. What are the relevant criteria to evaluate the performance of current suppliers of direct materials in the automotive LIB industry?
2. What is the relative importance of the identified performance evaluation criteria?

The first research question will provide clarity about the common metrics for the evaluation of supplier performance basing on the retrieved academic literature and on the experience of involved industry experts from the case company. The second research question will clarify how to correlate the identified supplier performance metrics basing mainly on the experience of the involved senior professionals. The final aim is to develop a model to be used in the case company for regularly evaluating the performance of existing suppliers of direct materials, in line with the requirements of IATF 16949:2016.

1.4 Scope and delimitations

The purchasing process implies the distinction between direct and indirect procurement (Scott et al., 2011). In this respect, Vos et al. (2016) define as direct procurement all necessary purchases for the production process of a company, while indirect procurement includes all the purchases that do not directly relate to the production process. Interestingly, de Boer et al. (2003) argue that direct procurement represents a considerable part of the purchases in manufacturing operations, accounting for about 70% of the total purchasing expenditure. For these reasons, the focus of this thesis is limited to the inbound supply chain and particularly it is defined within the scope of direct procurement. Figure 2 illustrates the delimitation of the scope of this thesis within the inbound supply chain of the case company.

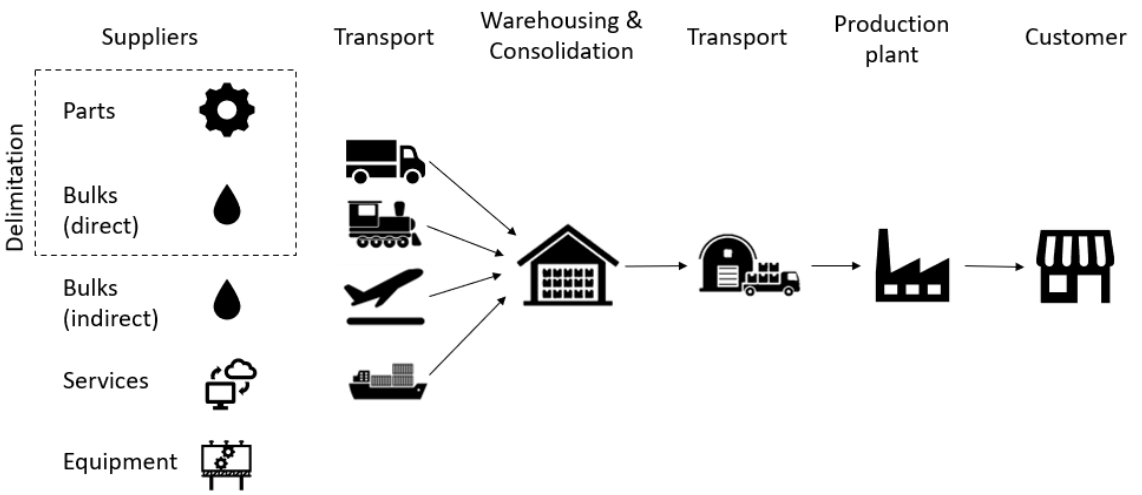

Figure 2. *Delimitation of the thesis within the inbound supply chain.*

As figure illustrates, the focus of this thesis is limited to the definition of a vendor management system (VMS) which embraces suppliers of bulk materials and production parts. Specifically, the delimitation extends to direct purchases, excluding all bulk materials and parts not specified on the bill of materials (BOM), which defines the components required in each unit of a product (Hua and He, 2010).

In this thesis, the VMS is analysed focusing on three main processes, namely supplier selection process, supplier performance monitoring process, and supplier development process. After a meeting held with the representatives of the case company, it was decided to prioritize the development of the process for evaluating supplier performance. Figure 3 illustrates the delimitation of the scope of the thesis within the vendor management process.

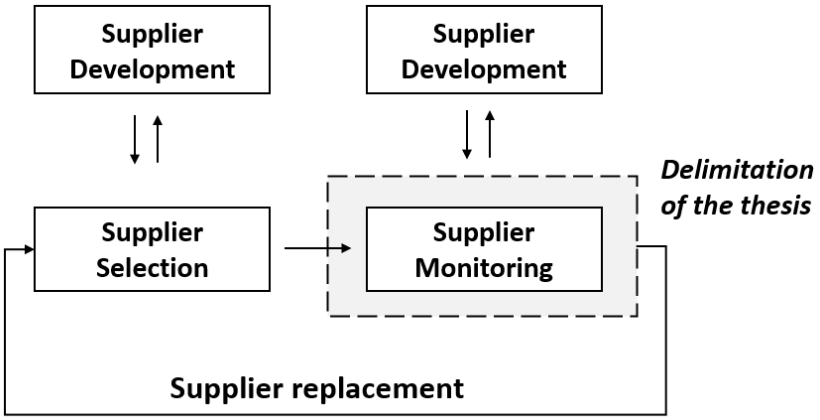

Figure 3. *Delimitation of the thesis within the vendor management process.*

As the figure depicts, the scope of this thesis is delimited to the study of the supplier monitoring process, which is part of a more extensive supplier management process.

Specifically, this study focuses on the development of a model for evaluating the performances of current suppliers. More specifically, the target of this study consists in the identification of criteria for evaluating the performance of already selected suppliers, which deliver products at the conditions specified in supply agreements. In this respect, the continuous process of evaluating of the performance of existing suppliers is kept clearly distinct from the process of evaluating the performance of new suppliers, which is instead a cardinal part of the supplier selection process.

1.5 Data gathering and research process

In literature, scholars generally refer to two approaches for the definition of a research method, namely qualitative research approach and quantitative research approach. As argued by Eriksson and Kovalainen (2008), in a qualitative research the collection and the analysis of empirical data are sensitive to the context of the study, aiming at a holistic understanding of the object of the research, whereas a quantitative research is more liable to structured, standardized, and abstracted modes of collecting and analysing empirical data. Baxter and Jack (2008) argue that a case study research allows the researcher to address both simple and complex problems while enabling to answer to ‘how’ and ‘why’ questions. Furthermore, the researcher should remember that a case study aims to provide a better understanding of complex phenomena by using empirical data as a basis, and it does not aim to prove already conceived ideas (Gummesson, 1993).

The approach of this thesis is a qualitative research approach for two reasons. First, the subject of this research must be studied from both a theoretical and practical perspective. Second, a qualitative research approach is exploratory, and it is indicated to study subjects of which the variables are initially unknown (Creswell, 2014). In this respect, Saunders et al. (2009) point out that case studies are often used in exploratory research. For these reasons, this research was conducted as a case study.

As all research must be supported by existing knowledge (Rowley and Slack, 2004), one of the most important aspects in developing a case study is the selection of the most appropriate data generation method. Interestingly, Gummesson (1993) indicates that qualitative data generating methods are often used in case study research. Moreover, document analysis, interviews, and workshops are usually part of the main activities in a case study (Stuart et al., 2002). In this respect, Eisenhardt (1989) adds that the case studies generally rely on combined data collection methods such as interviews, questionnaires, and observations.

In this thesis, the main data generation method is action science because the author was directly involved in the development of a model for evaluating the performance of current suppliers in the case company. Nevertheless, other methods such as existing material, questionnaire surveys, and qualitative interviews were used. To retrieve the data and information needed for the development of the identified solution, the research process needed to rely on a robust methodology. The schematic research process adopted in thesis is depicted in Figure 4.

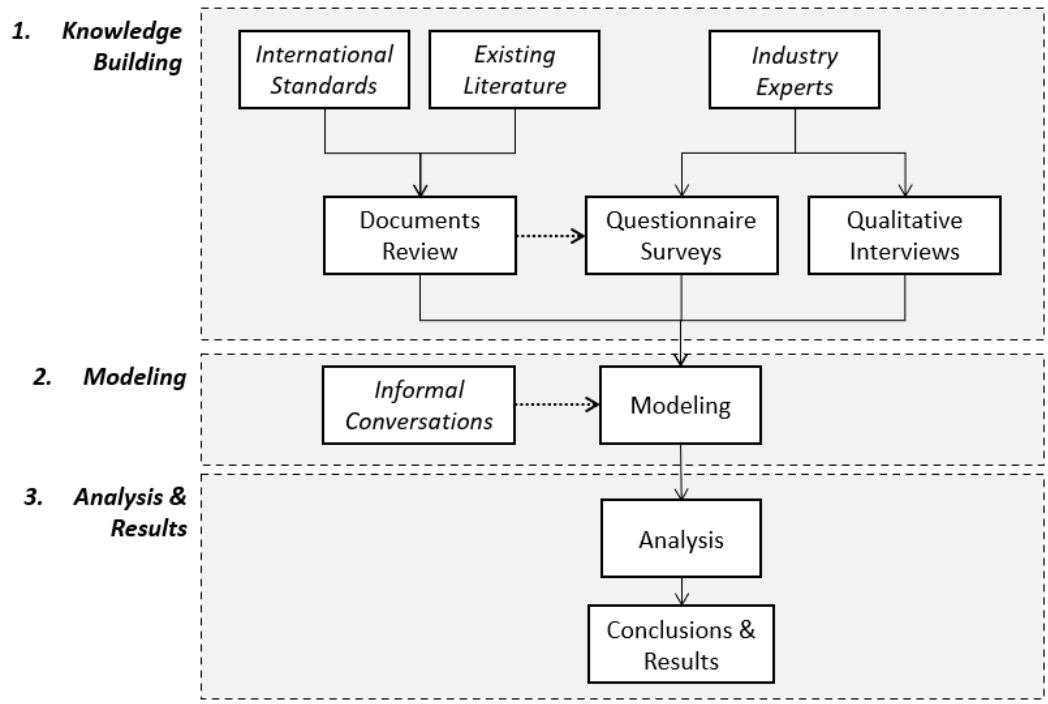

Figure 4. *The research process of this thesis.*

As the picture shows, in the research process of this thesis it is possible to identify different steps which correspond to different activities. These activities are grouped in three phases:

1. Knowledge was built by analysing information retrieved through existing literature and international standards, as well as by interviewing industry experts within the case company
2. A model for evaluating the performance of suppliers was developed. Informal conversations within the case company also contributed to further define the proposed model
3. The results were analysed, presented and discussed. During this phase, feedbacks from senior professionals from the case company helped the researcher to refine the outcomes of the modelling phase.

The research process of this thesis spanned throughout April 2020 to October 2020. The timeline of this thesis is depicted in Figure 5.

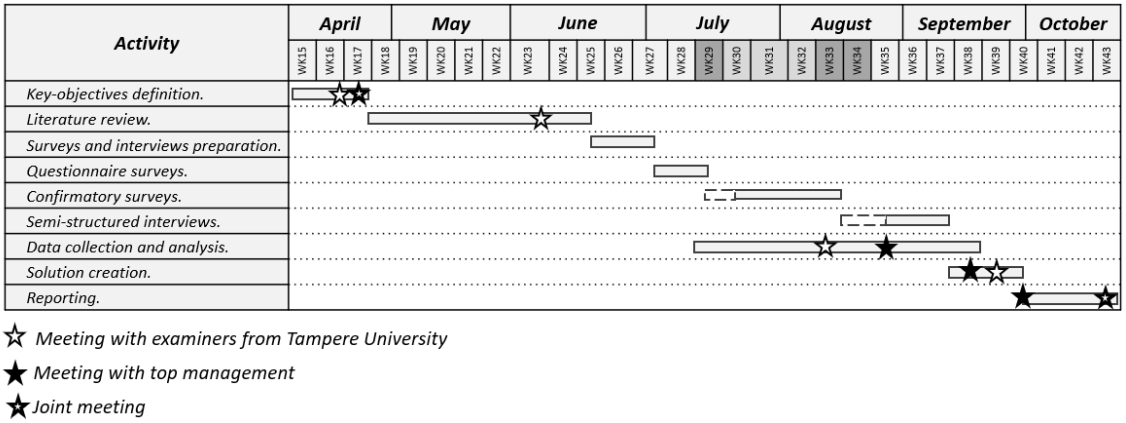

Figure 5. *Timeline and steps of the research.*

As illustrated, the objectives of this research were first defined in April 2020. This thesis work started with a kick-off meeting held with the supervisors from Tampere University and the Senior Director of Quality of the case company. Afterwards, an extensive literature review was carried out. As the project initially discussed was shortly considered too broad for the scope of this study, in early June 2020 the expected outcomes were revised with the supervisors. Consequently, a new literature review was carried out focusing on the agreed new targets. Basing on information retrieved from existing literature, the questions for questionnaire surveys and semi-structured interviews were defined.

As the time planned for the confirmatory surveys and the semi-structured interviews coincided with the summer vacation season, the schedule originally planned for these activities was extended of approximately three weeks. After having retrieved the necessary data and information, the development process of the solution began. As last step of the process, the outcomes of the study were reported.

During the development of the project, the top management of the case company was directly involved in five occasions: during the kick-off meeting with the examiners from Tampere University, during the presentation of the results of the surveys, during the review of the developed supplier performance evaluation models, during the final review of the outcomes of this study, and during the closure meeting with the examiners from Tampere University. This close collaboration with the senior managers from the case company provided good guidance and ensured that the outcomes of the study were aligned with the needs of the case company.

1.6 Structure of this thesis

This thesis is made of five chapters. The objectives and the contents of the different chapters are the following:

1. Chapter 1 is an introductory chapter that describes the research context, the case company, as well as the scope and the delimitations of this study. Moreover, this chapter details the research approach and the data generation methods applied in this thesis
2. Chapter 2 presents the results of the literature review. Specifically, the concepts of supply chain, purchasing process, vendor management process, and vendor rating are investigated in this chapter
3. Chapter 3 presents the deployed methodology for data collection and analysis. Moreover, this chapter explains the defined criteria for the selection of the senior professionals involved in questionnaire surveys and qualitative interviews
4. Chapter 4 presents the development of vendor rating models, which are used for evaluating the performance of active suppliers. First, the knowledge base built with the information retrieved through reviewed academic literature, surveys, and interviews, was used to identify appropriate metrics for evaluating supplier performance. Secondly, this chapter presents the deployment of the analytical hierarchy process (AHP) for determining comparative weights associated to the identified supplier performance metrics. Finally, this chapter illustrates the obtained vendor rating models and the defined roadmap for the implementation of a supplier performance evaluation system at the case company
5. Chapter 5 is the last chapter of this thesis and it describes the achievements of the research and possible managerial implications. Furthermore, the limitations of the research and the suggestions for possible development and future research are presented in this chapter.

2. LITERATURE REVIEW

2.1 Introduction

As Rowley and Slack (2004) indicate, during a literature review the researcher encounters the messy nature of knowledge. To cope with this issue, a systematic literature review (SLR) is necessary to respond to the addressed research questions (Tomé et al., 2016). For this reason, a systematic method for the literature review for this research can be defined. The method for a SLR is depicted in Figure 6.

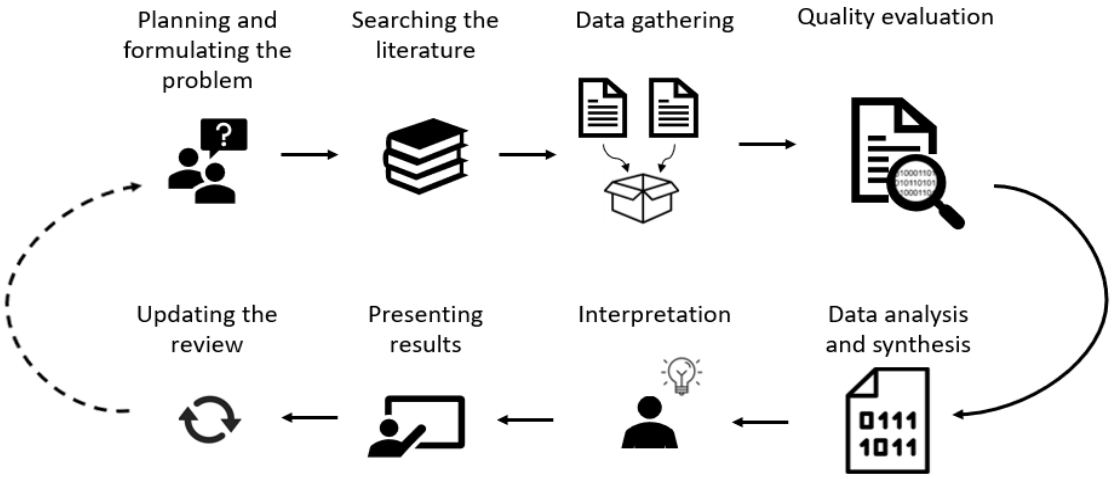

Figure 6. *Systematic literature review (Tomé et al., 2016).*

As the figure illustrates, a SLR is based eight steps, namely planning and formulating the problem, searching the literature, data gathering, quality evaluation, data analysis and synthesis, interpretation, presenting results, and updating the review. Referring to the SLR, this chapter introduces the results of the reviewed literature to define the ground for this research. First, the concepts of supply chain and the complexity of supply chain networks are introduced. Consequently, a simplified model of purchasing process is depicted. It is then described how the purchasing strategy concurs to achieve the strategic goals of an organization. Moreover, the vendor management process and its key elements are presented. Afterwards, the process for evaluating the performance of active suppliers is discussed in detail, and the concept of vendor rating and an overview of its implementation process from literature are illustrated. Finally, a summary of the main academic contributions to this thesis is presented.

2.2 The supply chain

Most of the manufacturing companies are organized as interconnected manufacturing and distribution networks to procure raw materials, to transform raw materials into finished products, and to distribute finished products to the customers (Lee and Billington, 1992). In literature, scholars have proposed multiple definitions of supply chain. As a result, the terminology in literature seldom overlaps (Lewis and Slack, 2003). Table 1 introduces the differences among some definitions of supply chain in literature.

Table 1. *Definitions of supply chain in literature.*

Definition	Authors
"Activities associated with the transformation and flow of goods and services, including their attendant information flows, from the sources of raw materials to end users".	Ballou (2004)
"All the stages involved directly or indirectly in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customer".	Chopra and Meindl (2001)
"Network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer".	Christopher (1992)
"The set of entities, including suppliers, logistic services providers, manufacturers, distributors, and resellers, through which materials, products, and information flow".	Kopczak (1997)
"Networks of manufacturing and distribution sites that procure raw materials, transform them into intermediate and finished products, and distribute the finished products to customers".	Lee and Billington (1993)

To provide clarity, a schematic representation of the main elements of a generic supply chain can be beneficial. Figure 7 illustrates a generic example of supply chain.

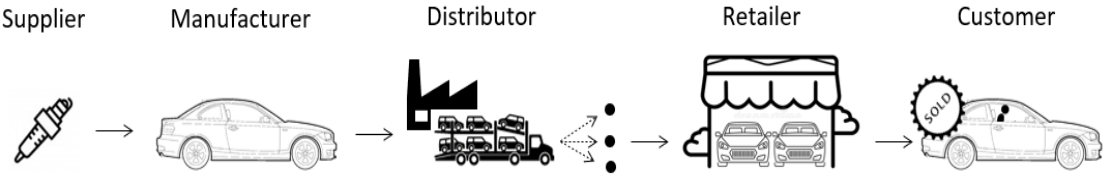

Figure 7. *The main elements of a supply chain.*

Despite the simplicity of the figure above, scholars have pointed out that supply chains in fact are not linear. In this respect, Lambert et al. (1998) underline the multidimensional nature of supply chains, which can be depicted as complex networks of organizations. For these reasons, a supply chain can also be defined as a system of organizations which are fully involved in upstream and downstream process-based activities (Kozlenkova et al., 2015). Figure 8 illustrates the concept of networked supply chain.

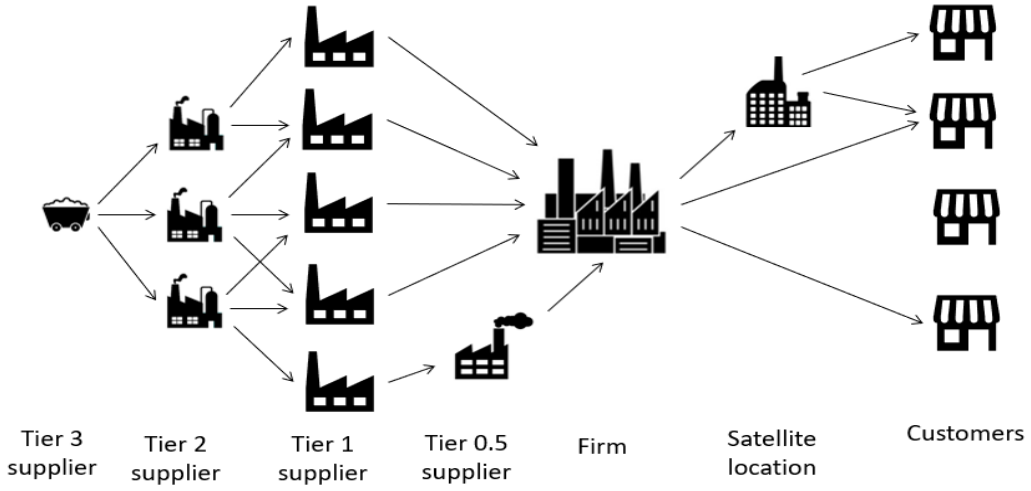

Figure 8. *Networked supply chain (Stevens and Johnson, 2016).*

As the figure shows, in practice a supply chain consists of a network of relationships. At the beginning of the supply chain network, raw material suppliers provide the products to be used in the early steps of the manufacturing process. The provided raw materials are first refined and then utilized to manufacture different products. These products are then integrated into more complex product configurations which are designed to satisfy the needs of the end customers. Finally, the finished products are delivered either directly or through intermediaries to the end customers. By recognizing the complexity of this network of relationships, the firms involved in the supply chain can improve their performances and their operational efficiencies (Stevens and Johnson, 2016).

According to Lee et al. (2014), a supply chain can be divided in three main elements, namely inbound supply chain, intra-company supply chain, and outbound supply chain.

1. The inbound supply chain includes the entities and activities that provide raw materials or semi-finished products to the manufacturing sites
2. The intra-company supply chain is mainly about the material flows within the manufacturing sites
3. The outbound supply chain includes the entities and the activities that provide and deliver the final products to the end customers.

Interestingly, Couzin et al. (2015) have identified several factors that directly affect the inbound supply chain. These factors are collaboration and globalisation, modular strategy and reduced number of suppliers, supplier parks, and outsourcing and insourcing. As organizations increase their focus on the resources and capabilities that enhance their strategic advantage, they increasingly outsource non-core activities. This allows them to take advantage of market opportunities by combining their strategic core competencies (Handfield and Bechtel, 2002).

The more a firm is oriented to outsource its non-core activities, the more complex the inbound supply chain network becomes. In this respect, the evaluation of the effects of outsourcing a task versus maintaining it within the organization is the first issue that a purchaser must consider (Baiman and Rajan, 2002). As in modern business world competition lies between supply chains and no longer between companies (Kumar and Pugazhendhi, 2012), the role of procurement and the purchasing process becomes even more crucial as purchasing activities contribute to the generation of competitive advantage (John, 2001).

2.3 The purchasing process

In literature, the analysis of the organizational buying process is commonly based on a generic multistage decision-making model (Day and Barksdale, 1994). At the most elementary level of detail, the purchasing process can be defined as a sequence of six steps, namely determining specification, selecting supplier, contracting, ordering, expediting, and follow-up and evaluation (Van Weele, 2018). The linear sequence of these steps is depicted in Figure 9.

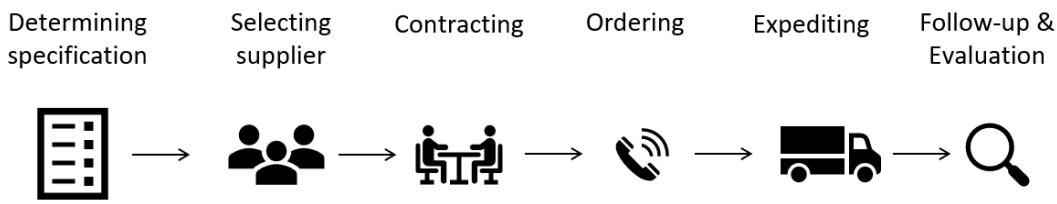

Figure 9. *The purchasing process (adapted from Van Weele, 2018).*

As the picture illustrates, the purchasing process begins with the definition of specifications that clarify the necessary quantity and quality of the object of a purchasing transaction. Sollish and Semanik (2012) argue that the clear definition of the purchase needs which are stated on specifications is a key factor for the positive outcome of the whole purchasing process. After the definition of the purchasing needs through the release of specifications, different potential suppliers are screened, and the best supplier is selected basing on specific evaluation criteria. This process is essential for mitigating the uncertainty derived from the complexity of supply chains (Chen et al., 2016). Afterwards, a contract is negotiated with the selected suppliers and, basing on the agreed contractual conditions, purchase orders are placed. Finally, the selected supplier delivers the ordered goods, and the performance of the supplier are followed and evaluated by the buying organization.

Within a general procurement process, is possible to distinguish between the definition of direct procurement and indirect procurement. On the one hand, direct procurement consists of all necessary purchases for the production process of the buying company. On the other hand, indirect procurement consists of all the purchases that are not directly related to the production process (Vos et al., 2016). In this respect, Van Weele (2018) defines multiple categories to classify different purchased materials and services. The different categories of purchased materials and services are summarized in Table 2.

Table 2. *Categories of purchased material and services (Van Weele, 2018).*

Purchased Material or Service	Category
”Materials which have undergone no transformation or only minimal transformation, and they serve as the base for the production process”.	Raw Materials
“Materials not absorbed physically in the end product. They are used or consumed during the production process”.	Supplementary Materials
“Products that have already been processed once, and that will be further processed at a later stage. They are physically present in the end product”.	Semi-Manufactured Products
“Products which will not undergo additional physical changes. They are built into an end product”.	Components
“Products which are purchased to be sold”.	Finished Products or Trade Items
“Products which are not consumed immediately, but whose purchasing value is depreciated during the economic life cycle”.	Investment Goods or Capital Equipment
“Materials needed for keeping the organization running in general, and for the support activities in particular”.	Maintenance, Repair and Operating Materials
“Activities executed by third parties or other business units of the company, on a contract basis”.	Services

Interestingly, also the definition of purchasing differs remarkably in literature. Van Weele (2018) defines purchasing as the management of the external resources of an enterprise in a fashion to secure the supply of goods, service, capabilities, and knowledge which are needed for running, maintaining, and managing the primary and support activities of the company. In this respect, Porter (1998) marks a distinction between the terms procurement and purchasing, arguing that purchasing refers exclusively to the buying operation, while the term procurement has a broader connotation which embraces a wide range of strategic activities. In this respect, the broad definition of procurement makes it a difficult subject to study (Brewer et al., 2014).

The strategic importance of the purchasing process has been deeply discussed by scholars and practitioners. Notably, several authors focused on studying the impact of

purchasing strategy on the buying organization. Ellram and Carr (1994) identify three different types of purchasing strategy:

1. The specific strategies employed by the purchasing function
2. The role of the purchasing function in supporting the strategy of other functions
3. The employment of purchasing as a strategic function of the firm.

Generally, the main challenge for the purchasing function is to develop and to coordinate its internal resources and activities in a fashion to support both the relationship with the suppliers and with the end customer (Bastholm and Munksgaard, 2020). The organization of the purchasing function greatly affects the outcome of the purchasing process because what a supplier can do for the buying company depends on how the two parties combine their resources and capabilities (Mota et al.,2015; cited in Bastholm and Munksgaard, 2020).

The purchasing strategy can be depicted through different conceptual models (González-Benito, 2007). In this regard, Hesping and Schiele (2015) highlight the difficulty to formulate a single overall strategy within the same purchasing function, suggesting that a purchasing strategy may be seen instead as a series of multiple layers. The model of the different purchasing strategy layers proposed by Hesping and Schiele (2015) is illustrated in Figure 10.

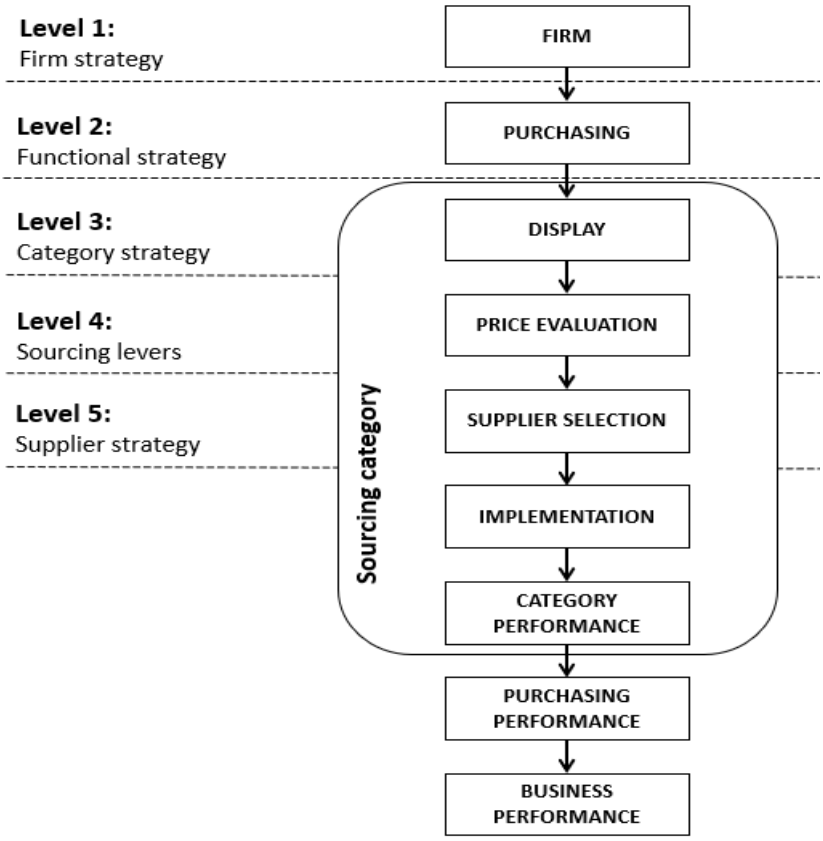

Figure 10. *Layers of purchasing strategy (adapted from Hesping and Schiele, 2015).*

As the figure shows, the strategy of an organization and its purchasing strategy can be extended to include category strategies, sourcing levers, and supply strategies. At the highest strategic level, the strategy of the firm coordinates and includes activities of the different functional units within the organization. Basing on the targets defined by the strategy of the firm, functional strategies determine the strategic goals of the different functions within the organization (Hesping and Schiele, 2015). In this respect, the purchasing strategy must be aligned with the business strategy, and the purchasing function must be informed of the strategic direction of the firm (Paulraj et al., 2006). In particular, the functional strategy of the purchasing function can be decomposed on three levels:

1. Category strategy, which refers to the activities related to the management of commodities, defined as categories or groups of suppliers of services (Rendon, 2005). Through category strategies, the organization tackles the diversity within the supply markets
2. Sourcing levers, which are sets of actions such as price evaluation, pooling of demand, and process improvement, defined to tackle the peculiarities of each different sourcing category. Through sourcing levers, the sourcing organization plans to achieve the goals set for the commodity strategy

3. Supplier strategy, which defines the ways to approach a specific supplier within a sourcing category. Consequently, different supplier strategies can be applied within the same sourcing category.

This hierarchical model of the strategy within the purchasing organization is only one of the several models that scholars have proposed as result of studies that focused on the analysis of collaborative strategies (Oke and Kach, 2012), partnership sourcing (McIvor and McHug, 2000), or strategic sourcing (Talluri and Narasimhan, 2004). Interestingly, Ahola et al. (2008) argue that the purchasing strategy adopted by the purchasing organization can significantly affect the value created for the buyers. In fact, assisting the suppliers with knowledge, skills, and experience, the buying organization can benefit from improved supplier performance (Lee et al., 2001). As the performance of the purchasing organization is related to the performances of the suppliers (Nair et al., 2015), the vendor management process plays a crucial role for achieving the operational and financial targets of the buying company (Reuter et al., 2010).

2.4 Vendor management process

The dynamic capabilities view (DCV) of the firm indicates that the contribution of a function to the competitive advantage of the firm depends on the fit of its strategy and processes to its external environment (Eisenhardt and Martin, 2000). Hence, the degree to which the organization accommodates the interests of the stakeholders also influences and affects the supplier management process. The strategic impact of procurement is especially evident in terms of cost containment, quality, delivery, and innovation (Nair et al., 2015). Constantly looking for opportunities for performance improvement, organizations have started to manage their supply base as an extension of their manufacturing system (Nayak et al., 2011). In this respect, Zimmer et al. (2015) identify three key subprocesses in the vendor management process, namely supplier selection, supplier monitoring, and supplier development.

First, through the supplier selection process the organization selects the right suppliers both to increase the competitiveness of the supply chain (Chen, 2011; Govindan et al., 2018; Yildiz and Yayla, 2015) and to mitigate risks (Yoon et al., 2018; Chen et al., 2016; Ernst et al., 2007). This process has been indicated by several authors as the most important step of the whole purchasing process (Braglia and Petroni, 2000; Dweiri et al., 2016; González et al., 2004).

Second, the performances of suppliers are monitored and evaluated against criteria such as quality, delivery, cost, and technical and managerial capabilities (Hahn et al., 1990).

The performance evaluation methods adopted for monitoring the performance of suppliers vary from company to company. In general, for this scope, buying organizations can adopt different tools and techniques such as spreadsheets, qualitative assessments, vendor ratings, supplier audits, and cost modelling (Van Weele, 2018).

Third, the supplier development process is defined to maintain the competencies of the supply network and to improve the current supplier capabilities (Hahn et al., 1990). During the supplier development process, the buying organization identifies the suppliers to be developed, the methods to be applied, and the follow-up of these processes (Bai and Sarkis, 2011).

For these reasons, the decision of whether to develop or to switch a supplier plays strategic role for buying organizations (Friedl and Wagner, 2012). The identified sub-processes within the vendor management process are depicted in Figure 11.

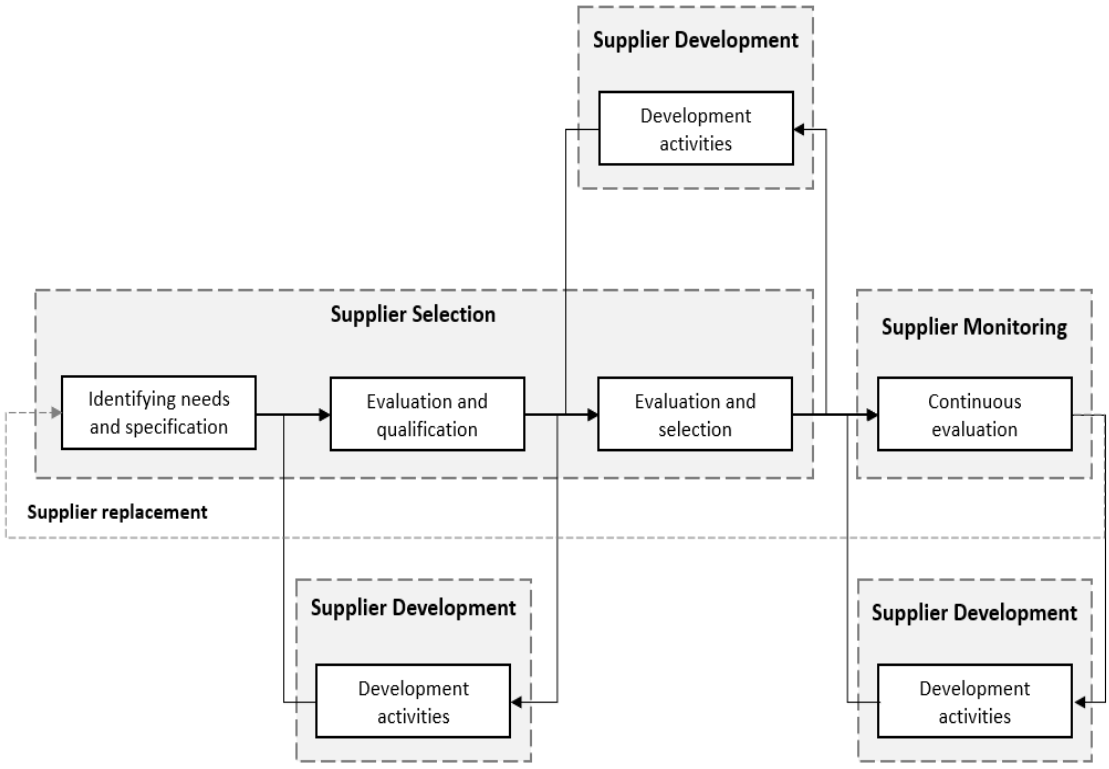

Figure 11. *Vendor management process and sub-processes (adapted from Zimmer et al., 2015).*

As the picture shows, the supplier selection process starts with the identification of needs and specifications, in line with the process proposed by Van Weele (2018). After a first evaluation and qualification of potential suppliers, the qualified suppliers are selected. Once the selected supplier has been awarded with a supply contract, the performances of the supplier are continuously evaluated. Through the continuous evaluation of the

supplier performances, the buying organization can direct the suppliers towards performance improvements (Cousins et al., 2008). Consequently, development activities aimed to recover supplier performance and to identify new opportunities for improvement are designed. The supplier development process is triggered by the performance evaluation of existing suppliers during the monitoring process or by preliminary assessments of potential new suppliers during the selection process (Hahn et al., 1990). Interestingly, Zimmer et al. (2015) point out that these three independent processes are in fact interrelated. For instance, an analytical supplier selection approach can lead to improved supplier performance (Kaufmann et al., 2012) which is a critical element for companies to be competitive in the global marketplace (Burki and Buvik, 2017). Furthermore, through the evaluation of the performance of active suppliers, the buying organization can direct the suppliers towards performance improvements and can define development activities (Cousins et al., 2008).

2.5 Monitoring supplier performance

The first performance measurement models that emphasized the link between the internal and external performance of a firm were introduced in the early 1990s (Giannakis, 2007). However, practitioners still often confuse the concepts of productivity and performance (Tangen, 2005). In fact, while the former term is a multidimensional concept mostly related to the ratio between input and output of a process, the latter term can be described as an umbrella concept that covers both operational and economic aspects (Tangen, 2005). In respect of the procurement process, after that new suppliers have been selected, the purchasing organization needs to periodically evaluate their performance to retain those suppliers who meet the requirements of the company (Braglia and Petroni, 2000). Moreover, the measurement of the performance of suppliers plays an important role to align the supplier relationship with the strategy of the firm (Cousins et al., 2008). Through the supplier monitoring process, the buying organization retrieves information used for providing feedback and improving the performance of the suppliers (Talluri and Sarkis, 2002). In line with this principle, Park et al. (2010) propose a framework for the assessment of supplier relationships to segment vendors in different groups and to develop them differently. The supplier relationship assessment model developed by Park et al. (2010) is illustrated in Figure 12.

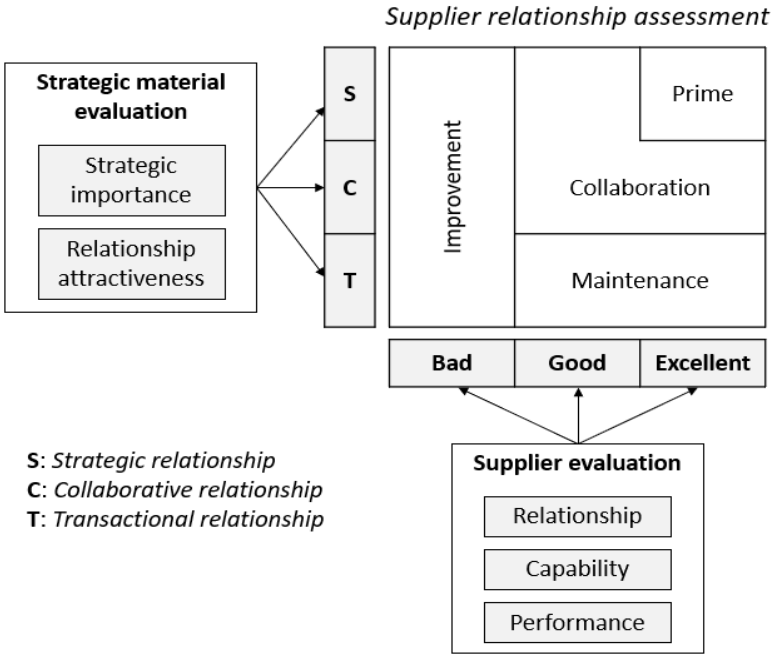

Figure 12. *Supplier relationship assessment (adapted from Park et al., 2010).*

As the figure illustrates, in Park et al. (2010) the assessment of the supplier relationship is based on the strategic importance of the supplied material and on the evaluation of the supplier. In this model, the evaluation of supplier performance is part of a more extensive supplier evaluation, which is based also on the evaluation of the relationship between the supplier and the buying organization, as well as on the evaluation of supplier capability. At the same time, the strategic importance of materials based on a portfolio strategy and the evaluation of the relationship attractiveness define three types of supplier relationship, namely strategic, collaborative, and transactional relationship. As result of these evaluations, Park et al. (2010) define four groups of supplier development strategies:

1. Prime group focuses on strong incentives and on constructing long-term trust
2. Collaboration group increases mutual benefits by improving the cooperation
3. Maintenance group maintains pursues benefit for both the parts
4. Improvement group focuses on inspections and improvement activities.

In literature, multiple frameworks for performance measurement have been proposed (Cousins et al., 2008). One of the most widely adopted is the balanced scorecard developed by Kaplan and Norton (1992). Interestingly, Bhagwat and Sharma (2007) highlight the imbalance between financial and non-financial measures when measuring supply chain performances. In this respect, the balanced scorecard provides the means to incorporate non-financial variables to measure organizational performances (Balaji et al., 2018), allowing the decision-makers to evaluate performance through four perspectives,

namely financial, customer, internal business process, and learning and growth. Despite the existence of multiple approaches for the evaluation of supplier performance, none provide a general method to combine multiple criteria into a single performance measure (Li et al., 1997). Santos et al. (2019) developed a supplier scorecard basing on several supplier key performance indicators (KPIs), assigning different scores to suppliers basing on their performance. Similarly, Luzzini et al. (2014) included commercial, logistics, and quality indicators for monitoring the performance of suppliers of direct materials. In particular, the evaluation of the defined appropriate KPIs supports the teams in the organization to align with the strategy of the firm (Parmenter, 2020). Interestingly, Parmenter (2020) points out that organizations seldom realise and are conscious of the true meaning of KPIs. In this study, the terms key performance indicator and performance indicator are used interchangeably without semantic distinction.

To collect the information needed for evaluating the performance of its current suppliers, the buying organization may adopt different methods such as questionnaires, systems, site visits, and third-party certifications (Gordon, 2005). Figure 13 illustrates the different methods for collecting information about supplier performance.

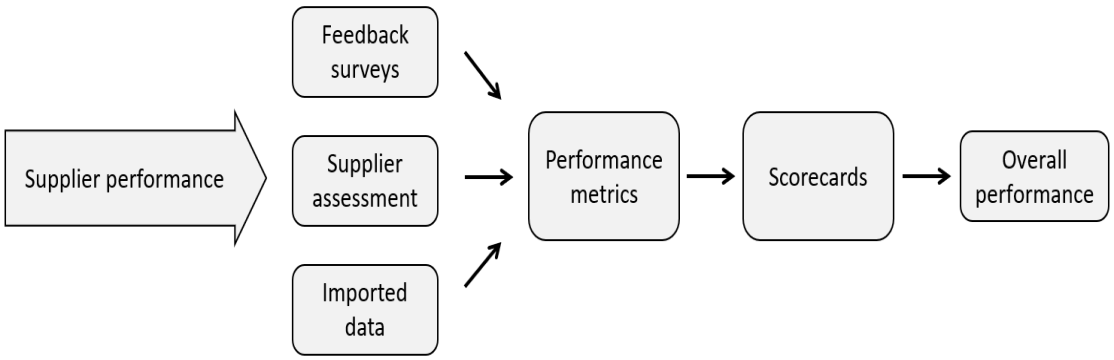

Figure 13. *Supplier information outputs (adapted from Gordon, 2005).*

As the figure shows, the outputs of the different method for collecting information about the supplier performance contribute to the generation of different performance metrics. The identified performance metrics are then combined into supplier scorecards which provide a summary view of the supplier performance results. In literature, the first set of criteria for the evaluation of supplier performance was identified by Dickson (1966), who defined 23 indicators. Afterwards, Rao and Kiser (1980) greatly increased the number of existing criteria, identifying 60 performance indicators. Similarly, the number of indicators proposed by Ellram (1990), Stamm and Golhar (1993), and Huang and Keskar (2007) varied significantly. Table 3 illustrates the number of indicators for measuring supplier performance identified by different authors.

Table 3. *Example of number of supplier performance indicators in literature.*

Reference	Number of supplier performance indicators
Dickson (1966)	23
Rao and Kiser (1980)	60
Ellram (1990)	18
Stamm and Golhar (1993)	13
Huang and Keskar (2007)	101

As the table illustrates, the list of potential metrics for evaluating the performance of active suppliers appears to be inexhaustible, making the identification of appropriate metrics a hard task (Bongsug, 2009). In this respect, Gunasekaran et al. (2004) argue that the evaluation of suppliers performance involves the definition of performance measures which are important at strategic, operational, and tactical level, and that the buying organization shall monitor, on a periodic basis, the ability of its suppliers to meet the long-term needs of the company. In particular:

1. Strategic-level performance measures include lead time, quality level, cost saving initiatives, and purchasing price
2. Tactical-level performance measures include the efficiency of the purchase order cycle time, cash flow, quality assurance, and capacity flexibility
3. Operational-level performance measures include the ability to adhere to the schedule and to avoid complaints.

To tackle the problem of identifying the most common criteria for the evaluation of supplier performance, Ho et al. (2010) viewed 78 journal articles published between 2000 and 2008. The results of this research are summarized in Table 4.

Table 4. *Common supplier performance metrics in literature (adapted from Ho et al., 2010).*

Supplier performance metrics	References, number of articles	%, out of 78 reviewed articles
Quality	69	88%
Delivery	64	82%
Price/cost	63	81%
Manufacturing capability	39	50%
Service	35	45%
Management	25	32%
Technology	25	32%
Research and Development (R&D)	24	31%
Finance	23	29%
Flexibility	18	23%

Reputation	15	19%
Relationship	3	4%
Risk	3	4%
Safety and Environment	3	4%

As shown in the table, quality, delivery, price/cost are the supplier performance metrics most frequently mentioned in the reviewed journal articles. From the table it is also possible to observe that the traditional single-criterion approach based exclusively on price/cost evaluation is no longer appropriate in modern vendor management (Ho et al., 2010).

2.6 Vendor rating and AHP

Once the buying organization has defined the most important metrics for measuring the performance of its current suppliers, a vendor rating system is essential for identifying their weaknesses and strengths (Yahya and Kingsman, 1999). Hence, the vendor rating ends the vendor evaluation process by assessing the performance e of the selected suppliers through different KPIs (Luzzini et al., 2014).

Several authors (Yahya and Kingsman, 1999; Chan, 2003; Ganguly, 2014; Dweiri et al., 2016) adopted a multi-step approach based on the analytic hierarchy process (AHP) for the definition of the comparative weight assigned to the criteria of hierarchy systems such as vendor rating systems. Specifically, the AHP is a method developed by Saaty (1977) for decomposing a complex situation into simpler parts, which are arranged according to their relative importance in order to identify the variables that influence the most the outcome of the situation (Ganguly, 2014). The AHP provides a solution to the difficult duty of having to identify comparative weights to be associated to a set of criteria by only requiring the decision-makers to judge the relative importance of the criteria, which are pairwise compared (de Boer et al., 2001). In such way, the AHP supports the decision-makers by systematizing emotions, decisions, opinions, and allowing to integrate personal experience in the decision-making process (Galankashi et al., 2016). Figure 14 illustrates the main steps of the development a vendor rating system which includes the deployment of the AHP.

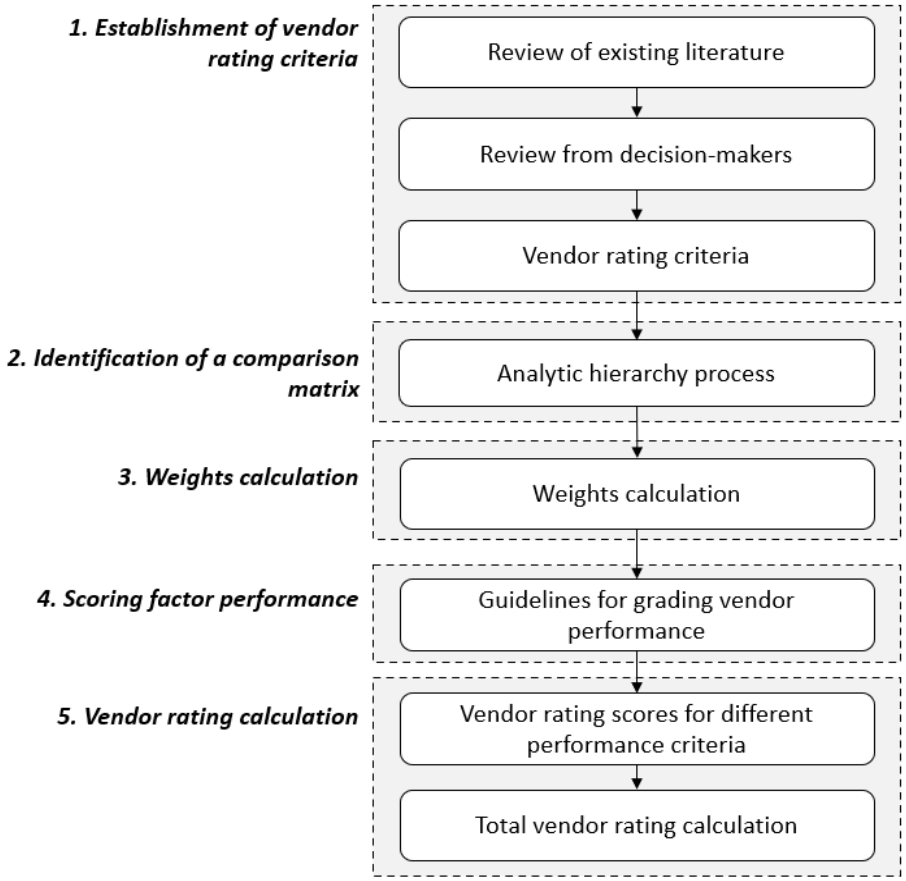

Figure 14. *Vendor rating development (adapted from Yahya and Kingsman, 1999).*

As the picture illustrates, Yahya and Kingsman (1999) defined a process for the development of a vendor rating based on five main steps: establishment of vendor rating criteria, identification of a comparison matrix, weights calculation, scoring the performance factors, and calculating the vendor rating. For each process step, more specific actions can be identified.

First, basing on the results of literature review, multiple criteria for supplier evaluation are identified and presented to the decision-makers for selecting the most appropriate metrics to be included in the vendor rating.

Second, the AHP is deployed to calculate the comparative weights of the metrics in the vendor rating. Deploying the AHP, the criteria are first listed in a pairwise comparison matrix and then compared to each other using a comparison scale from one to nine. An example of pairwise comparison matrix is reported in Figure 15.

Vendor Rating	Q	D	TC	F
Quality (Q)	1	2	5	5
Delivery (D)	1/2	1	4	4
Technical Capability (TC)	1/5	1/4	1	3
Facility	1/5	1/4	1/3	1

Figure 15. *Example of pairwise comparison matrix (Yahya and Kingsman, 1999).*

Third, basing of the obtained comparison matrix, a set of weights are associated to each criterion in the matrix. The weights are calculated by dividing each element in the comparison matrix by the sum down the corresponding column. As a result, a normalized matrix is obtained. Figure 16 illustrates the obtained normalized matrix calculated basing on the previously obtained pairwise comparison matrix.

Vendor Rating	Q	D	TC	F
Quality (Q)	0.526	0.571	0.484	0.385
Delivery (D)	0.263	0.286	0.387	0.308
Technical Capability (TC)	0.105	0.071	0.097	0.231
Facility	0.105	0.071	0.032	0.077

Figure 16. *Normalized matrix obtained from the previous pairwise comparisons.*

The weights for the different criteria are then identified by calculating the average values across the corresponding rows of the obtained matrix. Figure 17 provides an example of the set of weights identified for the different vendor performance criteria previously illustrated.

Performance criteria	Weight
Quality	0.492
Delivery	0.311
Technical Capability	0.126
Facility	0.071
Total	1.000

Figure 17. *Comparative weights for different vendor performance criteria.*

As figure illustrates, the identified set of weights associated to the different vendor rating criteria must add up to unity. However, in practice the values of the weights are generally indicated in percentage. In linear algebra, the identified weights are called eigenvalues of the pairwise comparison matrix (Krejcí, 2017).

Fourth, to score the performance of the vendors, the performance must be measured in a fashion to avoid the effects of biases and ensure consistency. For this reason, a set of standard guidelines are defined. These guidelines clarify how to evaluate the performance of the suppliers basing on different grades, which correspond to different performance levels. Therefore, it is important to clearly identify the definition of the different grades for the different performance criteria under analysis. In this respect, Giannakis (2007) argues that performance should be measured against benchmarks, which can be divided in four groups:

1. Historical standards, to compare the current performance to previous performance
2. Target performance standards, to compare the current performance to appropriate performance levels
3. Competitor performance standards, to compare the current performance to performance of competitors
4. Absolute performance standards, to compare the current performance to theoretical limits

Finally, basing on the vendor rating scores calculated for each performance criteria, the total rating for the overall performance of the supplier is calculated. An example of total vendor rating calculation is illustrated in Figure 18.

Performance criteria	Weight	Criteria score	Sub-total
Quality	0.492	8	3.936
Delivery	0.311	7	2.177
Technical Capability	0.126	9	1.134
Facility	0.071	9	0.639
Total Vendor Rating			7.886

Figure 18. *Example of vendor rating (adapted from Yahya and Kingsman, 1999).*

As the figure illustrates, multiplying the weights associated to the different criteria by the grades achieved by the supplier for each performance criteria, a sub-total rating score is calculated. The total vendor rating is calculated by summing the different sub-total vendor rating scores for the different performance criteria.

As discussed, the AHP is frequently applied to complex decision-making problems. As part of this process, a consistency test of the intuitive judgments from the involved decision-makers is mandatory (Galankashi et al., 2016). In fact, to be considered valid, the given responses should be consistent from a comparison set to another. To evaluate the

consistency of the pairwise comparison matrix, Saaty (1990) suggests using the consistency index (CI) calculated as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)},$$

where n is the number of criteria in the pairwise comparison matrix and λ_{max} is the maximal eigenvalue of the matrix. In conditions of perfect consistency, $\lambda_{max} = \lambda = n$. To test the consistency of the pairwise comparisons, CI is compared with a random index (RI) obtained by averaging the CI of a randomly generated reciprocal matrix (Saaty, 1980; cited in Tesfamariam and Sadiq, 2006). The RI values for matrices up to n=10 are reported in Table 5.

Table 5. *RI values for consistency tests in AHP (adapted from Tesfamariam and Sadiq, 2006).*

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

The consistency ratio (CR) is then calculated to evaluate the final inconsistency in the obtained pairwise comparison matrix. The CR is calculated as follows:

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

A CR value smaller than 10% is evidence of high consistency, whereas a CR value greater than 10% is evidence of inconsistency. In case of inconsistency, the elements in the tested pairwise comparison matrix should be adjusted, and the consistency test should be repeated (Galankashi et al., 2016).

2.7 Summary of the main academic contributions to this thesis

In this thesis, an extensive literature review was carried out to provide a solid base for the definition of the deployed models as well as for justifying necessary assumptions. To provide clarity, a summary of the literature that contributed the most to the development of this research is presented in this chapter.

In literature, scholars have developed several models to depict the conceptual networks deployed in the different research studies. One visual tool generally used to define elaborate conceptual networks is mind mapping. Dhindsa et al. (2011) indicate that mind mapping consists in the organized representation of knowledge in a network or other non-linear diagrams. Furthermore, as argued by Janczukowicz and Rees (2017), a mind map provides visual support to understand structured information and hierarchy of attributes. For this scope, mind mapping was identified as the preferred method for depicting

a summary of the most influential retrieved literature for this thesis. Farrand et al. (2002) define the main steps for producing a mind map:

1. Place the main topic of the study in the centre of the mind map
2. From the main topic, extend several major branches representing the topic subheadings
3. Write the important detail included under each subheading upon smaller branches projecting from the subheadings.

Following the indications of Farrand et al. (2002), a mind map of the retrieved literature that contributed the most to the development of the case study of this research is developed. The obtained mind map is illustrated in Figure 19.

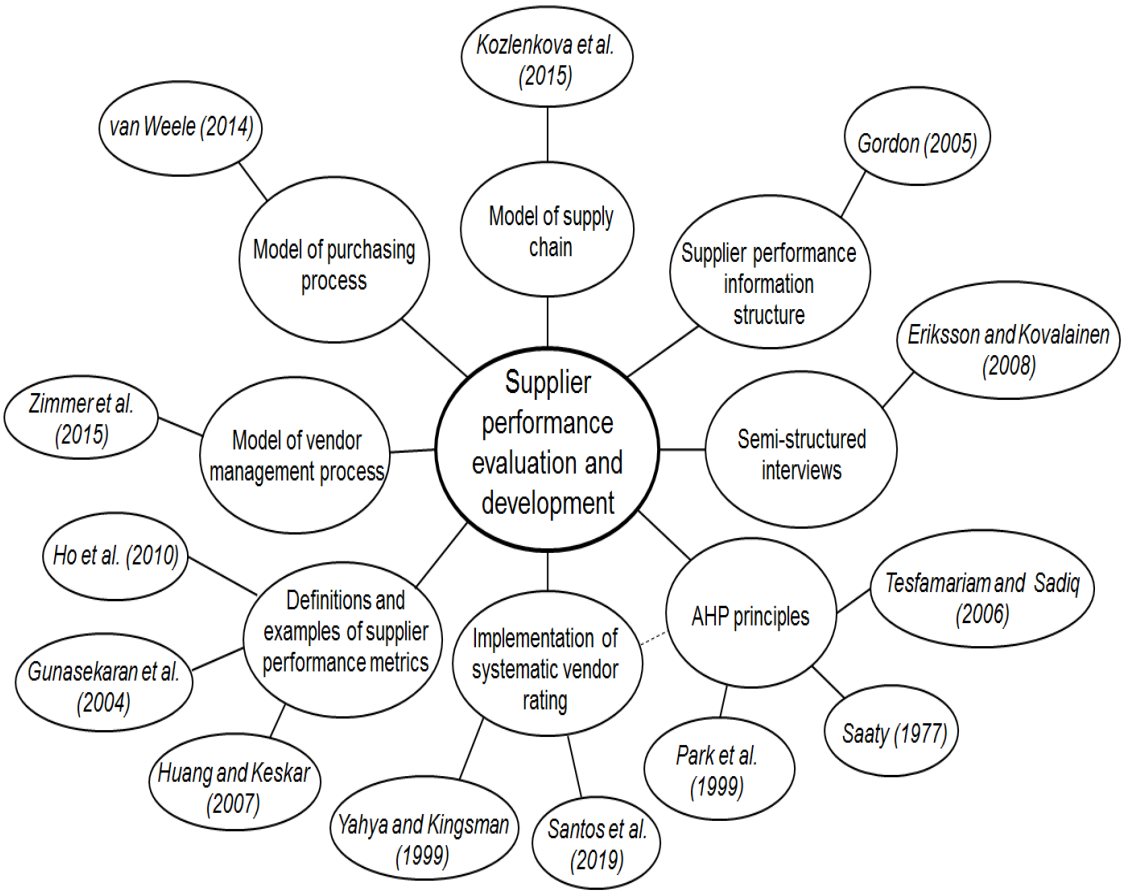

Figure 19. *Mind map of retrieved literature for the scope of this study.*

As the figure illustrates, 13 academic articles resulted particularly relevant for the development of this study. Specifically, the models of supply chain, purchasing process, and vendor management process retrieved from existing literature provided the ground for clearly delimiting the scope of this study.

The information related to qualitative interviews retrieved from Eriksson and Kovalainen (2008), was used to identify semi-structured interviews as the optimal data gathering methodology in this study. Specifically, the comprehensive list of supplier performance metric gathered from Ho et al. (2010), Huang and Keskar (2007), and the definitions retrieved Gunasekaran et al. (2004) provided the knowledge base for designing appropriate questionnaire surveys.

The conceptual frameworks presented by Santos et al. (2019) and Yahya and Kingsman (1999) were both used to develop a systematic vendor rating in the case study. Finally, the supplier performance information model and the principles of the AHP methodology were adopted both for defining the hierarchical structure of the developed vendor rating models and for determining the weights associated to each supplier performance metric. As the main target of the case company consisted in developing processes aimed to the obtainment of the IATF 16949:2016 certification, the requirements of the QMS international standard were also fundamental for the correct definition of the models that needed to be developed.

3. DATA GENERATION PROCESS

3.1 Introduction

This chapter presents the possible data generation methods existing in literature and it illustrates the process deployed for collecting and analysing data in this study. Then, this chapter introduces the criteria for the selection of the senior professionals involved in surveys and qualitative interviews. Finally, the complete list of semi-structured interview held with the selected representatives of the case company is presented.

3.2 Data generation methods

In literature, qualitative cases have been seldom criticized for lack of rigor and the inability to generalize the claims from a limited number of case studies (Stuart et al., 2002; cited in Bals et al., 2018). According to Gummesson (1993), there are several methods for generating data in a case study. Figure 20 depicts the data generation methods described by Gummesson (1993).

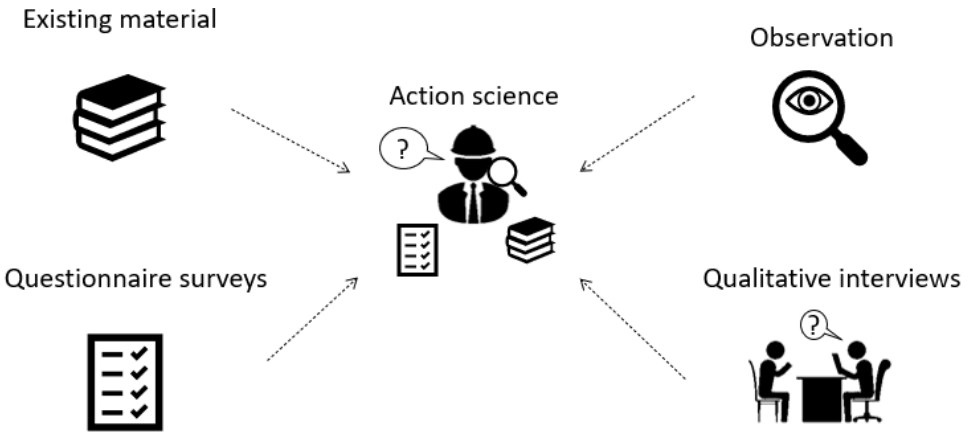

Figure 20. *Data generation methods for case study research (Gummesson, 1993).*

As the figure shows, Gummesson (1993) defines five groups of data generation methods, namely existing material, questionnaire surveys, qualitative interviews, observation, and action science.

First, existing material generally includes data stored in books, research reports, computer data bases, brochures, films, photos, and other forms of publication. Interestingly, existing material can be used either as main data gathering method or as a complementary one.

Second, questionnaire surveys are tools used for generating quantifiable data with the aid of standardized questionnaires. Questionnaire surveys can be used as quantitative methods as well as qualitative methods in case studies.

Third, qualitative interviews are the most common method to generate data in case study research. The data is generated by interviewing the interested parties. Qualitative interviews can be divided into formal interviews and informal interviews. While formal interviews are carried out using questionnaires, informal interviews are closer to a free-form conversation, as the questions are not addressed in a specific order. Informal interviews are the most common method for gathering data in case study research.

Fourth, observation can be divided in direct observation and participant observation. Direct observation requires less involvement of the researcher, while participant observation requires a higher level of involvement of the researcher. Interestingly, Gummersson (1993) argues that interviews and questionnaires can also be used during observations to obtain additional data.

Finally, action science, or action research, includes elements of all the already mentioned methods. In particular, in action science the researcher is an active participant that influences the process under study. In action science the goal is to make the action effective while constructing a body scientific knowledge (Coughlan and Coghlan, 2002).

In this study, the main adopted data generation method is action science because the author directly participated in the development of models for evaluating the performance of active suppliers in the case company. Nevertheless, other methods such as existing material, questionnaire surveys, and qualitative interviews were largely used.

3.3 Process overview

In this study, selected representatives of the case company actively participated in the process of providing data and information which served as a base for the following modelling phase. During this process, surveys and individual semi-structured interviews were used as data generation methods. Figure 21 illustrates the process for generating data and information in this study.

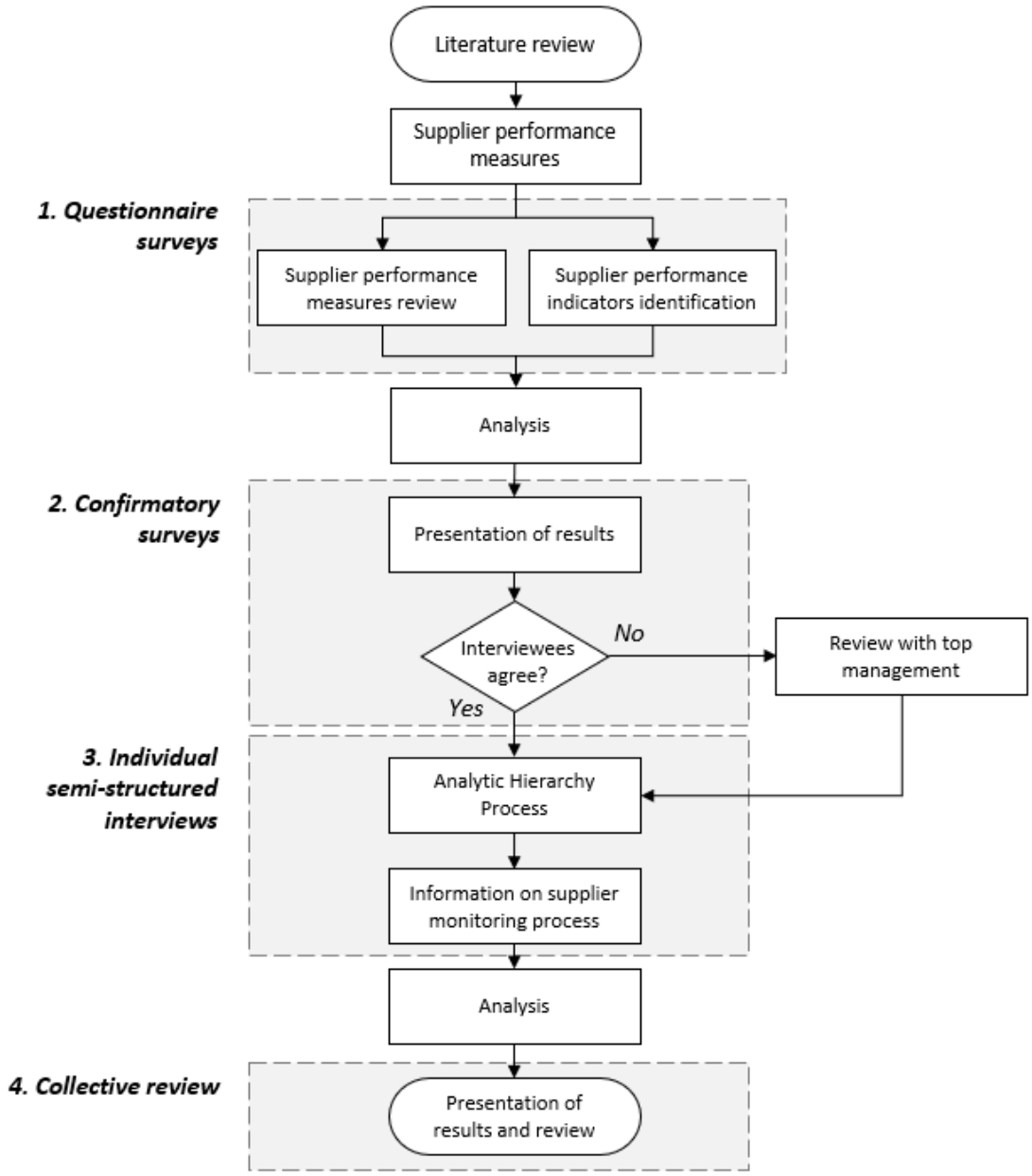

Figure 21. *Process for data collection and analysis through questionnaire surveys and semi-structured interviews.*

As the figure illustrates, four steps can be identified in the process for collecting and analysing data and information. For each process step, more specific actions can be identified.

First, the information about supplier performance measures retrieved from the academic literature were reviewed and collected to design a questionnaire survey. In particular, the research questions of this thesis and the retrieved literature provided a guide for the identification of the questions to be addressed (Skålen et al., 2015). During the questionnaire survey, the participants were asked to evaluate the presented supplier performance measures and to make their own proposals for additional measures. Moreover, during

this step the participants were asked to define different supplier KPIs for each of the presented supplier performance measures.

Second, after collecting and elaborating the results of the questionnaire surveys, a confirmatory survey was conducted to confirm the results of the analysis and to possibly reduce the number of criteria identified at the previous step. In this step the participants were asked to review the list of identified performance measures and to indicate only the criteria that were considered appropriate to be implemented in the vendor rating system. In case a consensus would have not been reached, the results would have been reviewed involving top management.

Third, once a consensus about the definition of the measures to be included in the vendor rating system was reached, individual semi-structured interviews were held. During the individual semi-structured interview, the selected interviewee was led by the author through the application of the AHP method for determining the weights of the identified performance measures and KPIs. Afterwards, the outcomes of the interviews were collected, and the weights of the different vendor rating metrics were identified by calculating the average of the weights obtained by the different interviewees. In addition, during the interviews the involved senior professionals provided useful insights about the evaluation of supplier performance.

As final step, the results of the activity were presented to top management for review. In this step, the need to modify the suggested performance metrics could have raised from the involved senior managers.

3.4 Questionnaire surveys and confirmatory surveys

For this research, questionnaire surveys were used to collect information about the definition of the most appropriate supplier performance measures and supplier KPIs for the case company. As the nominated interviewees had a different background in terms of industry expertise and area of responsibility, structured questionnaires were identified as the preferred methodology for the execution of the initial investigation. Indeed, elements of arbitrary subjectivism are significant for choosing the most appropriate investigation methods, and structured questionnaires are generally used in this case (Bent et al., 2010).

In this study, the designed questionnaire survey consisted of different parts. Figure 22 illustrates the structure of the designed questionnaire surveys.

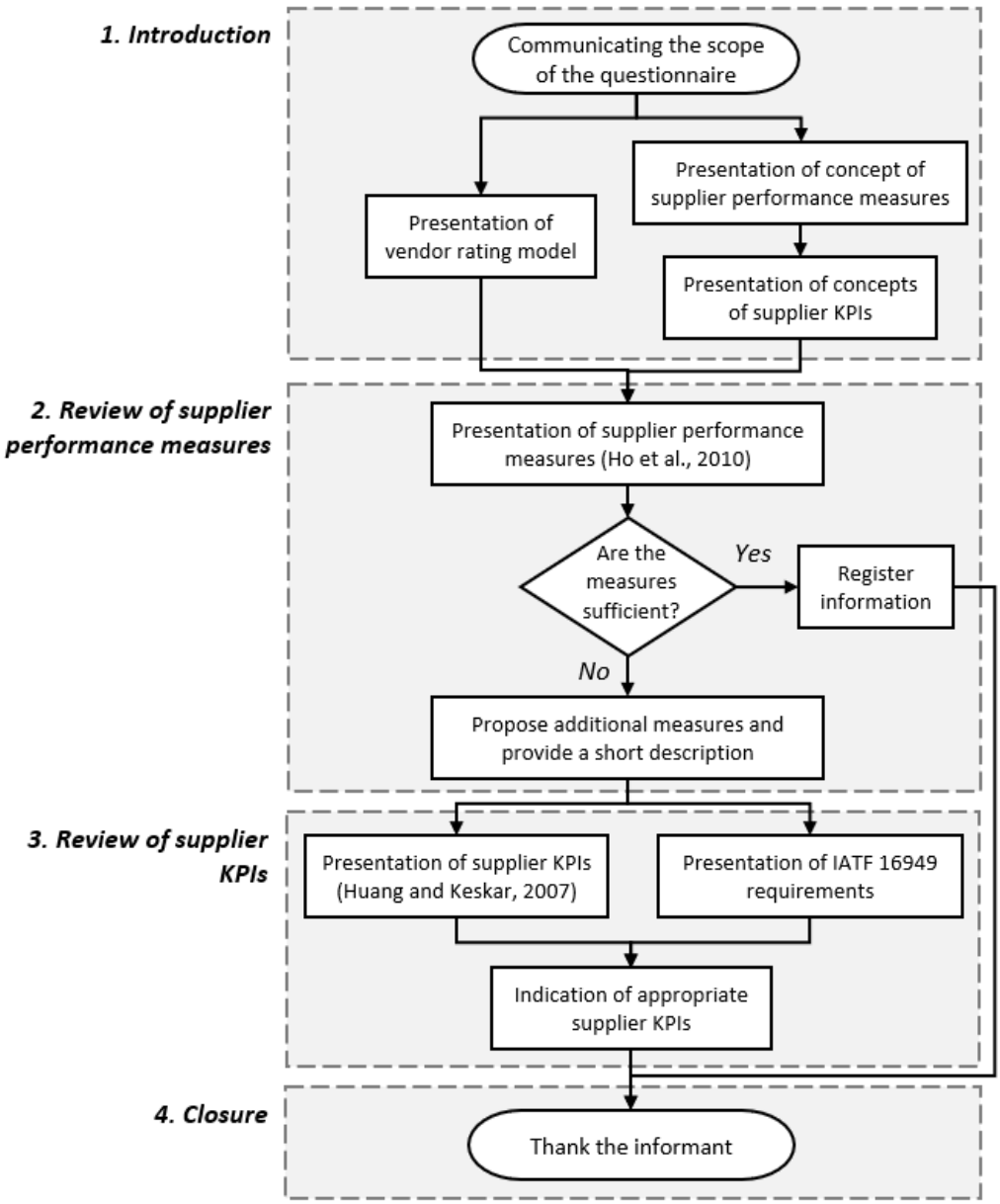

Figure 22. *Structure of questionnaire survey.*

As the figure illustrates, the designed questionnaire surveys consisted of four parts, namely introduction, supplier performance measures review, supplier performance indicators definition, and closure. First, a schematic illustration to display the correlation between performance measures and performance indicators in the context of a vendor rating was presented to the informants. This figure helped the researcher to align the informants on the terminology used in the questionnaire survey. Second, the top three performance measures identified by Ho et al. (2010) were presented to the informants. To clarify the meaning of the presented three supplier performance measures, examples from Gunasekaran et al. (2004) were given. Consequently, the informants were asked if the presented measures were sufficient to evaluate the performance of active suppliers.

The interviewees could make their own proposals for additional performance measures basing on their own experience. When suggesting additional measures, the interviews were also asked to list their suggestions in order of priority, from high to low. To facilitate the identification of possible additional measures, the complete list of performance measures identified by Ho et al. (2010) were reported in the questionnaire survey, for reference. Third, the interviewees were asked to suggest at least three performance indicators for each performance measure. To facilitate this task, some examples from Huang and Keskar (2007) were reported in the questionnaire survey, for reference. Furthermore, the supplier performance indicators mentioned in IATF 16949:2016 were presented to the informants. Finally, in the last part of the questionnaire, the interviewees were thanked for their contribution and informed about the next steps of the process.

The designed questionnaire survey is reported in Appendix A. All the returned questionnaire surveys were collected and archived by the researcher. Afterwards, the collected information was analysed, and the results were used for preparing the questionnaire for the following confirmatory survey. The designed confirmatory survey is reported in Appendix B.

3.5 Semi-structured interviews

Generally, an interview consists of a talk organized in a series of questions and answers (Eriksson and Kovalainen, 2008). Interviews are also commonly used as method to gather data in case study research. Qualitative interviews can be grouped in different types such as structured and standardized interviews, guided and semi-structured interviews, unstructured, informal, open, and narrative interviews. The different types and characteristics of qualitative interviews are summarized in Table 6.

Table 6. *Types and characteristics of qualitative interviews (Eriksson and Kovalainen, 2008).*

Structured and standardized interviews	**Guided and semi-structured interviews**	**Unstructured, informal, open, and narrative interviews**
The interviewer has reduced flexibility to respond to the concerns of the interviewees.	Systematic interviews but maintaining conversational and informal tone.	Useful approach to broadly explore a topic from the point of view of the interviewees.
Preferable option in case of inexperienced interviewers.	The interviewer must ensure to cover all the topics of the interview while probing for more in-depth responses from the interviewees.	The interviewer is free to move the conversation in any direction. The main purpose is to produce a narrative and to provide insights that the interviewer could not have anticipated.

For this study, structured interviews were not deemed suitable to gain further information about the object of the research. The researcher needed to have the possibility to address additional questions in case the information gathered from the interviewees were insufficient. According to Farquhar (2012), semi-structured interviews are usually preferred in qualitative data generation as they allow flexibility and adaptation to the context while following an interview guide. In other words, when preparing a semi-structured interview, the interviewer prepares an outline of the topics of the interview, reserving the possibility to change the wording and the order of the questions (Eriksson and Kovalainen, 2008). For these reasons, semi-structured interviews were used in this research.

As argued by Voss et al. (2002), when the subject of the study may have different viewpoints, the researcher may involve different interviewees. To ensure rigor in the data collection process, informants with profound knowledge about the topics of the research questions were selected within the case company. Referring to the studies of Geiger (2017) and Laubert and Geiger (2018), the criteria for the identification and selection of the participants to the questionnaire surveys and to the semi-structured interviews were defined. The following criteria were applied for selecting the informants:

1. Experience in purchasing, logistics, supplier quality, and supplier development. Alternatively, extensive experience in supply chain management
2. Experience within the automotive industry. Alternatively, experience within other highly regulated industries such as chemical, pharmaceutical, and electronics
3. Current role closely related to the vendor management process.

Eventually, 14 senior professionals were identified through the mentioned selection criteria. When contacting the informants via email, the scope of the research, the survey and the interview process, and the expected contribution of the participants were described. The list of the selected informants is reported in Table 7.

Table 7. *Table of selected informants from within the case company.*

Interviewee	**Experience**			**Department**
	Department	**Industry**	**Years**	
IP01	Global Supply Chain, Quality	Pharmaceutical	16	Quality
IP02	Supplier Quality, R&D, Production	Automotive	15	Quality
IP03	Supplier Quality, Production	Automotive	5	Quality
IP04	Supplier Quality, Project Management	Automotive	14	Quality

IP05	Logistics, Production, Supplier Quality	Automotive	31	Quality
IP06	Supplier Quality, Procurement	Electronics	13	Quality
IP07	Procurement	Automotive	40	Procurement
IP08	Procurement	Automotive	14	Procurement
IP09	Procurement	Chemical	16	Procurement
IP10	Project Management	Automotive	7	Procurement
IP11	Procurement	Automotive	14	Procurement
IP12	Procurement	Mining	15	Procurement
IP13	Procurement	Electronics	22	Procurement
IP14	Logistics	Automotive	15	Logistics

During the interviews, the selected interviewee was led by the researched through the application of the AHP for identifying the normalized weights of different supplier performance measures and supplier KPIs within the developed vendor rating models. The interviewees shared also important knowledge about the supplier performance evaluation process. The list of interviews held with the selected informants is reported in Table 8.

Table 8. *List of qualitative interviews held with the selected informants.*

Interview	Interviewee	Date [dd/mm/yyyy]	Duration [min]
IN01	IP07	27/08/2020	68
IN02	IP05	28/08/2020	50
IN03	IP02	28/08/2020	44
IN04	IP09	31/08/2020	50
IN05	IP10	31/08/2020	45
IN06	IP06	21/08/2020	71
IN07	IP04	01/09/2020	45
IN08	IP12	01/09/2020	50
IN09	IP01	01/09/2020	51
IN10	IP08	03/09/2020	61
IN11	IP14	07/09/2020	53
IN12	IP11	08/09/2020	60

As the table shows, eventually 12 informants accepted the invitation for interview. As the response rate was 86%, the number of interviewees was considered adequate to assist the researcher in this study. Therefore, a total of 12 semi-structured interviews were conducted with the selected interviewees between August and September 2020. The selected questions for the semi-structured interviews are presented in Appendix C. All the interviews were held through Microsoft Teams and transcribed.

4. ANALYSIS AND MODELING

4.1 Introduction

This chapter describes the results obtained from the questionnaire surveys, the confirmatory surveys, and the semi-structured interviews held with the selected representatives of the case company. The retrieved information was analysed and used to develop a vendor rating system and to define a roadmap for implementation, in line with the targets of the case company.

4.2 Analysis of questionnaire survey results

In this study, the 14 selected informants were first asked to evaluate if quality, delivery, and price/cost, which are the supplier performance measures most mentioned in literature according to the extensive literature review carried out by Ho et al. (2010), were considered sufficient for understanding the overall performance of current suppliers. In case the indicated measures were considered insufficient, the participants were asked to suggest additional performance measures and appropriate KPIs. To guide the informants and to provide clarity about the definitions used in the questionnaires, illustrations and selected examples of supplier performance measures and KPIs from academic literature were included on the questionnaire survey. Interestingly, about this strategy, one participant pointed out:

“I think that, by guiding the interviewees with examples, you might influence the provided answers”.

In this respect, Gorrell et al. (2011) warn that the effects of bias must be carefully taken in consideration when interpreting research results. For this reason, when designing the questionnaire survey, the possible risk to induce a biased response from the informant was accurately taken into consideration. In fact, three possible strategies were identified:

1. To not include any reference to existing supplier performance measures from academic literature
2. To include only selected examples of existing supplier performance measures from academic literature
3. To include an extensive list of supplier performance measures from academic literature.

To better support the respondents in their task, the full list of supplier performance measures identified by Ho et al. (2010) was presented to the participants to the questionnaire survey. The main reasons that pushed the author to take this decision were the following:

1. The extensiveness of the study conducted by Ho et al. (2010), who reviewed 78 academic articles published from 2000 to 2008
2. The definition of selection criteria for the identification of specific measures to be presented in the questionnaire was considered to imply high risks for the outcome of the study.

Specifically, the risk that the contribution of the interviewees could have been affected by the provided limited examples of supplier performance criteria presented in the surveys was considered in the definition of the information reported on the questionnaires.

In literature, scholars have often referred to performance evaluation models based on two levels of performance (Yahya and Kingsman,1999; Hald and Ellegaard, 2011), namely performance measures and supplier performance indicators. This model was also adopted in this research because most of the participants were already familiar with such structure, as it emerged from informal discussions held before the questionnaire surveys. Figure 23 illustrates a performance evaluation model based on two levels of performance.

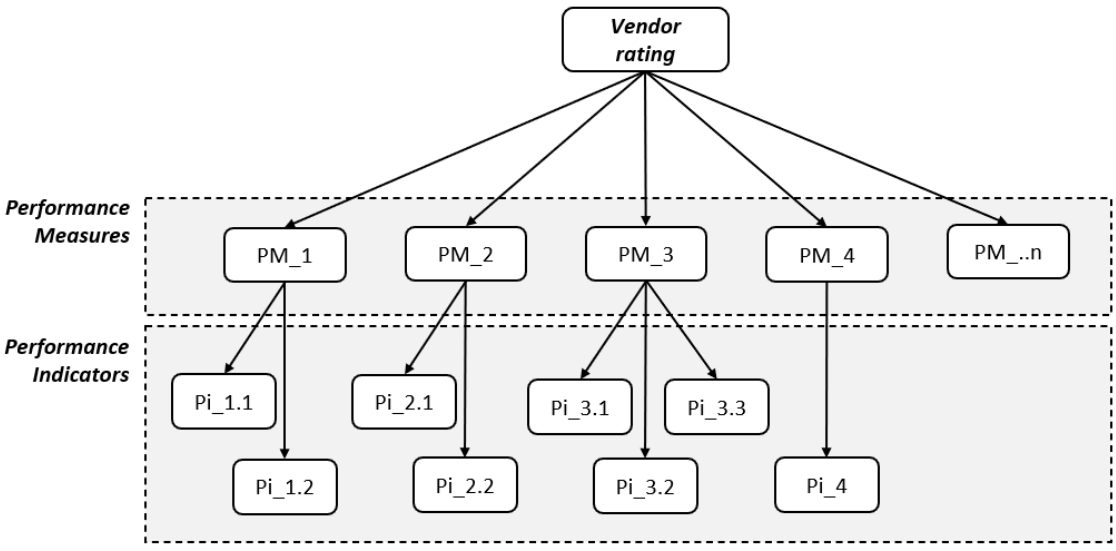

Figure 23. *Vendor rating structure (adapted from Yahya and Kingsman, 1999).*

In this illustration, the performance of the vendors is evaluated basing on criteria organized on two levels, namely performance measures and performance indicators. First, performance measures represent the different high-level perspectives for describing the

supplier performance. Therefore, the combined evaluation of the different performance measures results in the evaluation of the overall supplier performance. An example of performance measures from literature is quality (Doolen et al., 2006). Second, each performance measure includes different performance indicators, also mentioned as KPIs, which are related to specific performance measurements. Examples of supplier KPIs for quality are parts per million, factory disruptions, faulty analyses, corrective action (Doolen et al., 2006).

During the questionnaire surveys, the informants were asked to include a short description of the suggested additional performance measures and performance indicators. These descriptions supported the author in the identification of possible similarities among the suggestions coming from the 14 informants. Moreover, the questionnaire survey included the possibility to rank the suggested supplier performance measures in order of priority, from high to low.

4.2.1 Suggested supplier performance measures

Interestingly, all the participants pointed out that quality, delivery, and price/cost were not sufficient to evaluate the overall performance of suppliers. Consequently, all the informants pointed out one or more additional supplier performance measure when returning the questionnaire surveys. The additional supplier performance measures suggested by the informants are reported in Table 9.

Table 9. *Identified supplier performance measures as result of the questionnaire survey.*

Performance Measures	**Short Description**
Localization	Ability to produce locally, ability to provide local support
Capacity/flexibility	Lead time for changes, ability to deal with change in forecast
Risk	Capacity shortage, financial risk, changes in management structure, risk to production
Business impact	Evaluation of supplier impact on the business of the company
Sustainability	Environmental, safety and social responsibility aspects
Environment	Environment management system evaluation
Carbon Footprint	Ability to deliver solutions at the lowest possible carbon footprint
Sustainability index	CO_2 footprint, energy consumption, waste/recycled
Safety and environment	Sustainability and risk of safety issues
Financial power	Credit rating, market strength
Finance	Financial situation at the supplier
Financial stability	Company stability and solidity
Management	Corporate social responsibility (CSR) rating, credit rating, financial structure, technical capability, relationships

Supplier strategy	Turnover growth, diversification, customer and product portfolio, reputation, partnership
Compliance	Code of conduct, code of ethics
Development Capability	Capability to develop products further and to remain competitive
Development	Ongoing project development, validations on time, support from the supplier, adherence to agreed milestones
Engineering	Ability to deliver fit for purpose solution, concurrent engineering
New projects	Production Part Approval Process (PPAP) approved on time
Logistics	Supplier's logistics management evaluation
Service on time	Service provided in accordance with agreed schedule
Service in full	Were all the items collected and delivered?
Technology expertise	Assessment of company know-how and expertise
Manufacturing capability	Ability to manufacture the required quality in time
Cost (serial)	Continuous improvement, inflation mitigation, forex mitigation
Non-conformities	Non-conformities in relation to the provision of the service

As the table shows, 26 additional performance measures were suggested by the informants. To reduce the number of variables and to simplify the following confirmatory survey phase, the collected performance measures were divided in 10 different groups. The description provided by the selected informants were used to group the collected performance measures. Furthermore, for the identification of the appropriate groups, the supplier performance measures indicated by Ho et al. (2010) were used. Table 10 illustrates the results of the new aggregation of the supplier performance measures suggested by the selected 14 informants.

Table 10. *Aggregated supplier performance measures.*

Supplier performance measures (adapted from Ho et al., 2010)	**Additional supplier performance measures from questionnaire surveys**	**%, out of the 26 indicated performance measures**
Safety and sustainability	Sustainability Environment Carbon Footprint Sustainability index Safety and environment Compliance	23 %
R&D	Engineering New projects Development Capability Development	15 %
Delivery and service	Logistics Service on time Service in full	12 %
Finance	Financial power Finance Financial stability	12 %
Flexibility	Localization	8 %

	Capacity/flexibility	
Risk	Risk Business impact	8 %
Management	Management Supplier strategy	8 %
Manufacturing capability	Technology expertise Manufacturing capability	8 %
Quality	Non-conformities	4 %
Price/cost	Cost	4 %

As the table shows, safety and sustainability, R&D, delivery and service, and finance were the most recurrent performance measures identified by the interviewees. Interestingly, these results are in line with the mission of the organization, which is:

"To build lithium-ion batteries with the lowest carbon footprint and the highest ambitions for recycling".

In fact, referring to the model developed by Hesping and Schiele (2015), as sustainability is central in the strategy of the case company, it is also central in the functional strategy level deployed by the purchasing organization.

4.2.2 Suggested supplier performance indicators

During the questionnaire surveys, the involved senior professionals were asked to suggest and to provide the definition at least three supplier KPIs for each additional supplier performance measure that they could have possibly indicated. In total, 163 supplier performance indicators were collected from all the involved informants. Consequently, the collected KPIs were analysed basing on the short descriptions provided by the participants.

During the review of the collected results, it was observed that multiple KPIs addressed the same or similar performance evaluation criteria. Consequently, the collected KPIs were grouped by similarity. In case of ambiguity, the informants were contacted to provide further clarifications. As a result, 19 distinct KPIs were identified. Table 11 illustrates the distribution of the suggested supplier KPIs along the corresponding performance measures.

Table 11. *Frequently suggested supplier KPIs.*

Supplier performance measures	Supplier performance Indicators	Number of times the KPI was suggested
Quality	Defect Rate	14
	Number of complaints	12
	Countermeasures lead-time	8
	Quality audit results	6

Price/cost	Cost/competitiveness	14
	Cost savings	12
	Transparency	4
Delivery and service	Lead time stability	12
	Delivery in full	4
Risk	Financial risk	7
	Dependency	1
Flexibility	Delivery flexibility	5
	Schedule flexibility	4
Safety and sustainability	Carbon footprint	4
R&D	PPAP completed on time	4
Finance	Turnover	3
Manufacturing capability	Process capability	4
Management	Partnership	1
	CSR rating	1

As the table illustrates, for quality, delivery and service, and price/cost, the involved senior professionals suggested identical or similar supplier KPIs. This result was expected as the mentioned three supplier performance measures were already given to the informants in the questionnaire surveys. Interestingly, all the informants indicated defect rate and competitiveness as two necessary KPIs. At the same time, lead time stability was suggested by 12 informants, counting for 86% of the total involved senior professionals. The complete list of indicators grouped in 53 different KPIs is reported in Appendix D.

4.3 Analysis of confirmatory survey results

To define the metrics to be included in the vendor rating model, the set of measures identified through the questionnaire survey was individually presented to each interviewee during the confirmatory survey. In this phase, the interviewees were asked to indicate which criteria could be used to regularly monitor the performance of active suppliers of direct materials, and which criteria could instead be excluded from the model. This task turned out to be particularly challenging for some of the informants. In this respect, one informant pointed out:

“I think all of these performance measures are relevant. We might take in consideration some of these measures also during the initial supplier evaluation and selection process”.

Interestingly, this observation resulted to be relevant also for the following development activities in the organization. In fact, as part of the implementation process of a VMS compliant to automotive requirements, the representatives of case company were also

called to refine the supplier selection and evaluation process in the company as per the indications of IATF 16949:2016. Furthermore, the same informant also said:

"Within certain supplier performance measures, some of the aggregated KPIs may be relevant for the vendor rating. However, in some cases the aggregated KPIs may not be that relevant".

Other informants pointed out the necessity to aggregate differently the presented KPIs within the given supplier performance measures. More specifically, three informants suggested to implement the following actions:

1. Incorporate the KPIs currently listed in manufacturing capability measure into quality measure, then erase manufacturing capability measure from the list
2. If the KPIs currently listed in finance measure are considered as financial risks, incorporate these KPIs into the risk measure. Afterwards, erase finance measure from the list
3. Incorporate the item PPAP, listed within R&D measure, into quality measure. Afterwards, erase R&D measure from the list.

The confirmatory surveys were sent to the selected informants on the 21st of July 2020. In total, 13 representatives of the case company completed the confirmatory survey, corresponding to 93% of the total informants. The completion and the collection of these surveys resulted to be a particularly slow process, as this period partially overlapped with the summer vacation period of most of the informants as well as with the deadline for the execution of other critical projects in the case company. In average, 12 days had been necessary to collect the results of the confirmatory surveys. The results of the collected confirmatory surveys are presented in Figure 24.

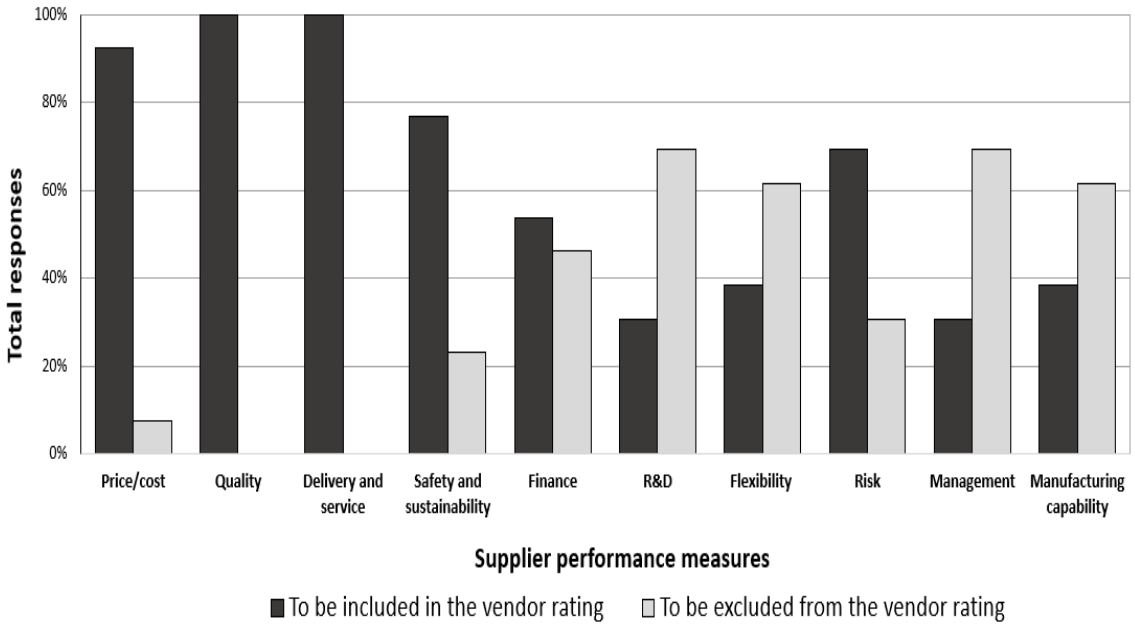

Figure 24. *Results of confirmatory surveys and distribution of responses for each supplier performance measure.*

As the picture shows, the involved senior professionals largely agreed on including price/cost, quality, delivery and service, safety and sustainability, and risk in the vendor rating. Finance measure resulted to be favoured only by seven respondents, whereas six respondents declared that this measure could have been excluded from the vendor rating. Finally, most of the respondents excluded R&D, flexibility, management, and manufacturing capability measures from the vendor rating. While price/cost, quality, and delivery and service were measures already presented by the researcher in the questionnaire survey, the high preference for safety and sustainability and risk measures, as well as the low preference for R&D, flexibility, management, and manufacturing capability can be further investigated.

First, sustainability values lie at the very core of the mission of the case company. Hence, the high preference to maintain safety and sustainability performance measure is also aligned with the high number of KPIs that the informants suggested during the questionnaire survey.

Second, risk measures were considered needed in the vendor rating due to the relevant impact of low financial performance or of weak financial position of suppliers on the whole purchasing strategy. Several risks can be identified within the inbound supply chain. In general, the risk related to purchase decisions decreases when the organization gains experience with the purchase of a specific product (Van Weele, 2018), while risk of disruption can be mitigated by multiple sourcing strategies (Chopra and Meindl, 2001).

Nevertheless, some strategic products might be procured only by one supplier, from which derive relevant risks (Caniëls and Gelderman, 2007).

Third, R&D measures were considered not essential in the vendor rating as many informants indicated that the only KPI present in in this measure could have been added to the KPIs already included in the quality measure. In this way, the vendor rating model could have been simplified. Similarly, several informants pointed out that the only KPI presents in the measure manufacturing capability could have been included within the quality measure as well. Hence, the measure manufacturing capability was considered not essential in the vendor rating.

Finally, flexibility and management measures were considered by several senior professionals as not relevant for evaluating the performance of current suppliers. In fact, many informants pointed out that such measures could have been relevant for the evaluation of new potential suppliers, but not for suppliers that were expected to be already delivering products to the buying organization.

4.4 Selection of appropriate vendor rating criteria

The selection of appropriate measures and KPIs to be included in the vendor rating system is critical for evaluating the performance of suppliers. In particular, the involvement of several actors in achieving the strategic objectives of the buying organization makes the identification of appropriate criteria for measuring the performance of suppliers a complex task (Estampe et al., 2013). As among the involved senior professionals a general consensus over the appropriate supplier performance measures was not found, the top management of the case company was involved with the target to identify only the metrics to be eventually included in the final vendor rating model. Figure 25 illustrates the different roles of the involved informants in this phase.

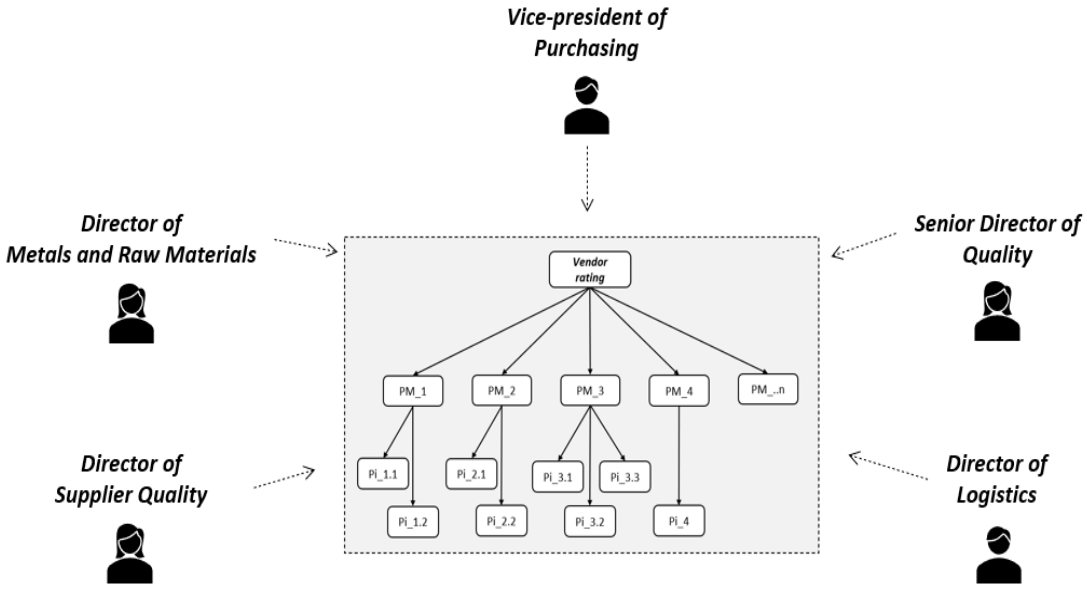

Figure 25. *Involvement of top management in the review of vendor rating criteria.*

As the picture illustrates, in this phase the informants involved in the collective review of the measures and KPIs were selected exclusively within the top management of the case company. During the collective review, the senior managers proposed to develop two different vendor rating models for evaluating the performance of current suppliers.

First, a vendor rating model was proposed for evaluating the operational performances of suppliers. All the KPIs defined for a short-term evaluation of the supplier performance were included in this model.

Second, a different vendor rating model was proposed for evaluating the performance related to the organization of the suppliers. All the KPIs for a long-term evaluation of supplier performance were included in this model. Figure 26 illustrates the different frequencies for the evaluation of supplier performance.

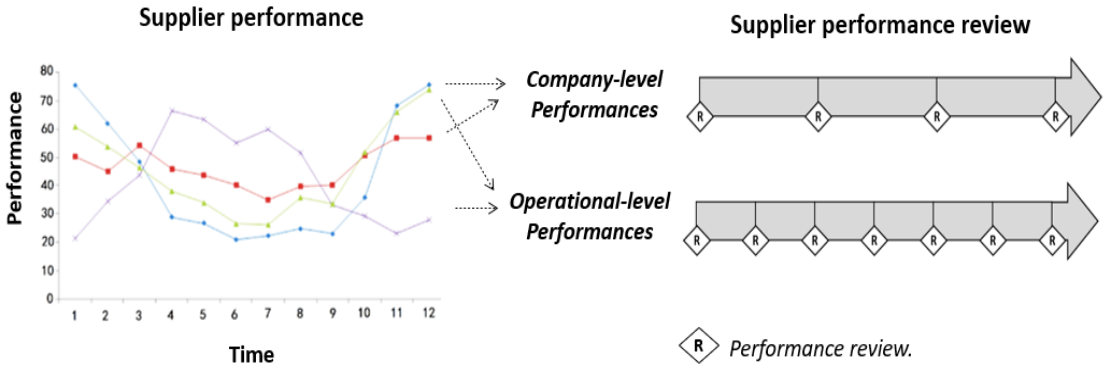

Figure 26. *Different frequencies for evaluation of supplier performance.*

Interestingly, the proposed evaluation methods resemble the classification of different levels of supplier performance metrics defined by Gunasekaran et al. (2004), which

divided measures in three levels, namely strategic level, tactical level, and operational level. During the collective review, to identify the KPIs to be included in the two different vendor rating models, the involved top managers aligned on the needed frequency for the evaluation of the different supplier performance indicators. As the time initially planned for the collective review was insufficient, the top managers independently reviewed the list of retrieved supplier KPIs and performance metrics and selected the most appropriated ones, returning the results of the selection to the researcher via email.

Basing on the selections returned by the involved top managers, the identified vendor rating metrics were placed in the two different vendor rating models by the researcher. The resulting vendor rating models were then shared again with top management for final review and approval. Eventually, a unilateral consensus was reached, and the final vendor rating models were defined. Figure 27 depicts the structure of the vendor rating defined for evaluating the performance related to the organization of current suppliers.

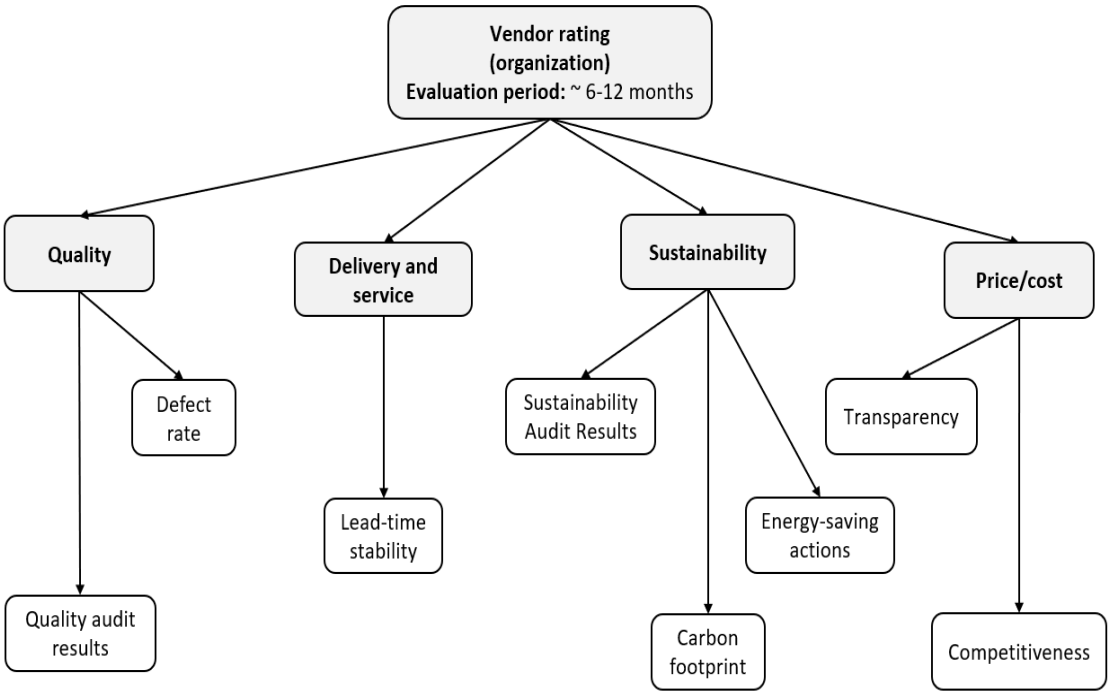

Figure 27. *Vendor rating model for evaluating the performance related to the organization of a supplier.*

As the figure depicts, quality, delivery and service, sustainability, and price/cost were the measures that the top management decided to adopt for evaluating the performance related to the organization of suppliers. Interestingly, sustainability resulted to be the performance measure which included the highest number of KPIs. The structure of the vendor rating for evaluating the operational performance of current suppliers is depicted on Figure 28.

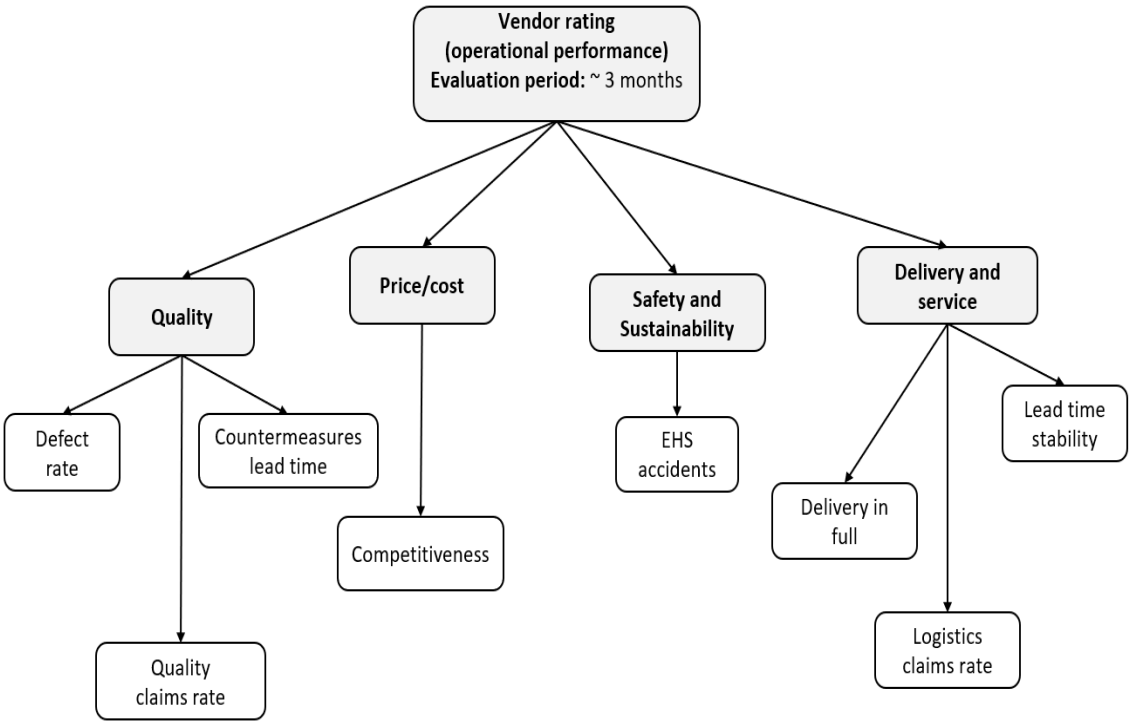

Figure 28. *Vendor rating model for evaluating the operational performance of a supplier.*

As illustrated, price/cost, safety and sustainability, quality, and delivery and service were the measures that top management decided to adopt for evaluating the operational performance of current suppliers. Despite the limited number of involved informants, long discussions were needed to select the criteria to be used in the different vendor rating models.

Overall, almost eight weeks were needed to retrieve and elaborate the data needed to sketch the vendor rating models. Aside the summer vacation period and impellent deadlines that kept most of the informants poorly available, the selection of the metrics to be included in the vendor rating turned out to be a challenging task for almost all the involved informants.

4.5 Semi-structured interviews and deployment of AHP method

To identify the weights to correlate the different metrics in the developed vendor rating models, the AHP was deployed during the semi-structured interviews held with the selected informants from the case company. Figure 29 illustrates the main steps of this process.

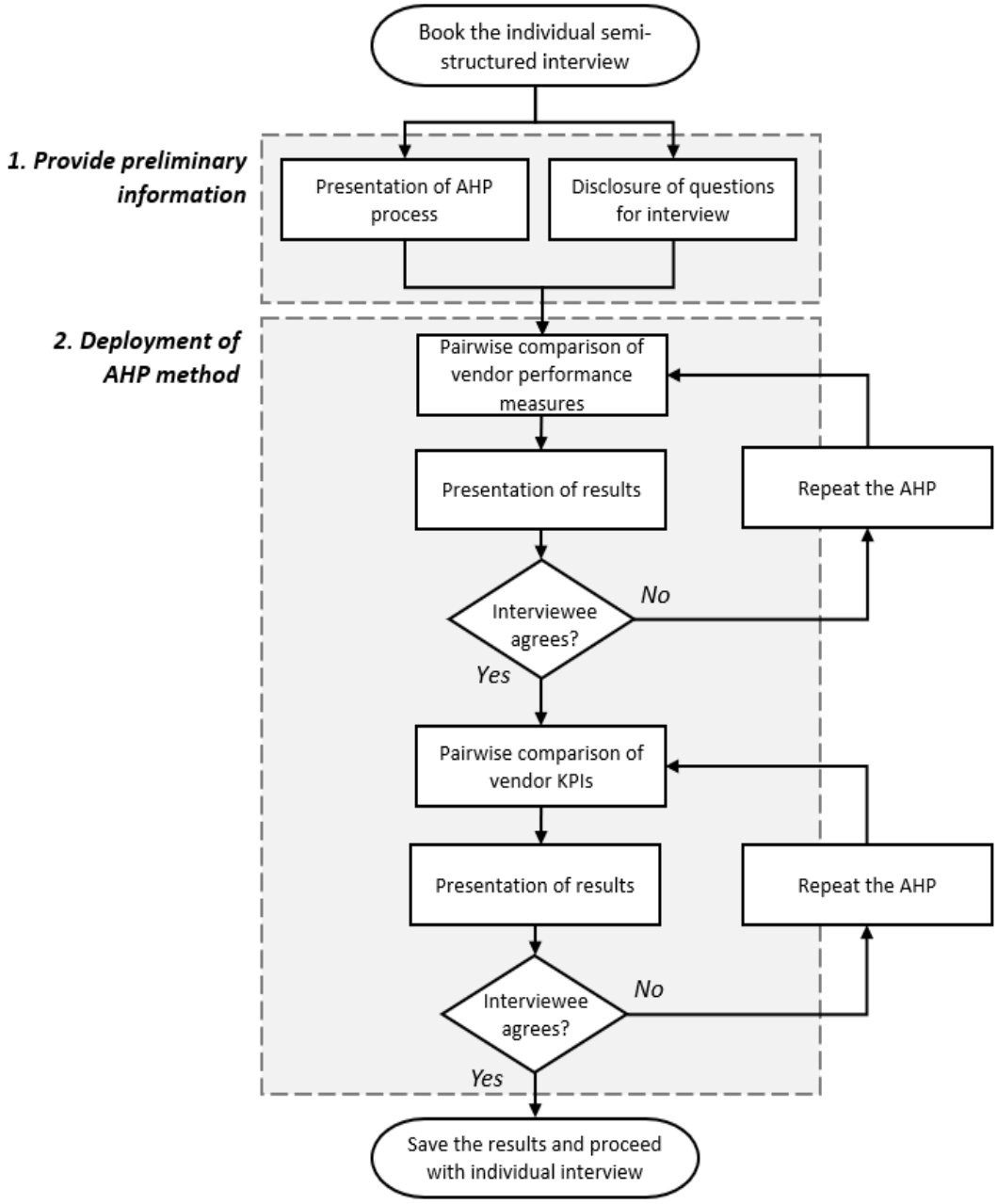

Figure 29. *Deployment of AHP method as part of individual semi-structured interviews.*

As the figure illustrates, prior each individual semi-structured interview the interviewees were briefly informed about the AHP and its scope with a short presentation in PowerPoint© prepared by the researcher. Furthermore, the expected outcomes and the estimated duration of the activity were presented.

During the semi-structured interviews, each interviewee deployed the AHP by using an Excel© tool developed by the researcher. Specifically, the developed Excel© tool consisted in multiple worksheets, each one dedicated to the evaluation of different pairs of performance metrics. In fact, following the deployment process of the AHP, each

interviewee was asked to evaluate the presented pairs of performance metrics by using a guideline based on scores from one to nine to evaluate the relative importance of the given metrics.

To facilitate the execution of the task, the vendor rating model was displayed during the whole execution of the AHP. Referring to the hierarchy of the criteria in the vendor rating model, the interviewees could understand and compare the contents of the different supplier performance measures. In this sense, each supplier performance measure was defined by the description of the KPIs placed at a lower level in the hierarchy. The dialogue window developed by the researcher to lead the interviewees through the deployment of the AHP is illustrated in Figure 30.

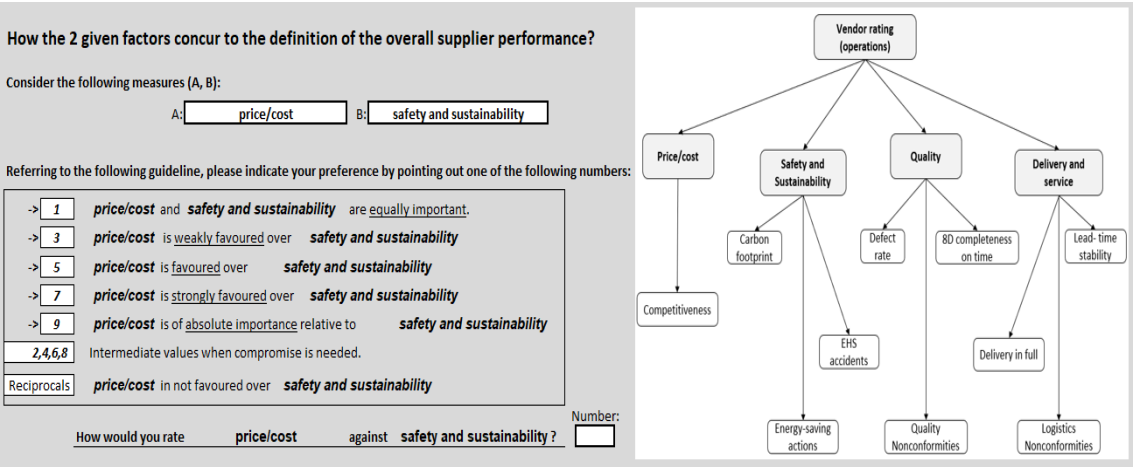

Figure 30. *Dialogue window used to lead the interviewees through the deployment of the AHP.*

The score given by the interviewees to each single pairwise comparison was reported in dedicated cells of the Excel© worksheets. The different scores were then automatically copied to a separate calculation sheet and reported in a pairwise comparison matrix. In the calculation sheet, the weights of the different vendor rating metrics were calculated and plotted in bar charts for a more intuitive evaluation from the involved interviewee. The designed calculation sheet is illustrated in Figure 31.

Pairwise comparison matrix

	A	B	C	D
A	1	3	1	1
B	0,33	1	1	1
C	1	1	1	3
D	1	1	0,33	1
	3,33	6,00	3,33	6,00

Normalized matrix				Weight	Measures
0,30	0,50	0,30	0,17	32%	Price/cost
0,10	0,17	0,30	0,17	18%	Safety and sustainability
0,30	0,17	0,30	0,50	32%	Quality
0,30	0,17	0,10	0,17	18%	Delivery and service

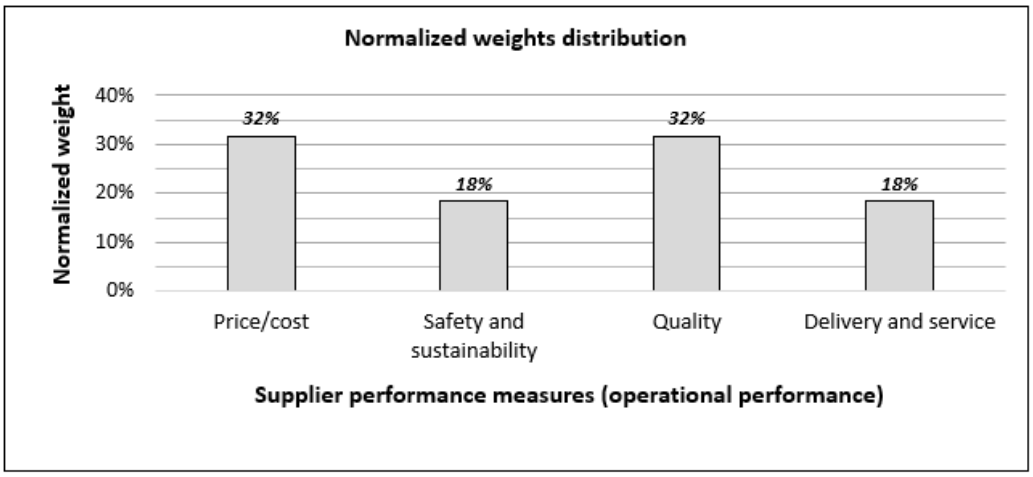

Figure 31. *Calculation sheet for identification of vendor rating weights and graphic representation of weights distribution.*

Once the analysis of the supplier performance measures was completed, the obtained weights were disclosed to the interviewees. At this stage, the interviewees were asked to evaluate the obtained weights and, in case, to repeat the pairwise comparisons to modify the obtained results. Afterwards, the interviewees were guided throughout the deployment of the AHP applied to supplier KPIs. Eventually, the AHP method was applied to the two different vendor rating models and it was iterated two times for each model: one time to the supplier performance measures, and one time to the supplier KPIs. As first step for the deployment of the AHP, the following question was addressed to the interviewees:

"How the two given factors concur to the definition of the overall supplier performance?".

For each pair of performance measures, the interviewees were asked to evaluate the relative importance of the two given factors by assigning different scores reported on a comparison scale. Table 12 illustrates the scores, indicated with ω_{ij}, for the pairwise comparison different vendor performance criteria, namely *i* and *j*.

Table 12. *Standardized pairwise comparison scale for AHP method.*

AHP rate [ω_{ij}]	Definition
1	*i* and *j* are equally important
3	*i* is weakly favoured over *j*
5	*i* is favoured over *j*
7	*i* is strongly favoured over *j*
9	*i* is of absolute relevance over *j*
2,4,6	When compromise is needed
Reciprocals, from 1/2 to 1/9	When *j* is instead favoured over *i*

The assigned scores concurred to the definition of different pairwise comparison matrices. One comparison matrix was realized for the comparison of the different supplier performance measures, while other comparison matrices were realized for the comparison of the different supplier KPIs.

The definition of the pairwise comparison matrices is a fundamental step for the deployment of the AHP. To define the comparison matrices, it is possible to consider a single matrix as composed by two specular parts, namely upper part and lower part. The scores given by the interviewees were copied into the upper part of the matrix, whereas the values in the lower part of the matrix were obtained by calculating the reciprocals of the given scores. A general example of comparison matrix is illustrated in Figure 32.

Performance measures (operational performance)	**A**	**B**	**C**	**D**
Price/cost (A)	ω_{AA}	ω_{AB}	ω_{AC}	ω_{AD}
Safety and sustainability (B)	$1/\omega_{AB}$	ω_{BB}	ω_{BC}	ω_{BD}
Quality (C)	$1/\omega_{AC}$	$1/\omega_{BC}$	ω_{CC}	ω_{CD}
Delivery and service (D)	$1/\omega_{AD}$	$1/\omega_{BD}$	$1/\omega_{CD}$	ω_{DD}

Figure 32. *Pairwise comparison matrix for supplier performance measures.*

From the given guideline for the pairwise comparative analysis of the vendor rating metrics it is possible to deduce that $\omega_{AA} = \omega_{BB} = \omega_{CC} = \omega_{DD} = 1$. An example of pairwise comparison matrix obtained by one of the interviewees is illustrated in Figure 33.

Performance measures (operational performance)	A	B	C	D
Price/cost (A)	*1*	*3*	*1*	*1*
Safety and sustainability (B)	*1/3*	*1*	*1*	*1*
Quality (C)	*1*	*1*	*1*	*3*
Delivery and service (D)	*1*	*1*	*1/3*	*1*

Figure 33. *Example of obtained pairwise comparison matrix.*

As illustrated, referring to the given guidelines, the interviewee weakly favoured price/cost over safety and sustainability. Similarly, quality was weakly favoured over delivery and service, while the remaining performance measures were considered equally important for the definition of the overall supplier performance.

The second step of the AHP method consisted in calculating the normalized values for the factors in the pairwise comparison matrix. To obtain the normalized values, the total sum down each column was calculated. Finally, each factor in the pairwise comparison matrix was divided by the obtained sums. Figure 34 depicts the results obtained from the previously illustrated pairwise comparison matrix.

Performance measures (operational performance)	A	B	C	D
Price/cost (A)	*0,30*	*0,50*	*0,30*	*0,17*
Safety and sustainability (B)	*0,10*	*0,17*	*0,30*	*0,17*
Quality (C)	*0,30*	*0,17*	*0,30*	*0,50*
Delivery and service (D)	*0,30*	*0,17*	*0,10*	*0,17*

Figure 34. *Normalized values calculated from the pairwise comparison matrix.*

The final step for the identification of the normalized weights consists in the calculation of the average values across each row of the normalized matrix. The obtained results are the searched normalized weights. Figure 35 depicts the weights calculated for the previously illustrated performance measures.

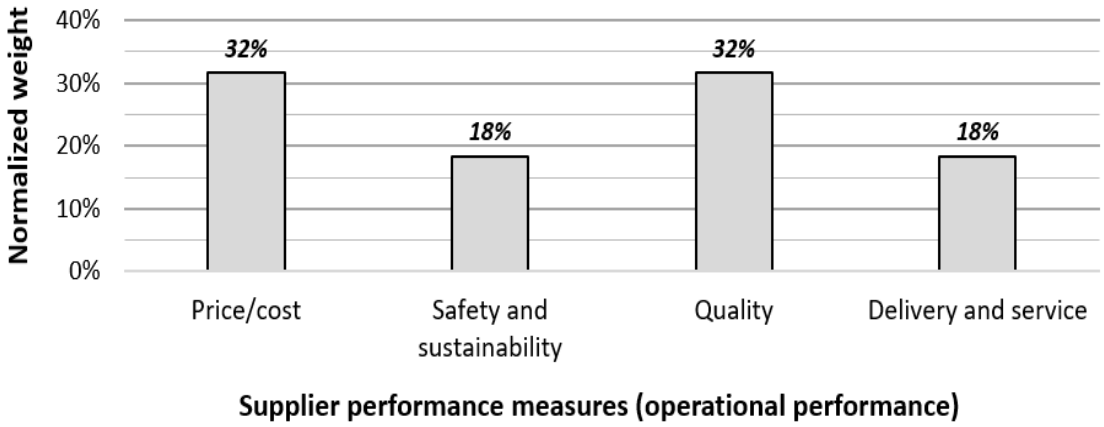

Figure 35. *Distribution of weights calculated for supplier performance measures.*

As the figure depicts, the interviewee obtained the same weight value associated to price/cost and quality metrics, and the same weight value associated to safety and sustainability and delivery and service metrics. In particular, the weight associated to price/cost and quality metrics resulted heavier than the weight associated to safety and sustainability and delivery and service metrics. Consequently, in the vendor rating resulting from this example, price/cost and quality will be the more relevant metrics for the evaluation of the performance of the operations of suppliers.

The AHP method was then applied to the different KPIs at the lower hierarchical level in the vendor rating models. In this step, the following question was addressed to the interviewees:

“How the two given KPIs concur to the definition of the supplier performance measure?”.

During this step, for each performance measure in the defined vendor rating model, the relative importance of the different KPIs was evaluated by the interviewees. As a result, the distribution of the normalized weights of the KPIs in the vendor rating models was obtained. Figure 36 depicts the normalized weights for the KPIs of the quality performance obtained by one interviewee.

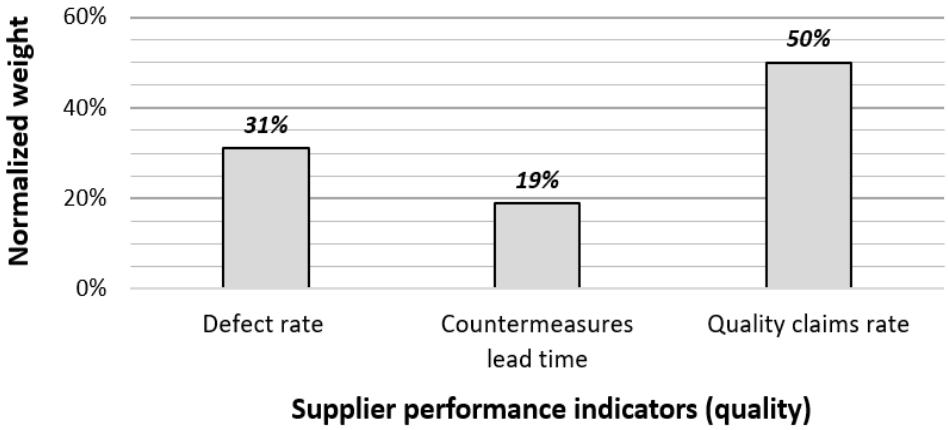

Figure 36. *Distribution of weights calculated for quality KPIs.*

As the figure shows, in this example the rate of quality claims accounted for 50% of the total normalized weight, whereas the lead time for the implementation of countermeasures was considered the least relevant KPI for evaluating supplier quality performance. Interestingly, the interviewee that obtained the illustrated distribution argued that these results truly illustrated his view about these KPIs. The following three motivations were given by the interviewee:

1. Quality claims rate represents the number of quality nonconformities on the number of received batches from suppliers. Consequently, this KPI closely measures the number of disturbance events in the company due to poor quality from suppliers
2. Defect rate represents the quantity of received nonconforming material on the quantity of ordered material. Consequently, this KPI closely measures the disturbance effect of the poor quality from suppliers on the organization. In certain situations, this KPI can be closely related to the quality claims rate, but not necessarily a high defect rate implies a high-quality claim rate
3. Countermeasures lead time measures the lead time for the implementation of permanent corrective actions following a structured problem-solving methodology defined on eight steps (8D). Consequently, this KPI was greatly dependent on the number and nature of the previous two KPIs.

In total, for each interviewee, four charts illustrating the distribution of the normalized weights in the vendor rating model for performance of supplier operations. Six charts were instead obtained for the distribution of the normalized weights in the vendor rating model for performance of supplier organization.

The last step of the deployment of the AHP method is the calculation of the CI for each obtained pairwise comparison matrix. Finally, the calculated consistency indices were

evaluated against the acceptability level defined by Saaty (1980). The CI values obtained for the different pairwise comparison matrices by the involved senior professionals are reported in Table 13.

Table 13. *Calculated CI values for different pairwise comparison matrices.*

Pairwise comparison matrices	Number of factors	Interviewed Person (IP)											
		IP01	IP02	IP03	IP04	IP05	IP06	IP08	IP09	IP10	IP11	IP12	IP14
Operations (measures)	4	*35%*	*12%*	*18%*	*3%*	*10%*	*4%*	*10%*	*7%*	*28%*	*3%*	*25%*	*9%*
Safety and sustainability (KPIs)	1	-	-	-	-	-	-	-	-	-	-	-	-
Quality (KPIs)	3	*0%*	*29%*	*1%*	*30%*	*0%*	*0%*	*7%*	*66%*	*29%*	*3%*	*0%*	*43%*
Delivery and service (KPIs)	3	*13%*	*3%*	*0%*	*45%*	*13%*	*13%*	*26%*	*29%*	*87%*	*0%*	*13%*	*16%*
Organization (measures)	4	*4%*	*0%*	*4%*	*13%*	*10%*	*5%*	*38%*	*4%*	*8%*	*19%*	*28%*	*4%*
Quality (KPIs)	2	-	-	-	-	-	-	-	-	-	-	-	-
Price/cost (KPIs)	2	-	-	-	-	-	-	-	-	-	-	-	-
Delivery and service (KPIs)	1	-	-	-	-	-	-	-	-	-	-	-	-
Sustainability (KPIs)	3	*29%*	*8%*	*0%*	*72%*	*13%*	*23%*	*13%*	*39%*	*29%*	*3%*	*16%*	*35%*

As the table illustrates, in several cases the calculated CI values did not satisfy the acceptable level of consistency defined by Saaty (1980). On the one hand, due to stringent time constraints, in case of CI>10%, the researcher did not have the possibility to repeat the deployment of the AHP with the involved senior professionals. On the other hand, a review of the obtained comparative weights with the involved interviewees was included in the process for the deployment of the AHP method.

As the involved interviewees were each time required to provide a feedback about the obtained weights and their distribution, after possible new iterations of the AHP method and after receiving a positive feedback about the obtained weights, the obtained results were judged acceptable for the prosecution of the project.

4.6 Comparative average weights and vendor rating models

To define the weights of the metrics in the final vendor rating models, the average weight ρ_{AVG} for each supplier performance measure and supplier KPI was calcualted basing on the different weights ρ_i identified by the interviewees as result of the deployed AHP. Therefore, for each vendor rating metric, the average weight was identified through the calculation of the arithmetic mean of the weights. Specifically, the arithmetic mean is calcuated by divdinging the sum of a given data set by the number of data (Neal, 2012). In other words, the average weight ρ_{AVG} is calculated as follows:

$$\rho_{AVG} = \frac{\sum_{i=1}^{n} \rho_i}{n} ,$$

where ρ_i represents the values of the weights identified by the different interviewees and *n* is the total number of weights that are being averaged. Figure 37 illustrates the calculation process of the average weight of a set of vendor rating criteria by deploying the defined arithmetic mean.

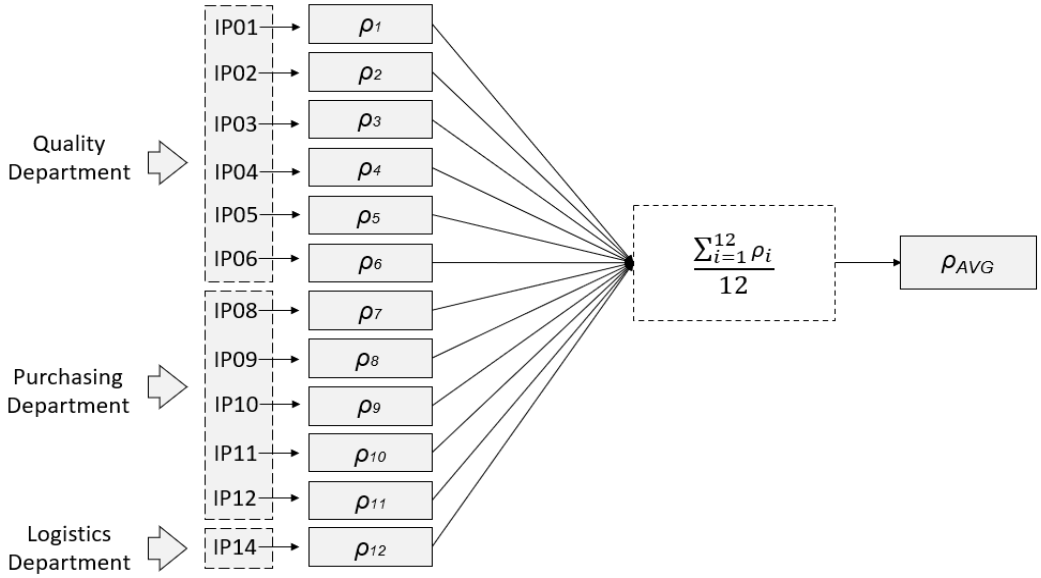

Figure 37. *Calculation of arithmetic mean to determine average weights.*

Interestingly, other calcualation methods can be deplyoed for the identifiacation of the mean. For instance,the gemetric mean is obtained by multiplying together all the ρ_n weights, then taking the *n*th root (Everitt 1995). In other words:

$$\rho_{AVG} = \sqrt[n]{\rho_1{}^{*}\rho_2 * \ldots * \rho_n} ,$$

where *n* is the number of weights that are being averaged. Interestingly, Kirkwood and Sterne (2003) argue that the average calculated with the geometric mean it is less influenced by large values in a skewed distribution that the results of the arithmetic mean (Kirkwood and Sterne, 2003). For these reasons, the average weights of the vendor rating criteria resulting from the deployment of the AHP method was calculated using the geometric mean. Nevertheless, despite the more accurate average results, it was noticed that the deployment of the geometric mean did not satisfy the fundamental condition that the sum of weights for each criteria must add up to unity (Yahya and Kingsman, 1999). Consequently, the average weights calculated using the arithmetic mean were used in this study.

To avoid unrealistic and unbalanced weights distributions, the number of interviewees involved in the deployment of the AHP was accurately defined considering the strategic relevance played by different performance metrics for the function of the informants. In particular, the researcher involved a balanced number of informants from quality department and from procurement department. In this study, the possible misleading interpretation of the calculated arithmetic mean for each supplier performance criteria was a cause of major concern for the researcher and a deeper analysis of the obtained results was carried out. To better understand the reliability of the calculated arithmetic means, an evaluation of the relative variability of the data set is beneficial. One of the most common measures to quantify the dispersion of a data set is the standard deviation (Neal, 2012) which defined as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(\rho_i - \rho_{AVG})^2}{n-1}}.$$

Interestingly, in several studies (Castigliola et al., 2017; Mucha and Witkowski, 2013; Gauri, 2005; Jiang et al., 2014; Dixon and Jones, 2005) the standard deviation is used to analyse the relative dispersion of a data set by evaluating the calculated coefficient of variation (CV). In statistics, the CV is expressed by the ratio of the standard deviation to the arithmetic mean (Teoh et al., 2017). In other words:

$$CV = \frac{\sigma}{\rho_{AVG}}.$$

Consequently, the CV values were calculated for all the weights associated to the metrics in the different performance hierarchy levels of the developed vendor rating models. Afterwards, the obtained CV values were analysed to identify the vendor rating criteria that presented the highest variation. The CV values for the weights associated to the supplier performance measures of the vendor rating models are reported in Table 14.

Table 14. *Calculated CV values for weights of supplier performance metrics.*

Vendor Rating Model	**Measure**	***ρ***	***σ***	***CV***
Supplier Operational Performance	Price/cost	0,151	0,261	0,578
	Safety and sustainability	0,158	0,216	0,733
	Quality	0,107	0,385	0,279
	Delivery and service	0,081	0,138	0,584
Supplier Organization	Quality	0,106	0,334	0,316
	Delivery and service	0,070	0,171	0,411
	Price/cost	0,170	0,224	0,760
	Sustainability	0,189	0,271	0,698

As illustrated in the table, within the vendor rating model defined for evaluating the performance of supplier operations, safety and sustainability and price/cost were the two measures that presented the highest level of variability. Whereas, within the vendor rating model defined for evaluating the performance of supplier organization, risk and price/cost were the two measures that presented the highest level of variability.

Interestingly, is possible to observe that quality was the measure in which the interviewees obtained the most consistent weight values. Similarly, the evaluation of the CV values was repeated on the lower hierarchical level of supplier performance in the two different vendor rating models. Hence, the CV values for the for the weights associated to the supplier KPIs were calculated. Table 15 illustrates the results of the calculations.

Table 15. *Calculated CV values for weights of supplier KPIs.*

Vendor Rating Model	**Measure**	**KPI**	***ρ***	***σ***	***CV***
Supplier Operational Performance	Quality	Defect rate	0,145	0,408	0,354
		Countermeasures lead time	0,043	0,107	0,399
		Quality complaints rate	0,138	0,484	0,284
	Delivery and service	Lead-time stability	0,175	0,394	0,444
		Logistics complaints rate	0,189	0,337	0,561
	Safety and sustainability	EHS accidents	-	-	-
	Price/cost	Transparency	-	-	-
Supplier Organization	Quality	Defect rate	0,217	0,667	0,326
		Quality audit results	0,217	0,333	0,652
	Delivery and service	Lead time stability	-	-	-
	Price/cost	Transparency	0,283	0,535	0,529
		Competitiveness	0,283	0,465	0,608
	Sustainability	Carbon footprint	0,210	0,407	0,516
		Sustainability audit results	0,188	0,413	0,455
		Energy-savings actions	0,151	0,179	0,843

As the table shows, the lowest CV values are associated to defect rate, number of quality complaints rate, and lead time stability within the vendor rating model for evaluating the performance of supplier operations. Whereas the CV values associated to defect rate, lead time stability, and sustainability audit results were the lowest within vendor rating model for evaluating the performance of supplier organization.

Considering the obtained CV values, and taking into consideration the differences between the arithmetic mean and the geometric mean in the calculation of the average weights, a new review with the top management of the case company was held in late September. During the review, the obtained weights were disclosed and discussed. As a result, the top managers agreed on the obtained weight distributions, but also pointed

out some needed corrections in the vendor rating models. Interestingly, it was noticed that certain KPIs should have not been included in the vendor rating models as it was pointed out that certain performance parameters and limitations were actually defined on the supply agreements that were signed off between the case company and its selected and approved suppliers. For instance, a KPI initially defined to measure the number of deviations from code of conduct committed by the suppliers was erased from the vendor. On the one hand, the company could not tolerate any deviations from the code of conduct committed by the suppliers. On the other hand, in case of occurrence of similar deviations, the event would have been considered of breach of the supply contract, with severe implications for the current customer-supplier relationship. Consequently, during the meeting with top management, it was argued that similar breach of contract conditions should have been not included in the regular evaluation of the performance of active suppliers.

Interestingly, during the review with top management it was also pointed out that overly and misleadingly precise weight values should be avoided in the final model. In other words, the senior professional suggested both to decrease the number of decimals of the obtained weight values, limiting the indication to integer values, and to round the obtained weight values to the approximated nearest value multiple of five. As result of these considerations, the final weight values for each vendor rating criteria were included in the graphical representation of the revised vendor rating models. Figure 38 illustrates the final vendor rating model, defined for evaluating the performance of the organization of current suppliers.

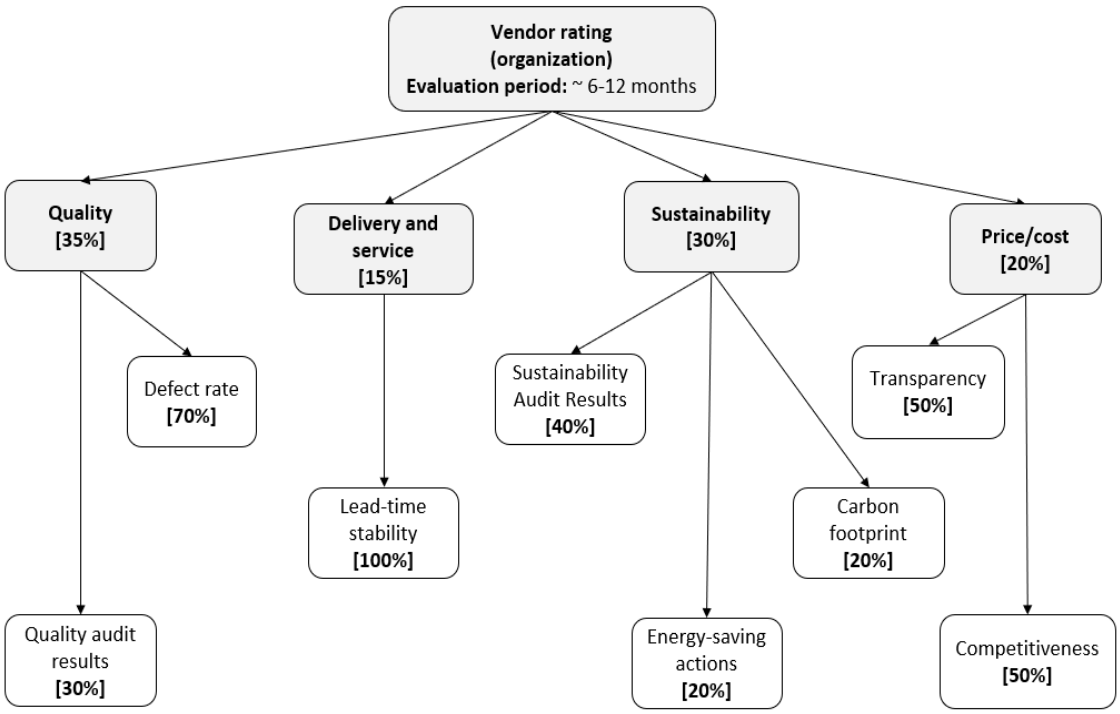

Figure 38. *Vendor rating model (performance of the organization of a supplier).*

As the figure shows, in this model, quality is the most relevant measure for the evaluation of the performance related to the organization of suppliers. Interestingly, the weight value associated to delivery and service resulted to be the lowest among the measures of the entire vendor model. Figure 39 illustrates the final vendor rating model, defined for evaluating the performance of the operations of current suppliers.

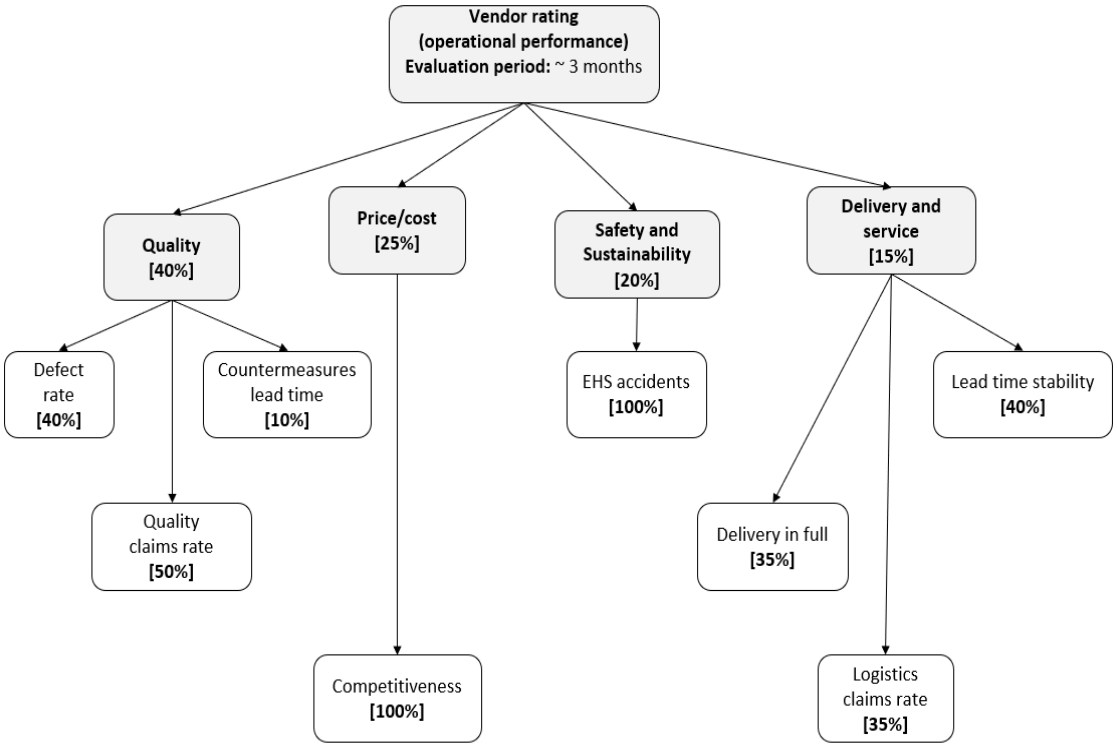

Figure 39. *Vendor rating model (operational performance of a supplier).*

As the figure illustrates, also in this model, quality is the most relevant measure for the evaluation of supplier operational performance, while delivery and service resulted to be the least relevant performance measure. Interestingly, during the review of the obtained normalized weights, one of the involved top managers shared his opinion about the obtained weight distributions:

"I believe these distributions well reflect our strategy and take into consideration the needs of our customers. We want our suppliers to deliver top quality performance, while providing competitive products and being proactive towards ethical, environmental, and safety issues".

Furthermore, the senior manager commented the weight value assigned to service and delivery performances:

"Service and delivery performances are definitely important, but we should not prioritize such metrics, as in our organization poor quality can cause disastrous effects on both our final products and on our assembly lines".

Once the vendor rating models were defined and finalized, the senior managers asked for details about the next steps in the implementation of the proposed supplier performance measurement system. Consequently, a roadmap was proposed, identifying short-term actions as well as long-term actions.

4.7 Implementing a supplier performance evaluation system

To implement an effective supplier performance evaluation system, in late September 2020 a clear roadmap was developed and presented to the senior management of the case company. Following the retrieved recommendations from literature (Yaha and Kingsman,1999; Santos et al., 2019) and the suggestions from the involved senior managers, five implementation steps were defined. Figure 40 illustrates the proposed implementation roadmap.

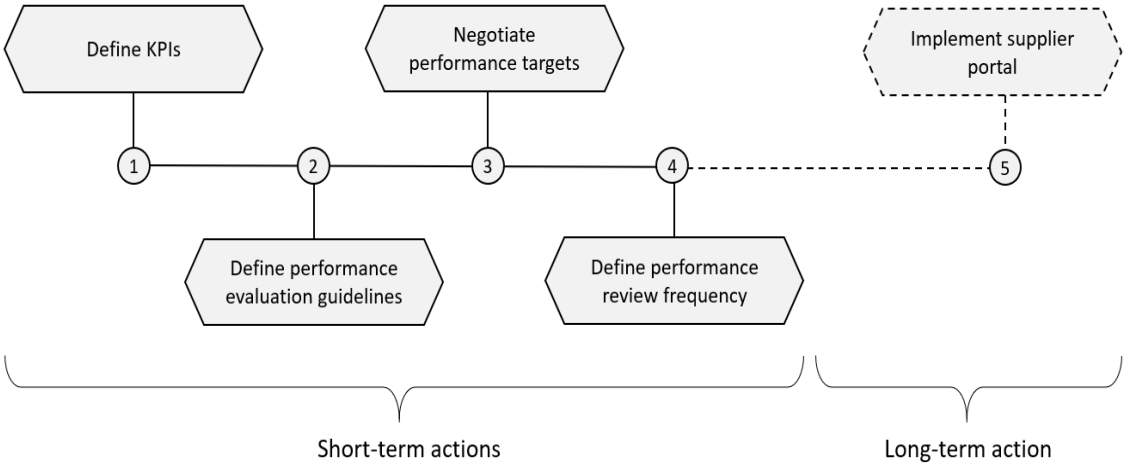

Figure 40. *Roadmap for implementing a supplier performance evaluation system.*

As the figure illustrates, the defined implementation roadmap consisted in four short-term actions and one long-term action. Specifically, the identified short-term actions were define KPIs, define performance evaluation guidelines, negotiate performance targets with suppliers, and define the frequency of the review of the supplier performance.

First, specific mathematical formulas must be defined to unequivocally calculate each supplier KPI. The mathematical formulas for the definition of the different supplier KPIs are generally made visible to the suppliers for enhancing a better understanding over the actual expectations of the buying organization (Volvo, 2020).

Second, guidelines ensure consistency of the evaluation of supplier performance, avoiding possible bias (Yaha and Kingsman,1999). A set of standard guidelines were defined with the support of the involved senior managers. Specifically, performance scores were defined basing on a performance grade scale. On the one hand, the higher the number of performance points in the grade scale the higher the difficulty to assign the corresponding grade for each KPI. On the other hand, the lower the number of performance points in the grade scale the more difficult would have been to improve supplier performances by defining reasonably progressive supplier performance improvements targets. An example of supplier performance evaluation guideline is illustrated in Figure 41.

Score	Grade	Supplier performance level
5	Exceptional	Has been in 'excellence' band for last 12 months
4	Excellence	Exceeds expectations
3	Good	Meets expectations
2	Needs attention	Does not meet minimum acceptable level
1	Poor	Well below minimum acceptable level
0	Bad	Has been in 'poor' band for last 12 months.

Figure 41. *Supplier performance evaluation guideline.*

In the example above, the supplier performance is divided on six levels, basing on the ability of the suppliers to meet performance expectations as well as on historical data. Similar approaches are common in automotive industry as such scoring systems allow to identify excellent suppliers as well as supplier that should be phased out (Volvo, 2020; Santos et al., 2019).

Third, supplier performance expectations must be defined and negotiated with the suppliers. After that the performance expectations have been agreed between the supplier and the buying organization, the current supplier performance level is measured against the defined expectations. In this respect, the agreed performance expectations become performance targets that the supplier shall meet or exceed. As result of the interview with the selected senior professionals, several recommendations were collected for the identification of performance targets. Table 16 illustrates the recommendations from the involved senior professionals for identifying supplier performance targets.

Table 16. *Recommended methods for identifying supplier performance targets.*

Approach	Detailed recommendation
Historical data	Targets are defined basing on past performance, generally defined on yearly basis
Risk-based model	Understand the impact of poor supplier performance on internal processes, customer satisfaction, and company reputation. Other risks to be considered are: • Importance of the product • Ease of supplier replaceability
Expert consultation	Discussions with industry experts are used to identify performance targets for different products, applications, and technologies
Benchmark	Targets are defined basing on performance level goals commonly defined in the industry, for the same markets, and for similar product applications
Customer requirements	Targets are defined basing on current customer requirements and aligning the suppliers at the performance target level given by the customer

As the table illustrates, the collected recommendations partially matched with the definitions of the different groups of benchmarks presented by Giannakis (2007). Nevertheless, in the specific case of the case company, historical data could not be utilized for defining supplier target performance, as the firm is a start-up with no previous historical supplier performance data.

Finally, the frequency of the evaluation of supplier performance must be defined and communicated to the suppliers. In this respect, all the involved senior professionals pointed out the necessity to communicate the performance results to the suppliers at least on yearly basis. Nevertheless, depending on the importance of the specific suppliers, shorter evaluations could be possible. Furthermore, the suppliers must be involved during the review of their performance, possibly during meetings face to face.

In the long term, the suppliers will be able to regularly review their own performance by accessing to a supplier portal, an application that enables organizations to share information by providing users a single gateway (Shilakes and Tylman, 1998). Studies have proved that new communication channels through information and communication technologies (ICTs), such as supplier portals, positively affects the buyer-supplier relationship (Leek et al., 2003). By receiving an account and accessing the portal, the suppliers can review their performance as well as upload or download documentation such as shipping documentation, product documentations, drawings, orders and order confirmations (Laukkanen et al., 2007). However, the complexity of such systems results in a long implementation process (Garcia et al., 2019).

4.8 Supplier performance visualization

To tackle the challenge of representing the outcome of different levels of performance for different performance measures in an intuitive way, a graphical presentation can be used. Interestingly, Saary (2008) points out that a radar chart is an efficient way to display a wide variety of data in a single picture. For instance, radar charts are commonly used in the field of organizational development to measure quality (Kaczynski et al., 2008). In Excel©, a radar plot can be easily generated by selecting the data set that must be illustrated in the chart, and selecting the radar plot option, which is one of the varieties of charts already available in the software. To test the effectiveness of the proposed graphical representation, a simulation was carried out during a meeting with top management in late September 2020.

To start the simulation, different performance levels for each supplier KPI were defined and reported on a worksheet in Excel©. Afterwards, different scores from zero to five

were assigned to the different performance levels by using the designed performance evaluation guidelines. Finally, an overall performance score was calculated for each performance measure in the specific vendor rating model by applying the simple linear weighted average method. Figure 42 shows the numerical simulation run with the involved senior managers to illustrate the use of the proposed radar chart.

QUALITY

KPIs	Score	Weight	Sub-total
Defect rate	4	40%	1,6
Quality claims rate	3	50%	1,5
Countermeasures lead time	4	10%	0,4
Total			3,5

DELIVERY AND SERIVCE

KPIs	Score	Weight	Sub-total
Delivery in full	2	35%	0,7
Lead time stability	3	40%	1,2
Logistics claim rate	2	35%	0,7
Total			2,6

SAFETY AND SUSTAINABILITY

KPI	Score	Weight	Total
EHS accidents	4	100%	4,0

PRICE/COST

KPI	Score	Weight	Total
Competitiveness	3	100%	3,0

SUPPLIER OPERATIONAL PERFORMANCE

Performance measures	Score	Weight	Sub-total
Quality	3,5	40%	1,40
Delivery and service	2,6	15%	0,39
Safety and sustainability	4,0	20%	0,80
Price/cost	3,0	25%	0,75
Total			3,34

Figure 42. *Numerical simulation used to generate a radar chart in Excel©.*

As the figure illustrates, a score is assigned to each different performance criteria by referring to the designed supplier performance evaluation guidelines. The evaluation of the overall operational performance level of the supplier is obtained by combining the performance level achieved in each single performance measure. As a result, the overall performance is calculated. In the example, the total performance score is 3,34 which corresponds to a score between good and excellent.

Finally, the performance level achieved by the supplier for each performance measure are plotted in a radar chart. Figure 43 illustrates the obtained radar chart for the previously introduced numerical simulation.

Figure 43. *Excel© radar chart for visualizing supplier operational performance.*

As the figure shows, the vertices of the radar chart are determined by different performance metrics. In the picture, the different performance levels for each measure are represented by four spokes, respectively indicating the magnitude of quality, delivery and service, safety and sustainability, and price/cost performance. In the figure, the performance of the supplier result poor in terms of delivery and service, while are excellent in terms of safety and sustainability. Analysing further the supplier performance in the given example and observing more in detail the achieved performance scores for each KPI, it is possible to conclude that poor performance in delivery and service are originated mainly by poor performance in terms both of delivery in full and logistics claim rate.

The proposed radar chart can be used both to illustrate the overall performance level with a single picture as well as to highlight possible areas of improvement. Interestingly, during the meeting with top management, most of the involved senior managers declared to be already well familiar with the use of radar plots.

The evaluation and improvement of the performance of current suppliers contribute to the long-term supply chain competitiveness (Yang, 2010). Therefore, the developed vendor rating models and the defined implementation roadmap for the periodic supplier performance evaluation system can support the supply chain competitiveness of the case company. As a result of the evaluated performance level, specific development programmes aimed to overcome the performance gaps of current suppliers can be defined though the identification of strengths and weaknesses of each vendor.

5. CONCLUSIONS

5.1 Summary of the key empirical findings

This thesis focused on the area of supplier performance measurement from the perspective of management control (Chenhall, 2003). The aim was to develop a model to be used to periodically evaluate the performance of active suppliers to support the strategy of the purchasing function in the case company, and to align it with the strategy of the firm (Hesping and Schiele, 2015). The following two research questions were formulated at the beginning of this study:

1. What are the relevant criteria to evaluate the performance of current suppliers of direct materials in the automotive LIB industry?
2. What is the relative relevance of the identified performance evaluation criteria?

The first research question aimed to provide clarity about the common metrics for the evaluation of supplier performance basing on the retrieved literature and on the experience of involved industry experts. The second research question helped to clarify the correlations between the identified supplier performance metrics basing mainly on the experience of the involved senior professionals. The outcomes were then used by the researcher to develop a model to be adopted in the case company for regularly evaluating the performance of existing suppliers of direct materials, in line with the requirements of the automotive standard IATF 16949:2016. The answers to both the formulated research questions are provided in Chapter 4.

Basing on the review of existing literature and on interviews with industry experts, the developed model for the evaluation of the performance of existing suppliers consists in a hierarchical structure based on two performance levels, namely performance measures and performance indicators. In this study, two different hierarchical structures were developed, respectively for the evaluation of supplier operational performance and for the evaluation of the performance related to the organization of the supplier. The developed structures differ both for the performance metrics that they include and for the defined frequency of evaluation. Specifically, a higher evaluation frequency was defined for the review of the operational performance of the suppliers.

The contribution of this study to the existing research is twofold. First, this study contributes to the already extensive existing literature about supplier performance evaluation by presenting the most relevant evaluation criteria in the specific context of the relatively

recent automotive LIB industry. Second, this research attempted to define a framework for the development and implementation of a system for regularly measuring the performance of active suppliers. In literature, several authors (Dickson, 1966; Rao and Kiser, 1980; Ellram, 1990; Stamm and Golhar, 1993; Huang and Keskar, 2007; Ho et al., 2010) identified comprehensive lists of criteria for the evaluation of supplier performance. Nonetheless, these studies were seldom related to a defined industry context. Moreover, most of the retrieved academic literature focused on the identification of criteria for the evaluation of new suppliers. This study revealed that quality, delivery and service, safety and sustainability, and price/cost are the most relevant performance evaluation criteria for current suppliers in the LIB industry. Interestingly, these results partially align to the findings of Ho et al. (2010). Nevertheless, Ho et al. (2010) found that safety and sustainability criteria are the least commonly adopted measure in literature. This dichotomy may be explained with the increasing importance of corporate responsibility (Reuter et al., 2010) environmental factors (Vanalle and Santos, 2013; Zimmer et al., 2015) and social risks (Zimmer et al., 2017). Furthermore, in modern world companies merely profit-oriented are less and less accepted by the public (Van Weele, 2018). In the specific context of this study, the relevance of safety and sustainability performance is essentially driven by the mission of the company, which puts the commitment to tackle the contingent environmental issues at the core of its values. In this respect, the purchasing strategy is aligned with strategic direction of the firm (Paulraj et al., 2006).

In this study, different weighs were identified following the simple linear weighted average method to correlate the supplier performance criteria in each vendor rating model. For the development of the vendor rating models, the framework deployed by Yahya and Kingsman (1999) was applied. As part of the development process, to identify the set of different weights, the AHP was deployed. In the existing literature the same approach has been adopted by several authors (Yahya and Kingsman, 1999; Chan, 2003; Ganguly, 2014; Dweiri et al., 2016) while other authors (Barzilai, 1998; Whitaker, 2007; Belton and Gear, 1984) criticized its formulation.

The study revealed that the adoption of AHP is particularly challenging if the informants are not involved together during its deployment. In particular, individual inconsistencies and wide variation of the obtained normalized weights within the pool of involved informants are factors that highly influence the reliability of the overall outcome of the AHP. Furthermore, the necessity to determine unique weights which shall be representative of the overall results obtained by all the involved interviewees during the deployment of the AHP raises the challenge of identifying appropriate mathematical approaches for the definition of the final average weights. These findings align with the efforts of several

authors to identify appropriate variations of the traditional AHP developed by Saaty (1980), such as fuzzy-AHP (FAHP) (Kwong and Bai, 2003; Ayhan, 2013; Singh and Prasher, 2019; Adebanjo et al., 2016), or analytical network process (ANP) (Ergu et al., 2014; Pan et al., 2014; Sarkis and Talluri, 2002).

In this study, senior professionals from the case company also provided insights about different approaches for the identification of supplier performance targets. Interestingly, the obtained results align with the definitions formulated by Giannakis (2007). In particular, the use of existing historical data and benchmarking with performance level goals commonly defined in the industry for the same markets and for similar product applications are also recalled by Giannakis (2007). Nevertheless, in the highly regulated automotive industry the systematic risk management approach, introduced already in the standard ISO 9001:2015 (Popova et al., 2019), provides new means for the identification of appropriate supplier performance targets.

5.2 Managerial implications

This study provides an answer to the needs of the case company, which is called to develop a clear roadmap to obtain the certification to IATF 16949:2016. In this respect, the development of a process for the periodic evaluation of the performance of active suppliers is needed for the obtainment of the automotive QMS certification.

This study has also managerial implications. First, it provides a guideline for the implementation of a systematic vendor rating system and the consequent development of a periodic supplier performance evaluation process. Second, it analyses the correlations between different supplier performance metrics, identifying different weights in line with the linear weighted average method. Hence, the developed vendor rating models offer a starting point for the purchasing department to periodically evaluate the performance of active suppliers of direct materials. Third, the identified models can support the decision makers in the case company in defining specific supplier development programmes basing on the assessment of the performance of the suppliers as part of a more extensive supplier evaluation process (Park et al., 2010). In fact, through supplier development efforts, the buying organization can satisfy both the short- and long-term supply needs (Sang Chin et al., 2006). Finally, the framework adopted in this study can also be deployed by the case company in different contexts when it is required to identify importance ratings from a given set of criteria. Specifically, in similar cases the AHP is a widely adopted approach due to its simplicity, ease of use, and flexibility (Li et al., 2009).

According to IATF 16949:2016, the measurement and evaluation of supplier performance must be based on at least four performance indicators, namely product conformity to requirements, OEM disruptions at the receiving plant, delivery schedule performance, and occurrence of premium freights. The criteria included in the developed vendor rating models satisfy the IATF requirements concerning product conformity and delivery performance. However, OEM disruptions and occurrence of premium freights are not part of the developed models. Hence, the case company will need to monitor these performance indicators outside the defined vendor rating system.

5.3 Limitations and criticism

This study is subject to limitations, as are most of qualitative studies (Jääskeläinen, 2018). In this study, vendor rating models were developed basing on a solid knowledge base built upon existing literature, questionnaire surveys, and semi-structured interviews held with 12 industry experts carefully selected through specific criteria. Nonetheless, the distribution of the interviewees along the different functions in the company highlighted an unbalanced presence of representatives from the purchasing and quality functions, whereas the logistics function was represented merely by one interviewee. It can be supposed that a larger representation of logistics department could have resulted in different identified criteria and in different weights distributions. To overcome this limitation, the review of the results was carried out involving exclusively the top management of the case company. Specifically, the involved top managers were selected in order to bring balance to the representation of the different functions involved in the deployment of the supplier performance evaluation process. Moreover, this thesis investigated the research questions merely from the standpoint of the buying organization. Therefore, the perspective of suppliers or customers would be beneficial for a comprehensive analysis.

In this study, time was a major constraint which obliged the researcher to simplify the traditional AHP approach in order to expedite the development and the execution of the project. Specifically, as described in Chapter 4, the results of reliability studies highlighted a high degree of inconsistency in the obtained normalized weights for certain pairwise comparison matrices. Nevertheless, multiple AHP iterations were not possible for time reasons. To overcome this limitation, after deploying the AHP the obtained results were each time discussed and reviewed with the involved interviewees.

Time constraints severely impacted also on the actual definition of the identified supplier KPIs. In fact, the mathematical formulas defined to unequivocally calculate each supplier KPI will be identified after the conclusion of this study. On the one hand, several KPIs were immediately and unequivocally identified by the whole pool of involved informant,

as in the case of defect rate and lead time stability. On the other hand, some KPIs require more accurate definition. In fact, the definition of quality claim rate and logistics claim rate raised several question marks, such as the impact of the severity of the quality claims on the weight of the KPI or the exact definition of logistic claims. Therefore, comprehensive procedures such as nonconformity management procedures must be defined. Furthermore, additional performance levels might be included in the developed vendor rating models to separately evaluate different KPIs such as defect rate in incoming inspection, in process, in outgoing inspection, and at the premises of the customer.

Finally, the obtained overall weights distribution has been obtained by calculating the arithmetic mean of each set of weights obtained the different interviewee for each supplier performance criteria. The geometric mean could have been preferred as method for calculating the average weights because it is less influenced by large values in a skewed distribution (Kirkwood and Sterne, 2003). Nevertheless, it was proved that the average weights calculated through geometric mean did not sum up to unity, as required for the weights of the set of criteria in the vendor rating system. In similar cases, to overcome this issue, scholars (Ayhan, 2013; Singh and Prasher, 2019; Adebanjo et al., 2016), have applied the geometric mean to FAHP methodology, combining fuzzy theory concepts to the AHP method. Therefore, the time constraint affected the execution of this research as it is legit to suppose than the deployment of FAHP could have returned different sets of normalized weights.

5.4 Implications for the future research

Earlier research has identified multiple criteria for the evaluation of the performance of suppliers. Nevertheless, the peculiarities of the EV supply chain have received less attention than other topics (Kalaitzi, 2019). Furthermore, EV-related publications in the area of operations management are still very rare (Luo et al., 2014).

This study adds to the discussion of defining appropriate criteria for evaluating supplier performance in the context of the novel BEV industry. The challenges that this industry is facing bring interesting opportunities for novel research in the fields of purchasing and supply chain management. Fast paced technological transformation, vertical integration strategies, application of automotive processes in traditionally non-automotive industries such as chemical industry and mining industry are just few of the challenges of the rapidly growing BEV industry. In the effort to understand how this novel industry will impact on the existing supply chain networks, this research may be repeated later in the future, once the industry will reach a higher degree of maturity, to assess possible differences in the defined supplier performance evaluation criteria.

In this study, the defined vendor rating models were developed taking into consideration exclusively the peculiarities and the needs of the business unit of the case company that is dedicated to the design, development, and production of LIBs mostly to serve the automotive market. Examining the peculiarities and the needs of the business unit that is dedicated to the design, development, and production of complete battery systems could provide new insights for the development of a more general process for the periodic evaluation of supplier performance, embracing both the requirements of the highly regulated automotive market and the quest for versatility of other markets such as the industrial market or the consumer electronics market.

Finally, in this study, the use of the AHP implied some limitations which other studies in literature have overcome by applying alternative derivate approaches such as FAHP or ANP. Consequently, it would be valuable to repeat this study applying different approaches and to compare the outcomes of the studies to identify and analyse possible differences.

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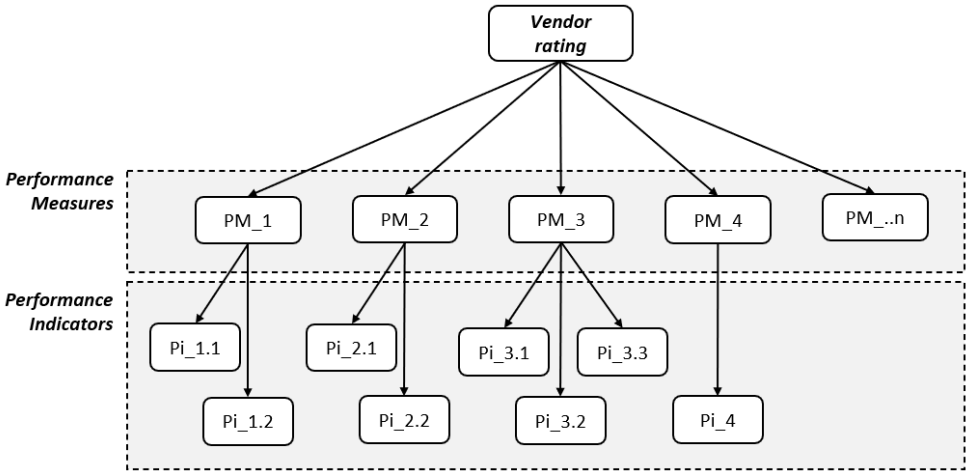
APPENDIX A: QUESTIONNAIRE SURVEY

Survey Number: QS

Foreword:

Please, observe the following figure.



Basing on the definitions reported on the figure above and on your own experience, please provide your answers.

Supplier Performance Measures:

Please consider the following performance measures:

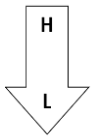
Performance Measure	Examples (adapted from Gunasakaran et al., 2004)
Quality	Product quality Quality assurance
Delivery	Delivery cycle time Delivery reliability On time delivery
Price/cost	Price variation Cost saving initiatives Product cost Supply chain and logistics costs

1. In your opinion, are the presented three performance measures sufficient to understand the overall performance of active suppliers? Please, place a '**X**' to indicate your opinion.

Yes	No

i) If no, what additional supplier performance measures would you indicate? Please make your own suggestions including a short description. If possible, indicate the additional supplier performance measures in order of priority from 'High' to 'Low'.

Some selected examples of supplier performance measures mentioned in academic literature are reported lower below, for your reference.

Priority	Additional Performance Measures	Short description
		

Examples of Supplier Performance Measures

Supplier Performance Measure (adapted from Ho et al., 2010)	
1	Quality
2	Delivery
3	Price/cost
4	Manufacturing capability
5	Service
6	Management
7	Technology
8	Research and Development
9	Finance
10	Flexibility
11	Reputation
12	Relationship
13	Risk
14	Safety and environment

Supplier Performance Indicators:

2. For each additional ***supplier performance measure*** identified at the previous point (refer to point 1.i), please suggest the most appropriate ***performance indicators***. On the next page of this questionnaire, please write at least three ***performance indicators (KPIs)*** for each ***supplier performance measure.***

i) When formulating your suggestions, please also consider the following requirement of IATF 16949:2016 (8.4.2.4):

> The following supplier performance shall be monitored:
> **A**. Delivered product conformity to requirements
> **B**. OEM disruptions and the receiving plant, including yard holds and stop ships
> **C**. Delivery schedule performance
> **D**. Number of occurrences of premium freight.
>
> If provided by the customer, the organization shall also include the following:
> **E**. Special status OEM notifications related to quality or delivery issues
> **F**. Dealer returns, warranty, field actions, and recalls.

ii) If previously you have proposed some new performance measures (refer to previous point 1.i), please <u>add</u> the new proposed performance measures in the tables ''Other-additional'', then write the corresponding **supplier performance indicators.**

Some selected examples of supplier performance indicators mentioned in academic literature are reported at page 4 of this questionnaire, for your reference.

Performance Measures	**Description of Suggested Performance Indicators (minimum 3 Indicators)**	
Quality	1	
	2	
	3	
	4	
	5	

Price/cost	1	
	2	
	3	
	4	
	5	

Delivery	1	
	2	
	3	
	4	
	5	

[Other -Additional]	1	
	2	
	3	
	4	
	5	

[Other -Additional]	1	
	2	
	3	
	4	
	5	

[Other -Additional]	1	
	2	
	3	
	4	
	5	

[Other -Additional]	1	
	2	
	3	
	4	
	5	

Selected Examples of Supplier Performance Indicators

Performance measures	Performance Indicators	Description (adapted from Huang and Keskar, 2007)
Reliability	Order received damage free	Number of orders received damage free divided by total number of orders processed in measurement time.
	Orders received complete	Number of orders received complete divided by total number of orders processed in measurement time.
	Orders received on time to commit date	Number of orders received on time to commit date divided by total number of orders processed in measurement time.
	Root cause/ corrective action	Supplier meets established timeline for fault analysis of defective parts.
	Scrap expenses	Expense incurred from material failing outside of specifications and processing characteristics that make rework impractical as percentage of total production cost.
Responsiveness	Published delivery cycle time	Typical standard lead time after receipt of order currently published to customers by the sales organization.
	Return product velocity	Average time required for process of returning the defective, incomplete, or damaged orders and reshipping of the order to customer.
Cost and Financial	Warranty costs	Costs related to materials, labour, and problem diagnosis for product defects.
	Freight	Costs of transporting component from supplier facility to customer facility.
Assets and Infrastructure	Legal claims	Pending or filed legal claims against the supplier.
	Inventory days of supply	Total gross value of inventory at standard cost before reserves for excess and obsolescence including inventory on company books only excluding future liabilities

Closing the questionnaire survey

Thank you very much for participating in this survey!

This short questionnaire was the first step of a three-step process.

In the next step, the answers to this questionnaire surveys will be collected and analysed. In case of relevant gaps between the different answers from the different interviewees, a very short confirmatory survey will be prepared.

As final step of the process, an individual interview will be held. During the individual interview, specific questions about the supplier performance monitor process and supplier development process will be addressed. You will receive the full list of questions for the interview beforehand.

APPENDIX B: CONFIRMATORY SURVEY

Survey Number: CS

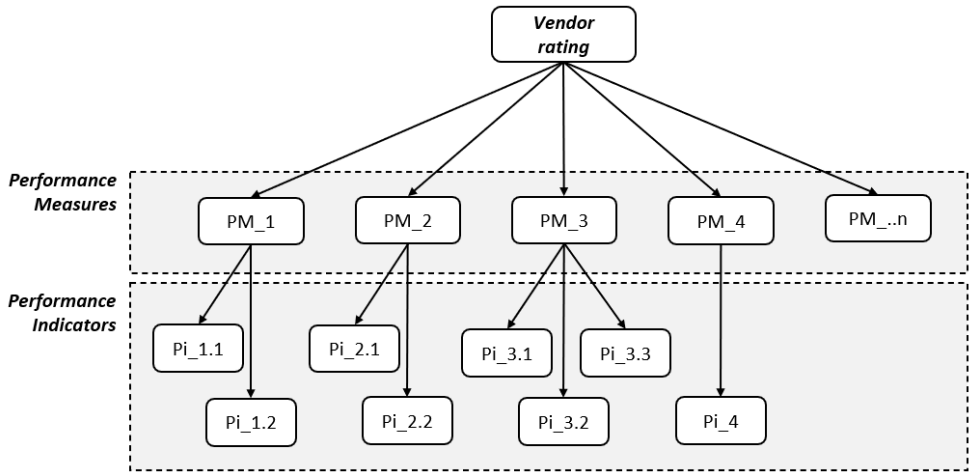
Foreword:

Thank you for participating to the previous Questionnaire Survey for the identification of appropriate supplier performance measures and supplier performance indicators!

The results of the previous Questionnaire Survey have been collected and summarized. In total, 10 supplier performance measures were identified by the 14 respondents that answered to the Questionnaire.

Short list definition:

Please, consider the following picture:



For each supplier performance measure reported in the table on the next page, please indicate if the measure shall be included in the short list or not. Note that the selected supplier performance measures will become part of the final vendor rating model.

Note:

As part of the supplier performance evaluation process, the supplier performance measures refer to active suppliers, already selected through the supplier selection process.

Performance Measure	Performance Measure Definitions	To be included in short list? [Y/N]
Price/cost	Actual cost, cost roadmap, yearly commercial and technical productivity. Continuous improvement, inflation mitigation, forex mitigation.	
Quality	Ranking, quality, PPM, and commitment. Non-conformities discovered and reported in relation to the provision of the service.	
Delivery and service	Supplier's logistic management evaluation, service provided in accordance with agreed schedule. Service rate, delivery on time, packaging, logistics. Were all the items collected and delivered.	
Safety and sustainability	Environmental, safety and social responsibility aspects. Environment management system evaluation. Ability to deliver solutions at the lowest possible carbon footprint. Sustainability performance. Sustainability development plan. CO2 footprint, energy consumption, waste vs recycled, Risk of safety issues, code of conduct, code of ethics.	
Finance	Credit rating, market strength. Company financial stability and solidity.	
R&D	Ability to analyse functional requirements and deliver fit for purpose solution, ability to do concurrent engineering. PPAP approved on time.	
Flexibility	Ability to produce in Europe and deliver to company's locations, ability to provide local support. Lead time for changes. Ability to deal with change in forecast and orders.	
Risk	Capacity shortage, financial risk, changes in management structure, risk to production. Evaluation of supplier impact on company's business.	
Management	Turnover growth, diversification, customers portfolio. Products portfolio, reputation, partnerships.	
Manufacturing capability	Assessment of company know-how and expertise. Ability to manufacture the required quality in time.	

Closing the confirmatory survey

Thank you very much for participating in this survey!

This short survey was the second step of a 3-step process. As final step of the process, an individual interview will be held. During the individual interview, specific questions about the supplier performance monitor process and supplier development process will be addressed. You will receive the full list of questions for the interview beforehand.

APPENDIX C: QUESTIONS FOR SEMI-STRUCTURED INTERVIEWS

Deploying the AHP:

1. Please rank the relative importance of the following supplier performance metrics by referring to the given pairwise comparison scale.

AHP rate [ω_{ij}]	Definition
1	*i* and *j* are equally important
3	*i* is weakly favoured over *j*
5	*i* is favoured over *j*
7	*i* is strongly favoured over *j*
9	*i* is of absolute relevance over *j*
2,4,6	When compromise is needed
Reciprocals, from 1/2 to 1/9	When *j* is instead favoured over *i*

a. Pairwise comparison of supper performance measures (operations)

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Price/cost	1	2	3	4	5	6	7	8	9	Safety and sustainability
Price/cost	1	2	3	4	5	6	7	8	9	Quality
Price/cost	1	2	3	4	5	6	7	8	9	Delivery and serivce

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Safety and sustainability	1	2	3	4	5	6	7	8	9	Quality
Safety and sustainability	1	2	3	4	5	6	7	8	9	Delivery and service

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Quality	1	2	3	4	5	6	7	8	9	Delivery and service

b. Pairwise comparison of supper KPIs (quality)

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Defect rate	1	2	3	4	5	6	7	8	9	8D completeness on time
Defect rate	1	2	3	4	5	6	7	8	9	Quality claims rate

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
8D completeness on time	1	2	3	4	5	6	7	8	9	Quality claims rate

c. Pairwise comparison of supper KPIs (delivery and service)

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Lead time stability	1	2	3	4	5	6	7	8	9	Logistics claims rate
Lead time stability	1	2	3	4	5	6	7	8	9	Delivery in full

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Logistics claims rate	1	2	3	4	5	6	7	8	9	Delivery in full

d. Pairwise comparison of supper performance measures (organization)

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Quality	1	2	3	4	5	6	7	8	9	Delivery and serivce
Quality	1	2	3	4	5	6	7	8	9	Price/cost
Quality	1	2	3	4	5	6	7	8	9	Sustainability

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Delivery and serivce	1	2	3	4	5	6	7	8	9	Price/cost
Delivery and serivce	1	2	3	4	5	6	7	8	9	Sustainability

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Price/cost	1	2	3	4	5	6	7	8	9	Sustainability

e. Pairwise comparison of supper KPIs (price/cost)

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Defect rate	1	2	3	4	5	6	7	8	9	Quality audit results

f. Pairwise comparison of supper KPIs (price/cost)

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Transparency	1	2	3	4	5	6	7	8	9	Competitiveness

g. Pairwise comparison of supper KPIs (sustainability)

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Carbon footprint	1	2	3	4	5	6	7	8	9	Sustainability audit results
Carbon footprint	1	2	3	4	5	6	7	8	9	Energy-saving actions

Factor	Equal		Weak		Strong		Very strong		Absolute	Factor
Sustainability audit results	1	2	3	4	5	6	7	8	9	Energy-saving actions

Presenting the outcomes of the AHP:

1. What do you think of the obtained distribution of the comparative weights?
    a. Would you change your ratings?
        i. If yes, please repeat the AHP process one more time.

Questions about the process of evaluating supplier performance:

1. In your experience, are the individual performance levels achieved by the suppliers reviewed and discussed with the vendors?
    a. If yes, how often?
2. What methods would recommend to define the performance targets for the vendors?

APPENDIX D: LIST OF SUPPLIER KPIS

Supplier Performance Measure	Supplier KPI	Number of times the same KPI was indicated by the informants
Quality	Defect rate	14
	Number of quality complaints	12
	8D completeness on time	8
	Audit Results from Quality	6
	Quality Certifications	2
Price/cost	Cost/Competitiveness	16
	Cost Savings	12
	Transparency	4
	Payment Terms	2
	Scrap Cost	1
	Warranty Cost	1
	Contracts & T&C	1
Delivery and service	Delivery and service	35
	Lead time stability	12
	Delivery in full	4
	OTIF (on time and in full)	3
	Number of premium freights	2
	Customer care	1
	Number of air freights	1
	Audit Results from Logistics	1
	Number of logistics complaints	1
	Communication	1
	Lead time reduction	1
Risk	Financial Risk	7
	Partnership	1
	Escalation status	1
	Risk Management	1
	Dependency	1
	Influence	1
Safety and sustainability	Carbon footprint	4
	Audit Results from Sustainability	2
	Energy-saving actions/year	1
	EHS Certification	1
	LCA results	1
	EHS accidents	1
	EMS Certification	1
Flexibility	Delivery flexibility	5
	Schedule flexibility	4
	Capacity	1
	Local value	1
R&D	PPAP on time	4
	Investments	2
	Portfolio	1
	Validation on time	1
	Capacity ramp-up / versus plan	1
	Patents	1
Manufacturing capability	Process capability	4
	Roadmap Alignment	2

Finance	Turnover	3
Management	Partnership	1
	CSR rating	1