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SYSTEMATIC COMPLAINT DATA ANALYSIS IN A SUPPLY CHAIN NETWORK CONTEXT TO RECOGNISE THE QUALITY TARGETS OF WELDING PRODUCTION

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium 2310 at Lappeenranta University of Technology, Lappeenranta, Finland on the 1st of April, 2017, at noon.

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Abstract

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The network context has moved into a focus of discussions on enhancing productivity and profitability of manufacturing in welding production. At the same time, the quality of manufacturing is taken under consideration in both internal and external functions of manufacturing. The advantages of network structure in production are not fully exploited in supply development, relationship and intercommunication management, or perceiving surroundings with the aim of increasing profit outcome. This thesis discusses welding production in a supply chain network context with the aim to comprise the state of welding production in the supply chain context and concretise quality issues on production in light of a supplier network. The research establishes a relationship between complaints to the supplier network and intercommunication in the supply chain network context with a systematic complaint data analysis. The methodology of the study is based on combined research methods with the nature of the research context. The case study method and mixed method approach with quantitative and qualitative approach is used. In this research, an overall picture of the welding supply chain network, its actors, and their relationships with each other as well as their intercommunication activities is composed. Information share is found lacking and results in discrepancies in production. To establish the goals to decrease complaints to the supplier network, a systematic model is created. Future research is needed to extend the perspective of research to the supplier network and to find the effect of complaints with complaint management perspective on financial benefits in the production chain and the end product.

Keywords: complaint management, data analysis, supply chain network, welding production, welding quality

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Jenni Toivanen
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Contents

List of publications

This thesis is based on the following papers. The rights have been granted by publishers to include the papers in the dissertation.

I. Toivanen, J., Martikainen, J., and Heilmann, P. (2015). From supply chain to welding network: A framework of the prospects of networks in welding. *Mechanika*, 21(1), pp. 8-11.

II. Toivanen, J., Kah, P., and Martikainen, J. (2015). Quality Requirements and Conformity of Welded Products in the Manufacturing Chain in Welding Network. *International Journal of Mechanical Engineering and Applications*, 3(6), pp. 109-119.

III. Toivanen, J., Eskelinen, H., Kah, P., and Martikainen, J. (2016). Connection Between the Number of Complaints About Welding Suppliers and End Product Quality: The Case of Customized Welding Production. *International Journal of Mechanical Engineering and Applications*, 4(2), pp. 43-49.

IV. Toivanen, J., Eskelinen, H., Kah, P., Martikainen, J., and Heilmann, P. A New Approach to Manage Welding Quality in Supply Chain Networks: A Supplier Network Complaints Perspective. *International Journal of Mechanical Engineering and Applications*. Accepted for publication 2017.

Author's contribution

Jenni Toivanen is the principal author and investigator in papers I–IV. The present author was responsible for the literature review, research design, collection of the data and result analysis in all publications. In papers III and IV, the research design and data analysis was assembled together with Dr. Eskelinen. The papers were written with the assistance of co-authors.

Abbreviations and definitions of key terms

A	Assembly of welded structures
C	Component manufacturing
GMAW	Gas Metal Arc Welding
ISO	International Organization for Standardization
M	Machining operations
O	Other reason
PDM	Product Data Management
RACI	Method for identifying roles and responsibilities
S	Surface treatment
SCM	Supply Chain Management
SCN	Supply Chain Network
SME	Small and medium-size enterprise
W	Welding

Key terms

Business network	Complex structure of business environment embedded with relationships with many actors and tiers that strongly depend on cooperation
Data analysis	Information flows of a supply chain network including numerical data and quality data supported by observations of production are integrated to recognise the quality targets of welding production
Supply chain	Structure of companies, facilities and distribution with several sequential and dyadic relationships
Supply chain network	Structure of companies, facilities and distribution with several cross-linked and multilateral relationships
Welding quality	Quality of welding manufacturing in context of actors to enhance profit outcome

1 Introduction

This chapter presents an introduction of the aim and the scientific framework of the thesis. To form an overall understanding of the positioning of this research, the nature of networks, quality and complaint behaviour are introduced with their special features in welding.

1.1 Background

Business now encounters the challenge of globalisation and multiple relationships. To pursue greater efficiency in production in industrial manufacturing, the need to understand the business processes and linkages with actors gains importance in business. The focus has shifted from viewing manufacturing processes or supply chains in isolation to considering different functions and relationships in a wider context, in networks. Network studies have become an important factor to develop business processes, relationships and enhance profitability. Some researches discuss the aspects of network-oriented behaviours which might affect firm performance (Thornton, et al., 2015). It has also been proved that both process thinking and network development during a specific time period can be utilised to improve network performance (Bizzi & Langley, 2012). In the welding industry, the supply chains are typically more general with focused on development targets or quality in welding processes or production (Ghosh, et al., 2017; Benyounis & Olabi, 2008) There is less research on network level. Network context turns single development targets to an advanced view in the context of multiple actors and their surroundings in a manufacturing chain.

Companies see their mutual relationships as dyadic and rarely think of being a part of a whole network context (Ramos, 2008). The understanding of a network is subjective and changes from actor to actor (Ford, et al., 2002). The focal company may see suppliers as a supply chain, a value chain, a competition business model or a distribution channel (Ramos, 2008). The culture of an organisation and the communication across functions and network members affect the integration within the organisations (Pagell, 2004). Building strategic relationships with key suppliers gives strategic advantage (Cousins & Spekman, 2003). Recognising the connections of suppliers influences the control and managing of supplier network relationships (Roseira, et al., 2013). Knowing the strategic actors in the supply chain network and the development targets needed to reach a profitable outcome with the managing network relationships are valuable in business, thus the actors a company deems relevant might are not those they act with (Ritter, et al., 2004).

The quality of information share (Cao, et al., 2010) and the quality of manufacturing work together as enhancers to achieve competitive advantage (Xie, et al., 2011). In respect to manufacturing quality, the quality of the suppliers’ relationships (Ivens & Pardo, 2007) is essential. The effectivity of the production chain reflects on the end product with quality and profitability as well as productivity. However, it is discovered that the defect rate raises with production efficiency (Sharma, 2011) and defects are one approach for observe production quality (Xiao, et al., 2012). Quality and complaints are indicators of production performance (Ahmad & Dhafr, 2002) and, thus complaints mirror the quality of the supply chain and network.

With multiple network studies and their different aspects there is still a lack of studies in the specific field of manufacturing. This research fills the gap of supply chain network studies with focus on welding manufacturing and secondly, extends the knowledge of networks with the perspective of welding production. This research concentrates on the special features of welding in a supply chain network structure (Chang, et al., 2012) with the focus on the supplier network (Dyer & Hatch, 2006; Dyer & Nobeoka, 2000). This research creates the state of network level in a welding manufacturing structure with cooperation and managing. This research uses a novel approach with complaint data to find the development targets on the quality of welded structures in the supplier network using a complaint indicator.

The objective of this research is to compile an overall picture of the state of welding production with its special features and to concretise the quality issues of production by establishing the relationship between complaints to the supplier network and intercommunication in a supply chain network context. This research uses case welding productions in small and medium-sized enterprises (SMEs) to get an overview of the state of welding production in a wider context and to conceptualise a method to observe quality of manufacturing by concentrating on complaints in a supply chain network structure. This can help companies to concretise the picture of discrepancies in the supply chain network and thus create a basis for development targets and also promote network marketing with a profitable outcome. The results show a clear relationship between complaints and a lack of information share. The results indicate that recognising the targets for improvement in a supplier network causes a reduction of complaints in the supplier network.

1.2 Research problem and the motivation of the thesis

Network research in the industrial field is generally concentrated on business, relationships and cooperation, management or other business advantages and is not dependent on the field of production or special characteristics of manufacturing (Chang, et al., 2012; Dass & Fox, 2011; Wilhelm, 2011; Camarinha-Matos, et al., 2009). On the other hand, welding research is concentrated on developing processes or focused on variables in welding (Guillo & Dubourg, 2016; Spoesser, et al., 2016; Benyounis & Olabi, 2008). Even though there is information available on the field of welding manufacturing to develop quality (Panthee, et al., 2015; Sumesh, et al., 2015; Shackleton, 2006), there is a lack of detailed knowledge about the flow of welding manufacturing in a supply chain network and an environments of SMEs.

Network behaviour, complaint behaviour and complaint management are key factors in business relationships (Gruber, et al., 2010). Complaints are among the key indicators of manufacturing performance (Ahmad & Dhafr, 2002). Complaint data is used in measuring suppliers' quality discrepancies rather than using the data to develop manufacturing functions. However, if available, in supply chain network structure complaint data could show targets for development with division into categories and root causes. This thesis gives a new approach to using the RACI (R (Responsible), A (Accountable), C (Consulted) and I (Informed)) matrix at the network level to recognise roles and responsibilities, and allocate complaints, development targets and corrective action to apposite actors.

The research problem is formed from three partially overlapping and cross-linked aspects. First, the complaint data is very sensitive information for the preservation of suppliers and therefore scientific research is needed for detailed analysis of complaint data in the supply chain network context. Secondly, at the same time, there is an increasing requirement to improve manufacturing performance and quality in production in a network environment and to understand the demands of welding manufacturing in a network. Thirdly, the complaint data can be addressed in different ways inside the supply chain network, and therefore it is difficult to recognise the most effective data flow paths to ensure required quality and productivity. Especially in industrial cases, a systematic way which helps to understand how to interpret data in a supply chain network context could help to better understand quality improvement targets and increase cooperation and network behaviour. However, at present, there is a lack of these kinds of systematic ways or approaches for analysing complaint data in this kind of a network environment.

This thesis uses a case of welding supply chain networks with gas metal arc welding processes (GMAW) to create a typical configuration for the research to validate systematic complaint data management to enhance the quality of welding production. This does not include all structures of welding production, but gives a typical configuration of a welding supply chain network with focal company dominance. Welding quality has been determined in detail with a number of standards, and the case supply chain network with defined processes gives an opportunity to apply the method to other supply chain structures with allocated processes and demands.

1.3 Theoretical positioning of the research and research questions

In terms of their structure, business networks including supply structures are generally accepted as complex (Ramos, et al., 2012; Liu & Cruz, 2012; Ritter, et al., 2004), evolving relationships and consist of multiple interconnections between the actors (Wilhelm, 2011). Furthermore, network studies can be divided in different types e.g. technical, social and industrial networks (Bizzi & Langley, 2012). Researchers have studied networks from different viewpoints and with different approaches in the recent years e.g. network design (Dass & Fox, 2011; Pan & Nagi, 2013; Zhang & Zhou, 2012), network management (Bellamy & Basole, 2013), network competencies (Barnes & Liao, 2012), network economy and quality (Castillo-Villar, et al., 2012), and network relationships (Chang, et al., 2012; Barrat & Barrat, 2011; Wilhelm, 2011; Camarinha-Matos, et al., 2009). One research theme used to describe data flow analysis of networks in scientific context is information and knowledge sharing in networks. This aspect is discussed e.g. by Kang & Hau (2014) from the viewpoint active knowledge transfer. In addition, there are several concepts for dividing research approaches and objectives such as network dimensions (Ford, et al., 2002), network insights (Mouzas, et al., 2008), network dynamics (Abrahamsen, et al., 2012; Ford & Redwood, 2005; Anderson, et al., 1998), network horizon (Holmen & Pedersen, 2003) or network pictures (Ramos & Ford, 2011; Leek & Mason, 2009; Henneberg, et al., 2006).

According to Halinen & Törnroos (2005), the only way to handle the complexity of a network as a real-life system is to choose an appropriate theoretical perspective for the study. Therefore, it is necessary to set the boundaries and limits for the research presented in this thesis. The network studies of this research focus on the supply chain network and its relationships in welding production. This research is focused on finding ways to identify development targets in the supplier network, with reference to complaints on the quality of welding manufacturing in a supply chain network. The theoretical positioning of the research ambition is illustrated in Figure 1.1.

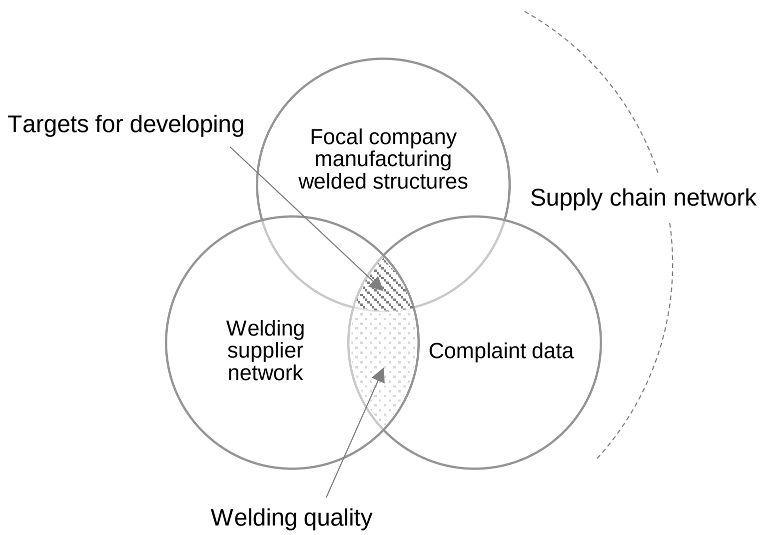


Figure 1.1: The theoretical positioning and the ambition of this research. Information on the activity of the focal company and the supplier network, and complaint data together form the targets of development in a supply chain network which is discussed in this research.

The objective of this research is to describe the special features of the overall picture of welding production in a supply chain network and to establish a relationship between complaints to the supplier network including the cooperation and information sharing of the supply chain network.

From the research problem and the objective of this research the following three research questions are derived: What are the key supply chain network actors and suppliers and their relations which suffer most under the lack of information and why? What kinds of systematic ways might work in analysing complaint data in supply chain network? What are the key disadvantages which decrease the flow and quality of manufacturing of welding production in supply chain network?

This research uses case welding productions to get an overview the state of welding production in a wider context. To be able to solve the research problem and to gain the research objectives, the research questions to be answered are described in Figure 1.2 with connections to Publications I, II, III and IV.

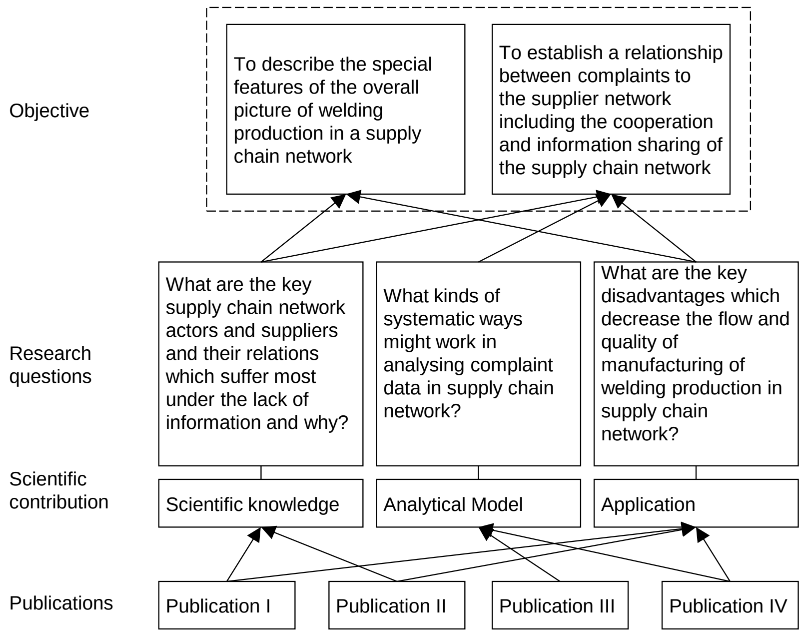


Figure 1.2: The objective and its research questions with connections of Publications related to this thesis.

This thesis claims that the developed systematic method for complaint data analysis based on complaint data filtering from the supplier network, understanding the structure of networks, and taking into consideration the existing quality demands can enhance the quality of welding production in a supply chain network. This method is valid if the roles and responsibilities between network actors are recognised, if complaint data is unambiguously identifiable, and if development actions are executed.

1.4 Novelty value of research results

The unambiguous research results of this thesis compose an overall picture of the welding supply chain network and a new method to utilise complaint data to find the particular disadvantages in production in a supply chain network context. The new knowledge and novelty value of this research is divided into three categories:

1. Systematic complaint data analysis: This research produces new knowledge to create a systematic method for improving the quality of welding production in a supply chain network. In this research, the output is an organised approach controlling the network actors who produce complaint data based development targets, particularly in manufacturing. The new knowledge is based on 18 889 individual complaints allocated in the supply chain network in this research.
2. Supply chain network context: New knowledge is produced by compiling the survey and the complaint data effectively to enhance the quality of welding production. This research applies the conventional roles and responsibilities of the RACI matrix to a new, network-supported mindset in four categories: 1. recognising the responsibilities and assignments, 2. allocating the instigator of complaints, 3. recognising the actor responsible for of corrective actions, 4. allocating actions and determining who carry out and which are the corrective actions.
3. Improvement of welding production quality: The method in this research gives allocated information of network actors which have the best possibilities to influence the quality of welding production and which need to be informed of the development of actions to meet quality requirements, aiming to decrease complaints. This research also presents conditions for the generalisation of the method. At best, applying the systematic method of this research in the case welding supply chain network could recognise allocated development activities at a 56% accuracy to decrease complaints by a particular supplier. This deduction can be made if the combined information of the method from previous years could have led to actions to prevent the quality discrepancies in the current year.

1.5 The structure of the thesis

The thesis is divided as follows. In the introduction, the subject of the research with leading background information is described. Chapter two (2) presents a theoretical background of network studies, relationships of actors and quality of supplier networks with complaint behaviour. Chapter three (3) describes the research design with applicable methods. The research results are presented in chapter four (4) and discussed in chapter five (5). Chapter six (6) presents conclusions of the work. The related Publications are presented at the end of the thesis.

2 Theoretical background

This chapter presents the theoretical background of the thesis. To form an overall understanding of the network complexity, the chapter introduces business networks with variations and concepts with the specific features in network research. In this research, the network focus is on supply chain network with the special features and quality of welding production. The chapter presents the current research on defects and complaints in relation to welding quality in a supply chain network structure. The theoretical background follows the theoretical positioning of the research in this thesis (Figure 1.1).

2.1 From supply chains to business networks

Today´s companies see their actions connected in a wider context of business (Ritter, et al., 2004). Business Networks, which include a supply structure, exhibit a considerably complex environment (Ramos, et al., 2012; Liu & Cruz, 2012; Ritter, et al., 2004) with multiple relationships (Chang, et al., 2012; Dass & Fox, 2011; Brass, et al., 2004; Knight, 2002), and create challenges for manufacturing (Mourtzis, 2016; Miltenburg, 2009) and management (Ford, et al., 2002; McGuire, 2002). In literature, there are discrepancies concerning supply chains and networks and concepts with generally accepted definition are dependent on the researchers' focus and ambition. Many researchers describe business and manufacturing processes as supply chain networks (Paksoy, et al., 2013; Pan & Nagi, 2013; Singh & Sharma, 2014; Castillo-Villar, et al., 2012; Chang, et al., 2012; Simangunsong, et al., 2012; Zhang, et al., 2011; Nagurney, 2010) which result in multidimensional networks with an unofficial definition but limit the aim to a narrowed focus of network perspective. This might help researchers to amplify targets with supply chain in network context. The studied supply chain networks have more supply chain features than network behaviour. This posits the network studies on their own level in its extent with its multiple concepts. A supply chain can be described as a network of companies (Dass & Fox, 2011), facilities and distribution entities (Singh & Sharma, 2014) with different relationships, but networks are embedded within a net of relationships with many actors and tiers (Chang, et al., 2012) and are strongly dependant on cooperation (Wilhelm, 2011; Camarinha-Matos, et al., 2009; Brass, et al., 2004) in a wider context. Networks can rather be described to consist of many supply chain strings (Wilhelm, 2011) in an extended operating area than the same deduction of supply chain networks.

Observing network behaviour relationships is one of the key factors and particularly the relationships to suppliers have become an interest of focal companies with aim of strategic business development of (Holmen, et al., 2013). Relationships and network dynamics are evidently valuable and the focus should be more on networking than on observing the network (Bizzi & Langley, 2012). Communication is one affecting factor on dynamics, and understanding the dynamics of network diminishes unrecognized changes in network actions (Holmen, et al., 2013). When we mirror relationships to results in strategical decisions (Håkansson & Ford, 2002) the impact of managing is evident, and with purposeful tools of management and manufacturing, a profitable outcome can be achieved in production on network level.

In Publications I and IV, the background of networks and their complexity of management, linkages and connections of network members and surroundings have been presented. This background information helps understand the incomplete network behaviour in welding manufacturing, and thus it helps to better understand network behaviour and to develop welding supply chain network actions.

2.2 Quality as competitive advantage in supply chain network context

Supply chain networks contain multiple supply chains and actors with linkages in a unique context (Chang, et al., 2012) through production with suppliers, manufacturers, distributors and retailers (Liu & Cruz, 2012). Supply chain networking can be described as the energy of activities by the intensity of cooperation with profitable outcome. To achieve the flow of manufacturing, management of surroundings and quality of manufacturing is necessary. Information share is essential to enhance managerial advantage and performance increase with cooperation and relationships management (Barnes & Liao, 2012; Awheda, et al., 2016). Knowledge transfer is central for developing dynamic behaviour within the network (Mason & Leek, 2008) with competitive advantage, but it considered to be easier within a company than in the wider context between companies (Chen, et al., 2013). The lack of information share and knowledge transfer is one of the causes for defects and resulting complaints to suppliers in a supply chain network. With higher defect rates, deficits in cooperation result also in extra costs in the manufacturing chain.

To achieve competitive advantage, quality is an important factor in a supply chain (Xie, et al., 2011). Coordination (Akuz & Erkan, 2010), strategic management (Panayiotou & Aravosis, 2011) and strategic supplier selection (Nepal & Yadav, 2015) have become more central in manufacturing and to reach applicable quality. Product quality is necessary in profitable manufacturing and in a supply chain network context to ensure determinate performance level. However, defects are common in production and in supply chain networks (Xiao, et al., 2012). Complaint behaviour and complaint management are essential to ensure effective relationships in business (Gruber, et al., 2010; Bell & Luddington, 2006), and therefore to achieve competitive advantage with developing manufacturing functions.

Quality in network context includes several viewpoints starting from the global quality control strategy (Arndt & Lanza, 2016). To achieve an acceptable level of quality supply chain management (SCM) systems (Cao, et al., 2013) and conform business with quality management (ISO 9000, 2015) bring benefit to firms. The quality of assembly work includes both the aspects of management and quality of an assembly work (Xiaoqing, et al., 2010). The quality aspects of welding production and a final product is established based on the guidelines given in standard ISO 3834 (ISO 3834-1, 2005). According to this standard management needs to understand and recognise possible disadvantages for ensure effective manufacturing and implement appropriate practice and procedures for control. These guidelines can be seen as recommended ways to work in a network context.

In a supply chain network context, the focal company defines the end product's quality and price (Liu, et al., 2015) and is responsible for its supply chain network quality improvements (Zhu, et al., 2007). Thus, suppliers are connected in a network of multiple supply chains (Stjernström & Bentsson, 2004) and have different quality instructions and guidelines to follow. Suppliers do not always get proper feedback to increase manufacturability and instead of concentrating on quality or improvements they expect the focal company to cooperate for produce more cost efficient products (Stjernström & Bentsson, 2004). Managing this network structure is complex (Wang, et al., 2012) with its multiple actors around the manufacturing chain. Discrepancies in the supply chain network affect processing time, and result in rework and extra costs with incomplete profitable outcome. Resulting complaints always retard the flow of manufacturing. Appropriate complaint management is needed to maintain business relationships in the whole network (Gruber, et al., 2010).

Publication II presents the quality requirements in welding manufacturing with its special features and Publication IV discusses the quality and competitive advantage in a supply chain network context.

2.3 Welding quality demands related to complaints

Welding operations as part of effective manufacturing consideration of cost effectiveness bring an increase in profitability (Barckhoff, 2005). Failures in manufacturing affect a single function but can cause considerable damage in manufacturing chain. Manufacturing failures can be a result of welding defects (Shackleton, 2006) but also discrepancies in welding related manufacturing actions. Defects but also failure to recognise weld discrepancies during manufacturing process result in a loss of productivity caused by rework and breaks in manufacturing (LaPlante, 2011). Appropriate quality level and product specifications, and ensuring the requirements affecting welding are met in internal functions but also by the suppliers in the supply chain network, ensure profitable flow in production.

Welded products can be complex structures with multiple parts and high rate quality requirements (Liu, et al., 2013) but fulfilling the quality level is required and has considerable influence on product reliability and human safety (Shackleton, 2006). However, the developed defects in actual welding can be prevented by appropriate pre-actions and the expedient knowledge and skills and competence of welders (Barckhoff, 2005; Li, 2012). Furthermore, coordinating the welding related functions and distributing knowledge on welding and the demands in production to control quality and manufacturing demands in welding diminish non-conformance in the supply chain network. With welding, coordination has a significant role to stimulate cooperation of different functions of production.

Welding demands in manufacturing have been determined in detail with a number of standards, guidelines and specific requirements. These give consistent instructions for manufacturing and definitions to recognise failures and defects. Standard ISO 9000 (ISO 9000, 2015) defines the terms for quality subjects and actions and with ISO 9001 (ISO 9001, 2015) the production quality level can be managed. Welding is a specific manufacturing process and it needs precise coordination of actions. In standard ISO 3834 (ISO 3834-1, 2005), the quality levels with requirements and guidelines for cooperation with different functions in production are explained in the related parts of the standard. In this research welding quality is seen as presented in these three parts of ISO 3834 (parts 2-4) which include requirements for different quality level of welding production. These parts classify quality aspects separately for comprehensive, standard and elementary quality requirements The ISO 3834 provides the basis for quality of welding manufacturing and continuous improvement actions in production, and the standard series related to ISO 3834 gives specific quality requirements for welding. Key aspects, especially from the viewpoint of supply chain network, of quality related items to this research are according to three parts of ISO 3834 are as follows: review of requirements, sub-contracting, production planning, non-conformance and corrective actions, identification during process, traceability and quality records.

Publication II discusses the demands and requirements of welding manufacturing and welding production and explains the relationships between the manufacturing functions and the effect of nonconformity of manufacturing on network level. Also, the welding standards are presented and the impact of failures is discussed with costs of nonconformity. Publication III discusses the quality of welding with complaint behaviour related to specific end products, and touches on the costs of welded parts.

3 Research design and methods

Network studies with limited view give an incomplete picture of the surroundings but it is generally accepted by researchers to observe network activity using a restricted number of companies and multiple dyadic observations (Roseira, et al., 2013; Leek & Mason, 2010; Ford & Redwood, 2005; Ritter, et al., 2004; Holmen & Pedersen, 2003; Ford, et al., 2002). To formulate a successful supply chain network analysis, the structure and linkages of actors have to be recognised. Supply chain network research needs to identify the key nodes of the network and the multiple connections between the network actors with the volume of conveyed information to create an understanding of the activity in the network (Bellamy & Basole, 2013; Kim, et al., 2011). This research consists of different research methods based on the disposition of the research.

In this research, the focus is to determine the special features of welding production in a supply chain network context and to establish the relationship between complaints and information sharing in light of a supplier network. The case study method is deemed acceptable for network studies (Halinen & Törnroos, 2005) and to answer "how" questions with no effect on the behaviour of those involved (Baxter & Jack, 2008), and based on the organizational relationships in the industry, this research uses the case study method (Yin, 2003). The study also uses surveys to glean the perception of the network actors (Awheda, et al., 2016).

In data analysis, the mixed method approach (Guest, et al., 2013) is used in accordance with academic discipline (Kass, et al., 2014). The data collection utilises a quantitative analysis approach (Render, et al., 2003) with qualitative content analysis (Miles & Huberman, 1994). The method to establish the targets of quality disadvantages and production development is developed based on literature on supply chain network modelling (Pan & Nagi, 2013; Zhang & Zhou, 2012; Barrat & Barrat, 2011; Wilhelm, 2011; Smith, et al., 2008) and complaint data management (Gariñ-Muñoz, et al., 2015; Mateo, et al., 2014; Lapré, 2011) using the research methods of this research. The method is verified with particular case welding supply chain network with applicability of the method. The RACI matrix is used to recognise the responsibilities and liability distributions of actions without misplacing the valuable information and overloading the result analysis with unnecessary information. The overall flow of the research process is presented in Figure 3.1.

Table 3.1 below presents relationships between personal responsibilities, welding quality aspects and RACI matrix together with the corresponding section in standard ISO 3834-2 (2005). By utilising the RACI matrix it is possible to analyse the existing responsibilities in welding companies and supply chain network. In addition, the RACI matrix can be utilised to describe the changes of the responsibilities during different types of production inside supply chain network. This means that in this research RACI matrix is seen as a dynamic tool to evaluate changes of responsibilities and their connections with welding quality inside supply chain network. From the Table 3.1 it can be seen that according standard ISO 3834-2 the quality tasks are classified based on welding production but in many companies the quality tasks are combined to other tasks of different positions of worker in company. The utilisation of RACI matrix helps to recognise and interpret these kinds of situations.

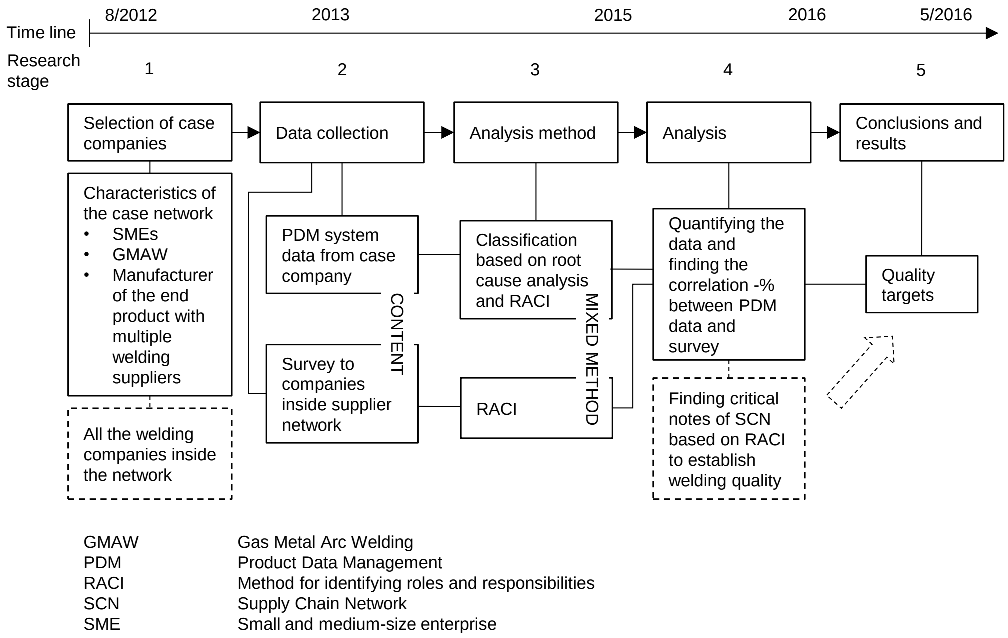


Figure 3.1: The overall flow of the research process.

Table 3.1: Integration of welding quality aspects production responsibilities and RACI matrix.

RACI abbreviation	RACI item	Relationships between personal responsibilities, welding quality aspects and RACI matrix	Possible positions in welding manufacturing company	Corresponding section in standard ISO 3834-2
R	Responsible	Welding coordination personnel	Welding coordinator, production manager, foreman, welder	7.3
A	Accountable	Indirectly presented in standards	Management personnel	
C	Consulted	Inspection and testing personnel	Quality personnel	8
		Sub-contracting	Purchasing personnel, Welding coordinator, production manager, foreman, welder	6
I	Informed	Welders and welding operators	Workers	7.2
		Sub-contracting		6

4 Results

The research results are presented and analysed in this chapter. The research uses data gathered during a ten-year period in a case welding supply chain network. The production contains of the focal company and its environment of SMEs with welding production with gas metal arc welding (GMAW) processes and its special features of manufacturing and quality. To determine the special features of a welding supply chain network and its cooperation relationships, three different welding networks are used. To establish the relationship between complaints and information sharing, the activity of a single case welding network is analysed. Publications I, II, III and IV, which are discussed, compose the base of the results.

4.1 Welding supply chain network behaviour

The current state of welding as network behaviour was studied with different welding networks with focal companies and their supplier networks with configuration of the focal company's dominance. The results show that intercommunication is mainly two-way in the first tier but partially breaks one rises to the higher tiers in the supplier network. The target group of the study consisted of five welding related functions of a focal company: design engineering, purchasing, welding engineering, quality department and logistic. In Figure 4.1, the welding supply chain networks are described with actors and linkages.

In light of welding operations, there is lack of internal information transfer. Thus, the communication level depends on the conventions of the companies. However, greater internal cooperation is needed between welding engineering, design engineering and purchasing functions. There is internal cooperation between welding engineering and quality department but it is often restricted and not able to handle deviations or quality assurance in a supply chain network consistently. The quality assurance is irregular in the supplier network and concentrated on the beginning of the cooperation or subject to periodic control. In individual cases, the purchasing and the quality department are closely bound with the supplier network but it is notable that the cooperation mainly consists of defect and complaint handling. Intercommunication and managing quality are dependent on the culture of the organisation and can vary between different supply chain network structures.

The focal company is responsible for ensuring that the quality requirements are met for every part of the end product, also in the supplier network. The research discovered that defects in welding and related functions are identifiable and known but actions to find the root causes are done less than corrections of failures. Also, the quality requirements focused on welding manufacturing or the product are unknown at many levels of the focal company which can cause continuous nonconformity in production.

The linkages of welding production and the impact of lacking information sharing in a supply chain network are shown in Publications I, II and IV. Supplying demands, challenges and quality in the whole chain with suppliers to the focal company are discussed in Publication II.

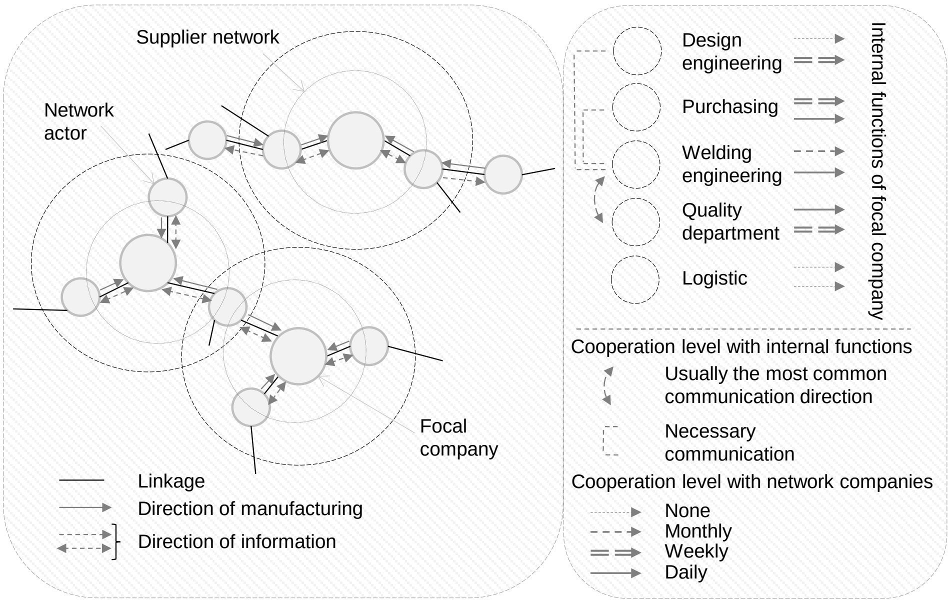


Figure 4.1: Case welding supply chain networks with actors and linkages. Information share and transfer is mostly lacking in the focal company, both internally and externally with the supplier network.

4.2 Establishing the targets for development

To enhance the quality of welding manufacturing and to increase profitability in the supply chain network, complaint information to the supplier network are essential. To diminish complaints, development targets need to be established. This five step method helps to determine targets by combining production data and information of the surroundings. The case welding supply network is used to concretise the method.

The first step for conceptualising a method to develop a process for complaints is to create an overview of the state of complaints to supplier network in the supply chain network context (Figure 1.1). The distribution of all complaints by year is presented in focus of the welding supplier network.

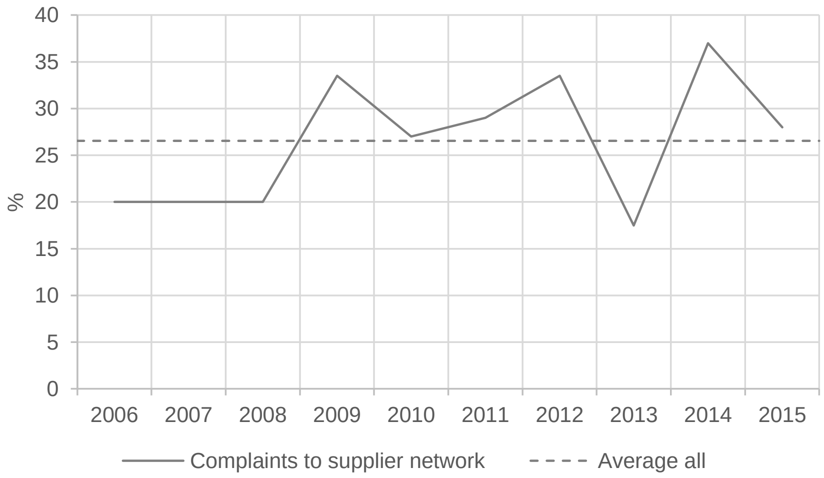


Figure 4.2: The percentual share of complaints to the welding supplier network in a ten-year period.

In this step, the complaint data is categorised with a focus on the supplier network and the root cause of the defects resulting in complaints. The categorisation is based on an analysis of the description in the complaint system, the response of the supplier, and the author’s expertise. Approximately 27% of the supply chain network complaints (n = 18 889) focus on the welding supplier (Figure 4.2). The categories of complaints related to the root cause of discrepancies are based on manufacturing activities which are shown in Figure 4.3.

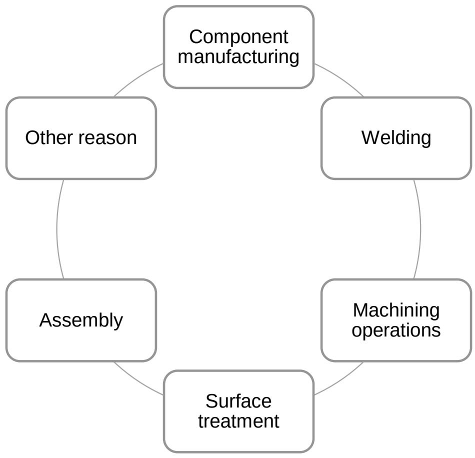


Figure 4.3: Categorisation of the root cause of defects resulting in complaints in the welding supplier network.

In the second step, the observation brings the case end products closer with classification. The result for root cause of complaints is close to same with five percentage point variation. It indicates the reliability with 32% average result of two different case end products with multiple items (n = 14 907). Dividing the root cause of defects resulting complaints to the supplier network follows the same rate in all complaints in the ten-year period and two case end products (Figure 4.4). The portion of a single root cause can change but overall the trend is similar in both instances.

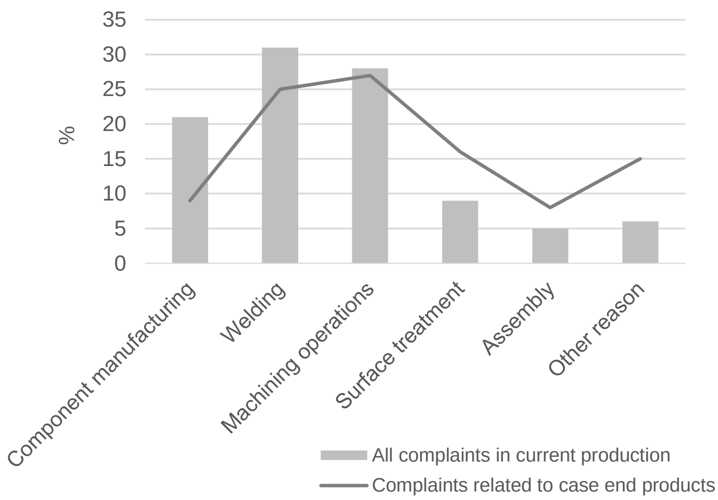


Figure 4.4: Root cause of complaint categorisation related to all complaints to the welding supplier network and particular end products of current production. The trend of root cause is similar in both instance.

To decrease complaints to the welding supplier network, enhancing organisational learning and information sharing is critical. Competencies and knowledge sharing are connected to defects and resulting complaints. The third step of the method takes into consideration the perception of the supplier network concerning the development targets. The welding suppliers (n = 10) in the supply chain network answered the following survey questions (Q1, Q2):

- Q1: What competence or comprehension should welders and managerial employees in the supply firm and employees in the focal firm enhance to decrease complaints from the focal firm?

- Q2: How could the focal firm decrease the number of complaints by improving knowledge transfer?

Q1 alternatives followed the categorisation of complaint data: welding operations, component manufacturing, machining operations, surface treatment and assembly of welded structures. In Q2, the alternatives included developing possibilities: improving or defining manufacturing drawings, increasing welding specifications, increasing assembly instructions and explicating the aim of quality requirements.

The fourth step of the method is integrating the data and finding relationships and correlations between the data from the previous steps with matrixes. The fifth step of the method defines the development targets of the welding supply chain network and is based on Step 4. In Table 4.1, the integrated data can be seen. Step 1 gives 19 clearly distinguishable reasons (≥ 20% of complaints) for the root cause of complaints focused on current supplier in the welding supply chain network. Step 2 gives 20 sub-areas that suppliers selected for activities to decrease complaints. Integrated data shows that 74% of clearly detectable reasons are a total match to the activities suppliers expect to increase competencies and decrease complaints. If the cases which recognised only by the supplier are analysed only 5% were a total mismatch. This shows the targets for development at the supply chain network level to diminish complaints. The development actives of welding production based on this combined information gives a 56% possibility to recognise the most potential development targets to decrease complaints, and thus, to enhance the quality of welding production with individual suppliers related to this data.

Table 4.1: Matrix of integrated data of the five step method gives 74% match for activities that suppliers expect to decrease complaints and complaint data.

	Welding operations		Component manufacturing		Machining operations		Surface treatment		Assembly of welded structures	
Supplier 1	2 %	x	49 %	x	40 %	x	4 %	x	0 %	x
Supplier 2	45 %	x	20 %	x	12 %		13 %		2 %	
Supplier 3	51 %	x	9 %		18 %	x	5 %	x	11 %	
Supplier 4	52 %	x	9 %		31 %		6 %		0 %	
Supplier 5	34 %	x	3 %		43 %	x	18 %		0 %	
Supplier 6	23 %	x	3 %		7 %		38 %	x	21 %	x
Supplier 7	42 %		9 %	x	45 %	x	3 %		0 %	
Supplier 8	22 %	x	0 %		68 %		6 %		5 %	
Supplier 9	0 %		0 %		100 %	x	0 %		0 %	
Supplier 10	80 %		20 %		0 %		0 %		0 %	

X Answers related to Q1.

Q1 match with biggest impact with complaints.

Q1 non-match with complaints.

To concretise, the combined data with end products with the data in Step 2 and survey result in Step 3 give allocated targets for cooperation. RACI matrix in Table 4.2 show the relation of key suppliers and complaints related to case end products. In RACI matrix, the part on the right with categorisation of complaint data related to items of end product gives the importance of suppliers with R (Responsible), A (Accountable) and C (Consulted) and I (Informed). In Q1, R indicates the majority of categorised complained items to the current supplier. A means responsible for the financial details and the quality of end product on network level in current action. C indicates a smaller and I a minor part of categorised complained items. Below the detailed information of reasons for Q1 categorisation are presented.

- R: $\geq$ 10 % of categorised complained items.
- A: financial and quality responsibility.
- C: 5–10 % of categorised complained items.
- I: < 5 % of categorised complained items.

In Q2, C indicates the majority of combined categorised complaints in categories component manufacturing, machining operations, welding and assembly. I indicates the suppliers that have to be informed of changes.

The results of the matrix are based on the data of complaints and the perception of suppliers based on the results of Q1 and Q2. The marked sections indicate the combined complaint data and survey results on how the suppliers see the potential development targets (see. Table 1). In the matrix the impact coefficient could be set as follows: R = 0.3, A = 0.4, C = 0.2 and I = 0.1. The values are based on logical order with importance of responsibilities. Results show the relation of each supplier to the complained items. This helps to find the key suppliers for key targets of development actions. The example of welding supply chain network suppliers and the combined data in the matrix show the suppliers S2, S3 and S6 have clearly best possibilities to affect manufacturing-related complaints involving end products during an eight-year period. The categorisation presents the development activities. The summarised results focus clearly on supplier S6 but also suggest that supplier S2 has potential, indicating that both, suppliers S2 and S6 are aware of the possibilities to make developments. Results also show that the focal company is financially responsible for the end products but also for the quality of manufacturing at the supply chain network level.

Table 4.2: RACI matrix of relation of suppliers and complaints related to the case end products. The matrix shows the key suppliers which have potential to decrease complaints.

Action		FC	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Component manufacturing	Q1	A	I	R	R		I	C/I				I
Machining operations	Q1	A	I	C/I	R	I	C/I	I	I	I	I	
Welding operations	Q1	A		R	R	R	I	R	I	I		
Assembly of welding structures	Q1	A	C/I	R	R			R		C/I		
Surface treatment	Q1	A		R	R	I	I	R				
Improve manufacturing drawings	Q2	R/A	I	C/I	C/I	I	I	C/I	I	I	I	I
Enhance welding specifications	Q2	R/A	I	C/I	C/I	C/I	I	C/I	I	I	I	I
Enhance assembly instructions	Q2	R/A	I	C/I	C/I	I	I	C/I	I	I	I	I
Explicate aim of quality requirements	Q2	R/A	I	I	I	I	I	I	I	I	I	I
Sub result	R	4	0	4	5	1	0	3	0	0	0	0
	A	9	0	0	0	0	0	0	0	0	0	0
	C	0	1	4	3	1	1	4	0	1	0	0
	I	0	7	5	4	6	8	6	6	7	5	5
		4.8	0.9	2.5	2.5	1.1	1.0	2.3	0.6	0.9	0.5	0.5
Summarized result	R	4	0	2	1	1	0	3	0	0	0	0
	A	9	0	0	0	0	0	0	0	0	0	0
	C	0	0	2	0	1	1	2	0	0	0	0
	I	0	5	2	1	1	4	2	2	1	2	0
		4.8	0.5	1.2	0.4	0.6	0.6	1.5	0.2	0.1	0.2	0.0

	C	M	W	A	S
S1	3.1 %	2.3 %	0.0 %	5.3 %	0.0 %
S2	34.4 %	9.3 %	14.1 %	15.8 %	19.6 %
S3	18.8 %	14.0 %	40.0 %	36.8 %	10.7 %
S4	0.0 %	3.5 %	14.1 %	0.0 %	1.8 %
S5	3.1 %	8.1 %	1.2 %	0.0 %	1.8 %
S6	9.4 %	3.5 %	22.4 %	10.5 %	46.4 %
S7	0.0 %	2.3 %	2.4 %	0.0 %	0.0 %
S8	0.0 %	2.3 %	4.7 %	5.3 %	0.0 %
S9	0.0 %	1.2 %	0.0 %	0.0 %	0.0 %
S10	3.1 %	0.0 %	0.0 %	0.0 %	0.0 %

Impact factor	
R	0.3
A	0.4
C	0.2
I	0.1
∑	1.0

FC Focal company
S1–S10 Suppliers
C Component manufacturing
M Machining operations
W Welding operations
A Assembly of welded structures
S Surface treatment

Publication IV contains detailed information on accomplishing the five step method in the case of a welding supply chain network and discusses the complaint data related to the case end products with categorisation. Publication III discusses which data is suitable for analysis related to complaints in overall data and focused on case end products. In Publication II, the root causes of nonconformity and discrepancies in welding production are discussed. In Publications I, II and IV, the welding related functions and activities are explained.

4.3 Reliability and sensitivity of results

The sensitivity of the results to filtering the data is assessed by sensitivity analysis to filtering the data and survey answering to supplier network. Figure 4.5 shows the stability of results in recognising development targets in Step 5 of the five step method. The change is 2.29% to 100 misinterpreted root causes in categorisation and classification of data. This would not decisively affect the result for filtering and thus the research can be considered valid.

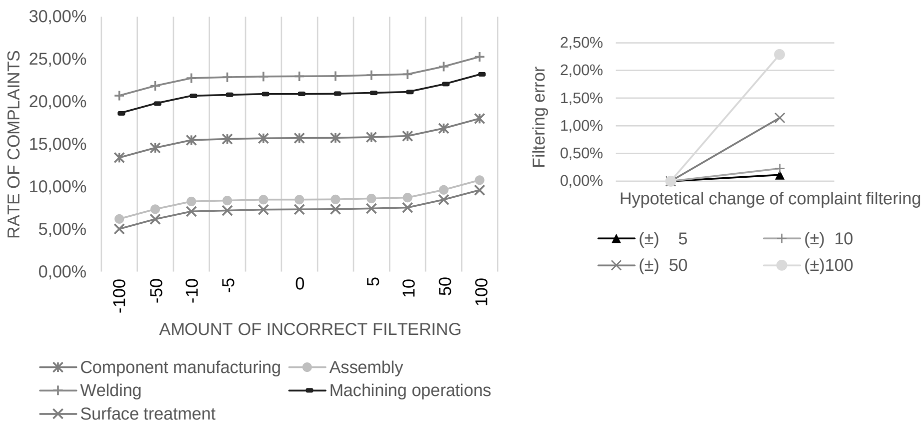


Figure 4.5: Sensitivity analysis of filtering the complaint data. Misinterpreted root causes of complaints do not critically change results used to recognise development targets.

To comprehend the effect of the survey results on the reliability of the five step method, a sensitivity analysis was conducted. The sensitivity to changes in supplier network answers would critically change the survey result. If falsified answers by suppliers raise over one, the change is over 10% and 26.32% to five falsified answers (Figure 4.6). This places the survey results and thus supplier network in a critical position in the method. However, the results of the survey do not change the filtering and the actions that need developing can regardless be seen in Step 4 and Step 5. Filtering is key for recognising development targets and essential, so that the reliability of the data of categorisation is valid. To ensure the sensitivity of filtering assess the method and research to be usable even with a critical change in survey results with falsified answers that have effect on adversary conception.

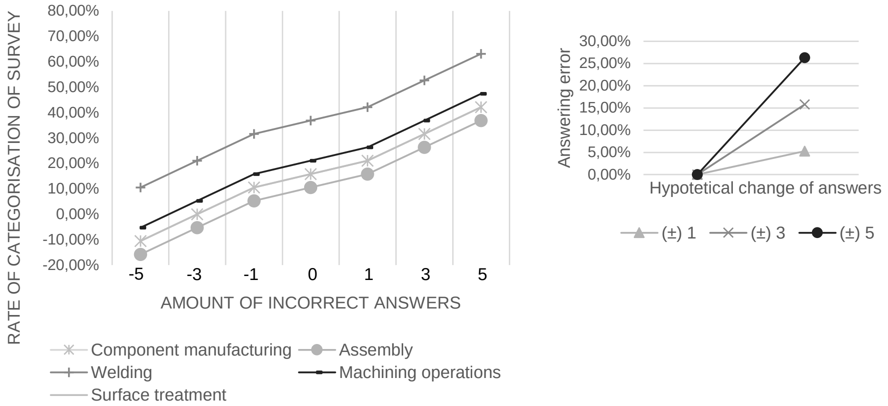


Figure 4.6 Sensitivity analysis of the supplier network survey’s effect on the results. Falsified answers change the results critically to recognise development targets.

5 Discussion

This research discusses the systematic complaint data analysis to improve welding production quality focusing on the supplier network with potential to enhance the end product profitability and affecting the flow of production. The research is composed of the state of welding production in a supply chain network context with surroundings of SMEs which can be perceived a typical welding production with GMAW processes and the structure of a focal company as the manufacturer of the end product with multiple suppliers.

The observation of welding supply chain networks shows potential to improve quality and profit outcome by developing manufacturing and appropriate relationships, competencies and knowledge transfer on network level. Former researches are supporting this kind of quality work. This way aims to increase positive effect to supplier connections and profitable and effective production (Dyer & Hatch, 2006; Dyer & Nobeoka, 2000). This research shows a lack of network behaviour with incomplete information share. It can be noticed that when the tier level of cooperation rises, the intercommunication with the focal company becomes non-existent. This affects the quality assurance of welding manufacturing in a supply chain network. This also affects the end product´s possibility to enhance profit outcome.

Welding manufacturing is just one function in welding production and the functions can be divided into design engineering, purchasing, welding engineering and quality department (Figure 5.1). Logistic function depends on the company's operations and the characteristics of products and, thus, has impact on the quality of welding production. The division can be continued for the supplier network with the function of welding manufacturing. Welding manufacturing can be divided into different manufacturing activities, i.e. component manufacturing, machining operations, welding operations, surface treatment and assembly. The previous are the activities where most of the complaints are developed. These all have impact on manufacturing success in welding manufacturing. The connection between the linkages between different functions and the activities on supply chain network level has to be coordinated to ensure a successful outcome. In Publications I, II and IV, the linkages of different functions and activities, and their effect on welding quality and productivity, are explained.

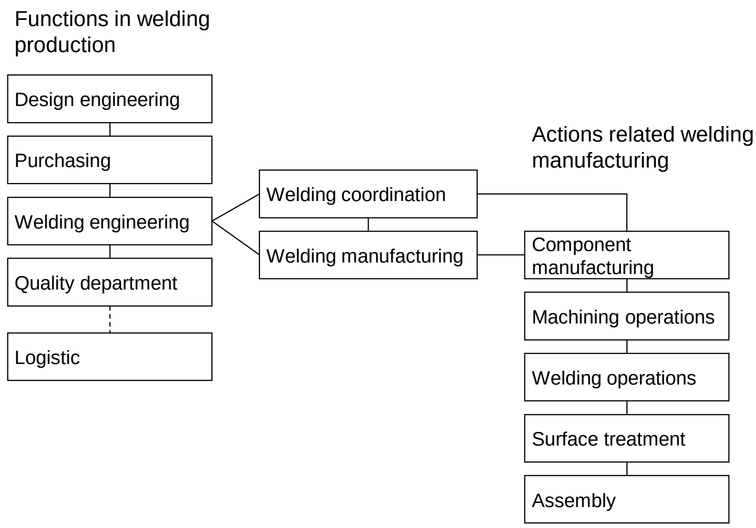


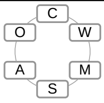
Figure 5.1: The division of welding related functions and manufacturing activities.

Defects are common in production and welding manufacturing. The importance of the focal company with its dominance on finding the development targets on supply chain network level is indisputable, due to its responsibility for quality and costs of production and its ambition to achieve profit. As shown in former researches, production performance can be observed with achieved quality and number of complaints (Ahmad & Dhafr, 2002). In addition, recognised quality defects can be regarded as an approach for studying production quality (Xiao, et al., 2012). Welding supply chain network follows the systematic complaint data in current production. That means the data of end products can help to recognise the difficulties existing in production and the data collected over several years can predict complaints in end product. Complaint data can be valuable in mapping the supply chain network manufacturing quality.

Some mathematical models are available for observing suppliers´ or items´ conformity or non-conformity (Radhoui, et al., 2009; Rezaei & Davoodi, 2008). This forms partially justification to the need of a systematic stepwise method to observe the root causes of quality defects. It also has been accepted that quality control development can be observed by utilising development steps (Arndt & Lanza, 2016). The five step method concretises the need for developing actions. In

Table 5.1, the method with its five phases and impact is illustrated. The method uses existing complaint data and information on how suppliers see the potential targets in an overall view. With applicable categorisation of complaint data, survey results and by combined information with matrixes, the development targets can be found. RACI matrix show allocated information of the key suppliers for key targets of development action.

Table 5.1: The steps of five step method to find the developing targets in supply chain network to diminish complaints to supplier network.

Stage	Target	Actions	Description	Impact
Step 1	Classification of the state of complaints	• Data collection • Data categorisation • Establishing the relative share of particular process in production		Allocation the data in supply chain network to the proper supplier and manufacturing action
Step 2	Filtering of relevant data	• Recognising the complaints related to specific products by analysing complaint data	Criteria dealing with welding quality specifications	Optimisation of prosessed data in a supply chain network
Step 3	Collecting observations from supplier network	• Survey to suppliers	Finding supporting observations	Making reliable the database information and increasing reliability of quality control
Step 4	The data integration	• Find the relationships and correlations between Step 1, Step 2 and Step 3 • Utilisation with matrix tools	Suggestion of improving knowledge skills or competences in specific welding processes	Key technique to improve the knowledge, skills or competences in welding with proper targets
Step 5	Recognise the development targets	• Selection based on Step 4	Finding practical improvements of welded constructions and key suppliers	Improvement actions for operation practices and products

General roles and responsibilities for quality operations are presented in standard ISO 9000. Requirements for a quality management system can be found from ISO 9001. Standard ISO 3834 focuses especially manufacturing processes, such as welding, but roles and responsibilities or management and leadership aspects are not included. This causes a problem when trying to develop manufacturing quality especially in network context. Resources and management have got less attention in business processes (Cabanillas, et al., 2011) even it is essential to develop business processes and supply chain network management activities. RACI is one effective tool for recognising persons in charges and doers in business processes (Cabanillas, et al., 2015). RACI matrix is used to define roles and responsibilities in multi-supplier business environment (Rajamäki & Vuorinen, 2013). RACI matrix is one of analysis method in this research to find the divided quality targets and responsibilities during welding production.

To utilise the method successfully, filtering the data is crucial. If the data in Step 1 and Step 2 is not identified with proper comprehension, the information cannot be utilised with full benefit and will lead to incorrect results in Step 5. To improve welding production quality with the method, it is essential to recognise the welding quality requirements and quality discrepancies with appropriate criteria. In the filtering stage, the complaint data needs to be combined and root causes need to be found by analysing the data. Step 3 resolves the connection between filtered data and the experience of the supplier network.

Analysing the development targets and key suppliers' actions in welding operations requires special knowledge, skills and competence in welding. Filtering as a key step of the method can be implemented in welding coordination and the method can be a valuable tool of welding coordinators together with related functions. The expertise in analysing is critical and faulty survey answers in Step 3 do not critically change the results to find activities which need development, but restrict the analysis to recognise targets to decrease complaints to the supplier network. With the five step method, the targets for development are divided into welding related activities in the manufacturing phases. Every activity has an impact on quality and profit outcome in manufacturing. In the case welding supply network, combined information gives a 56% possibility to recognise the development targets for decreasing complaints by a particular supplier if the combined information could lead to actions to prevent quality discrepancies. This shows that the method is useful in improving quality but needs actions to execute developments.

By summarising the discussion it can be concluded that new information about complaint data analysis in a supply chain network context has been produced. RACI matrix has been proven to be an effective tool to recognise the quality targets of welding production. In this research the term supply chain network describes better the operational environment than supply chain or business network. During in this research the utilisation of mixed research method has proved to be effective to integrate numerical data from supply chain network and observations of quality targets in welding production.

6 Conclusions

With business globalization and dynamic business processes, the focus has shifted from observing manufacturing processes in isolation or in supply chains to the consideration of the different functions and relationships in networks. Multiple studies provide general information on supply chain networks or focus on design and predict the outcome of different structures. Otherwise, the studies are concentrated on qualitative analysis using only survey results with the perception of participants. This research concerns the state of welding production in a supply chain network context with the capability to improve the quality of production with profit outcome. The research focuses on complaints to the supplier network with a focal company´s dominance and presents a new five step method to establish development targets in a supply chain network to increase the quality and profitability in production. Using complaint data with its sensitivity provides a new approach to quality improvement in a supply chain network with a focus on the supplier network.

To answer the research questions, the special features of welding supply chain network and its cooperation relationships were studied using case welding supply chain networks with acceptable restricted observation with a number of companies and multiple dyadic observations.

The first research question covers the welding supply chain network key actors and relationships, and lacking information sharing. Welding production is more characteristic of a supply chain than a network and to extend awareness of the surroundings, the supply chain network is the appropriate level to develop manufacturing functions and relationships of the supply network in a focal company dominance. The key actors depends on the viewpoint of development and the state of the focal company. Welding production with its multiple divisions of functions and activities is presented in this research to be suitable in particular case welding productions. In respect to production, end product and activities which affect its quality and profitability in a focal company, the division to design engineering, purchasing, welding engineering and quality department gives the action based categorisation. Using a division based on where the complaints are developed can be more accurate and actions allocated to the manufacturing activities in the supplier network. Lack of knowledge of welding, skills or competencies are reasons for complaints but moreover, lack of information can cause continuous nonconformity in production and can be explained with unrecognised quality requirements focused on welding at many levels of the focal company and unawareness of the demands for the result of manufacturing in a supplier network.

The second research question tries to find a systematic way for analysing the complaint data in a supply chain network. Complaint data is very sensitive information for the preservation of suppliers and to find the key suppliers to effect a decreasing of complaints to the supplier network, the focal company needs a systematic way to explicate the development targets. The five step method of this research helps the focal company to recognise the targets. The method is dependent on filtering the data in Step 1 and Step 2 and it requires knowledge, skills and competence to define the dimension, the categorisation and the classification of defects. Changes in method results can have an effect on managerial decisions in production and the filtering is critical.

The third research question comprises the key disadvantages which have a negative effect on the flow and quality of manufacturing in welding production in a supply chain network. This research shows that lacking cooperation between different functions and the lack of knowledge, skills and competences have a negative impact on manufacturing with instant or continuous nonconformity. In the systematic model, finding ways to decrease complaints to the supplier network through extended internal and external information sharing is the key element for the systematic control of discrepancies in production and complaint management in a supply chain network context. In this research the case supply chain network could be able to determine 56% of the targets for development to decrease complaints in the case of individual supplier if the combined information could lead to actions to prevent quality discrepancies.

Firstly, this research fills a gap in supply chain network research with a focus on welding manufacturing, and secondly, expands on the knowledge on networks in welding production. The results show both an internal and an external lack of communication. Deficiencies in information sharing in a supply chain network promote defects and result in complaints to the supplier network. The research shows that combined production data and information of the surroundings in welding production give a new approach with a new method to examine the supplier network and to find development targets for quality. The novelty value of this research lies in extending the applied conventional RACI matrix to respond to the complexity of networks, and the new method is stable even with changes in the network structure. The five step method helps companies to respond to quality discrepancies in supply chain networks.

This concrete and innovative approach and results help to understand prospects for managerial and strategical development. Recognising the targets of improvement in a supplier network promote better manufacturing and marketing decisions in the focal company and the results can be elaborated more on the level of suppliers. Though, the data collected from case companies included observations of GMAW processes all the results and conclusions can be widened to deal with any other industrial welding processes. Also the five step method can be applied to, in addition SMEs, to other sizes of enterprises. The research also provides a tool for different fields of manufacturing and business to establish development targets. The utilisation of RACI matrix as an analysing tool makes it easier to generalise the results to different areas of manufacturing production in network context.

There are limitations to this research. The research is focused on quality and profitability from the perspective of manufacturing and does not provide industrial engineering with calculations to clarify the state of production or predict outcomes with deep statistical analysis. In network studies, the observation of a single company is limited. Thus, the particular perspective can help to conceive the structure and understand the actions and relationships in their surroundings. This research observes supply chain network from the perspective of a focal company and this restricts the wider perception of surroundings. This research uses case welding supply chain networks and particular production to determine the state of welding network behaviour and the prospects to develop production in a supply chain network context. To generalise the method to all viewpoints and business functions more case studies are needed. Furthermore, to compile a more comprehensive picture of the cost impact in a particular production and for a particular end product, internal complaints in a focal firm must be considered in a systematic analysis.

For future research, I propose to extend the view more to the supplier network. The focal point of a supply chain network can be varied and compose a more extensive state of the network. The five step method of this research is developed with case welding production. To generalise the method with systematic complaint management is essential to observe financial benefits with calculation. This gives an interdisciplinary approach for future research. Furthermore, internal complaints in a focal firm must be considered when observing more the cost impact in a particular production and end product. The lack of communication and competencies can mirror complaints in production and the results of this research give clear evidence that complaints and actions of quality assurance are interrelated. The effect of complaint management in increasing information sharing and competencies is one perspective for future research. To develop the five step method to perform with full performance, the capability of a filter to recognise the reason of defect, but also the lack of knowledge and skills and competence behind the manufacturing, is interesting for further investigation.

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Publication I

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From supply chain to welding network: A framework of the prospects of networks in welding

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From supply chain to welding network: A framework of the prospects of networks in welding

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1. Introduction

Study of supply chains and business networks has become an important aspect of efforts to enhance efficiency in industrial manufacturing and modern business. It is generally accepted that business is becoming increasingly global [1-3] and competition becoming increasingly intense. This transformed business environment has changed manufacturing processes, especially connections between different functions in commercial activity, and has promoted the adoption of new technologies.

A business network can be defined as a set of nodes and the set of ties depicting the relationship between the nodes [4]. It has been suggested that networks with well-coordinated and managed connections between the different parts of the network and their actions can gain considerable benefits as regards organizational competitiveness [5]. Network studies can comprise different views depending on the focus of research and the perspective used to interpret the results; for example, network modeling can provide valuable information about network behavior [2, 6, 7]. Such modeling is an approach that gives a comprehensive overview of a network.

However, the variety of approaches used in the field have led to a lack of clarity regarding the conceptual division between supply chains and networks. Furthermore, despite the considerable amount of research, there is a lack of work dealing with specific fields of manufacturing, their characteristic functions and requirements. Additionally, it is not clear whether a supply chain or network approach is predominant and how the two approaches perform in specific manufacturing contexts. It is of interest to observe how different manufacturing processes in different industrial fields emphasize different linkages between different functions.

The purpose of this paper is to elucidate the network concept within the context of the welding industry. The paper reviews background information about networks and compares this theoretical information with practices in welding manufacturing. The paper studies the common attributes of welding networks and welding manufacturing chains dominated by a focal firm and presents an example of the internal and external linkages of a welding network.

The study is based on analysis of welding networks involving small- and medium-sized companies. In the empirical part of the work, the structure and different levels of welding networks were defined using experimental information about welding networks. The data was collected in 2010 to 2013 and is based on three welding networks consisting of three to four small- and medium-sized companies with welding workshop activity. The network structure in its entirety consisted of a larger number of firms. The linkages were defined experimentally and using data collected in numerous interviews, and from observations and production data. The observed linkages were followed upstream (suppliers) and downstream (customers), with focal firm dominance, and both internal linkages and external linkages of the welding network were explored. The paper also discusses increases in the profitability of welding functions that may be possible as a result of increased cooperation in the network.

2. From manufacturing supply chains to welding networks

Supply chains of many fields of industry have been studied by many authors, and the different parts of the manufacturing chain have been designated throughout its whole length, from raw material to final product and customer [8]. A typical supply chain contains the functions of supply, manufacturing, distribution and retailers or consumers [9-11]. Supply chains consist of many firms, which are defined by their individual relationships to each other [6]. Intercommunication in a supply chain is however commonly dyadic, e.g., between a supplier and customer (Fig. 1). The functions in the different parts of the supply chain have been surveyed from many different perspectives, from individual manufacturing processes to the economic life cycle of the manufactured product.

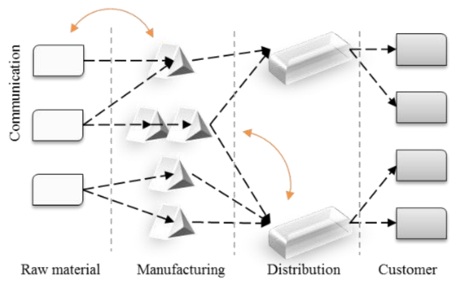

Fig. 1 Typical supply chain with dyadic intercommunication (Adapted) [10]

When making efforts to develop greater efficiency in the supply chain, the need to understand its business processes and linkages becomes more important [8]. Thus, the focus of research interest has shifted from viewing manufacturing processes in isolation to consideration of the different functions of the relationships within the supply chain. While much research still focuses on consideration of only one tier of the supply chain relationship, investigation of multiple levels of relationships and the various dynamics in communication and cooperation at an organizational level is becoming more prominent [4, 6]. The development of more complex relationships in the supply chain is leading to a greater emphasis on the network perspective.

The dividing line between supply chains and production networks is not clear-cut. Many authors [7, 11-17] describe business processes and manufacturing as being a part of the supply chain network. The conflated concept of supply chain and business network illustrates the change in business management viewpoints, but also illustrates the conceptual complexity of describing supply chains and manufacturing [18, 19] and uncertainty in business processes. Research interest in business networks has increased over the last decades as the importance and prevalence of networks has become evident [1].

Networks are considered a complex environment for managing business processes [20] formed of many suppliers who are participants in different relationships with many actors and tiers [12]. The complexity and multiple relationships in networks mean that they are strongly dependent on cooperation [3, 4, 21]. It is important to realize that strategic and management approaches differ when stepping from an individual firm perspective to a network environment [12]. Organizations aspire networks for a variety of reasons. However, one of the specific reason, in a general sense, it make possible to achieve some end that they could not have achieved independently [5].

Networks can also be seen as consisting of many supply chain strings which have linkages [21]. Network members with linkages are known as nodes in the network [4, 12]. Fig. 2 illustrates the complexity of networks and the possibility of multiple supply chain structures involving members in a network. The dashed line emphasizes the prospect of one particular manufacturing path in a network of possible route choices, illustrated with a continuous line.

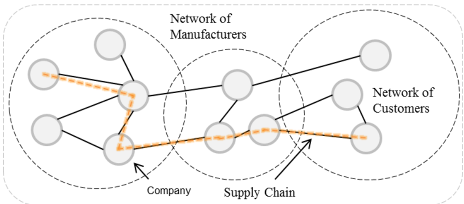

Fig. 2 Generic network structure of operations and linkages

In conventional supply chains and supply chain networks, the complex structure of relationships affecting business processes is not seen as strongly as in production networks. There is no strict division differentiating the network itself from the supply chain network but there is a fine noticeable difference in the complexity of the network structure and behavior of participants of the network. For example, a supply chain can be described as a network of companies [6] and facilities and distribution entities [11], and a supply chain network can consist of member firms and the links between them [18]. The network can have the same facilities, but the network view is an aggregated view of suppliers, the focal firm and customers [12].

Networks can be studied from many different perspectives. For example, network design and modelling, and network management and manufacturing processes are of interest in many studies of the global business environment. Depending on the perspective, particular aspects of networks can be observed, e.g., variables related to material supply, component fabrication, manufacturing, and final product distribution activities [7], or production, inventory and transportation [13], or manufacturing, storage and distribution [14]. Table 1 presents some recent research on network behavior based on the perspective and network aspects chosen for study.

Table 1

Perspectives of some recent research on networks divided by approach of network study

Approach	References
Network design and modelling	[2], [6], [7], [13], [14], [16], [20], [22], [23], [24], [25]
Network management	[15], [26], [27], [28]
Network Quality	[16], [17], [29]
Network relationships and cooperation	[3], [6], [12], [21], [27], [30], [31], [32]
Finance and economics in networks	[7], [14], [16], [17], [20], [25]
Network flexibility	[11], [33]
Uncertainty of network	[20], [15], [28]

Production networks often appear to have the same base facilities as supply chains [e.g. 14], that is, supply chains and networks include cognate entities in some instances. Nevertheless, both have their own distinguishable characteristics (Table 2). A key difference is that the combined effect of production chain management and business processes are analyzed at different levels and evaluation criteria for suppliers and customers differ. Generally, a network-based approach concentrates more on managing relationships between firms, and the business processes involved are more multi-tiered than dyadic. When comparing networks and supply chains, the focus of operational strategy is both vertical and horizontal in networks, rather than only vertical as in supply chains [1].

Table 2

Differences between supply chains and networks according to different approaches

Approach	Supply Chain	Network
Main focus area	Inter-firm	Intra-firm
Focus of linkages	Focus on the nodes	Focus on linkages between nodes
Focal firm	Focal firm dominant	Multiple focal firms
Manufacturing perspective	Suppliers – Manufacturer – Customer	Supplier network – Manufacturing network – Customer network
Coordination of manufacturing	Focal firm	Equivocal
Cooperation	Dyadic	Strongly dependent on cooperation at multi-tired levels
Cooperation direction	Vertical	Vertical and horizontal

In view of the fact that supply chains and networks appear to have their own distinguishable attributes, there is an unsystematic convention when using the supply chain or network notion, which, to a certain extent, seems to depend on the nature of research. The research view of networks appears to differ depending on the focus of the study. Furthermore, the functions, design and management of operations also seem to differ. This discrepancy in different aspects of network research is indicative of a need for more examination, particularly as there has been a lack of practical studies in network research in the last decade [22]. At present, there is a need for empirical network research of different aspects of business functions in different sectors of the manufacturing industry [15].

Researchers have observed networks from different viewpoints or concentrated on specific sectors or functions irrespective of the industrial field. Present studies have not paid sufficient attention to particular operations or functions in specific fields of manufacturing. Thus, there is a need for more specific investigation. Network research has commonly concentrated on economic aspects or relationships and there has been little focus on product and process quality. Moreover, studies mostly separate the supply chain and network for different operations in the manufacturing chain, i.e., the network view is seen as concentrating on management, and the supply chain as concentrating on transport or distribution. This approach restricts observations between different functions of a network. Furthermore, if networks are divided into different categorizes (e.g. entrepreneur, social and business activity [34]) it prevents development of a panoramic view of the whole manufacturing business.

When considering welding networks, empirical observations in this study have shown that more functions are focused on developing operations than promoting inter-function activity. At present, typical welding networks seem to have more the characteristics of a supply chain with focal company dominance than wider view network aspects (Fig. 3). The focal company dominates the transmission of demands of manufacturing. Harnessing the power of relationships and increased cooperation activity would enable emphasis on manufacturing throughout the production chain. Recent thinking on network behavior in manufacturing is bringing welding closer to dominant functions with a prospect of affecting the demands and quality of welding and at an earlier stage.

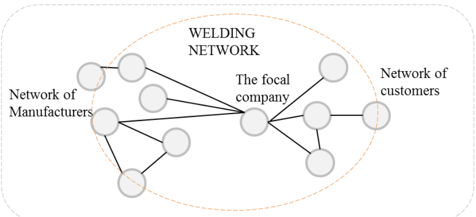

Fig. 3 Structure of a welding network with focal company dominance

As can be noticed, the dividing line between supply chains and networks is unclear from the manufacturing viewpoint and as a result supply chains and supply chain networks can be treated as networks, if the premise of the research is network studies, although differences in definition and variability in use of terms can lead to some uncertainty.

3. Linkages of welding networks

A typical supply chain in the welding industry is a welding supply chain in which the focal company is the dominant part of the chain and relationships between the focal company and one individual supplier are more common than relationships between suppliers or at multi-tiered levels. While the influence of different actions and relationships on network definitions is receiving more attention, the precise form of typical welding networks is still under discussion and requires closer observation. Observation and analysis of existing network models can be implemented in study of welding networks but there is no demonstration of the influence and behavior of different functions of welding and how to model functions under welding demands.

Profitable manufacturing is strongly dependent on fluent material flow and manufacturing competence. Furthermore as noted earlier, cooperation between different parts of a network and different internodal relationships are major influences in functional networks and effective management of production. A closer look at the linkages of networks is essential when looking at ways to improve business management [28]. The dynamics of everyday work is of importance and consequently the focus should be more on networking than observing the network [35] which emphasizes the importance of relationships between different functions of a network.

On the basis of previous research and in view of the lack of empirical studies focusing specifically on the field, welding, which is an established technology and a commonly undervalued action as manufacturing function in the manufacturing chain, is a subject of considerable interest. Welding manufacturing has the potential to enhance network profitability through the development of relationships, competences and functions. Consideration of welding operations as part of an effective and cost-effective manufacturing chain can bring a considerable increase in profitability [36].

The linkages of a network can be observed in different ways depending on the viewpoint chosen. Internal linkages, e.g. between production, marketing, purchasing and logistics functions, and external linkages, e.g., between retailers, manufacturers and suppliers [27], can be viewed differently when seen from the point of view of a focal firm at the upstream level, at the focal firm level and at the downstream level. In a network, the focal firm has a better network position relative to the downstream firms [12]. By setting the upstream level as suppliers and the downstream level as customers, the observation level is defined as the focal firm (Fig. 4). This simplified structure is outlined picture with welding workshop manufacturing.

With focal firm dominance a number of predominant functions determine the profitability of the welding

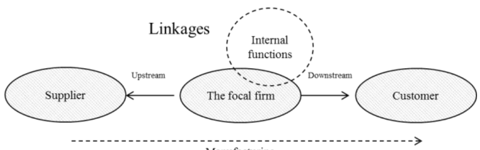

Fig. 4 Simplified structure of linkages of a welding network

network. The internal costs of the focal company and the area of responsibility of each function dictate the manufacturing costs and can affect optimizing functions at others' expense. Increasing the profitability of a welding network requires knowledge of the internal linkages and knowledge of network control. Design, purchasing and welding engineering within quality functions and logistics affect welding actions before, during and after actual welding and have an impact on the costs of manufacturing in the welding network. Coordination of welding is linking the functions together with responsibility of welding operations.

These main functions need the support of management to implement decisions regarding issues of welding manufacturing with a focus on the quality of welding and product and manufacturing requirements (Fig. 5). The welding requirements add complexity to ensuring the quality of welded products when there are many cooperative manufacturers in the welding network. Thus, welding networks with special demands, like the environmental demands of Arctic and offshore manufacturing, and the high safety demands involved in welding of pressure vessels and in the nuclear industry, need to observe particular responses and relationships. There is also need for understanding of the different relationships affecting the companies in the network structure even when no direct link exists [37].

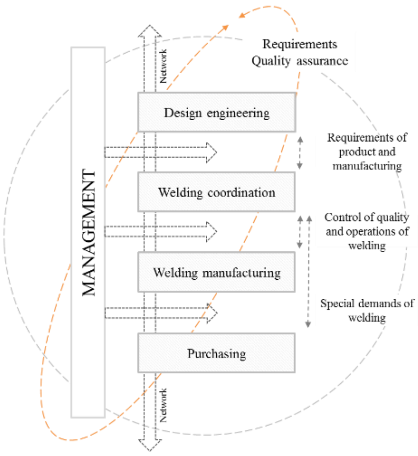

Fig. 5 Links between different functions of a company

Network quality is a significant concern when aiming to achieve competitive advantage [38] and when manufacturers expect continuous improvement of network members' performance [39]. When firms improve interaction with suppliers and with customers on issues related to materials flow and quality, firms can expect better time-related operational performances as delivery speed and punctuality [40]. In networks with focal firm dominance, the responsibility for assurance of the quality requirements rests with the focal company.

4. An example of a welding network

An example case welding network and its behavior was studied empirically through observation and information from data collection. The example network structure and its linkages discussed here consists of three different welding networks with focal companies and six first tier welding cooperation companies with focal company dominance. In this specific configuration, one individual firm is bound to have cooperation with two networks. These structures would widen if dominance in different aspects of linkages and cooperation is considered. More tiers are connected through the first tier.

The data was collected through multiple interviews, observation of focal companies and network members, and written interview study. The target group comprised welding coordinators and design engineers, purchasing operations, specialists of quality functions and welders.

Fig. 6 presents the structure of the three welding networks studied. The three different entities include customer networks, which are not discussed in this study; the focus is on linkages and cooperation of the focal company (in the middle) and suppliers (within the network). The tier level of the network was dictated by the welded product and different welding phases. Only welding functions were observed. Part of the manufacturing chain was beyond the focus area of the network and only a few main welding suppliers were studied in this structure.

Each different network has linkages to other firms. These connections describe the chain of welding manufacturing, and as can be seen, the direction of manufacturing is towards the focal firm. The direction of intercommunication is mainly two-way in the first tier of the chain. This indicates the importance of cooperation in manufacturing of welded products. If the tier level rises, it seem that intercommunication with the focal company becomes non-existent, which can affect quality assurance.

The cooperation level can be observed also from the communication patterns of different functions at the internal network level. A lack of internal information transfer and a need for greater cooperation between welding engineering, design engineering and purchasing functions can be seen. Normally, the quality department is a part of or close to the welding functions and cooperation is at an appropriate level. However, this cooperation is too often restricted to handling deviations or assurance of quality requirements in internal manufacturing.

Logistic with information transfer has minor effect compared to intercommunication and cooperation in order to develop welding manufacturing. Transport logistics is mainly outsourced and rarely has any significant influence on the welded product even if the manufacturing chain extends globally. This position requires systematic transport logistic design with applicability on particular welded products and when there is no special demands on transporting.

Cooperation between internal functions of the focal firm and other network members depends on company culture and the quality level of the welding functions in the focal firm. However, it is notable that purchasing and quality departments are closely bound with cooperation companies, and more remarkable is that the cooperation mainly consists of handling defects and complaints with suppliers. Quality assurance by the focal firm is irregular, either centered on the start of the cooperation or a subject of periodic control. The example welding network studied shows the enormous potential for improvements to the efficiency and profitability of welding networks.

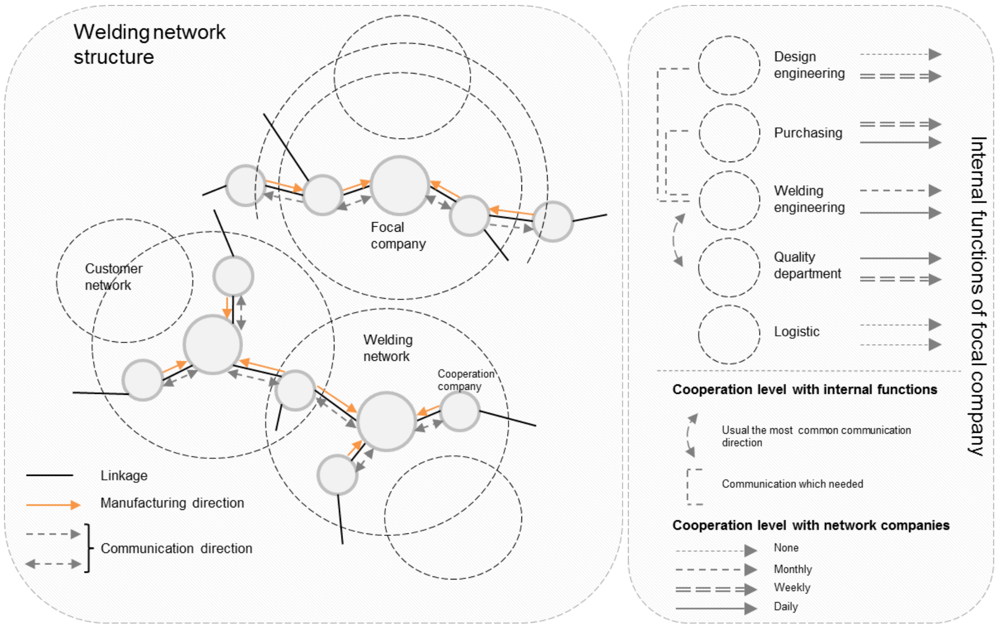

Fig. 6 Example of a welding network with linkages and cooperation level of internal functions and network

Improvements in the cooperation level and assurance requirements of the welding will be reflected in the quality and cost of the end product.

5. Conclusions

Welding manufacturing can potentially improve profitability by developing networks with appropriate relationships, competences and functions. The research in this work indicates that a lack of communication in internal functions within the focal company dominating the welding network can reduce efficiency and prospects of increasing profitability of welding manufacturing, and thus end product profit. This research has resulted in new insights into the changing business environment in welding manufacturing, welding network structure, and relationships of network members. The example draws attention to linkages of the welding network and potential for improvement.

There is a lack of research about welding networks and the cooperation level between linkages of network members, although linkages are clearly important in network behavior. Our example of a three welding network structure with multiple linkages shows that the direction of intercommunication is mainly mutual in the first tier of the chain, which demonstrates the importance of cooperation in manufacturing of welded products. However, when the tier level rises, intercommunication with the focal company partly breaks. It is also noted that the most common form of cooperation between the focal company and other network member deals more with defects and reclamations than quality assurance and welding coordination. This finding indicates a lack of internal information transfer and the need for more cooperation both internally and externally in order to achieve more development of manufacturing cooperation and profitability.

Welding networks have enormous potential to increase the profitability of production through effective management of internal cooperation linkages with design engineering, purchasing, welding coordination and welding manufacturing, and by focusing external cooperation on quality assurance and welding requirements. Transport logistics is mainly outsourced and rarely has any significant influence on the welded product even if the manufacturing chain extends globally. This position occurs when there exist systematic suitable logistic design on manufacturing for particular welded products.

Previous research on networks lacks empirical studies and the particular field of welding networks requires specific research. Future research is needed to study further the management of welding networks, such as the effect of linkages in welding networks and the cost-effect on the profitability of welding manufacturing of deficiencies in cooperation. The value of networks and their effect on the quality of welding manufacturing, including component manufacturing, welding, finishing and painting, and other manufacturing functions, and thus the profitability of the final product is an interesting aspect requiring further research. There is also need for observation of welding networks with special requirements, like welding for the offshore, pressure vessel, nuclear and Arctic industries.

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J. Toivanen, J. Martikainen, P. Heilmann

FROM SUPPLY CHAIN TO WELDING NETWORK: A FRAMEWORK OF THE PROSPECTS OF NETWORKS IN WELDING

S u m m a r y

This research has resulted in new insights into the changing business environment in welding manufacturing and welding network structure. It thus contributes to partly addressing the lack of network research within specific fields of network manufacturing, like welding, and research considering cooperation levels with linkages of network members. The study is based on theoretical insights into networks presented in the literature and empirical knowledge of the welding and manufacturing industry. An example provides evidence of the linkages of welding networks and areas that can potentially improve the profitability of manufacturing and the end product. It is found that the cooperation level in welding manufacturing is insufficiently developed for optimal network prospects and profitable network manufacturing. Additionally, the need for specific research of welding network management and their influence on improved quality and profitability throughout the manufacturing chain is noted.

Keywords: manufacturing network, network management, welding linkages, welding network, welding supply chain.

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Quality Requirements and Conformity of Welded Products in the Manufacturing Chain in Welding Network

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Abstract: The objective of this study is to examine the manufacturing and conformity of welded products and the significance of co-operation of different functions to welding quality. This study focuses on costs arising from nonconformity from the manufacturing perspective. It briefly discusses unnecessary costs, claim costs and warranty costs in the production chain. It furthermore takes an overview of challenges in welding manufacturing in the engineering field with empirical research in the industry and shows that failures and defects are identifiable and known in companies but very rarely the root cause of imperfections is investigated. The requirements from manufacturing go unrecognized at the many levels of organisation. One of the main obstacles to improving welding functions is the lack of co-operation and knowledge of the demands on welding. This can cause continuous nonconformity in products and in welding manufacturing. The observations have been collected from welding networks in engineering workshops where GMAW welding is a commonly used process. The results provide a framework for future research to define the importance of actions of different functions to the quality and costs of manufacturing.

Keywords: Welding Manufacturing, Welding Network, Product Conformity, Welding Quality, ISO 3834, Welding Production

1. Introduction

The product life cycle starts with different requirements and needs that are followed in manufacturing over the course of development and design phases [1]. Manufacturing is linked with many other stages, like design, purchasing and quality, and what becomes emphasised in welding. The quality of a product can have many different dimensions, for example, with regard to performance, conformity, service [2] and design [3].

It is generally accepted that different standards and requirements coordinate the level of quality in manufacturing. However, if these demands are not understood and met in the many stages of the manufacturing chain, it can cause unnecessary costs. This study concentrates on explaining the effects of quality of conformity, quality of performance and quality of profitability on the manufacturing chain in the welding network. Quality of performance comprises the relationship between design engineering and manufacturing.

The study is based on empirical research in a project focused on the development of welding networks. The functional framework of the welding manufacturing network is presented and discussed from overall quality and demand aspects. The study takes an overview of the challenges of welding manufacturing. It briefly discusses the unnecessary costs, claim costs and warranty costs in the production chain. The paper reviews the linkages between design, purchasing, manufacturing and quality. The quality requirements of welding by different functions and standards are also discussed. The observations at the empirical part of the study are collected from welding networks in engineering workshops where GMAW welding is a commonly used process, and the range of defects and costs studied relate to the process. This review creates a framework for future research on the profitability of the welding network from the viewpoint of manufacturing.

2. Relation of Functions in Welding

Welding is a special manufacturing process [4] because it is difficult to be verified and because of the many factors that affect the welding. Welding is nevertheless the most common joining process in the metal industry [5] and has an influence on several important aspects, for example, product reliability and human safety [6]. Operations before actual welding are an important factor in the quality of a complete weld. The requirements of welding raise complexity when ensuring the quality demands set for welded products with many co-operative manufacturers in the welding network. The product requirements and quality of conformity define the demands of manufacturing which every party of the manufacturing process have to follow.

2.1. Conformable Welding Network

Companies are confronting challenges with design, manufacturing and distribution time in a highly competitive environment [7, 8, 9]. At the same time they have to improve production efficiency and ensure cost control [9]. Supply chain quality is in a significant position when expecting to achieve competitive advantage [10] and because manufacturers continuously call for improvements in supplier performance [11]. Furthermore, products are getting more complex and they have to meet customers' expectations [12]. In a welding network, the focal company of the network in the manufacture of the end product [13] is responsible for quality demands being fulfilled at every stage of the manufacturing chain.

The manufacturing failures of welded structures and products can be a result of defects in the welded joint [6] but also due to imperfections in other activities in manufacturing. It is important to define the right quality level and product specifications, and to ensure the requirements of all functions in a company that affect welding. Manufacturers rarely know the actual welding cost in their production [14]. Coordinating welding operations closely internally but also among co-operating companies in the network may decrease unnecessary defects and claims. Knowledge on requirements and possible defects has a notable effect on achieving quality. Failure to recognise weld discrepancies and nonconformity during manufacturing when fulfilling the requirements results in costly rework and lost productivity [15]. Manufacturers who understand welding economics and value added techniques are more successful in local and also global markets [14].

2.2. Impact of Design Engineering on Welding Manufacturing

Welding as a manufacturing process deeply depends on the decisions of design engineering. The design and development processes include many tools that are utilised to assess manufacturing and increase co-operation with other functions of manufacturing and have a positive impact on costs. The concurrent engineering (CC) approach shortens the time from design to delivery where many phases of the product process are running simultaneously [16]. A wider perspective on product manufacturing can be gained with product life cycle management (PLM) which is a strategic approach to manage and support the life cycle of a product from development to withdrawal. All the information of the life cycle is determined in digital solutions. It is also an integrated approach to control and monitor the phases of product development [8.].

Usable approaches to increasing manufacturability and noticing the demands of manufacturing are the design methods from the perspective of other functions [17]. The design for X (DfX) method can be used to improve product design and the design process, for instance, manufacturability and assemblability [17]. The most commonly used DfX perspective, design for manufacturing (DFM) focuses on manufacturability in product design in the chosen manufacturing chain [17], whereas design for assembly (DFA) focuses on assembly by minimising the assembly efforts of a product [16]. Weldibng assemblies are subject to properly fitting parts and understanding the demands of welding. Design for manufacturing and assembly (DFMA) comprises both DFM and DFA [18] and enables reducing manufacturing costs while developing the product or designing a new one [19]. Fig. 1 describes the DFMA process where both aspects, manufacturing and assembly, have to be observed in a welding network where welded parts and sub-assemblies have to fit regardless of the different welding workshops where they are manufactured.

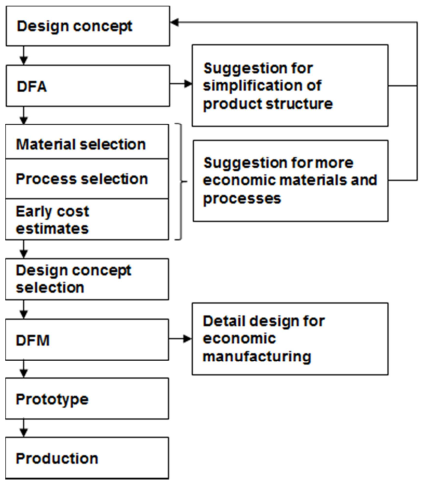


Figure 1. *Simplified DFMA process in product design engineering [17] (Adapted).*

2.3. Welding Linkages

Design engineering is not the only important function, but all departments of a company have their own specific subject field standards which define some issues of how things have to be done. Welding manufacturing includes four typical functions that have a remarkable influence on the success of producing products conforming to every demand assessed. If welding is one of the main manufacturing processes, all the other functions, like design engineering, manufacturing engineering, purchasing and quality control, also have a significant impact on welding. Therefore welding demands need to be understood in those functions of the company. Welding operations can be divided in three sections: before welding, during welding and after welding. The actual welding action can be mostly affected before welding, which is illustrated below in Fig. 2 on the important functions of welding.

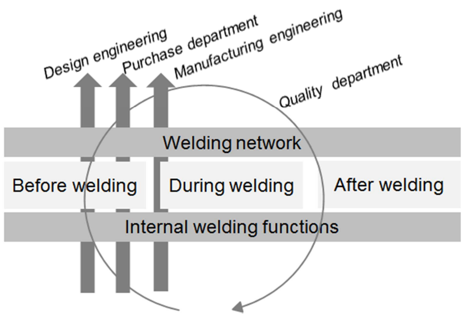


Figure 2. *Important functions of welding in welding manufacturing.*

The effectiveness of the linkage between design engineering and manufacturing mostly depends on the relations of people, employees' personal skills and capabilities, the willingness and ability to do intra-organisational co-operation, increasing knowledge and knowledge management practices and the commitment of the management to develop skills and co-operation [20]. Knowledge on welding is important in design and manufacturing [5]. Increasing knowledge and co-operation between the different functions is very important for the quality of manufacturing. Co-operative design tools, like DFM and DFMA, where manufacturing is considered at the early stage of the design process encourage co-operation with designers and manufacturing engineers and others affecting the costs of the end product at the early stages of design [17].

3. Conformity of Welding

Welding as a manufacturing process involves many different standards, guidelines and demands. Standards and technical reports are intended to help determine product specifications and quality requirements. The requirements do not, however, take into account all the demands of welded structures, the behaviour of material and the effects of the welding process. With great responsibility, design engineering and welding engineering require profound knowledge of process consequences. Product conformity assessment ensures the structure and quality requirements of the product. ISO 9000 defines the terms related to conformity: conformity, nonconformity, defect, preventive action, corrective action, correction, rework, regrade, repair, scrap, concession, deviation permit and release [4]. These terms can be divided related to welding actions possibly affecting before welding, actions which probably follow from welding and other actions after welding as shown in Fig. 3. The manufacturer of the end product defines the demands and quality requirements of the product. However, the end product can contain other conformities by standards or other third party requirements. These usually regard safety and environmental risks. Manufacturers can use valuable tools to prove the quality of a product. A sign of the good quality of welding manufacturing, controlled welding operations decrease production costs [21].

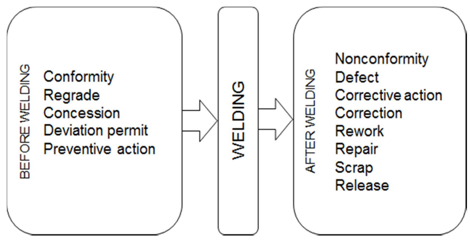


Figure 3. *The terms of conformity in welding according to ISO 9000:2005.*

3.1. Welding Quality Requirements

When a product involves complex requirements, composition or manufacturing processes, it can be defined as a complex product [22]. A welding assembly cannot be produced by choosing a fitting part for a sub-assembly or assembly, like the selective assembly technique which focuses on the fit between assembly components [22]. Therefore it is important to focus on the quality of each welded part.

Total product quality consists not only of the context of design, manufacture and post-sale service, but also of purchasing which are linked together [2]. The manufacturer, customer and third parties have many expectations with regard to the end product. Because welding processes have a significant influence on the quality of a product [23], the end result must meet all these expectations. The key to improving quality is to focus on the prevention of nonconformity [24]. Quality assurance verifies the conformity of a product and it has to reach the production process and cover the whole life cycle of a product [1]. Preventive actions can be, for example, design reviews, education, training, supplier selection, capability reviews and process improvement projects [24].

Quality can be understood in many different ways depending on the aspect. It is mostly related to product differentiation. Production quality can be understood by production efficiency [3], but it is also dependent on many functions around manufacturing. In welding production, it is important to consider the entire manufacturing process. Welding can be more effective with different tools, increased automation and fluent production. Regardless of the manufacturing technique, the product has to meet the requirements set. Control of faults and overall quality are the main things in welding design and manufacturing [25]. The quality demands of products, which are also related to the whole production efficiency, are examined in the following.

3.2. Control of Welding Operations

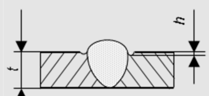
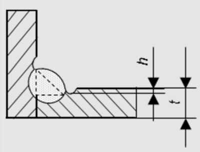
Table 1. *ISO 3834 standard: Quality requirements for fusion welding of metallic materials.*

ISO 3834 Quality requirements for fusion welding of metallic materials.	
ISO 3834-1:2005	Part 1: Criteria for the selection of the appropriate level of quality requirements
ISO 3834-2:2005	Part 2: Comprehensive quality requirements.
ISO 3834-3:2005	Part 3: Standard quality requirements.
ISO 3834-4:2005	Part 4: Elementary quality requirements.
ISO 3834-5:2005	Part 5: Documents with which it is necessary to conform to claim conformity to the quality requirements of ISO 3834-2, ISO 3834-3 or ISO 3834-4.

The ISO 3834 standard provides the basis for quality of manufacturing. It guides welding manufacturing by standards, which help organise manufacturing. It is a guideline to good welding production and continuous improvement. The standard emphasises the importance of welding coordination and control of welding operations. Adopting ISO 3834 to the course of actions can prevent critical damages because of controlled manufacturing [6]. The standard has five parts: the first one helps to choose the appropriate level of quality requirements, the subsequent three parts define quality requirement levels and the final part is a list of documents necessary when using and conforming to the quality requirements of ISO 3834-2, ISO 3834-3 or ISO 3834-4 [23]. Table 1 presents the parts of the ISO 3834 standard.

"ISO 3834 therefore provides a method to demonstrate the capability of a manufacturer to produce products of the specified quality" [23]. ISO 3834 thus provides the basis for welding operations. It includes many standards that are important when a product is manufactured by welding. It does not take account of design engineering details but emphasises co-operation between design and manufacturing. There are also many other standards that affect actual welding. For example, design engineering has own requirements to assess the demands of a product structure, but also most of the welding decisions are made in design engineering. There are standards that define the general overview of welding and also have a direct effect on welding functions, the welding process and welding details, like ISO 5817 and ISO 13920 [26, 27], or define the details of manufacturing, for example, the welding process and welding consumables, like ISO 14341 and ISO 14175 [28, 29]. Table 2 presents examples of weld requirements according to the ISO 5817 standard. The examples illustrate the expected result of welding with limits depending on the quality grade.

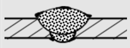
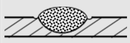
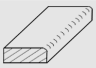
Table 2. *Limits for imperfections divided according to quality levels of ISO 5817 [26] (Adapted).*

Imperfection designation	**Remarks**	***t*, mm**	**Limits for imperfections for quality levels**		
			D	**C**	**B**
Continuous undercut Intermittent undercut	Smooth transition is required. This is not regarded as a systematic imperfection.	0.5 to 3	Short imperfections: $h \leq 0.2\ t$	Short imperfections: $h \leq 0.1\ t$	Not permitted
	 	> 3	$h \leq 0.2\ t$, but max. 1 mm	$h \leq 0{,}1\ t$, but max. 0.5 mm	$h \leq 0.05\ t$, but max. 0.5 mm
Spatter		≥ 0.5	Acceptance depends on application, e.g. material, corrosion protection		
Surface pore	Maximum dimension of a single pore for - butt welds - fillet welds	0.5 to 3	$d \leq 0.3\ s$ $d \leq 0.3\ a$	Not permitted	Not permitted
		> 3	$d \leq 0.3\ s$, but max. 3 mm $d \leq 0.3\ a$, but max. 3 mm	$d \leq 0.2\ s$, but max. 2 mm $d \leq 0.2\ a$, but max. 2 mm	Not permitted

The link between design engineering and manufacturing is complex because different demands affect each other. Besides ISO 5817, there can be other demands that have an effect on weld quality, e.g. finish requirements. The ISO 8501-3 standard provides requirements for painting or related products. The requirements have to be noticed already in welding preparation and also during the welding process, such as finishing. The standard ISO 8501-3 includes preparation grades which describe the quality of product surface before painting. Preparation grades are P1 – Light preparation, P2 –

Thorough preparation and P3 – Very thorough preparation. P1 allows an unfinished surface or only minimum preparation. P2 and P3 demand more remedial efforts [30]. Table 3 shows requirements for each preparation grade of the current standard.

Table 3. *Imperfections and preparation grades according to ISO 8501-3 [30] (Adapted).*

Type of imperfection	P1	P2	P3
Welding spatter  a) b) c)	Surface shall be free of all loose welding spatter [see a)]	Surface shall be free of all loose and lightly adhering welding spatter [see a) and b)] Welding spatter shown in c) may remain	Surface shall be free of all welding spatter
Welding slag 	Surface shall be free from welding slag	Surface shall be free from welding slag	Surface shall be free from welding slag
Undercut 	No preparation	Surface shall be free from sharp or deep undercuts	Surface shall be free from undercuts
Rolled edges 	No preparation	No preparation	Edges shall be rounded with a radius of not less than 2 mm (see ISO 12944-3)

Companies can also have other international or national standards in use and define their own requirements for products and manufacturing. Table 4 presents one national standard on the requirements for welding. It sets extra demands for companies when usually quality grade 05 is used [31]. This particular grade assures a good base for painting, and the requirements have to be applied in every section of manufacturing, including welding. If the main supplier adopts quality level C of welding imperfections and other specific demands, like SFS 8145 offers, the same demands apply to the welding network. These supplementary demands are not necessarily known throughout the company or the whole network. The requirements of different standards can cause confusion about the total requirements of quality in products and manufacturing.

Table 4. *Quality grades for mechanical preparations [31].*

Object	No.	Action	Quality grade of preparation					
			01	02	03	04	05	06
Weld joints	1	Weld slag is to be removed	—	—	—	—	—	—
	2	Pieces of wire electrode are to be removed		—	—	—	—	—
	3	Welding spatters that can be loosened with a scraper are to be removed		—	—			
	4	Welding spatters are to be removed				—	—	—
	5	Open pores are to be repaired					—	—
	6	Undercuts are to be repaired					—	—
	7	Sharp peaks are to be removed				—	—	—

Product quality requirements have to coincide with the parts designed so that they can be manufactured without rework or extra costs. The lack of knowledge on the manufacturing challenges can cause increasing manufacturing costs due to claims and warranty costs. Standards help to determine the requirements, but designers have to understand manufacturing to satisfy the level of quality and yet achieve profitability. Steel products, commonly used in welding structures, are an example of this. The tolerance rates of raw material can be a challenge to manufacturing and have a direct influence on functionality, costs and quality of manufacturing [32]. Narrow tolerances can cause high costs [33, 34] but also problems with succeeding welds without preparation, finishing or rework. On the other hand, too wide tolerances can cause variability in the products [33, 34]. The focal company can have its own level of tolerances depending on the part, but the requirements that affect the tolerance need to be understood in manufacturing engineering or by the welding coordinator to achieve appropriate and competitive production.

The EN 10219-2 and EN 10210-2 standards define requirements for hollow section steel products [35, 36]. Corresponding international standards are ISO 10799-2 and ISO 12633-2 [37, 38]. Some common causes of unnecessary fixing or rework in welding are the concavity x1, convexity x2 (Fig. 4a), twist v (Fig. 4b) and straightness e (Fig. 4c) of these kinds of products. Standards enable imperfections in dimensions. This jeopardises compatibility when parts are meant to be fitted into each other, demonstrated in Fig. 5, or in other tightly dimensioned joining.

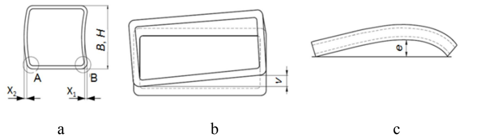


Figure 4. *Concavity (a), convexity (b), twist and straightness (c) in hollow section steel products [35, 36] (Adapted).*

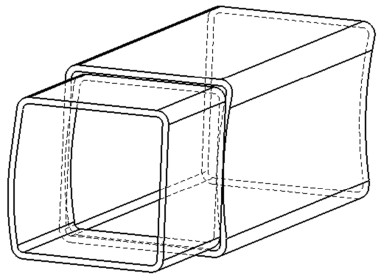


Figure 5. *An example of compatibility risked due to dimensional imperfections enabled by standards for a square tube.*

Empirical research shows that the requirements focused on products and manufacturing are insufficiently recognised at the many levels of a company. This causes deficiency of knowledge on the quality and manufacturing demands. This is one reason of nonconformity in manufacturing. Departments of design engineering and purchasing are inadequately aware of the extent of welding quality standards. The consequences of welding and preventive actions are also unknown at the management level. The management understands the importance of quality and pressures to decrease defects, but the foundation of possible welding development remains unrecognised. The control of the quality department is usually not focused on following the defect rate of welding operations in-house, but on the conformity of deliveries from collaboration partners and suppliers.

Welding is a challenging manufacturing method, and not all the challenges can be solved when applying standards and other regulations. The purpose of use of the end product can present even more requirements, for example, with regard to quality and strength, which have to be taken into account in design engineering. Also, the requirements of welding need to be understood. The welder's professional skills are primarily notable after appropriate requirements for welding. Defects can occur in actual welding which can be prevented with suitable pre-actions and the sufficient knowledge and training of welders [21, 39]. Welding coordination is in a significant role to stimulate co-operation among the departments of the company and distribute welding knowledge in every requisite stage as a response to control over quality and manufacturing demands in the welding network.

4. Costs of Conformity

Usually quality costs focus on an individual company and internal costs instead of the whole production chain [40]. In a welding network, quality costs are more closely followed by the focal company. Quite often internal quality costs are understood to include daily work rather than own countable costs. From a wider perspective, costs can be divided into different departments or other functional areas with responsibility for own departmental costs [41]. It has been known for a long time that quality costs are measurable; they can be planned, analysed and prevented and are higher when failures are detected at the end of production or by the customer [42]. Still, the focal company rarely uses this information effectively in every day work in a network. Empirical research proves that failures and defects are identifiable and known in companies, but actions to find the root of the problem are fewer, which creates continuous costs.

4.1. Quality Costs

The manufacturing process generates costs, also related to quality. Costs of quality result from not producing requisite quality or ensuring quality in accordance with requirements. Quality costs have more strategic and economic importance than earlier costs [40] by affecting profit and helping to identify the weak points in the process [43]. Many models have been developed to measure or identify quality costs. The most basic scheme is to find prevention, appraisal and failures of the process and costs.

The traditional model of developing the quality level of a company is the prevention-appraisal-failure (PAF) model [44]. It is a commonly used method for measuring quality costs [24], and it is the basic scheme in many reconstitutions of quality cost count models. Fig. 6 illustrates the PAF model. The model focuses on finding the quality level that is suitable for a company determined by specifications and the total quality costs which increase concurrently with the quality level [44]. Quality level q of a product can be defined considering a number of non-defective items, and defect rate d defective items. When increasing the quality level, it is profitable to invest in prevention and appraisal functions [44]. When total quality costs rise over the optimal quality level q, quality costs C(q) contradict with the profitability of product manufacture. Many authors divide quality costs in two parts where quality costs C(q) are a summary of prevention cost C(p) and appraisal cost C(a): C_(q=C_p+C_a), and the total quality costs TC(q) are a summary of C(q) and failure costs N(q): 〖TC〗_(q=C_q+N_q) [24]. Another way to divide quality costs is to regroup the total quality costs into costs of conformance (prevention and appraisal costs) and costs of non-conformance (costs of internal failure and costs of external failure) [43].

The PAF model is based on the notion that higher quality causes higher costs. This view does not support the idea of continuous improvement and decreasing quality costs with higher quality. However, it has been shown that it depends on the effectiveness of the company's quality improvement program whether the quality costs are increasing or decreasing when producing higher quality and a more effective quality improvement program decreases quality costs and produces higher quality [44]. Poor design quality can also create higher production costs [3], and too narrow tolerances can generate unnecessary production costs, even though the variability of the product decreases, the quality of manufacturing improves and quality losses are reduced [34]. The balance between the requirements and manufacturing quality has to be observed.

Continuous improvement is important when the company wants to improve product quality and the flow of production. Fig. 7 describes the quality cost rates of prevention, appraisal and failure costs in continuous improvement. It has been noticed that the failure cost and total quality cost rates never reach zero because of the uneconomical aspect and because the rate turns upward at some point [42]. Figures 6 and 7 are not completely accurate for welding where qualitativeness cost more than increased quality, when quality assurance is at a sensible level with all design and manufacture demands. To maintain competitive advantage, continuous improvement of product quality is essential [1]. The main supplier has to ensure this improvement in the network.

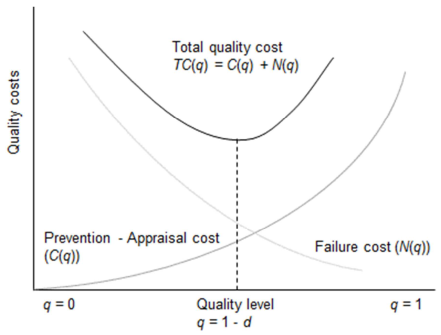


Figure 6. *PAF model for quality costs [44] (Adapted).*

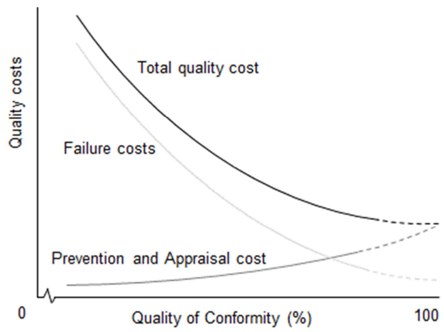


Figure 7. *Quality cost behaviour according to continuous improvement [42] (Adapted).*

Failure costs can be divided into internal and external failure costs. Internal failure costs result from a product that does not conform to the requirements before it meets the customer, whereas external failure costs occur if the product is already shipped to the customer with defects [40]. Table 5 shows examples of reasons for quality costs divided into categories prevention, appraisal, internal failure and external failure costs.

Table 5. *Example reasons for quality costs divided by different categories [44] (Adapted).*

Prevention costs	Appraisal costs	Internal failure costs	External failure costs
Process control Product and service design and redesign Process design Supplier relations, audit and screening Preventive maintenance Training and quality circles	Raw material inspection In-process inspection Final inspection Inspection material and services Quality audit	Scrap Rework Equipment repair Process downtime Re-inspection of products	Warranty charges Litigation and liability Complaint handling Returns Rework on returns Lost sales Penalties and allowances

Table 6. *Actions affecting welding quality before welding, during welding and after welding.*

	ACTIONS AFFECTING QUALITY		
	Before welding	**During welding**	**After welding**
APPRAISAL	Specifications Quality requirements Manufacturing processes Training Welding knowledge Welding network control Material procurement Manufacturing details Workshop control Quality input Co-operation Design & Development	Visual inspection Welders professional skills Equipment performance Welding area control Specifications follow	Visual inspection Other quality inspections
CORRECTIVE	Quality processing	Scrap Rework	Unnecessary inspections Grinding Fine-tuning Finishing Scrap Rework

Besides considering the cost of quality, quality costs can also be assessed to manage losses. There are a lot of hidden costs that come from manufacturing loss and design loss. They are identified when quality actions are unsuccessful and generate costs. [45.] The welding manufacturing process involves unnecessary quality costs when products do not meet the requirements set on conformity. Table 6 shows actions affecting quality divided into categories before welding, during welding and after welding. The preventive actions of quality assurance create costs, but they have to be integrated into every day work and related to the level of quality and requirements. Relating quality and profitability is the most effective way to prevent failures [24]. It is also important to invest in productivity and quality knowledge to get efficient benefits to produce cost reductions and quality increase [46]. Training is one of the most important things to increase knowledge and skills in welding. Increasing welding knowledge and training is remarkably important in developing welding production and decreasing costs [21].

4.2. Influence of Nonconformity

Related to production costs, the most important decisions regarding costs and quality demands are usually made during the design stage [47]. The design phase includes the specifications of the weld structure, like the component shapes, positions of joints and also joining methods, but the whole welding network, including suppliers' own collaboration partners, has an effect on product costs by their actions in production.

Decisions made during design and manufacturing have an influence on reliability [48] and can prevent unnecessary costs caused by nonconformity. Waste can be defined in several ways. Waste losses can be related to time, motion and process flow and come from waiting, non-value added time, inappropriate layout and poor communication [49]. The waste costs of welding result from the process not working properly. Co-operation among the management, design engineering, manufacturing engineering, welding coordination, welding manufacturing and quality assurance is in an important role in profitable welding manufacturing (Fig. 8). Welding coordination links the functions together with responsibility for welding operations [13]. Each function has a specified role to achieve high quality and a profitable result.

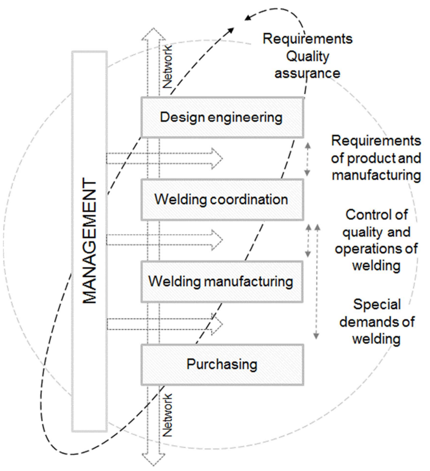


Figure 8. *Links among the different functions of a company [13].*

Costs arising from defects, faults, complaints and warranties are unprofitable items to a company. Cost of defects are gathered from different processes [49], and from the focal company's viewpoint, nonconformity costs from faults and defects arise not only from internal welding manufacturing, but also from the network. They are usually handled as complaints if defects are noticed by the focal company. Nonconformity is more costly than proper preventive actions in quality assurance. The work costs are only part of the total costs resulting from complaints and remanufacturing. Indirect costs come, for instance, from notice of defective processing, manufacturing engineering, welding engineering and other actions that follow from rework.

Often the closer the product is to the customer in the manufacturing chain, the greater the effect on corrective actions. Fig. 9 mirrors the cost effect from prevention to subsequent actions. The arrows present increasing quality costs during manufacturing with defects, faults, complaints and warranties. Warranties are signed between the manufacturer and the client and they oblige the manufacturer to answer for the product's operation during the warranty period [50, 51], and recovery actions create costs. It is not unambiguous how warranty costs occur, e.g. from warranty service and warranty maintenance, whereas defects, faults and complaints are connected to the manufacturing process and arise from the focal company to the network.

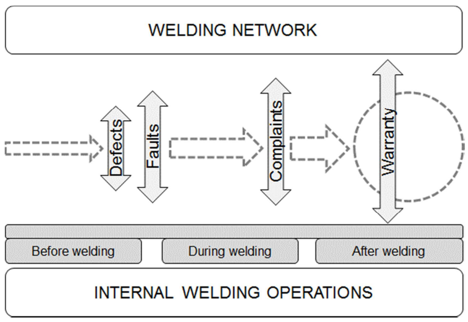


Figure 9. *Cost effects from preventive to subsequent actions in welding manufacturing.*

5. Conclusion

Welding is the most common joining process in the metal industry, and the customer has many demands on the end product to which the main supplier has to respond. Confronted with the challenges of a competitive environment, companies are improving their production efficiency and reducing production costs. When more than one producer is involved with a product, the whole production chain has to meet the requirements. The focal company has the responsibility to fulfil the requirements for every part of the whole final product. This also includes quality costs which come from ensuring the quality requirements. The welding process affects the costs of manufacturing and profitability; the costs have to be in control at every stage from the product's design to the manufacturing process and quality assurance. When a company manufactures products using welding in their main manufacturing process or some critical components by welding, it is important that all functions around welding are controlled. This denotes co-operation among different functions, like design engineering, purchasing, manufacturing engineering and the quality department. It is a deceptive presumption that the demands of welding need to be mastered only in the welding workshop.

Coordinating welding functions gives an advantage for profitable and quality manufacturing. For example, the ISO 3834 standard ensures welding quality requirements and gives guidelines to good welding production. It emphasises continuous improvement, controlling of welding operations and the importance of a welding coordinator. By using standards, the tool of whole production to improve welding operations, the benefits are wider than the mere focus on welding action. It is important that the company itself can answer the different quality requirements with the standards or use the standards to determine its own quality level and guidelines clarifying production to increase productivity and profitability.

Empirical research on a welding network shows that failures and defects are identifiable and known but actions to find their root cause are few. The requirements focused on product or welding manufacturing are unrecognised at the many levels of organisation, which can cause continuous nonconformity in products. One of the main obstacles to improving welding functions is the lack of co-operation and knowledge of demands on welding. This shows as deficiency in reviews on the requirements of design engineering, the purchasing department and welding coordinators and uncertainty over manufacturing demands fulfilling the quality requirements of products. Furthermore, the lack of welding knowledge among welders causes defects and also disinclination to consider the relationship of various functions affecting welding. Observing only the complaint and quality costs of network co-operation companies does not give the right idea of all the nonconformity costs of production. By increasing welding knowledge and training and clarifying the requirements of product and manufacturing among all the parties of the manufacturing chain, the demands become distinct and easier to control.

Further work will be needed to analyse the detection of defects to find the root cause of defects, faults, claims and complaints. The impact of costs of quality and complaints at the network level and the effect on the end product is an interesting area for study to further enlighten the impact of nonconformity on manufacturing.

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Publication III

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Connection between the Number of Complaints about Welding Suppliers and End Product Quality: The Case of Customized Welding Production

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Connection Between the Number of Complaints About Welding Suppliers and End Product Quality: The Case of Customized Welding Production

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Abstract: Although undesirable, manufacturing defects leading to complaints are almost inevitable in the production of manufactured products, and consideration of manufacturing quality is therefore an essential aspect of management of supply chains with multiple suppliers. This study evaluates the relationship between complaints about the end product and welding production in a multiple supplier chain. In the studied case, it was noticed that there is potential for improved welding production management by suppliers to increase profitability by decreasing the number of welding defects that cause complaints. This study shows one approach to analysis of the relation between complaints in the supply chain and their effect on the end product.

Keywords: Welding Production, Welding Suppliers, Complaints, Welding Quality, Productivity Improvement, Empirical Study

1. Introduction

Supply chain quality and manufacturing have been the subject of active research interest and the topics have been examined from many perspectives, for instance, from the viewpoint of management [1, 2, 3], partnership [4], products [5, 6] and costs [7, 8]. From the point of view of manufacturing quality, the quality of supplier relationships [9] is an important aspect in supply chain management. Quality management is usually separated into segments such as internal actions of operations managers within organisations and external actions with purchasing and logistic functions [1].

Researchers have studied issues related to the supply chain such as production with defects [10], customer complaints about service [11, 12] and data modelling for organizational learning from complaints [13]. Researchers' interest has also been drawn to complaints related to latent defects with no discovered reason [14], false failure returns [15] and the impact of supplier production rate on defects and production costs [16]. When studying human factors, Mateo et al. [17], using production data, found that there is no significant relation between complaints and absenteeism, and Gajdzik and Sitko [18] found a relation between complaints and human errors in steel sheets manufacturing.

Generally, existing research on complaint management and complaints in production are based on modelling [19] and interviews or questionnaires [3, 20]. Furthermore, the studies tend to be general in nature, giving generic recommendations. Despite the importance of general results, which give valuable information about issues of concern and suggestions for management of relevant aspects of complaints handling, there is a need for more substantive data-based results and more profound observation of complaints and their effect on production and costs. Of particular interest is mirroring complaints data to complete product data as a means of discovering prospective processes to increase profitability.

This paper evaluates the effect of complaints on the end product in a welding production supply chain with multiple suppliers. The approach provides new insights into the effect of complaints about a specific manufactured product and manufacturing process and indicates actions that may lead to increased profitability. The study considers the following research questions: firstly, how the characteristics of complaints about welding reflect the quality and costs of the end product; and secondly, whether there is potential to influence the quality and profitability of manufacturing of the end product by improved control of the welding supply chain. Results of the studied case show clearly the role of welding production in end product quality in multisectoral manufacturing and thus its importance in manufacturing quality. The paper consists of two parts: a theoretical part considering the theoretical background and an empirical research part utilizing complaints data of the case focal company in the welding supplier chain.

The novelty value of this research is based on the new viewpoint of complaint analysis, which is supported by statistical data and reliability calculations to which data is collected from both the PDM system and complaint system. The results of this analysis are verified with more than 14 000 real case examples.

2. Complaints Run Out from Profitability

Quality of manufacturing is important thus complex with multiple manufacturer in supply chain. Coordination of supply chain [21], strategic supply chain management [22] and thus, strategic supplier selection is acting more significant role in manufacturing [23]. In welding manufacturing the one typical structure of manufacturing is structure where the focal company dominates the manufacturing with multiple suppliers [24]. This kind of structure leads to especially dyadic contacts but the increase of cooperation between network members also enables multi-tiered relationships and augmented manufacturing. However, its complexity introduces multiple functions and linkages that can have an effect on defect incidence and end product quality [25].

The focal manufacturer in such a network defines the product quality and price [26], which encompass, among other costs, the costs of development and manufacturing. Inadmissible parts in production inevitably cause disturbances in the manufacturing chain, and defects and failures generate unnecessary expense in the form of rework and waste. The costs arising from defects consist of internal failure costs from scrap, rework and delay, and external failure costs from repairs, warranty claims and lost custom [27]. These additional costs reduce the profitability of the end product and therefore complaints do not promote profitable outcomes. Complaints leading to additional waste also complicate efforts to reduce the negative environmental impacts of manufacturing [28].

However, defects leading to complaints are almost inevitable in production with multiple member manufacturing chains and the effect of inadmissible results can magnify across the multiple actors involved. Complaints can originate for many different reasons, for example, product defect, damage during transportation, or even as a result of misunderstandings. It should be noted that even false failures or returns for no reason are detrimental to suppliers [15], and they cause unnecessary expenses for both the supplier and the focal company. Complaint behaviour and complaint management are essential to ensure effective relationship in business [20] and effective relationships enable essential in profitable manufacturing. Competitive advantage in manufacturing need continuous improvement of product quality [29] and thus cost of quality seems to have more strategic and economic importance compared to previous time [7].

Quality design plays an important role in business decisions concerning quality level and actions, and, thus, the costs of quality. In a dynamic manufacturing chain, far-sighted (i.e., economically long-term focused) quality behaviour results in a more price-sensitive demand than a myopic (i.e., economically short-term focused) approach. The myopic approach provides consumers with a higher quality–price ratio and more quality sensitive but less price-sensitive market [26]. The balance between quality and product costs is difficult to define when coordinating a complex manufacturing chain. Product quality data can be valuable for managing suppliers and product quality. Based on information from monitoring the quantity and type of complaints generated, the focal company can take remedial and optimization actions to gain improved profitability and enhanced production quality at the network level of the dynamic manufacturing chain. Quality data thus form an important basis for decision making regarding activities related to quality control, management and improvement [29]. Effective utilization of complaints data can assist the focal company in control of quality costs.

3. Research Methods

In this study, numerical data of complaints relating to welding suppliers and two welded case products were gathered and analysed. The case products, which are two different mobile machines, are end products with a large number of different parts that are sourced from many suppliers. Analysis of the complaints data focused on items manufactured by welding suppliers and their effect on quality and profitability in the welding network.

3.1. Data Collection

Case end products, Machine A and Machine B, are mobile machines designed for work in demanding environments, and the machines consist of multiple welded parts and structures with multiple items. The products consist of 3 891 different items and the total number of parts is 14 907. Data about the parts used in this study are from the company's PDM (Product Data Management) system and data about complaints are from the company's complaints system. The gathered data were tabulated and percentage portions were calculated and scaled to find links between complaints and potential for increased production profitability. Identification of the links was based on observations of curve shape variations together with peak values found from tabulated data. Finally, a tentative curve fit to describe the changes in the number of complaints was tested based on learning curve. The data also contain summarized numerical information about items and complaints but the focus is on welding supplier information.

The studied data comprise information about the number of individual items, where the total number of items in the end product is not given. The category total number of items includes also the number of the same items (Table 1). Complaints are observed similarly at a general level and also focusing on items manufactured by welding suppliers. In this analysis, welding supplier items are outsourced parts manufactured by a supplier who does welding manufacturing of parts or subassemblies for the focal company. Complaints values show the number of individual complaints and do not take into account the number of items within a single complaint. Either observing costs are only indicated items, not manufacturing activities. The welding supplier data were divided into different categories for analysis with a mixed method approach [30] with numerical data and clarification results according to the root cause of the complaints.

Table 1. *Data calculation example of number of individual items and total number of items. The number of individual items describes every new item number in the end product.*

Item number	Item description	Quantity
34966	Fastener	12
42815	Cover sheet	6
43467	Shaft	2
21201	Sleeve	4
Number of individual items		4
Total number of items		24

* The data are collected from an item group of 3 891 individual items where the total number of items is 14 907.

The machines studied illustrate the number and cause of complaints in the end product. The complaints data used are general information about complaints regarding items in production and, in this work, are not assigned to particular machines. However, the data show the connection between welded items and the volume of complaints and thus indicate prospects of improving production profitability. Complaints can be observed with general categorization of all complaints in a welding network whereas this study focuses on studying complaints from the viewpoint of an example end product.

3.2. Finding Connections Between the Content of Complaints and the Items of the End Product

This research concentrates on three main areas. One focus is summarization of numerical information about items and complaints concerning two example end products (Machine A and Machine B) over an eight year period. This part also shows information about complaints in the launching year of the product. The second focus is study of costs related to items that have been the subject of complaints and analysis of the correlation of these costs to the end product. The third focal point is categorization of complaints on the basis of root cause.

The number of complaints relative to the number of items for Machine A and Machine B is presented in Table 2. The table includes the percentage share of items manufactured by welding suppliers and the total number of items, and also the number of complaints relative to the number of items manufactured by the welding suppliers. The share of items related to welding suppliers relative to the number of items about which complaints are received is considerable, thus the impact of welding suppliers on the end product is evident. As explained earlier, these results are the share of complaints linked to an individual item and as the end products may include several of the same items, the value does not take into consideration the total number of items or complaints. Therefore, Table 3 shows the share of the total number of items manufactured by the welding suppliers. The total number of items in Machine A is 4.06 times and in Machine B 3.74 times the number of individual items. The total number of complaints, including complaints not related to the welding suppliers, was for Machine A 1.38 times and for Machine B 0.65 times the total number of complaints about individual items. From Table 2 and Table 3 it can be seen that the share of individual items related to welding suppliers has reduced by 13% - 15% but the complaints to welding suppliers is still prominent when the difference in composition of the items, e.g. multipart welded structures and bulk items, is taken into consideration.

Table 2. *The share of number of complaints, items related to welding supplier and complaints related to welding supplier for Machine A and Machine B.*

Description	Machine A	Machine B	Average
Number of complaints / Number of individual items	24.18%	14.65%	19.42%
Items related to welding suppliers / Number of individual items	22.55%	27.73%	25.14%
Complaints of items related to welding suppliers / Number of complaints	29.70%	37.65%	33.68%

* The data are collected from an item group of 3 891 individual items where the total number of items is 14 907.

Table 3. *Total number of items manufactured by welding suppliers and complaints related to welding suppliers for the case end product.*

Description	Machine A	Machine B	Average
Total number of items related to welding suppliers / Total number of items	8.74%	10.74%	9.74%
Total number of complaints related to welding supplier / Total number of complaints	21.62%	19.29%	20.45%

* The data are collected from an item group of 3 891 individual items where the total number of items is 14 907.

Total complaints in the year of launch of the machines, 2008, the number of complaints related to welding suppliers was 24% and in 2014 25%. The total number of complaints was 4.68-fold (for Machine A) and 2.05-fold (for Machine B) the number of complaints about individual items. However, the number of complaints in the year of launch related to case products is presented in Table 4. The difference in the results for Machine A and Machine B can be explained by the totally new design and assembly of Machine B and therefore the sensitivity of the welded items to complaints.

Cost of items of particular end products are counted using information about the total number of related items. The complete end products contain some very expensive items as welded items, e.g. motor and power transmission. Excluding the three most expensive items, the total cost of items manufactured by welding suppliers raises, and by excluding the five most expensive items, the amount continues to grow. Table 5 shows the relative cost of items about which complaints have been received by welding suppliers for all parts and when the most expensive items are excluded.

Table 4. *Launching year information of complaints of items related to welding supplier and total quantity of welding supplier complaints.*

Description	Machine A	Machine B	Average
Number of individual complaints related to welding suppliers in launching year	14.29%	37.02%	25.65%
Total number of complaints related to welding suppliers in launching year	5.34%	37.74%	20.04%

* The data are collected from an item group of 3 891 individual items where the total number of items is 14 907.

Table 5. *Relative cost of items in the case end products for all items and without the most expensive items.*

Description	Machine A	Machine B	Average
Cost of items related to welding suppliers	9.93%	13.28%	11.61%
Without 3 the most expensive items	29.31%	26.91%	28.11%
Without 5 the most expensive items	33.38%	28.21%	30.80%
Cost of complained items related to welding suppliers	6,35%	5,08%	5,72%
Without 3 the most expensive items	18,74%	10,30%	14,52%
Without 5 the most expensive items	21,35%	10,79%	16,07%

* The data are collected from an item group of 3 891 individual items where the total number of items is 14 907.

The ratio of the number of complaints related to the number of items in the end products manufactured by welding suppliers to all complaints to the welding suppliers divided in years is given in Fig. 1. General market conditions and investment in product development is reflected in the number of complaints in a particular year. Machine A has been under development for several years with revision of many items, which affects the rate of complaints. Machine B is a totally new design structure and the number of complaints first rises continuously before settling down. One approach to interpretation of the curves in Fig. 1 is utilization of learning curve theories. The learning process is complex [31] and learning rate is not constant [32]. It can be expected that quality is lower and costs are higher when there is a lack of learning [32]. Consequently, after initial launch of a product, the trend of complaints is a rising curve that peaks before starting to decrease. The continuous line in Fig. 1 describes production of Machine A, where the number of welding errors increases to a peak in 2012 before falling due to the effect of organizational learning. Assuming that organizational learning for Machine B follows a similar pattern, the dashed line can be expected to peak after a few years and then decline. The welding error lines resemble each other but learning is at different stages of the learning life cycle with different intensity of development. Curve behaviour depends on how much development and how many revisions are made and therefore the number of complaints will probably never drop to zero.

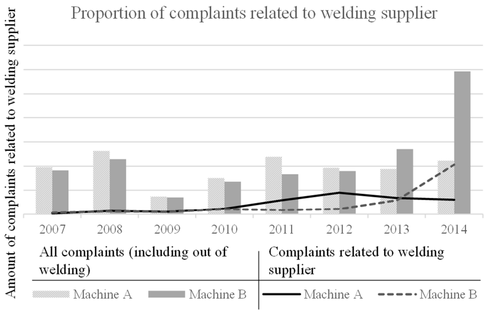

Figure 1. *Complaints related to welding suppliers in the studied machines for 2007–2014. From the two curves it can be concluded that the trend of complaints is rising and presumably after reaching a peak it will start to decrease.*

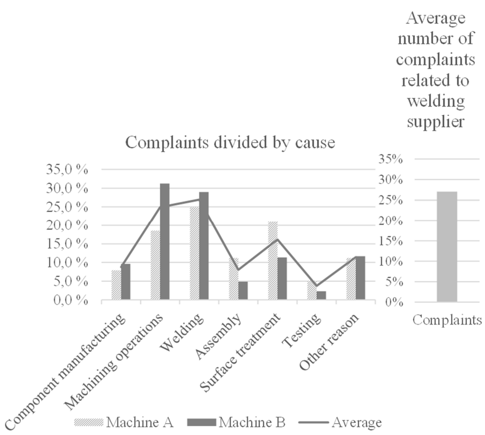

Figure 2. *Proportion of complaints related to welding supplier in particular machines divided by root cause phases in welding manufacturing in years 2007–2014. From the diagram it can be concluded that welding-related functions are important factors in welding manufacturing.*

The data in Fig. 1 do not relate to a specific reason or cause of complaint. However, to improve manufacturing productivity and decrease the number of defects, it is important to establish the underlying cause of complaints. Complaints for 2007–2014 related to welding suppliers are categorized by root cause and phase in welding manufacturing in Fig. 2. Welding includes supporting activities and actual welding is only one part of the welding functions needed to reach the quality requirements of the manufactured product. In Fig. 2, welding activities are divided by actions related to welding activity. The figure also shows the average proportional share of the average number of complaints related to welding suppliers when the number of the items and total quantity of items are included.

4. Discussion

Defects are common in production [10] and despite existing models of quality costs [7] companies are still required to deal with defective manufacturing. Liu et al. [26] states that the manufacturer is responsible for product quality and price, and this responsibility drives companies to make efforts to ensure conformity of manufacturing throughout the supply chain. Complaints are non-compliant actions in manufacturing and inevitably cause extra costs. Reducing such non-lucrative activity might increase production profitability. The achievable gain depends on the efforts required to reduce the number of complaints by investing in quality actions and improvements in different functions of the production chain.

In the study, the end products are two different machines constructed of multiple items and designed for equivalent end use. Approximately 25% of the individual items are manufactured by welding suppliers, which forms approximately 10% of the total number of items utilized in production. This correlates with the notable role of welding in manufacturing because the number of welded parts relative to all items is disproportionate. Welded items usually entail bigger workload and the required number of pieces is smaller than ancillary items like bulk items, which have all individual item number. The coefficient of the number of items relative to the individual number of items confirms this finding.

Observing the complaints more closely, individual items manufactured by the welding supplier (Machine A and Machine B) caused 34% of the total complaints about individual items. Over the period studied, complaints made to welding suppliers show that the mean amount of complaints dealing with Machine A and Machine B is about the same as in the whole welding production (Fig. 3). The number of complaints varies depending on production volume but the rate is visible. In Fig. 3, the launching year position of welding supplier complaints can be seen. Even though the complaints are not related to particular machines and show the number of marked complaints and do not take into account the number of items inside a single complaint, the results gives an overview of the significance of complaints in welding production.

Cost of items of end products is not contained in manufacturing costs and therefore is not relevant for observing the total cost of the end product. However, the cost of items indicate the material investment and therefore have a big impact on total costs. As noted earlier, the end products contain multiple items and different items will involve different workload. The cost of items manufactured by welding suppliers is approx. 12% of total cost of items of product. Excluding the five most expensive items, the figure is 2.7-fold compared previous and excluding only the three most expensive items, the figure is still 2.4-fold. This shows that welding suppliers are responsible for a third of the manufacturing potential of the end product, and therefore managing supplier quality occupies a very important position in the manufacturing operations. The cost of items manufactured by welding suppliers about which complaints are received follows the same rate as total items manufactured by welding supplier with 2.8-fold (excluding five items) and 2.5-fold (excluding three items) results compared to without excluding any of items. Excluding the five most expensive items gives the result of 16% of total items that welding suppliers are responsible for.

The total number of complaints to the welding suppliers varies over the eight years period. It is difficult to analyse any regular trend by items of particular end product of these years. Although, these case end products seem to be close to general trend of all complaints. The launching year of the end product and the general market situation also have an impact on production. Categorizing the complaints of case machines by root cause of manufacturing phase indicates the importance of welding-related functions. Actual welding is near third of reason for complaints related to welding suppliers.

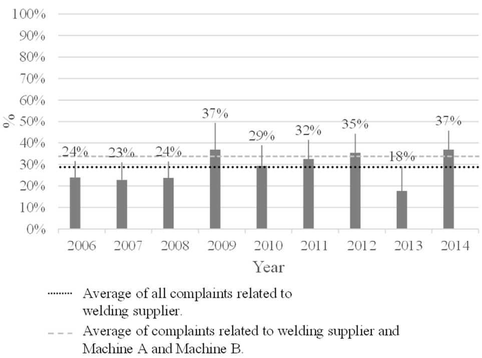

Figure 3. *The number of complaints related to welding suppliers seems to remain relatively stable year-on-year.*

5. Conclusion

Pettersson and Segerstedt [33] state that manufacturing costs are only one part of supply chain costs. This study shows the potential of welding production functions to increase production profitability by reducing manufacturing defects that cause complaints. In the light of the results presented, the effect of complaints on quality and costs is evident. The results also indicate the potential to influence the quality and profitability of the end product by control of complaints in the supplier chain. This shows the prospect to impact disadvantages on welding production.

This research observed complaints and costs from the viewpoint of items, in future research it would be interesting to focus on costs of manufacturing through complained items and therefore their impact on total costs of the end product. Such information is essential when making efforts to improve manufacturing quality and profitability from whole welding network viewpoint. This research shows one approach to study of the effect of manufacturing in the supply chain on end product. Other studies could concentrate on categorization of complaints in a welding supplier network by root cause and finding the link between complaints, knowledge transfer and competencies. Additionally, the effect of complaints on revisions of welded items in a welding supplier network would be interesting to define. Wider observation is needed in the state of network pictures of welding network and influence on the amount of complaints in welding production.

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Publication IV

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A New Approach to Manage Welding Quality in Supply Chain Networks: A Supplier Network Complaints Perspective

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Abstract: This study presents a five-step method for analysis of supply chain networks from the perspective of the welding quality of manufactured products. The presented approach gives tools to take care of welding quality assessment in supply chain networks. The study uses data based analysis of complaints data and survey results to provide information that may assist managerial decision-making and supplier-related marketing activities. The results reflect the importance of information sharing as a means to reduce the number of complaints and show that combining production data and information about the production offers potential for manufacturing quality development in the supply chain network. The study uses applied RACI matrix and the case of a welding supply chain network to establish the findings. The case example discusses the observations dealing with GMAW process.

Keywords: Complaint Management, RACI Matrix, Supplier Quality, Supply Chain Network, Welding Quality Assessment

1. Introduction

As theories and doctrines of business process management change and develop to reflect changing business and societal contexts, manufacturing networks have been receiving progressively more attention. Networks are evolving relationships and embody multiple interconnections between network members [1] and, thus, business networks with suppliers are generally accepted as being complex environments [2]-[4]. Study of business networks has encompassed many different perspectives, for instance, network cooperation [1], network competencies [5], network learning [6], network strategy [7] and network management [1], [8], and many different concepts, e.g. network dimensions [8], network insights [9] and network dynamics [10], [11]. Recent research has tried to improve understanding of business networks through the use of network pictures [12], [13], which are different understandings of how business network actors subjectively comprehend their surroundings [13]. The approach has been considered from a number of different viewpoints, e.g. network pictures complexity [2], relationships to suppliers [14], supplier management [15], [16] and making pictures as organizational sense making [17]. Additionally, researchers have shown growing interest in stepping beyond the concrete to find understanding of sensing of business activities in operational actions rather than building forecasts of its entity [17], [18].

The extent of network studies is considerable and the topic has been considered from many different viewpoints. Manufacturing networks have been studied by many scholars, who have considered the issue from different perspectives of the supply chain. General reviews of network activity such as Wilhelm [1], Rudberg and Olhager [19] and Chang et al. [20] and study of quality management in the supply chain [21], while providing valuable information, do not specifically address complaint management and its role as a driver for improved production. Use of complaint data from a network perspective is a new approach to investigation of quality, efficiency, productivity and profitability in industrial networks and manufacturing.

In light of notions that networks encompass multiple viewpoints and contexts with dynamic relationships and activity [22], manufacturing networks can be seen as consisting of several supply chain strings [1] and supply networks [23], which can be sets of supply chains [24], and the supply chain can thus have different supply network structures [25]. This research focuses on the supplier network [26], [27] structure in a supply chain network [20].

Quality is an important collaborative advantage in network structures [28] and is presumed to provide competitive advantage [29]. This study aims to conceptualize a method to observe the quality of manufacturing by analysing the structure and interrelationships of complaints in a supply chain network. This information can help companies to concretize the picture of discrepancies in the supply chain network and thus create a basis for development targets and network marketing activities that promote profitability. Different types of optimizing approaches have been tried to handle the cases of a product change which allow the efficient production and a wide product variety [30]. The complaint data discussed in this research includes also observations, which are connected with different types of product changes.

This study uses the case of a welding supplier network exhibiting features specific to manufacturing. The case study is used to observe manufacturing supply chain network related phenomena on the basis of data collected from industry. The collected data deals with the observations of gas metal arc welding (GMAW) process. This work may help managers reflect on the importance of production data and sense of surroundings as tools to improve strategic performance and network behaviour. The study empirically investigates the impact of cooperation and knowledge transfer in a dynamic supply chain network. More specifically, the study considers the relation of deficient knowledge transfer regarding defects in welding manufacturing in the light of welding complaints in the supplier network. The results indicate that improved cooperation can decrease the number of complaints and promote enhanced network behaviour among network members. Conversely, deficiencies in cooperation and knowledge transfer can be observed in the nature of the complaints in the manufacturing network. The presented five-step method can help certain development targets in the light of manufacturing quality in the supplier network. The systematic way to recognize and analyse possible product and production failures [31] makes it possible to carry out improvements and increase the productivity in welding production.

The study explores the following research questions: how can a processing model of complaint data be created that recognizes development targets in the supply chain network using existent, recent data? How can development targets be directly identified with information about welding quality and production complaints? What are the benefits of the prospective analytical model and how the model supports welding quality assessment when a substantial volume of complaint data is to be analysed?

The paper is divided into a theoretical part and a practical research part. First, the paper reviews existing information on networks and supply chain networks that is related to quality of manufacturing and cooperation. Next, the research section describes the steps of the proposed five-step method comprising collection and categorization of the complaints data and its integration with observations and impressions of the supplier network. The paper examines the case supply chain network and explains the relation between existing information on quality and defects and the assumption of a need to increase cooperation and information sharing. Finally, the paper presents a new method for using complaint data to develop a quality, productive and profitable outcome. The paper presents conclusions based on analysis of the results and discussion of the research questions and concludes with proposals for further studies.

2. Perspectives of networking

To form an overall picture of the network environment under study, literature-based background information is presented dealing with the management of network structures in general and the special features of supply chain networks in particular.

2.1. Features of Business Networks

Networks exhibit considerable complexity [1]-[3] and they are a business environment that poses challenges for optimal functioning of firms with manufacturing entities. Networks consist of multiple relationships [6] and relationships are one of the most important factors to observe when studying network behaviour. The relationships with and between suppliers, in particular, have become a topic of interest for strategic development of the focal company's business [15]. It is evident that business networks are dynamic and their management as part of manufacturing chains imposes additional demands.

Today's business processes drive companies to cooperate and extend dyadic relationships [32]. Companies cannot be seen in isolation but need to be considered within the wider context of business [4] and companies are thus involved in a complex network environment with internal relationships [4] and a context of multiple actors [8]. At the same time, companies have to respond to the challenges of globalization of business strategies and demands for sustainability of supply chains [33]. Managing network relationships demands knowledge of the interconnections involved [16]. However, when managing network relationships, there can be a mismatch between the actors that a company sees as relevant and those with whom they interact [4].

The multiple actors involved and the dynamic nature of networks mean that networks have features of business activity with non-predictable outcomes [11] and they cannot be directed or controlled by a single company [11], [34]. Network activities are the result of the network structure, networking behaviour and network outcomes [8]. When investigating the directions of network behaviour, the horizontal direction is more complex than the vertical direction [1] but all directions of relationships with network members are important.

Even if networks cannot be viewed as a function of a single company and a single company perspective gives an incomplete view of the business context and may be considered an inadequate basis for understanding of network dynamics [8], such an approach to observing networks is not without merit [17] and can help to understand steps in the development of different functions and the business network. Investigation of the dynamics of a network promotes recognition of significant changes in network actions or rather diminishes the role of unrecognized changes [15]. To study a network´s behaviour or develop actions in a network, division of the network into constituent parts can be implemented to reveal detailed information. The network can be divided into sub-networks such as the logistics and distribution network [35], [36], production network [4], supply chain network [3], [20], [37], [38] or supplier network [15].

Managing network structures is complex and demanding [18] and researchers are searching for information that may enable a strategic tool to be developed that can enhance business advantage. Multiple network business models have thus been developed for analysis of network environments. Relationships are the result of strategic decisions and concomitant actions [39], and reflect the impact of management of the network structure. Thus, existing relationships can restrain the adoption of new ways of operating and managing business activities [39]. Researchers are trying to enhance transparency in network activities in efforts to develop network management strategies [18]. Clarity regarding operational activities between a focal company and suppliers can enhance strategic decision-making in the supply chain network [40], and appropriate forms of cooperation and network management can have a positive impact on the development of product quality and profitability in production.

2.2. Special features of Supply Chain Network

In a network, the connections are built with linkages that present via inter-firm transactions, interactions and ongoing relationships in the vertical direction or horizontal direction [41]. The extent of a supply chain network is determined by the number of linkages and the energy of activities by the intensity of cooperation. Supply chain networks contain multiple supply chains and actors connected with each other in a unique context [20]. Suppliers, manufacturers, distributors and retailers are connected through product, material, information and financial flows [3].

The upstream, downstream or collaborative connections and their linkages are directly related to cooperation flows. Continuous and unhindered cooperation and information transfer can be difficult to achieve even when the advantages that the network activity can bring are recognized. Information sharing and cooperation and relationships management can generate managerial advantage and improve performance [5], [36]. Knowledge transfer plays a central role in the development of dynamic models within the network and augmentation of competitive advantage gained from the network [42]. Generally, intra-firm knowledge transfer is considered easier than knowledge transfer between firms [43].

It is important to recognize the objectives that are want to be achieved with knowledge in the network [42]. Knowledge transfer and supply chain network advantages are related to competencies [5] and the capability of an individual or firm level to attain specific achievements [44]. Thus, tacit knowledge and experience of individuals, firms or network levels introduce complexity into network management because of changing configurations of cooperation [43]. In a supply chain network, manufacturing activity management and cooperation should include appropriate knowledge transfer between the entities involved. Management practices related to quality improvement and operational efficiency should also be included in information sharing for effective network behaviour [5].

Improved quality is one of the advantages of supply chain network collaboration [28] and value-adding processes [37] in which the focal company defines the product quality [45]. Consequently, the value of relationships in the supply chain network gain in importance. Cooperation and divided management with customer and supplier can bring increasing performance and competitive advance on manufacturing [46]. Deficits in cooperation can result higher defect rates in manufacturing. One actor in a supply chain network can cause quality failure in the end product [47]. Viewing product quality discrepancies from the perspective of incompetent cooperation [47] can reveal deficiencies in relationships and knowledge transfer. Supply chain networks are vulnerable to risks of financial uncertainty [3] but also have properties that can offer a sustained competitive advantage [20].

However, discrepancies in quality are common in production [48] and defects leading to complaints are almost inevitable in production involving a supply chain network context [49]. Managing complaints and complaint behaviour are notable factors in business relationships [50] and measuring of manufacturing performance [51]. In a supply chain network context, analysis of complaints can indicate targets for development. To maintain competitive advantage in manufacturing, continuous product quality improvement is essential and the effective use of quality data (e.g. complaint data) is a critical factor in business development [52]. The literature review has shown that network context analysis is a powerful tool to evaluate the influence of complaints on product and production.

3. Research basis and methods

To carry out successful supply chain network analysis, the key nodes of the network, the different types of connections between them and the volume of conveyed information first have to be identified (see e.g. [53], [54]). In this research, the focus is on determining the information content in the network context when the structure of the network and its actors are identified. In this study, the research methodology used for supply chain network analysis and development is based on three combined research methods. The research utilizes a case research method [55], which is a typical approach in network studies [56]. The case method is used to build a basis for a new method to develop supply chain network quality and improved performance with profitable outcomes. The resulting data are analysed with a mixed method approach [57] based on a number of different data collection and analysis methods [58]. The data collection and analysis utilize a quantitative analysis approach [59] and the data are analysed using qualitative content analysis [60]. The data for analysis consist of numerical data of complaints, empirical analysis results and a survey of the supplier network.

This study investigates the case industry network using existent numerical data about complaints concerning welded items manufactured in the supplier network. The study utilizes information about complaints (n=18 889) to clarify the prospects of improving network quality and profitability in the supplier network. The data are related to the end product with multiple items (n=14 907) and additionally utilize a survey of suppliers (n=10). The case end products that are used to concretize the data are two different mobile machines for applications in demanding environments and thus represent an example of a multi-level manufacturing process with multiple actors in the supply chain network. The combined complaint data and survey results are analysed using a data matrix and the RACI matrix, which is an approach commonly used for study of business processes [61], [62] and organizational management [63].

4. Study

To create a generalized method for establishing targets of development, a case of industrial production demonstrating the special features of welding technology is used. Toivanen et al. [64] studied the welding network and concluded that there was insufficient network behaviour. The lack of communication internally and at the network level can form of defects and complaints in the supply chain network. The lack of communication both restrains network development and decreases profitability in the network. On the basis of this prior assumption, a method is required for finding development targets. The method aims to find a way to integrate data of complaints and survey with relevant complaint information collected from suppliers without filtering out any important information to be analysed. The method should ensure that reliable production development targets can be found.

4.1. Classification of the State of Complaints

The first step of the process using complaints in a supply chain network was to create an overview of the type of complaints and thus the targets of development. In this step, the case supply chain network was studied with focus on the supplier network. Welding complaints compromised approximately 27 % of all complaints in the welding supply chain network with suppliers for the ten year period studied (Fig. 1). Self-caused defects are classified in the complaint category because of being manufactured in supplier. From the figure, it can be seen that it is difficult to predict accurately the volume of welding complaints relative to the total number of complaints received. Higher numbers of complaints in a certain year can be a result of changes in metal industry sales or the launch of a new product that includes more items manufactured in the supplier network. However, in Fig. 1 the launching year of the case machines in late 2008 and in 2014 correlates with an increase in welding complaints.

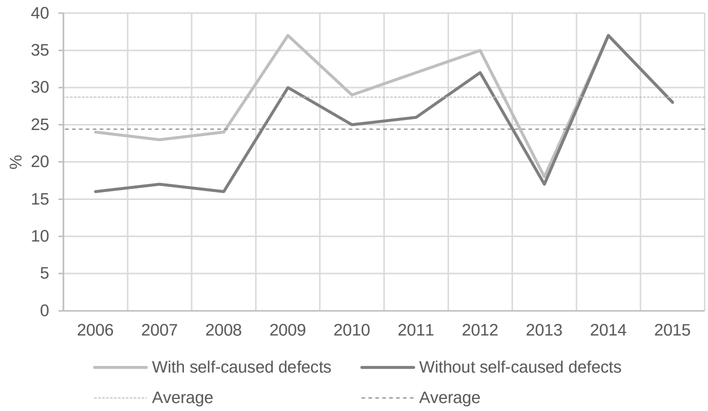

Figure 1. *Welding supplier network complaints in the case supply chain network as a percentage of total complaints for the ten year period under study.*

The complaints were divided on the basis of manufacturing and welding related activities, Fig. 2. The complaint data also contain self-caused defects of the focal company which result from, for example, the assembly phase following component manufacturing by suppliers. By excluding self-caused defects of the focal company, the division of complaints is more focused on suppliers and gives better results for supplier network actions. In this particular case, important sources of complaints with actual welding were machining operations and component manufacturing. Excluding the self-caused defects, the portion of these manufacturing phases increases the most and indicates the role of self-manufacturing and testing of focal company but also the focus of actual development targets in the supplier network. The category "Other" contains product development updates, and a substantial number of complaints in the "Other" category result from internal activity, namely, thorough testing of the complete machines, which can result in damaged and broken parts. When observing the end products of the supplier network more closely, the root cause trend of complaints is close similar for all welding complaints of the particular period (Fig. 3).

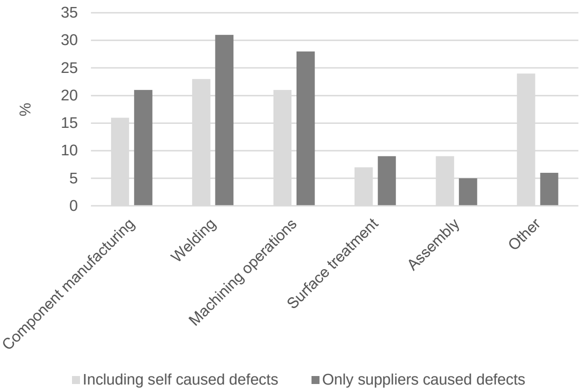

Figure 2. *Complaint data division in case welding divided in categories to indicate the role of related activities in welding manufacturing*

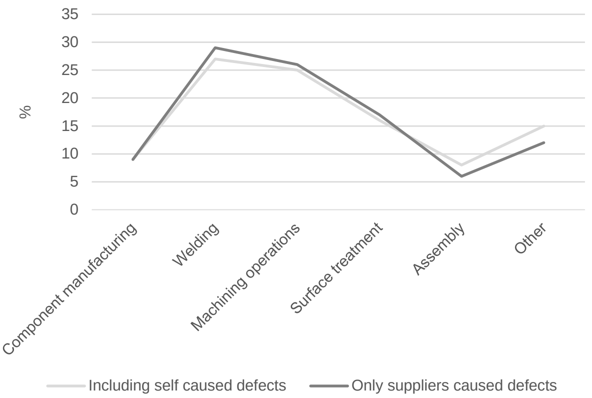

Figure 3. *Complaint data categorization in a case end products follow close similar trend as overall welding complaint data of a particular production.*

In Fig. 4, complaints related to the end products are shown for the number of items individually and for the total number of items in the case machine. The end products may include several of the same items and the total number of items is the result for all items. The data were collected from an item group of 3 891 individual items and the total number of items was 14 907. The relative number of complaints about welding suppliers shows a small increase from the average result of 27 % but also shows conformity with the sample and whole production. When excluding items which are originally manufactured in welding supplier network but are self-caused defects by the focal company, the total number of items manufactured in the welding supplier network decreases. This can be seen in the smaller number of complaints related to welding supplier items. Closer observation of case products in their entirety comprises the second step of the method.

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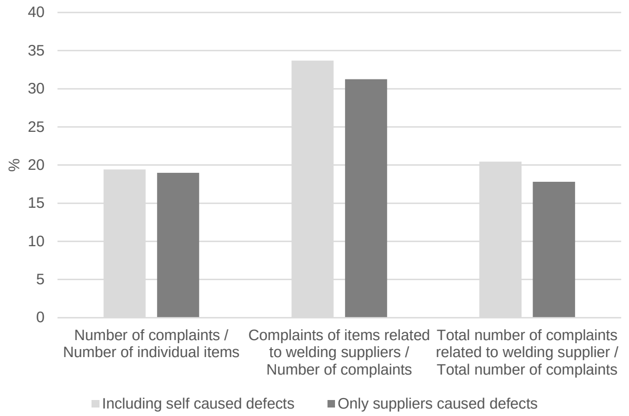

Figure 4. *Share of complaints to welding supplier network in case end products. The relative number of complaints about welding suppliers (bars in the middle) is close similar result than all complaints to welding supplier network in particular production.*

4.2. Collecting Observations from Suppliers

To decrease complaints, organizational learning and knowledge sharing are critical factors. Defects and the resultant complaints interrelate with competencies and knowledge transfer in the welding supply chain network. Result how suppliers see the potential influence to decrease the root cause of complaints indicate the targets for development of quality but also capability to fill quality demands of client.

Gathering information about the opinions of supplier network actors concerning possible development targets is the third step of the method. Welding suppliers in the supply chain network answered two survey questions: (Q1) what competence or understanding should welders, managerial employee in supplier firms and employees in the focal firm enhance to decrease the number of complaints received by the focal firm?; (Q2) how could the focal firm effect a decrease in the number of complaints through improvement of knowledge transfer? The alternatives offered as responses to Q1 followed the categorization of the complaint data: Welding operations, component manufacturing, machining operations, surface treatment and assembly of welded structures. Fig. 5 illustrates the welding supplier network view of activities related to welding in which there are prospects to decrease the number of complaints by increasing competence and information sharing and by taking actions to improve product quality.

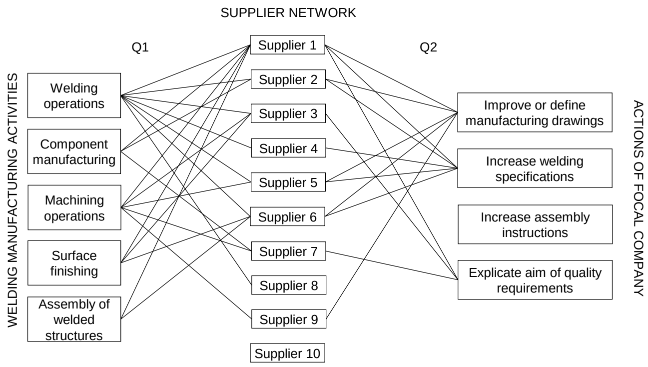

Figure 5. *Results and linkages of respondents concerning questions Q1 and Q2. Ascertaining the opinions of supplier network actors is one step to find potential development targets in the case welding supply chain network.*

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Responses to Q1 showed similar results to the complaints data and the survey results indicated a link between the complaints data and suppliers' view of activities needing an increase in competences. Studying the results of the survey, there is a strong connection with the categorized complaint data. Complaint data about self-caused defects and data from the survey together give a greater focus on the focal company, whereas by excluding the self-caused defects the focus turns more to the suppliers themselves and managerial employees. Excluding self-caused defects gives a better indication of the state of quality development in the supply chain network. This indicates the importance of information sharing of requirements, guidelines and instructions between the focal company and the supplier network. Investment in establishing development targets may lead to reduction in complaints and therefore greater productivity and improved profitability of welding production in the focal company and supply chain network. In responses to Q2, the improvement activities are focused on the actual welding and welding guidelines. This indicates that the focal company has potential to decrease the number of complaints by focusing on drawings and specifications.

4.3. Integrating the Complaint Data and Suppliers' Observations

Construction of an integrated matrix of complaints data for the ten year period and survey results of the supplier network actors is the fourth step of the method. Results of consideration of complaint data related to particular welding suppliers over the ten year period and the survey results for Q1 are presented in Table I. 19 clearly distinguishable reasons (≥ 20 % of complaints) can be seen as the root causes of the complaints with marked sections and 20 selections that suppliers selected for activities with potential to decrease complaints. 74 % of clearly detectable reasons fully match areas in which suppliers expected increased competencies to decrease complaints and if the cases which recognized only by the supplier are analysed only 5 % were a total mismatch. The results show the state of development targets at the supply chain network level.

Table 1. *Integrated complaint data of particular suppliers and suppliers' observations to show development targets in the welding production case.*

	Welding operations		**Component manufacturing**		**Machining operations**		**Surface treatment**		**Assembly of welded structures**	
Supplier 1	2%	x	49%	x	40%	x	4%	x	0%	x
Supplier 2	45%	x	20%	x	12%		13%		2%	
Supplier 3	51%	x	9%		18%	x	5%	x	11%	
Supplier 4	52%	x	9%		31%		6%		0%	
Supplier 5	34%	x	3%		43%	x	18%		0%	
Supplier 6	23%	x	3%		7%		38%	x	21%	x
Supplier 7	42%		9%	x	45%	x	3%		0%	
Supplier 8	22%	x	0%		68%		6%		5%	
Supplier 9	0%		0%		100%	x	0%		0%	
Supplier 10	80%		20%		0%		0%		0%	

x Answers related to Q1.
Q1 match with biggest impact with complaints.
Q1 non-match with complaints.

Concretizing the tabulated combined data with case end products results the key suppliers bearing relative to production and end products. The data of the second step is used with numerical information of categorized complaints related to end products and survey results. The combined result was analysed with the RACI matrix (Table II). The RACI matrix shows results related to the focal company and suppliers on the basis of potential developing actions and survey questions. The Q1 and Q2 results related to each supplier are shown with marked sections. R (Responsible) indicates the actual doer of the action in the manufacturing chain. In Q1 R based on complaints data of case products with majority part (≥ 10 %) of categorized complained items in second step of method. A (Accountable) indicates financial responsibility and responsibility for the quality of the end product at the network level. C (Consulted) describes in case Q1 the 5–10 % proportional amount of categorized complaints related to case end products in the second step of method and in Q2 C indicates the major amount of complains in the categories of manufacturing, welding and assembly. I (Informed) contains in Q1 < 5 % proportional amount of those categorized complaints and in Q2 suppliers that have to be informed of changes. The matrix contains the results of Q1 and Q2 to illustrate the key targets for development actions.

Table 2. *RACI matrix of combined result of complaint data of case end products and survey results to show important suppliers for development actions in production.*

Action		**FC**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**		**C**	**M**	**W**	**A**	**S**
Component manufacturing		A	I	R	R		I	C/I				I	S1	3.1 %	2.3 %	0.0 %	5.3 %	0.0 %
Machining operations		A	I	C/I	R	I	C/I	I	I	I	I		S2	34.4 %	9.3 %	14.1 %	15.8 %	19.6 %
Welding operations	Q1	A		R	R	R	I	R	I	I			S3	18.8 %	14.0 %	40.0 %	36.8 %	10.7 %
Assembly of welding structures		A	C/I	R	R			R		C/I			S4	0.0 %	3.5 %	14.1 %	0.0 %	1.8 %
Surface treatment		A		R	R	I	I	R					S5	3.1 %	8.1 %	1.2 %	0.0 %	1.8 %
Improve manufacturing drawings		R/A	I	C/I	C/I	I	I	C/I	I	I	I	I	S6	9.4 %	3.5 %	22.4 %	10.5 %	46.4 %
Enhance welding specifications	Q2	R/A	I	C/I	C/I	C/I	I	C/I	I	I	I	I	S7	0.0 %	2.3 %	2.4 %	0.0 %	0.0 %
Enhance assembly instructions		R/A	I	C/I	C/I	I	I	C/I	I	I	I	I	S8	0.0 %	2.3 %	4.7 %	5.3 %	0.0 %
Explicate aim of quality requirements		R/A	I	I	I	I	I	I	I	I	I	I	S9	0.0 %	1.2 %	0.0 %	0.0 %	0.0 %
													S10	3.1 %	0.0 %	0.0 %	0.0 %	0.0 %
	R	4	0	4	5	1	0	3	0	0	0	0						
	A	9	0	0	0	0	0	0	0	0	0	0						
Sub result	C	0	1	4	3	1	1	4	0	1	0	0		Impact factor				
	I	0	7	5	4	6	8	6	6	7	5	5		R	0.3			
		4.8	0.9	2.5	2.5	1.1	1.0	2.3	0.6	0.9	0.5	0.5		A	0.4			
	R	4	0	2	1	1	0	3	0	0	0	0		C	0.2			
	A	9	0	0	0	0	0	0	0	0	0	0		I	0.1			
Summarised result	C	0	0	2	0	1	1	2	0	0	0	0		Σ	1.0			
	I	0	5	2	1	1	4	2	2	1	2	0						
		4.8	0.5	1.2	0.4	0.6	0.6	1.5	0.2	0.1	0.2	0.0						

FC	Focal company
S1 – S10	Suppliers
C	Component manufacturing
M	Machining operations
W	Welding operations
A	Assembly of welded structures
S	Surface treatment

For the case example it is assumed that the impact coefficients could be set as follows: R = 0.3, A = 0.4, C = 0.2 and I = 0.1. The values are based on logical order where responsibilities are about twice important compared to information conveying and consulting is twice important compared to sharing information. The results are based on complaints data related to particular suppliers and the impressions of the suppliers. The matrix show the key suppliers related to complaints in a particular production phase or action. The results show that the focal company is financially responsible for the end products but also the quality of manufacturing at the network level. The suppliers S2 and S6 are clearly responsible for manufacturing related complaints in the eight year period.

5. Results

By combining the previous stages of the study it is possible to present a stepwise method which enables perception of development targets. The study concretizes actions for production development in the supply chain network. Based on complaints, development targets are focused on the supplier network. The results give an allocated targets for development.

The structure of the developed five-step method is presented in Fig. 6. The flow chart presents the generalized stages on the left and the items on the right are corresponding methods to support the stepwise analysis. The development targets can be found from the intersection of the complaint data and the survey of the suppliers. The target pointer of the developed method is indicated by the survey results and it is parallel to customer satisfaction and describes the state of the supply chain network.

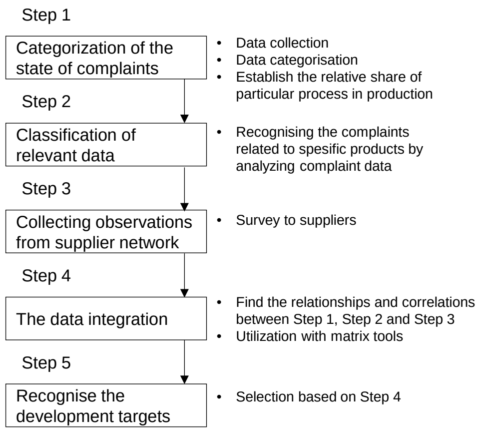

Figure. 6. *A five-step method to concretize actions for production process development in a supply chain network based on complaint data.*

6. Discussion

The study presents a new method to find development targets in a supply chain network. On the basis of complaints data, a five-step approach is used to establish areas of development to improve quality and profitability in production.

The study utilized complaints data about welding suppliers (n = 10) gathered over a ten year period. The results indicate that enhanced cooperation and knowledge transfer can decrease complaints and can reflect the state of particular functions in the supply chain network. A survey of supplier network members concretizes the sensed state of the supply chain network. Studied numerical data combined with survey information are at the heart of the new approach to understanding potential to increase profitability by quality assurance and control. Quantitative analysis enables data-based managerial decision making and with qualitative analysis permits problem solving [59], which makes a mixed method suitable for creation of a conception of the supply chain network.

To verify the model and to show evidence to allow the five-step method to be generalized it is necessary to discuss briefly the complaints data collected in the example case. When looking at complaints related to case welding suppliers categorized by root cause of the complaint, the origin of the complaints is similar in the end products and in the information about all welding complaints regarding a particular production. This exemplifies the systematic spread of complaints for products. Welding as the actual root cause of complaints rises nearly to a third of all related activities when self-caused defects are not included in the results. Reducing the number of complaints by removing self-caused defects gives a clearer picture of the state of the supplier network. The trend lines of the root cause of the complaints to welding supplier do not critically change when all complaints are analysed or when analysis is on the basis of complaints allocated to case end products. Perceptible change is related to the overall decrease in the number of complaints concerning welding suppliers, and thus the reason for self-caused defects can be seen in the change in the assembly category. When excluding self-caused defects, the number of complaints related to the assembly phase decreases and the portion of complaints in other categories increases. A similar trend can be noticed from small changes in the category ‘other’. Such a result can be expected when a supplier network is manufacturing welded items and subassemblies for product assembly in the focal company.

A lack of communication and competencies can be reflected in complaints related to production and the results of the research give clear evidence that complaints and conscious quality assurance actions are interrelated. Complaints data divided into categories have a clear relationship with the survey of suppliers’ ideas of improvement actions to decrease complaints received by the focal company. When considering only complaints that are a result of manufacturing defects by suppliers, the results direct attention more to suppliers at the managerial level. Naturally, examining complaints about items manufactured by welding suppliers but damaged by the focal company leads to greater emphasis on the focal company. The study gives better results for the state of the supplier network if self-caused defects are excluded. The results also show that the focal company may effect a decrease in the number of complaints by focusing on quality assurance through improved drawings and more accurate specifications. Such information will help suppliers in manufacturing operations to focus on particular quality demands.

The numerical data concretize the situation regarding complaints and when utilized together with the survey enable a more comprehensive picture of areas for development to be constructed than using only survey-based research. Suppliers believe that increased competencies of functions and activities related to welding can decrease complaints received by the focal company; this view is supported by the complaints data. By categorizing the survey results and quantitative complaints data in the same way, areas for development can clearly be seen. Matrix analysis of complaints data related to case end products and analysis of the survey concretized targets for developing. This approach can be useful for finding the quality development targets of products manufactured in a supplier network. Analysing the survey results by supplier and connecting this information to data of complaints of particular suppliers enables the root cause of the complaints to be concluded. This finding is supported by the 74 % matching rate of the results for the survey and complaints data and the activities seen as requiring development actions. Key suppliers for development actions to decrease complaints can be recognized using the applied RACI matrix. However, unmarked sections of the RACI matrix also indicate that activities for decreasing complaints are recognized only partly by suppliers. For example among suppliers S2 and S6 the difference between the most potential developments targets based on complaints data (R) and the unrecognized ones could be even 50 %.

This study shows that combining production data and information about the surroundings of welding production provides a new approach to developing quality manufacturing in a welding supplier network. Based on this information, managerial and strategic decisions can be made that enhance manufacturing and marketing in the supply chain network context. The information can be expanded further to the level of each supplier and also the different areas of manufacturing and different business functions.

This study answers the research questions using the developed five-step method of integrated data and survey results of suppliers. The crucial points of production development can be recognised by combining filtered data of complaints collected from suppliers and observations formed from opinions that are gathered from the supplier network. This integration makes it possible to decrease the number of complaints and gain enhanced quality and profitability in the supply chain network context. In practise, this means that the development targets can be found at the intersection of the complaints data and survey results by using a matrix for integration of the information. The main point is to recognise feedback from a multiplicity of complaint data alongside the impressions of the actors involved. This makes it possible to handle productivity issues which are connected with welding quality assessment aspects.

There are limitations to the research results presented in this paper. The research is trying to address supply chain network challenges by consideration of welding quality, productivity and profitability. The study considers supply chain networks in manufacturing industry and the research is illustrated with the case of welding manufacturing in a welding supplier network. Generally, companies see themselves as a centre of a network [65]. This research focus puts the focal company at the centre and surrounding associated companies view their position as a part of the focal company´s network. Thus, this study is focused on particular production in a supply chain network context. It is important to know that the case example and the collected data deal only with GMAW process and therefore the content of the first step (Categorization of the state of complaints) of the method is tuned for GMAW process. The research illustrates one way to link data about supply chain network activities and formulate a way to discover the main improvements targets for manufacturing or business processes. Further research is needed to generalize the method with systematic complaint management calculations, and there is a need to assess other manufacturing and operation functions with numerical based data and observations. Furthermore, internal complaints in the focal firm must be considered when observing in more detail the cost impact on particular production methods and the end product.

7. Conclusion

Multiple current studies provide general information about supply chain networks from perspectives of economical, managerial and production development. This research presents a new approach to the application of collected numerical production data in efforts to improve quality in supply chain network manufacturing and reduce the number of complaints. This research uses an industrial production example of a case study of a welding supplier network. The studied numerical data about complaints related to the supplier network combined with supplier survey information provide a way to understand potential for managerial, strategic and marketing development.

This study presented a new five-step method for analysing supply chain networks on the basis of complaints related to the supplier network as a way to improve quality and increase profitability in production. In this study, the case network was studied from different perspectives using complaints related to the supplier network found in numerical production data. Using a mixed method approach gave a concrete way to visualize and understand what is going on in supply network as it appertains to product quality. Quality data concerning complaints in the supply chain network related to welding manufacturing collected over ten years (2006–2015) was capitalized on to find a new way to observe potential for enhanced quality and profitability in manufacturing. Utilization of the data, integrated with the survey results, enabled the main targets for development to be established. Based on an assumption that a lack of communication and competencies can be reflected in complaints about production, the results demonstrate the importance of knowledge transfer and competencies in quality development and show their potential to increase network behaviour and assist in meeting strategic aims.

According to the results of this research, main development targets for production can be found from the intersection of complaint data and supplier survey results by using a RACI integration matrix. Use of data-based analysis with survey results and the five-step method may help managerial decision-making and efforts by suppliers to promote manufacturing quality. The results indicate clearly the feasibility of using the new approach to determine discrepancies in supplier network activities. This study provides a concrete way, using the presented five-step method, to see and understand what is going on in a supply chain network from the perspective of welding quality assessment and total product quality. Further research into how to formulate data handling and generalize the approach will allow its considerable potential to be realized.

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