TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

Investigation of Volume Flexibility and Product-Mix Flexibility in Batch Production

Mohammad Reza Arbabi

EXAM WORK 2015

Production Systems – Specialisation Production Development and Management

Postadress:	Besöksadress:	Telefon:
Box 1026	Gjuterigatan 5	036-10 10 00 (vx)
551 11 Jönköping		

This exam work has been carried out at the School of Engineering in Jönköping in the subject area of production development systems. The work is a part of the two-year university Master of Science programme.

The authors take full responsibility for opinions, conclusions and findings presented.

Examiner: Johan Karltun

Supervisor: Carin Rösiö

Scope: 30 credits (second cycle)

Date: 31.05.2015

Acknowledgements

I would like to express my gratitude to my industrial supervisor and Anders Wenell (direct manager at Laserkraft AB), who supported my experience of practical research in the Swedish industry and also provided me the opportunity to visit several factories. I would also like to thank my academic supervisor, Ms. Carin Rösjö for her guidance and efforts in correcting me during my research. Lastly, special thanks go to my family who provided for me and have supported me throughout the duration of my studies.

Mohammad Reza Arbabi

August 2015

Abstract

Today's business environment involves a globalised market, greater than before competition and more challenging customers, all factors which contribute to higher uncertainty and variability. Manufacturing flexibility is becoming more important in order to cope with the complexity of products through frequency volume changes and evaluations of the technological requirements of products.

The research for this thesis was performed within a subcontractor company, Laserkraft AB, who focus on laser cutting, turning and welding processes in their production. The company utilises a variety of volume and product mixes, which is in correlation with the objective of this study.

The purpose of this research was to investigate the common source drivers in order to achieve volume and product mix flexibility on batch production systems. First, a literature review was conducted in order to build the framework of common source factors between volume and product mix flexibility. Then, a single case study was conducted to examine the outcomes of framework on batch production. In this case, qualitative techniques included interviews and an observation of the shop floor.

The analysis of this study was conducted with empirical research on a case study and theoretical framework from literature. From the literature stand point; it was found that flexible manufacturing competencies (FMC) and strategic flexibility approaches are two main elements to determine internal source drivers between volume and product mix flexibility. The groups of common source factors were then analysed with respect to characteristics of batch production systems at the chosen company.

A comparison between the framework and the empirical findings identified source drivers in order to achieve volume and product mix flexibility. Due to the limited nature of the study, all source factors that have an impact on achieving volume and product mix flexibility might not be presented in this thesis. Besides, it is difficult to generalise the result on a single case study.

As a result, each organisation and industry refers to their product, process and type of layout, and requires a group of practices to achieve volume and product mix flexibility. This thesis concludes with the top three common source factors between volume and product mix flexibility such as: *set-up time reduction, multi-trained employees and advanced manufacturing technology*.

Keywords

Volume flexibility, product mix flexibility, production system, production process, advance manufacturing technology, setup time reduction, batch production, and cellular production.

Abbreviation

FMS ----- Flexible Manufacturing System

FMC ----- Flexible Manufacturing Competence

DFM ----- Design for Manufacturing

SMED ----- Single-Minute Exchange of Dies

JIT ----- Just in Time

UAMT ----- Use of Advance Manufacturing Technology

OIP ----- Operation Improvements Practice

BTO ----- Build-to-Order

MTO ----- Make-to-Order

ATO ----- Assembly-to-Order

WIP ----- Work in Process

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1 Introduction

This chapter will provide contextual information on the problem of manufacturing flexibility in order to introduce the objectives and identify the specific research questions.

1.1 Background

Manufacturing companies often face unpredictable demands, which can be seen in terms of differences in volumes, product mix and customisation requirements. In order to cope with these changes, and stay competitive and profitable, they need an essential degree of flexibility in their processes. Moreover, manufacturing companies have to focus on both internal and external uncertainties in order to survive and compete in the global market. The manufacturing environment is becoming more and more unpredictable and requires shorter product life cycles and faster technological evolution, as well as shorter delivery times, high customisation, more variety and higher product quality (Gerwin, 1993) (Wiliams, et al., 2000).

Flexibility is seen as the main answer to survival in markets characterised by frequency volume changes and evaluations of the technological requirements of products. Due to the quickly changing market demands, there is a need for flexible but still productive manufacturing systems. The biggest desire of all manufacturers today is to satisfy the orders more quickly and without pausing for retooling even with fixed volumes (Hosseini & Obrien, 2006).

Berry & Cooper (1999) claimed that gaining competitive advantage through increased product variety requires a clear understanding of the process choice for production, indispensable to support the expected range of product volume required for the maximisation of production capacity. They also revealed that investments in innovative production processes and improvements in the supply chain are the ways and means to achieve alignment between marketing and manufacturing strategies.

Furthermore, much research focuses on volume flexibility and product mix flexibility as a critical output among different types of flexibility (Salvador, et al., 2007). For instance, Zhang et al (2003) stated that volume flexibility is the ability of an organisation to operate at various batch sizes and at different production output levels in an economic and effective way. However, product mix flexibility amplifies a company's potential to switch from one product to another in lower set up time (Gerwin, 1993). Thus, from a literature point of view, it is clear that there is a fundamental relationship between the level of input and volume flexibility and product mix flexibility.

1.2 Problem Description

From a production point of view, establishing the volume and product variety of the output has a significant impact on shaping the design of a transformation system and the types of facility and layout (Meredith & Shafer, 2001). Figure 1 illustrates how product positioning is performed by means of a product process matrix.

Production layout

Type of characteristic		Job shop	Batch flow	Assembly line	Continious flow
	Variety	High	Moderate	Low	Very low
	process flexibility	High	Moderate	Low	Very low
	Volume	Very low	Moderate	High	Very high

Figure 1: Production layouts with different types of characteristics (Groover, 2001)

The aim of process choice in this study is to create a sequential flow for as many parts/products as possible and to increase the focus of research and narrow down the topic on a specific type of production. Job shop production has been recognised as an appropriate form of production, which can apply flexibility of small volume and a wide variety of products by separate departments for different processing (Figure 2). This type of transformation has separate departments for different processing (which require complicated managerial control), as the routes between different departments are not identical. However, batch flow production combines the advantages of job shop and the flow shop production to achieve the highest variety possible with job form and short response times, with the flow form based on batch sizing in-group technology (Figure 3), (Meredith & Shafer, 2001). Besides this, batch production is considered to be the most common type of production due to the possibility of using flow transportation in the less repetitive job shop environment (Groover, 2001).

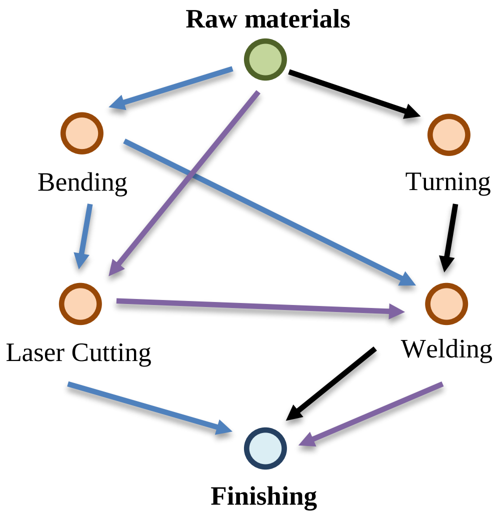

Figure 2: Job Shop

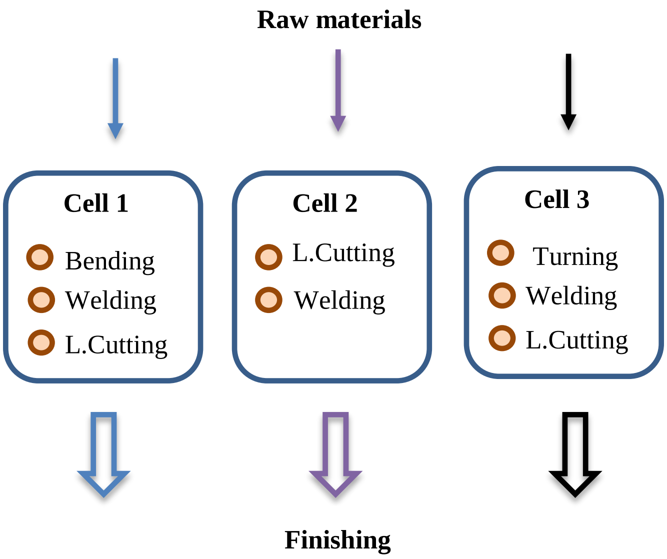

Figure 3: Cellular Production

*Different arrow colours indicate variation of products.

The majority of subcontractor companies with these specific challenges usually face high fluctuations of volume and product mix demand from their customers. Regarding different types of facilities and layout, batch production is amongst the most interesting choice for competitive manufacturing flexibility (Garavelli, 2001). Moreover, Bellgran & Säfsten (2009) advocated that batch production is one of the most suitable production choices to cope with producing unbalanced volumes, perhaps with many variants too.

Furthermore, regarding the choice of layout, (Ahkioon, et al., 2009) explained: "A functional layout copes well with high product variety but does not provide adequate throughput with high product volumes. In contrast, the line layout enables fast product throughput when production volume is high but does not cope well with product variety because of the need for frequent set-ups." Another related consideration in the problem formulation was whether output would be make-to-order or make-to-stock. Make-to-order is usually produced in a batch of a size set by the customer, in low volumes with high variety (Meredith & Shafer, 2001).
Nevertheless, there are still challenges with regards to the effect flexibility output has on the batch flow production. Furthermore, reflecting the scope of research and research design, the author examines the effect of flexibility output on outsourcing (subcontractor) by focusing on metalworking as a choice of sample. Generally, metalworking companies mainly supply to the automotive industry. Despite obvious differences, they do share some mutual performance and features in the business context such as the increase in product mix, decrease in product life cycle, market competition (especially on cost) and manufacturing lead-time. Not only that, but there are some common challenges regarding product volume and product variation when they face unpredicted orders from their clients. Since the mainstream of processes needs to be accomplished in sectional action, batch flow production (based on make-to-order output) is the most suitable way to cope with flexibility of production.

Laserkraft AB is a company that faces challenges regarding the complexity of producing a specific metal product family. The complexity comes from the product variety (Material, weight dimensions), and volatile customer demands (between 100 units/year to 100,000 units/year) which require a high level of flexibility. The increased demand for a specific metal product family requires development in the production line of Laserkraft AB. The main challenge for Laserkraft AB is to improve their overall operational performance. For example, welding processes joining the components in limited lead-time is one of the most important factors currently facing the company.

All this leads to the following questions:

- How should this development be conducted in a proper way?
- How should the production design be set up in a more efficient manner?

Therefore, this research attempts to investigate the different ways of dealing with: product and volume flexibility; the demand of a rising market; uncertainties as a cause of change; and development of the manufacturing system.

1.3 Purpose and Research Questions

The development of an appropriate production design with regards to variety complexity and wide ranging volume orders is the main debate of this research. The objective of this study is to gain insight into the driving source factors, which refers to the interrelation between volume and product mix flexibility. Not only that, but it is also to investigate different ways of achieving product and volume flexibility in a batch flow production system. Based on the purpose described above, two research questions have been formulated:

- *RQ1: What are the common source drivers between volume and product mix flexibility?*

As stated by Salvador et al (2007) a number of aspects typically used to increase volume flexibility have negative effects on mix flexibility and vice versa. The authors also suggested that volume flexibility and product mix flexibility may be achieved synergistically. Thus the purpose of the first research question is to formulate the relationship between volume flexibility and product mix flexibility. The term, *Common source drivers* refers to a combination of factors that focus on production subsystem aspects such as workforce and equipment, people, material handling and strategical decision (Gerwin, 1993), (Zhang, et al., 2006), (Hallgrena & Olhager, 2009). In order to answer this question, identifying the common source drivers that firms require to establish both volume flexibility and product mix flexibility is crucial.

- *RQ2: How can product and volume flexibility be achieved in a cellular layout for a batch flow production system?*

The second step in fulfilling the purpose is to investigate different ways in which product volume flexibility and product mix flexibility affects the production subsystem. Batch flow production or cellular production is the choice of production system here. To answer this question is to analyse the impact of volume flexibility and product mix flexibility on both production layout and processes.

1.4 Delimitations

Since this study investigates purely the technical aspects of a production system with a focus on metal processing subcontractor industries, some of the findings considered in this paper might not be suitable for other manufacturers with a different business structure. Thus, the contribution of this paper concerns the combination of technical aspects and process specific decision choices of real cases in metal working subcontractors. Also, as this research focuses on technical aspects, which affect volume and product mix flexibility, factors related to information and planning, are eliminated for this study. In addition, secondary data collection has been limited to those accessible through the Jönköping University library - both electronic and non-electronic material written in English.

1.5 Outline

The report is categorised in six chapters. Chapter two contains the theoretical background and definitions of major terminologies which play a key role in the framework of this paper. Moreover, in order to answer the first research question, the most cited source factors in literature are clarified, those which have a great impact on coping with volume flexibility and product mix flexibility.

Chapter three indicates the research methodology and strategies that the researchers have used to achieve the result. Chapter four presents the analyses of empirical data collected from observation and semi-structured interviews in order to answer the research questions. This investigation has been conducted based on the findings in the theoretical background section. Finally, chapter five concludes the thesis by discussing the methods, findings and analysis of the report. This chapter then ends with some ideas about future research and contributions towards addressing the problems highlighted for the case company.

2 Theoretical Background

The theoretical framework is designed specifically to fit the purpose of the research and the problems formulated. It attempts to illustrate the connectivity between the various theories considered useful in the task of answering the research questions. Thus this chapter refers to a brief review of the main theoretical concept in order to clearly define the scope of area under study for this research. As illustrated in figure 4, the central area of focus here is to study relevant production system terminology, batch flow production being the choice of production layout. It also focuses on volume flexibility and product mix flexibility as main challenging outputs of flexibility. The area of production system intends to set a context for the research and define key concepts and subsystems in regard to batch production for this thesis. However, the area of flexibility output has been divided into volume mix flexibility and product mix flexibility. Interactions between these areas have been identified as mutual source drivers between them.

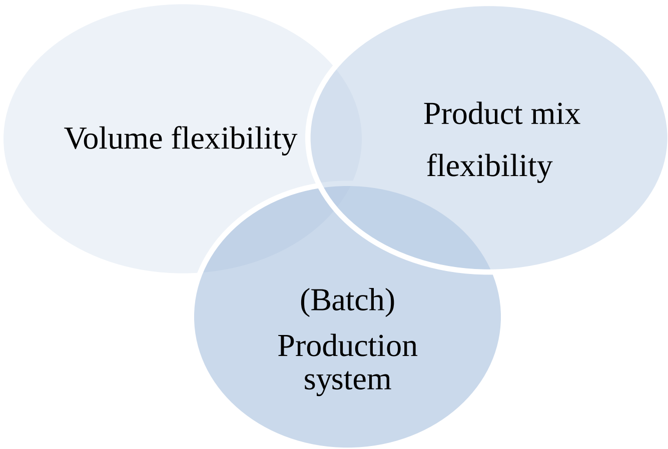

Figure 4: The research area in focus

2.1 Production System Design

In order to define a production system, we need to understand this term from a holistic perspective. 'Holistic perspective' intimates that the system should be designed with not only the physical and technical parts in mind, but the role of humans in the system and the relation among these elements as well (Bennet, 1986). According to Bellgran (2010), a system is divided into a collection of different components with unique characteristics, which play a fundamental role in the transformation of input to output. Rampersad (1995) stated that according to system theory, a system is a group of elements which can be either of geometric or of physical nature; moreover, between the elements in a system, relationships exist that determine a certain unity between them.
However, a subsystem is a subset of the elements in a system which allows one to gain a better insight into complex systems. In general, these elements interrelate by

means of processes in order to reach the desired state from the existing state (Rampersad, 1995). The production system thus represents the firm's ability to manufacture the goods, which includes manufacturing techniques and physical objects of manufacturing technology based on operational routines and required processes (Pisano, 1997).

The components of a production system that consists of five subsystems which affect the transformation process from raw materials to finished products are characterised as follows (Groover, 2001):

- Human System: refers to direct and indirect labor (e.g. operators, administrators, etc.)

- Technical System: hardware that is directly related to the production process (e.g. equipment, tools, machines, robot, fixtures, etc.)

- Material Handling System: hardware related to the operation in order to connect between processes or at stations (e.g. forklift, conveyor, pallet, etc.)

- Computer & Information System: software and hardware aimed at communicating data (e.g. software programs, information engineering, etc.)

- Building & Premises: buildings and their premises (e.g. floor, walls, ceiling, etc.)

2.2 Batch Production Choice of Process and Planning

The process choice plays a key role in aligning operational decisions within the production environment. The process choice has been considered in four main categories: job shop, batch shop, line flow, and continuous flow (Jeffrey, et al., 1994). This classification is related to the effect of the market, product variants and product volume characteristics on the decision of process choice (Safizadeh & Ritzman, 1997).

Regarding the different types of facilities and layout, batch production systems are recognised as the most interesting planning choice for competitive manufacturing flexibility (Garavelli, 2001). Besides that, Bellgran & Säfsten (2009) identified batch production as one of the most suitable production choices for coping with producing unbalanced volumes, perhaps in many variants. According to Groover, (2001) batch production is a process which enables items to be produced in bulk; the facility is then changed to produce other items. The flexibility of the tooling, machinery and workforce to enable quick turnaround of products is a key feature of batch production, which can easily be adopted to manufacture different products to meet specific customer requirements.

A number of past studies such as Safizadeh & Ritzman (1997); Olhager, et al (2001); and Salvador et al (2007) indicate that batch shop uses the customer orders as planning inputs to facilitate build-to-order (BTO), make-to-order (MTO), and assemble-to-order (ATO). Moreover, Safizadeh & Ritzman (1997) state that batch shop is the most suited type of production in order to respond to fluctuating levels of customer orders.

In addition, to compare batch production with other process choices, Safizadeh & Ritzman (1997) argue how production planning and inventory control decisions relate to the influence of process choice and consequently the impact on operational performance. This contributes to identifing key decision drivers in batch production, which differ from other processes. Safizadeh & Ritzman (1997) empirically considered different types of processes in order to comprise batch production and found that:

1. Operational performance improvement of batch production is achieved when firms can better handle complexity over shorter horizon planning, as well as effective manipulation of the labor capacity.

2. The production plan in batch shop relies more on the actual demand in contrast with continuous flow and line shop.

3. Batch production plants carry more raw material inventory and work-in-process inventory than line flow and continuous flow, which means that batch production tends to maximise equipment utilisation.

To be more elaborate, a batch shop production with cellular layout could obtain both flow shop and job shop advantages at the same time (Meredith & Shafer, 2001). According to Meredith & Shafer (2001) reduction of machine set-up times is one of the most crucial advantages of the cellular form of production, which provides several benefits. For instance, an increase in availability of equipment time and an increase in capacity, which means that the company can produce with less machinery and less shop floor space occupation. Furthermore, reduced set-up times make it more economical to produce small sizes of batches. Thus, small batch production reduces the work-in-process and lead times, consequently increasing the firm's product mix flexibility. Conversely, in certain situations where demand is dried up, there is a difficulty to balance the cells and equipment, which means batch production becomes more flexible for small and medium sized volumes.

2.2.1 Product Complexity

As Kotha & Orne (1989) state, the product complexity dimension refers to aspects such as product variety, product volume, end product experience and end product complexity. Product complexity is related to production planning. Thus, by better aligning between process choice decisions and product complexity, competitive advantages in the market will be developed (Spring & Dalrymple, 2000). Therefore, it should be distinguished that product complexity could be a key factor in the process choice decision.

2.2.2 Product Family

A product family is a collection of parts, which have similarity in geometric shape and size or in their manufacturing process (Groover, 2001, p. 525).

Grouping parts into families includes part classification and coding the similarities based on design attributes and manufacturing attributes. Then, the part design attributes with basic internal and external shapes, length and diameter, material types, tolerance and surface finishes are identified. Besides that, manufacturing attributes consist of major processes, operation sequences, machine tools, production cycle times, batch sizes, annual productions and fixture requirements. These families can then be used to form analytical machine cells in group technology (Groover, 2001).

2.2.3 Group Technology and Cellular Manufacturing (Physical Layout)

In order to improve manufacturing productivity, manufacturing companies have turned their physical layout to cellular manufacturing systems where people, machinery and equipment are grouped together to manufacture a specific family of parts (Krar & Gill, 2003). According to (Groover, 2001), sometimes the parts need to be produced in respect to the size of the equipment, the quality required, the skills of workers and many other overriding considerations. In other words, this is called the classification stage when items are classified into families by the analysis of their routing requirements, production requirements, part geometry and the like (Meredith & Shafer, 2001).

One of the requirements of cellular manufacturing is the identification of families of products. Thus, according to Groover (2001, p. 421) group technology is a manufacturing philosophy in which similar parts or products are identified and then grouped together to take advantage of their similarities in manufacturing characteristics, production, design and process. Groover (2001, p. 422) stated that in order to be more efficient, group technology must provide benefits such as:

- Promoting standardisation of tooling, fixtures and setups
- Reduction in material handling because parts are moved within a machine cell rather than within the entire factory

- Simplification in process planning and production scheduling
- Reduction in setup time, resulting in lower manufacturing lead times
- Reduction in work-in-process
- Labour satisfaction
- Higher quality work

2.3 Manufacturing Flexibility

Manufacturing flexibility is a complex, multidimensional concept that has evolved over the years (Sethi & Sethi, 1990). Zhang et al (2003) reflects on manufacturing flexibility as a set of basics, which are inherently designed and carefully connected to promote the assumption of processes and equipment to a variety of production tasks. Manufacturing flexibility is the ability of the manufacturing system to manage production resources and uncertainty to meet various customer requests.

Zhang et al (2002) divides manufacturing flexibility into flexible manufacturing competence and flexible manufacturing capability. Flexible manufacturing competence (FMC) from a firm's perspective includes the machine, labour, material handling and routing flexibilities. This is a key internal dimension of competition that is invisible to customers. Flexible manufacturing capability is an external dimension of competition that is valued by customers. The chosen capabilities in this research include volume flexibility and product mix flexibilities.

Suarez et al (1991) identified four types as the major constructs that capture the dimensions of flexibility required in a production system: volume flexibility, mix flexibility, product flexibility and delivery flexibility. However, according to Salvador et al, (2007) flexibility can be viewed from many perspectives. Sethi & Sethi (1990) argued that volume flexibility and product-mix flexibility are the two most widely used flexibilities; it is these which are the main focus of this study.

Zhang et al (2003) also suggests that FMC is the foundation for creating volume and mix flexibilities. In other words, FMC is the process and infrastructure that supports manufacturing flexibilities and enables firms to achieve high levels of performance.

Moreover, Zhang et al (2003, p. 176) included the FMC in machine flexibility, labour flexibility, material handling flexibility and routing flexibility. These competence factors increase the flexible manufacturing capability. Internally motivated, FMC provides the processes and infrastructure that enable firms to achieve the desired levels of flexible capability (Zhang, et al., 2003). Consequently, the relationship between FMC and flexible manufacturing capability (volume flexibility and mix flexibility) roots in customer satisfaction. Figure 5 illustrates that FMC including the machine, labour, material handling and routing flexibilities supports both volume flexibility and product mix flexibility.

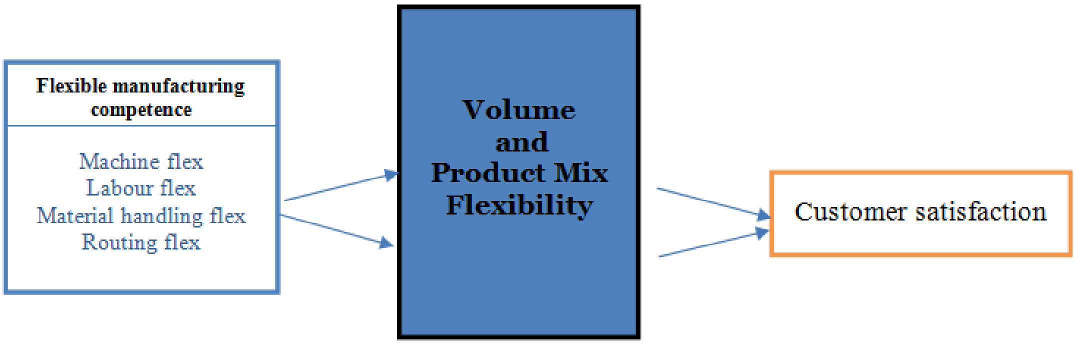

Figure 5: Zhang et al, (2003, p. 176): Relationship between FMC and volume and product mix flexibility.

Zhang, et al (2006) suggests the effects of internal aspects including the use of advanced manufacturing technology (UAMT) and operations improvement practices (OIP) on flexible manufacturing competence (FMC). In fact, they indicated how firms with a high level of OIP and UAMT achieved higher levels of FMC.

Moreover, in their study, Zhang et al (2006, p. 583) states that OIP includes key just-in-time (JIT) principles, which consist of set-up reduction, preventive maintenance, cellular layout, pull production, total quality management and continuous improvement. UAMT refers to a set of tools that automate and integrate steps in manufacturing in order to improve performance in production systems, which can be categorised as: product and process design, manufacturing planning and control, and integration between functions and process (Zhang, et al., 2006).

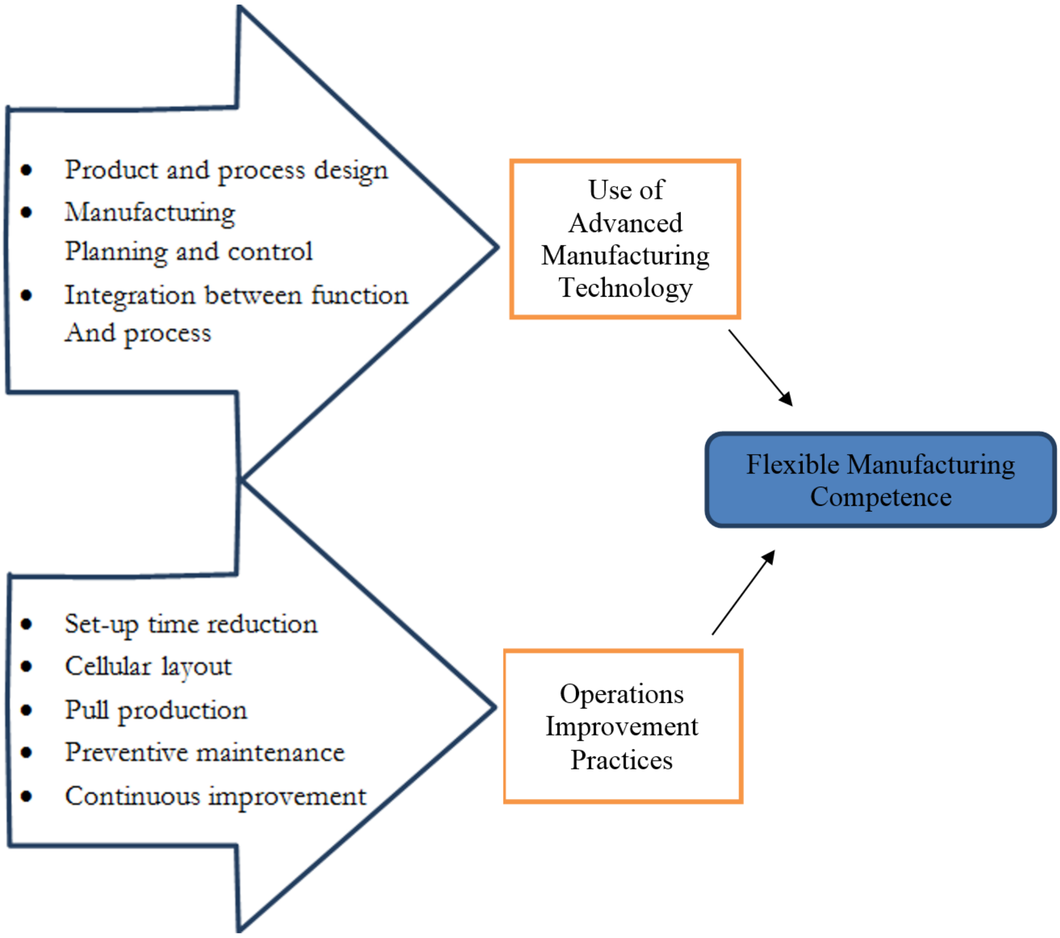

Figure 6: Effect of advance manufacturing technology and operation improvements practices on flexible manufacturing competence (Zhang, Vondermbse & Cao, 2006, s. 583).

In general, according to Zhang et al (2006), FMC plays a key role in identifying source drivers that influence flexible manufacturing capabilities. Flexible manufacturing capabilities also include volume and product mix flexibilities. Henceforth, those factors leading to UAMT and OIP could eventually influence volume mix flexibility and product mix flexibility achievements (Figure 6).

2.3.1 Volume Flexibility

The significance of volume flexibility has been widely discussed in the literature studied. Zhang, et al (2003) states that, volume flexibility is the ability of the organisation to operate at various batch sizes and at different production output levels economically and effectively. Volume flexibility reveals the competitive potential of the firm to increase and decrease production volume to meet increasing demands and to keep inventory low as demand fluctuates (Gerwin, 1993). Volume flexibility is also positively related to the measurement of firm, financial and market performance (Vickery et al., 1997). Suarez et al (1991) defines volume flexibility as the ability to vary production volumes without any detrimental effects on efficiency and quality. Jack & Raturi (2002) defined volume flexibility as the ability of an organisation to change volume levels in response to changing socio-economic conditions profitably and with minimal disruption; which concluded that volume flexibility has a positive impact on both financial and delivery performance. In assessing the strategic value of volume flexibility, it is critical to identify the main drivers and alternative sources that require a firm to change volume levels or product groups.

Jack & Raturi (2002) empirically identified the source factors of volume flexibility and their effect on operational performance is as follows:

Internal Sources

- Product and process technologies
- Batching
- Production planning and systems
- Capacity
- Set up time/cost
- Facilities and equipment
- Workforce/labor flexibility
- Layout

External Sources

- Supplier network
- Supplier relationships
- Network of plants

For instance, Waltera et al (2011) empirically evaluated the benefit of volume flexibility in order to provide guidance in car manufacturing. They emphasize five volume flexibility instruments which have economic benefits for European car companies such as: additional cycle time and additional shift models, allowing extra hours, longer balancing periods and a maintaining a sufficient supply of temporary workers.

Gerwin (1993) stated that a higher level of automation could increase volume flexibility, which would result in variable machine and system utilisations. Not only that; but Gerwin (1993) also mentioned that this flexibility could be achieved by having:

- Multipurpose machines (machine flexibility)
- A layout that is not dedicated to a particular process
- Sophisticated, automated and possibly intelligent material handling systems (not fixed route conveyors)
- Routing flexibility: the ability to handle breakdowns and to continue producing the given set of part types

In other words, Gerwin (1993) referred to machine and routing flexibility as comprehensive factors towards achieving volume flexibility.

2.3.2 Product Mix Flexibility

Besides volume flexibility, product mix flexibility is regarded as one of the most important flexibility dimensions in the literature reviewed. Product mix flexibility refers to the ability of manufacturing systems to produce a broad range of products with low changeover costs (Berry & Cooper, 1999). Gerwin (1993) defined product mix flexibility as the capability of producing a number of products/or numerous variations within a line. This flexibility amplifies a company's potential to switch from one product to another in a lower set up time. Gerwin (1993) also stated that this flexibility could be achieved by having efficient and automated production planning and control systems in place for both automatic operation procedures and automatic material handling.

According to Bengtsson & Olhager (2002) product mix flexibility refers to the ability of a firm to change relative production quantities among the products in a product mix. However, although simply increasing capacity will result in product mix flexibility, it also results in higher manufacturing costs. Considering that issue, (Berry & Cooper, 1999); Zhang et al (2003) define product mix flexibility from an economical and supply chain point of view in that it can rapidly change the mix of items being delivered to the market while maintaining cost effectiveness.

This ability of changes can be accomplished by different ways for different companies. Therefore, several authors have provided different interpretations of product mix flexibility based on and related to other flexibility capabilities. For instance, Sethi & Sethi (1990) related the product mix flexibility to three flexibility types:

- Product flexibility: the ease with which new parts can be added or substituted for existing parts
- Process flexibility: the set of part types that the system can produce without major set ups
- Production flexibility: the universe of part types that the manufacturing system can produce without additional major investment on equipment

2.2.3 Common Source Drivers between Volume Flexibility and Product Mix Flexibility

Undoubtedly there are numerous studies defining and investigating different aspects related to the level of flexibility output and subsequent production subsystems. Once a specific flexibility dimension has been focused on, then it may be possible to define the concept, measure it, and also evaluate different means for providing this flexibility dimension on production system designs. For instance, Zhang et al (2003) stated that volume flexibility is the ability of organisations to operate at various batch sizes and at different production output levels, economically and effectively. However, mix flexibility refers to the ability of a company to produce different combinations of products economically and effectively. Suarez et al (1996) have presented that volume flexibility has a positive impact on a firm's performance. Also, Suarez et al (1996) argued that the factors that affect volume flexibility in manufacturing plants are completely distinct from those that affect mix flexibility.

In order to realise the relationship between product mix and product volume flexibility, Salvador et al (2007) suggested a number of manufacturing methods typically used to increase volume flexibility, which correlate a negative effect on mix flexibility and vice versa. For instance, advance manufacturing technology is significantly emphasised by volume flexibility, while a modular design is most important for product mix flexibility. They also stated that the volume and mix flexibility might be achieved synergistically. For instance, they suggest that if the set-up time is reduced, the capacity will increase, which would provide an overall increase in volume flexibility. Since mix flexibility implies less time wasted in switching production from one item to another, the reduction of set-up time not only leads to an increase of volume flexibility, but also improves general mix flexibility.

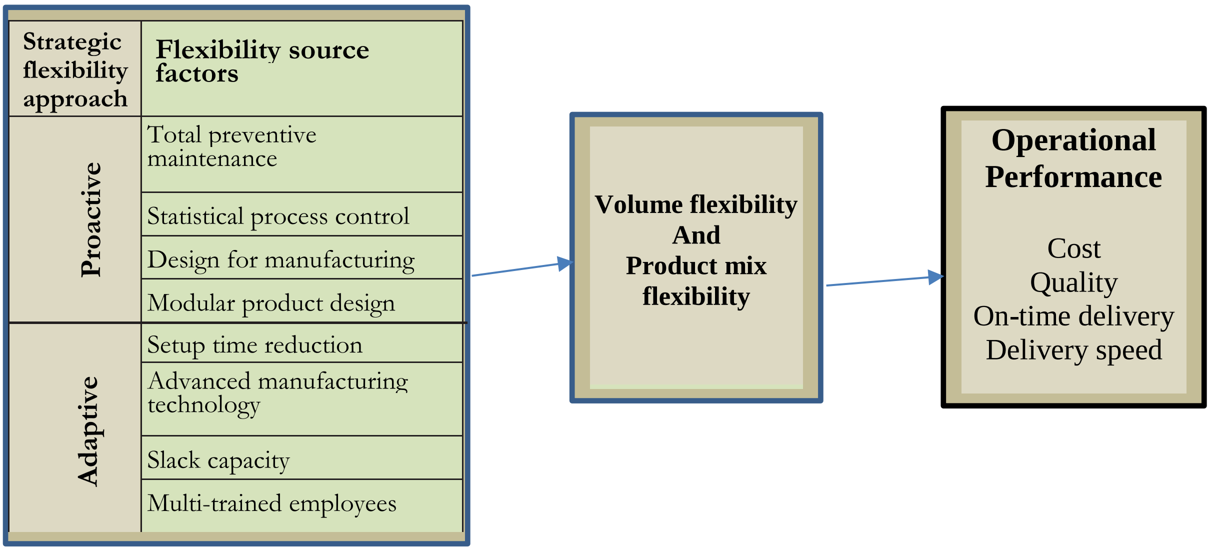

Figure 7: The relationship between strategic flexibility, flexibility source drivers, volume and mix flexibility, and operational performance (Hallgrena & Olhager, 2009, p. 750)

Hallgrena & Olhager (2009) found that the flexibility configuration based on high or low levels of mix flexibility and volume flexibility combinations could be achieved through different source factors and different strategic approaches.

For instance, in this work, they realised that firms with high levels of volume flexibility require all adaptive flexibility source drivers such as: set-up time reduction, advance manufacturing system, slack capacity and multi-trained employees. However, they suggest that design for manufacturing (DFM) and modularity are the most important factors required to achieve a high level of mix flexibility.

In summary, the common source drivers between volume flexibility and product mix flexibility have been identified through literature and are formed as a framework for this study. As it is illustrated in figure 8, these source factors have been identified through flexible manufacturing competencies and strategic flexibility approaches (Zhang, et al., 2003). In this case, Zhang et al (2003, p. 176) argued the significant effects of FMC in order to realise the common source drivers between volume flexibility and product mix flexibility as stated below:

UAMT

- Product and process design
- Manufacturing planning and control
- Integration between function and process

OIP

- Cellular layout
- Pull production
- Preventive maintenance
- Continuous improvement

However, Gerwin (1993) suggested some flexibility source drivers which are characteristically associated with adoptive and proactive strategic approaches such as:

Strategic Adoptive Factors:

- Set-up time reduction
- Advanced manufacturing technology
- Slack capacity
- Multi-trained employees

Strategic Proactive Factors

- Total preventive maintanance
- Statistical process control
- Design for manufacturing

Figure 8 is the outcome of common source drivers between volume flexibility and product mix flexibility identified among different literature reviews. This framework consists of internal source drivers that root both in strategic flexibility approaches and flexible manufacturing competences. However, external source drivers were determined from flexible manufacturing competencies, which have been recognised in order to investigate the volume and product mix flexibility. As a result, these source drivers based on competences and the strategic flexibility approach of a company lead to developing operations and performance in order to increase customer satisfaction.

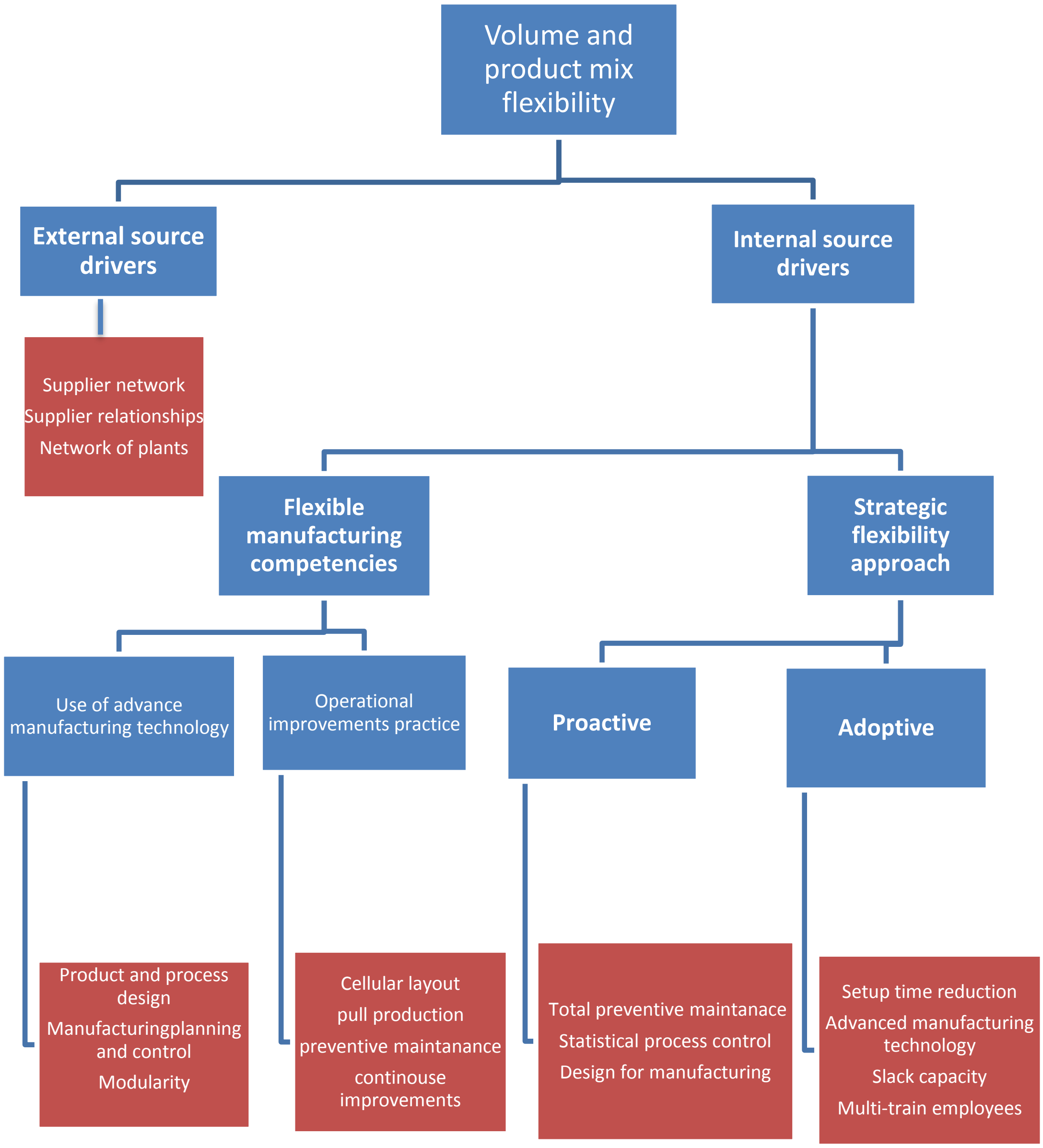

Figure 8: Common source drivers between volume and product mix flexibility

3 Method and Implementation

This chapter presents the methods used to perform the study. Initially the research approach is presented, then the methods which were used to gather empirical data and finally they are then analysed in order to arrive at the conclusion.

3.1 Research Procedure

The research on this case study ran between January to May 2015 in Laserkraft AB, for a master thesis under the Production Development and Management program at Jönköping University. After the first meeting with the company's representatives, the main path was drawn, and the project goals and available resources were described. Hence, to support the purpose of this research, Laserkraft AB represents a case to test the results in order to identify the most important factors towards achieving the volume flexibility and product mix flexibility through the study of their production system.

Data was collected at the company during the entire spring semester of 2015. To simplify both collection and interaction with company representatives, the student resided at the company, Laserkraft AB, at least once a week and also had access to the other facilities throughout the entire thesis period.

In the primary step, a background study and analysis of existing production was considered in order to understand the current process production of Laserkraft AB. Locking shaft is the sample of product family which was chosen to assess the objective of this research based on its operation specification. After establishing the primary project plan, a wide literature review in the field of volume flexibility and product mix flexibility was made, and by focusing on the choice of production related to the purpose, the research questions were formulated (Figure 9).

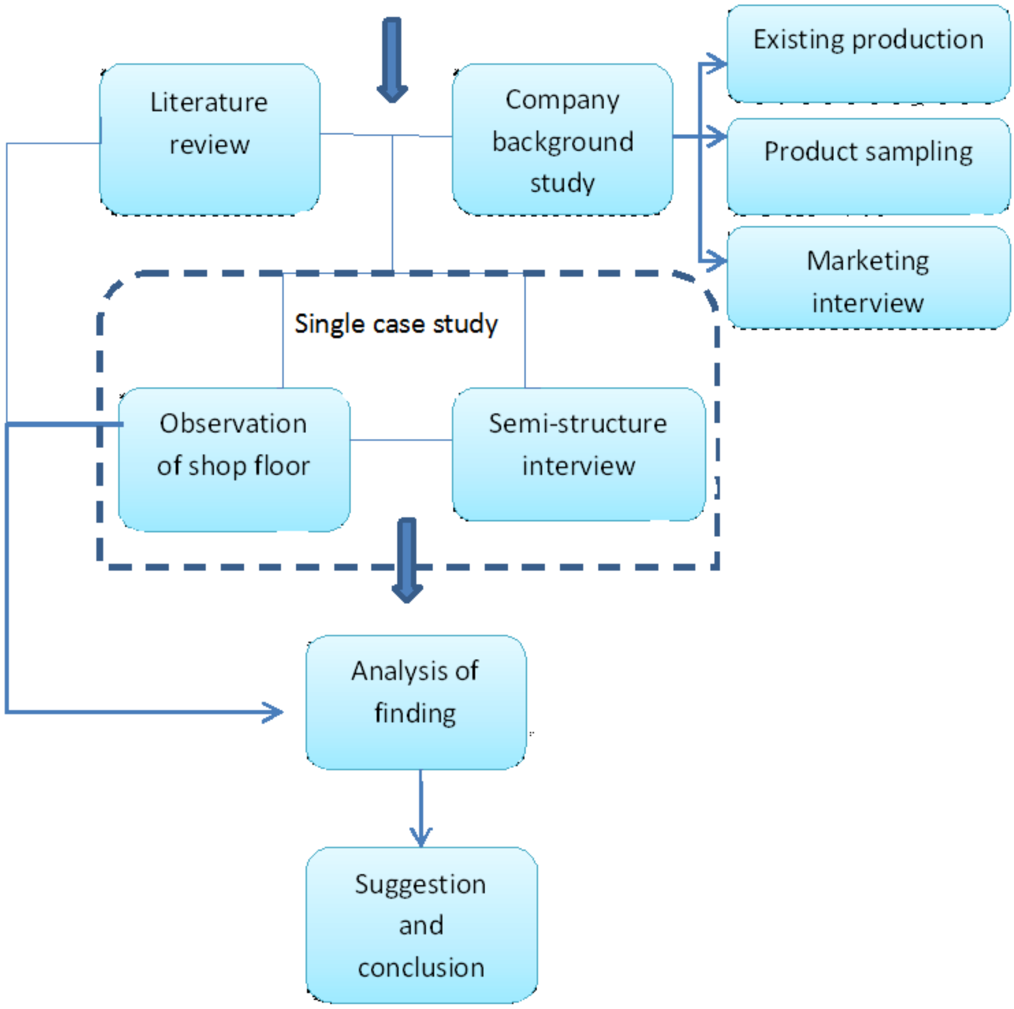

Figure 9: Research process diagram

The single case study method starts with discovering the roots, based on the literature reviewed, to identify the main aspects and main resources regarding the volume flexibility and product mix flexibility. In this term 'observation of shop floor' refers to the process in which the machinery and manpower reviews were conducted in parallel with a semi-structural interview. These concepts based on different literature resources were defined properly in order to build a framework for finding and analysing the section. Then the source factors were subsequently assessed based on comparison and were then bridged with the current production of the company in order to realise the related mutual source drivers in order to answer the first research question. Moreover, analysing the outcome of the first research question will be the basic assessment in the case of this under study to realise how volume flexibility and product mix flexibility are handled in batch production. Finally, the suggestions and conclusion are presented.

3.2 Research Approach

This sub-chapter presents a detailed description of choices regarding the design of the study.

In this research, combinations of quantitative and qualitative research techniques were used. Looking into the terminology, quantitative is mostly used as a term for representing any data collection technique or data analysis procedure that uses a statistical method. A qualitative approach, on the other hand, indicates any data collection technique or data analysis procedure that uses non-numerical data (Saunders, et al., 2009). Yin (2003) indicated content analysis, structured observation, surveys and questionnaires to be methods used in a quantitative approach; while document analysis, interviews and unstructured observations can be pointed out as methods used in a qualitative approach.

This study's research involved the use of a guiding theoretical framework, which provided a good basis for the empirical research. In addition, in this study, the term qualitative is mainly used for discussion, dialogues, and semi-structured interviews as a starting point for identifying problematic areas, and as a tool to discover how and what to measure and where to measure.

Besides, in this research, a deductive approach was used with theories in order to define the variables, and considered as a scientific research - where a theory is developed and empirical test is implemented (Saunders, et al., 2009). Hence, during this study, the research starts by defining the theoretical framework. Then there is a possibility to conduct empirical research through testing and comparing with the theoretical framework (Saunders, et al., 2009).

3.3 Case Study

In order to provide deeper knowledge about the challenges regarding product mix flexibility and volume flexibility in batch flow production and also to be able to suggest suitable solutions for the arisen issues, a case study was conducted.

A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2003).

According to Yin (2003), a case study is a flexible method, which can contribute to the investigation of challenges related to the research problem and understanding a real life phenomenon in depth. Moreover, research questions can provide an important indication regarding the appropriate research method to be used. So, choosing the case study will help to answer the research questions based on different techniques for data collection including interviews, observations and measurements.

One single case study will be presented in this research. More specifically, the production department of a metal subcontractor company will be the source of the primary data collection and gathering of findings. This single case study will be explained through the implementation of a single case study research strategy supported by a direct observation of the different groups.

The project in this study refers to the examination of three major operational processes of a metal product family. These processes are appropriate study references since the product variety and volume variety are based on different dimensions, sizes, and volumes (based on different orders from customers). Moreover, in order to fulfil the finding and analysis section, the author applied the theory model in terms of volume flexibility and product mix flexibility on the type of company production (batch production), based on the sample under study. In this case, the different aspects involved were identified and paralleled with the theory of study.

3.4 Data Collection

Data can be gathered through primary and secondary data (Bailey, 2007). These two methods are essential to effective data collection. Primary data can be gathered from field work undertaken by the researcher (Baily, 2007). In this study, primary data was collected through observations for measuring the time, and by understanding the actual processes and any potential problems being encountered. Open-ended interviews were also undertaken with key people in the company, as well as a review of organisational documents.

3.4.1 Interviews

An interview is one of the most important sources of case study information, and can provide a deeper understanding on the investigated area (Yin, 2003). Generally, the interview process includes two tasks. First, following the line of inquiry; second, asking conversational questions in an unbiased manner (Yin, 2003).

As preparation for the data collection, focused interviews were conducted with a set of pre-selected companies in order to better understand the scope of market demand and marketing investigation of the objects of interest (locking shaft); from which questions were formulated regarding volume and variants of products. Moreover, interviews were made with production respondents in the selected companies in order to investigate difficulties, challenges and source factors for coping with volume flexibility and product mix flexibility.

Since the researcher needed to investigate the source drivers' influence on volume flexibility and product mix flexibility, a non-structured interview was selected as the appropriate method because it helps to adjust the relative questions and direct the interview to the main objects of research. Non-structured interviews were conducted in order to provide a more detailed and in-depth empirical finding of important technical source drivers. Moreover, the interaction between the researcher and interviewee allowed the researcher to gain richer and more valid data in the case company.

In Laserkraft AB, the case company, the interviews were conducted with four key correspondents who were aware of the main problematic areas of this research's focus. The interviews mainly concentrated on links to the second research question, where people from different positions point out different challenges regarding how to achieve volume flexibility and product mix flexibility (Table 1).

Table 1: Correspondent Interviewees

Correspondent	**Focus**	**Mode of interview**	**Duration**
Direct manager	*Achieving volume and product mix flexibility*	*Semi-structured + Non-structured*	*8 hours/ several meetings*
Production consultancy	*Volume and product mix flexibility and product features*	*Semi-structured*	*1.5 hour*
Production manager	*Volume and product mix flexibility, batch production and facilities*	*Non-structured*	*2 hours/several meetings*
Production engineer	*Volume and product mix flexibility, tools and machinery*	*Non-structured*	*4 hours/several meetings*

Throughout the entire thesis period, the company supervisor (Managing Director of Laserkraft AB), along with many employees in different departments and functions, were available for questions and presentations on the findings, of which there were several. This ongoing dialogue created the foundation for identifying challenges related to volume flexibility and product mix flexibility, and for developing an understanding of the complexity of the batch production.

During the data collection of observation and cycle times, the operators were not only observed, but also participated in discussions. The information they provided can be seen as detailed aspects concerning the topic of under study, based on their own personal opinions of their working conditions. However, they mentioned that as this was not written down in a structured manner it cannot be seen as being based on real interviews. Still, the information from these discussions has been included in the analysis, and it has proved a very important aid for the researcher to be able to create as truthful a picture of reality as possible, and it has supported the conclusions.

3.4.2 Observation

Observational evidence is a useful technique in providing additional information in order to understand the context or the phenomenon being studied (Yin, 2003).

In order to investigate the main source drivers and answer the first research question, observation within the factory was conducted. The researcher played the role of "participant as observer" in the case company. All observations occurred by physical participation of the researcher on the shop floor.

This technique made it possible to gather data by watching the fundamental aspects influencing the shop floor such as: equipment and facilities, operator's behaviour, material handling, etc. The chosen process of observation was determined by focussing on a sample product under the study to gain knowledge and increase the understanding of important source drivers influenced in volume flexibility and product mix flexibility. Furthermore, the observation was formed across different meetings and informal discussions with the section process manager of each department (Table 2).

Table 2: Observation at the case company

No	**Department**	**Involved observation**	**Amount of observation session**	**Duration**
1	*Laser cutting*	*Operators and section manager*	*5 times*	*1.5 hrs*
2	*Turning and milling*	*Operators and section manager*	*4 times*	*1 hr*
3	*Welding*	*Operators and section manager*	*6 times*	*1 hr*

During this study, each step of the related production process was observed and as much data as possible was collected. The cycle time for each production step was manually clocked at each station. The operator's movements and behavior were also included in the observations. Notes were taken whenever something happened that could affect the cycle time. To be able to use these data in the analysis chapter, some of the important observations that seemed to have the most impact on the result of this study were recorded both as pictures and videos.

3.4.3 Documents

Secondary data is the sort of data that was previously collected for a different research purpose. However, the major advantages of secondary data in this research are to answer the research questions, which contribute to saving time and the cost of data collection processes for the researcher (Saunders, et al., 2009). This study relies on relevant written documents such as articles and books in the scientific field. The major source of secondary data used during this study includes literature reviews and company documents and databases, which clarify the rules and limitations that need to be taken into consideration.

Documents were collected in the form of PDF files for previous data about the products under study including the material specification, dimensions and prices. A PowerPoint presentation of the case company provided information about the history of the company, organisation, product range and services.

3.4.4 Literature Review

Literature review is the theoretical and methodological contribution of a particular topic which provides the opportunity to identify, locate and analyse concepts related to subject of research (Williamson, 2002). In order to perform this research, especially relating to the background and context of this thesis, the necessary data gathered is based on theoretical studies and literature reviews and depends on relevant books and articles. In this study the topic is broken into two main areas: batch flow production and flexibility output, which consist of volume flexibility and product mix flexibility.

In order to find reliable literature, databases were limited to those accessible English documents through Jönköping University library and Google Scholar, whether books or electronic materials. The following databases were chosen for the search of academic articles: Scopus, Primo and books related to production development design were found on Libris (Swedish search service which contains universities and public libraries) and ebrary (electronic databases of the library of Jönköping University). The search was implemented using the keywords “product volume flexibility”, “product mix flexibility”, and “source factors”. Besides, search words linked to type of production included “production system”, “batch production”, and “cellular production”. Afterwards, in order to narrow down the research, identified keywords were combined through the use of AND, OR, and NOT. Based on the relevance of these books and articles, primary data was collected. The investigation of literature regarding its relevance relies on the research questions and the aim of this thesis (Saunders, et al., 2009).

3.5 Data Analysis

In this section, the interpretation and synthesis will meaningfully align extracted data in order to answer the research questions. The analysis was based on information in the data collection step in addition to the studied theories. The aim of this work was to investigate the volume flexibility and product mix flexibility in batch flow production. To be able to realise the relationship between flexibility output and the type of production layout, different theories and literature were studied. The source factors were then derived from the theoretical background and were identified and then analysed. In order to arrive at the research conclusion, the collected empirical data was paralleled with the theoretical framework.

The fundamental factors from the theories, interview and observation were analysed by focusing on the outcome of the findings in order to get close to answering the research questions, based on bridging and comparing what others have previously done and how they integrated their results between the related topic areas (Cooper, 2009).

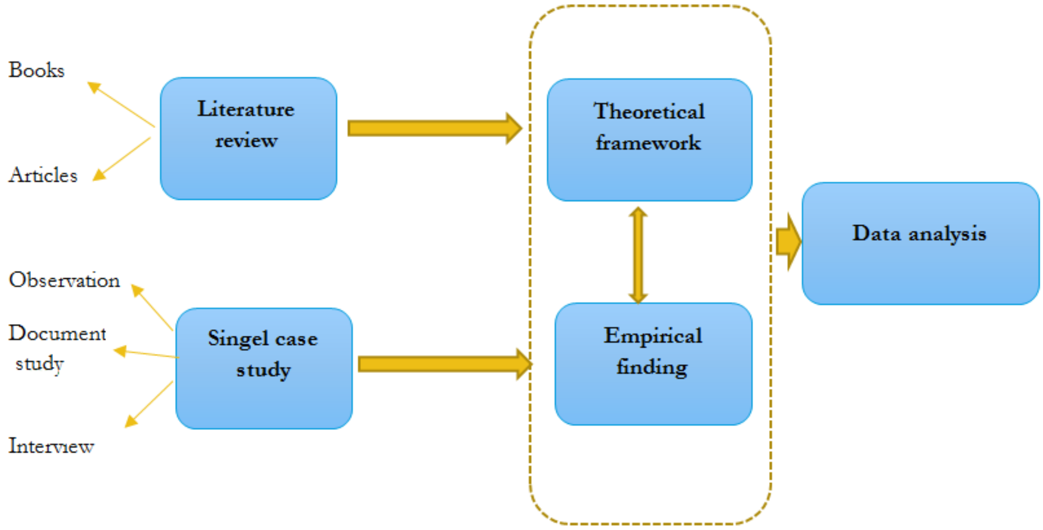

Figure 10: Data analysis

The data analysis illustrated in Figure 10 was performed in the form of a comparison between the identified source drivers in literature and transcribed data from interviews and observations. Then relevant source drivers were addressed with a focus on answering each research question.

3.6 Validity and Reliability

It is essential to have continuous quality control on the data collection process in order to maintain high quality research outcomes (Williamson, 2002). Validity and reliability are two fundamental criteria for judging the quality of research (Williamson, 2002). Basically, validity refers to measuring the accuracy of work, while reliability is defined as obtaining the same results and findings, which comes from the repetition of the study (Williamson, 2002). In fact, similar results contribute to reliable conclusions at the end of a research as well.

Moreover, validity can be assessed in two points, internal and external validity, which claims a difference between them. Internal validity is related to whether or not the result is based on chosen variables or if it has become influenced by unidentified factors. External validity states if the result gives a possibility to generalise, that is, to apply the same result to other populations (Williamson, 2002).

To be able to provide validity and reliability in this report, different data collection tools were implemented. In order to make sure that the research followed the right track, the researcher did not simply rely on the interviews as the only method, but also used observations to confirm the reasoning. Henceforth, observations enclose the actual events and eradicate the norms of the events that probably could be the outcome of the interviews conduction. In this case, to be closer to answering the research questions, the questions of the non-structured interviews were designed in parallel to the research objective in order to get a high internal validity.

Moreover, observations of three main production processes such as welding, turning and laser cutting and their equipment on the shop floor, were selected in order to support the internal validity. Concerning the external validity in this single case study research, it will be difficult to make a generalisation due to the limited empirical studies on specific operational processes of the case company and also studies on explicit metal components. However, this study could have generalised on the industrial metal work companies who have similar problem areas and similar types of production processes.

Basically, reliability refers to the dependency of the findings and reproducibility of the same result (Yin, 2003). The reliability of this study is considered good and with few errors due to the various sources used during the literature reviews. During data collection, some of the important observations that seemed to have the most impact on the result of this study were recorded both as pictures and videos. Notes were taken during interviews and during any possible encounters of the cycle time measurement. Furthermore, great care on the part of the supervisors both in Laserkraft AB (regarding the empirical findings) and Jönköping University (regarding the academic research point of view), allowed this research to produce highly reliable standards. It must be noted that in this study, the results might not be the same if another researcher repeated the exact same study.

4 Empirical Findings and Analysis

This chapter summarises the findings and analysis from the empirical studies. It also presents the analysis of the common source drivers between volume flexibility and product mix flexibility, as well as an analysis of the current technical capabilities of firms in order to identify challenges, strengths and opportunities needed for volume flexibility and product mix flexibility achievement.

To become closer to answering the second research question, the researcher analysed the theoretical findings on the firm's current production subsystems considering flexibility in three main processes (laser cutting, turning and welding), machinery, labour and material handling.

4.1 Context of Company and Current Production in Laserkraft AB

The main focus of Laserkraft AB is to grow their business of demanding industrial customers with a base in Scandinavia and the northern part of Europe. Thus, the main target market is focused on first tier customers, which require outsourcing the supplier in order to provide world-class quality metal products.

Laserkraft AB group, as a subcontractor, offers industrial metal works. The company was founded in Sweden in 1998. Today, they have 122 employees and 17.2 million Euros total turnover in 2014. The group has three industrial factory locations: Bredaryd (60 employees), Pikab in Hallsberg (37 employees), and Eurosvit S.R.O in Slovakia (25 employees).

The firm's business model is based on manufacturing metal components and welded/assembled subcomponents with direct deliveries to their customer's production lines. Raw materials, in terms of sheet plate metal and bar magazine, come into the factory where the different processes and operations such as laser cutting, press breaking, bending, milling, turning and welding converts them into the finished products. The type of materials used focus on the steel family, which is categorised as plain carbon steel and stainless steel. Thus, according to customer requirements based on properties and application of steel, raw materials are purchased and are then delivered directly to the warehouse.

According to the customer's demands, the company has to specify which tools and machines are required to be able to manufacture the products efficiently and in a competitive way. Basically, the physical positioning of machinery and equipment make an efficient flow layout in the shop floor. A pull system in production planning regulates the production flow on the shop floor, which is controlled by customer orders. After that, the production team, such as the factory manager, production manager and production engineers decide on a layout and design for the production system as a whole.

4.2 Product Sampling

The investigation for this research was accomplished through the implementation of batch production on a specific metal product family, which is internally called "locking shaft" (Figure 11). This sample indicates initial information about the case under study to realise how Laserkraft AB deals with volume flexibility and product mix flexibility.

After a marketing investigation was conducted on one of the main customers and a study of the previous data about these products, items were classified into the family product by inspection and analysis on their routing requirements and production facilities requirements. Besides that, a study on groups of their drawings provides information about geometry factors such as the size and diameter of the parts.

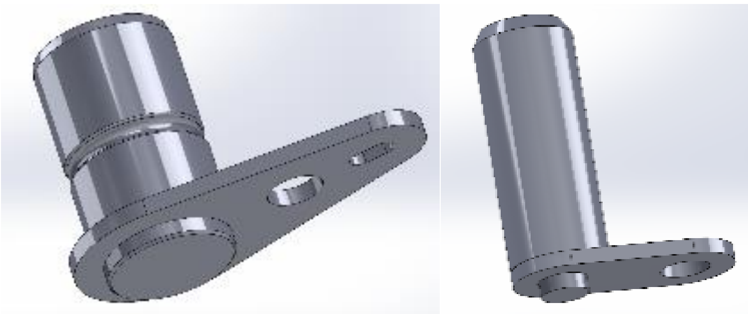

Figure 11: Examples of product sample (locking shaft)

Basically, the structure of this product family contains sheet plate parts and pins, which are assembled together at the end (Figure 12). The purpose of these products is mainly to connect two involved arms together. For instance, this component can be seen in lifting trucks, loader arms and in general through different industries such as heavy machinery equipment, agricultural machinery, and in the automotive industry.

In order to describe the products, it is essential to describe the properties and the type of materials used. Thus, properties such as resistance to corrosion, high resistance and ductility are the main requirement for choosing the right materials for this application.

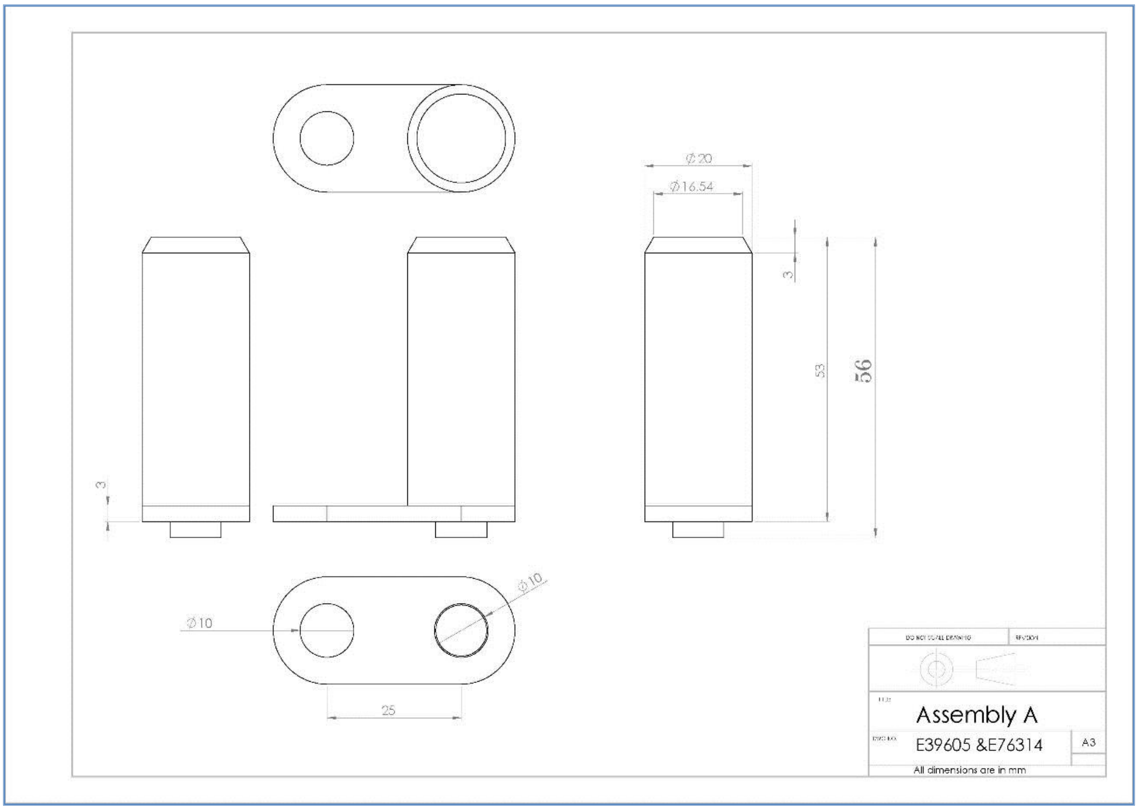

Figure 12: Example of a component's drawing

This product family is produced in three main processes. First, the sheet plates are cut into different thicknesses and shapes through the laser cutting machines. Then the pins are produced in the turning machinery, and at the end these components are welded together in an assembling process. In Figure 13, the group of random sampling of these products is presented based on an annual volume order and variety of products. As illustrated in the first diagram, the demand numbers of products change from a low volume of around 100 pieces up to a high volume of around 30000 pieces in a year. The length of the pins and thickness of the sheet parts vary in diameters and sizes. In general, this figure indicates the problematic area of the research under this study. Therefore, it is generally not feasible to classify all the outputs into one of the limited batches. This means that the section comprises of how the company deals with the volume and product variety in the production system.

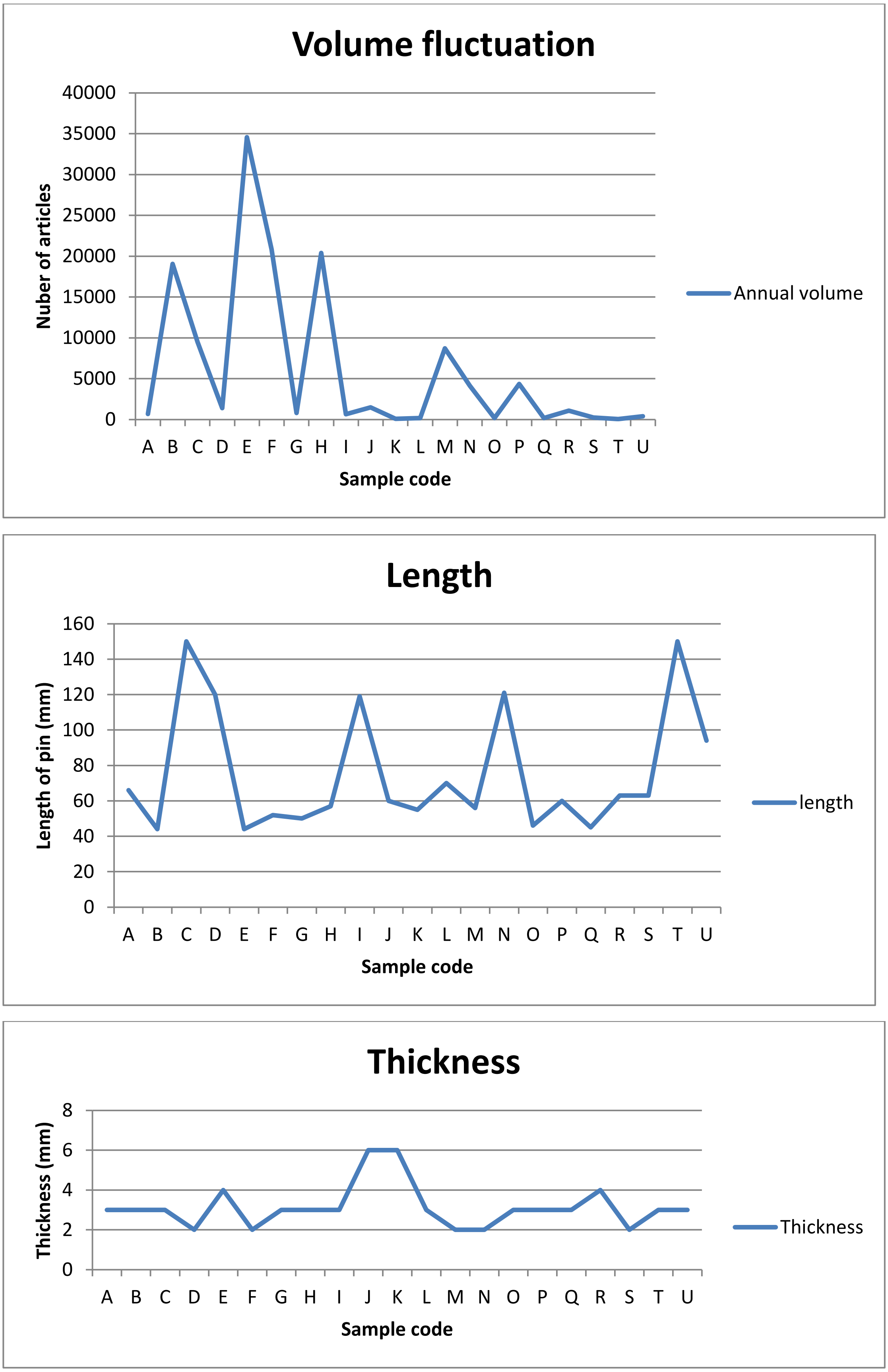

Figure 13: Characteristic of fluctuation in volume and variety of 20 samples

4.3 Production System and Processes

In this sub-section, the specific parts of production will be described in order to analyse how Laserkraft AB deals with volume flexibility and product mix flexibility. This empirical finding will contain the set of internal abilities of the company such as machinery, labor and material handling facilities in spite of realising their strengths, problematic areas and improvement opportunities in order to achieve volume flexibility and product mix flexibility.

The main operational cells are divided in laser cutting, machining and welding cells. The company uses an intermittent process flow. They have a cellular layout where usually two or more machines are used in the cells, which produce a limited variety of products in medium or high volumes. Figure 14 demonstrates the 3D visualisation of the layout and machinery positioning in the company as well as the direction of raw materials to the finished product. Moreover, semi-storage shelving and material handling movement can also be visualised in order to realise the different aspects of the subsystems in the batch production system.

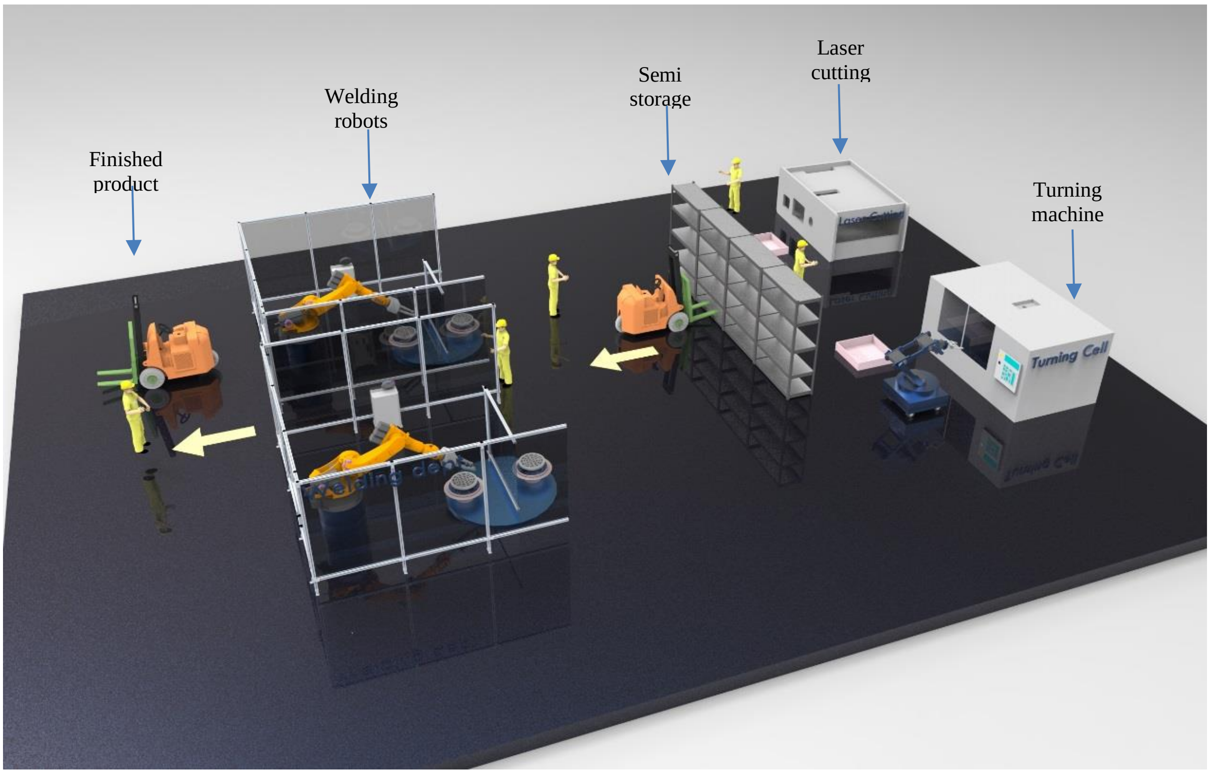

Figure 14: Visualisation of layout and machinery positioning (one cell)

4.3.1 Laser Cutting

At the laser cutting cell, the sheet metal parts with a thickness of up to 35 mm, are being produced. The machines use computer generated cutting pass techniques to make the sheet metal parts easily and inexpensively, in any size and shape. There are five automated laser-cutting machines in total, with a capacity of up to 6.3 KW. Based on the consumption of the laser beam, Laserkraft AB is able to cut steel sheet plates up to 25 mm thick and stainless steel up to 16mm. Not only that, but depending on the type of material consumption, the machines use Co2 fuel, which offers clean, effective and cheap cutting of stainless, and are able to cut sheet plates up to 35 mm and at a speed of 6ooo mm per min. While, in the case of the plasma laser cutting machine, it has a faster performance of 9000 mm per min, but produces thinner thicknesses of up only to 20 mm.

The machines automatically receive the metal sheets with dimensions of 3000*1500 mm from the inventory; then the sheets are fed into the cutting area one by one. The laser cuts the products, and the entire sheets are then moved out of the machine to the table where the products are collected by the operator.

The procedure of emptying the sheets of all the products and placing them onto the finished goods pallets is called plunder. It is a hard job, where the sheets are shaken to release the products and then the products are collected manually and placed on a pallet at floor height. This task is performed because the part of the machine that is supposed to do the same task (loading) does not work properly with small pieces (unloading).

The company has suitable facilities in this department, which in general laser cutting has a better level of flexibility due to the advanced automated technology in place. This variant of facility makes this process more flexible and efficient to deal with high volumes and many variants of products. However, there are some opportunities available such as solutions for automated unloading finished products in order to reduce cycle times in this process cell.

4.3.2 Machining and Turning

The machining processing cell includes four different machines, which are based on their specifications, performance milling and turning. At this station, the bar loader system automatically feeds out raw materials at the required distance from the chuck. Based on maximum machining diameters and the properties of the materials, the type of machine and process are selected. Each machine has between 20 to 36 tools in internal storage, which are automatically controlled during the process by a spindle (rotating axis). The maximum rotating speed of the spindle is one of the main specifications of the machine which plays a key role in the operation time (Figure 15).

In addition, to increase the flexibility of performance, there are two external tool stores. According to customer orders and complexity of the product, specific tools are chosen which are installed during the setup times. However, although this variety of external tools improves work flexibility, on the other hand it increases the setup times.

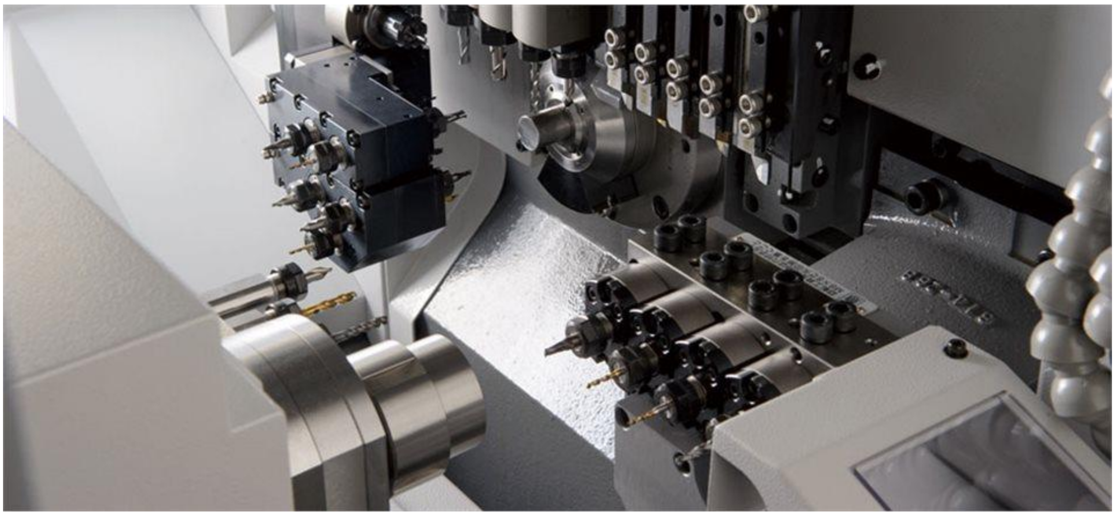

Figure 15: Flexible tool storage in turning machine.

A lot of energy and time goes into observing the machine and adjusting its settings. During observation and interview with the operator, it was realised that the set up time to organise tools for each product is the most challenging part of this process. In addition, due to the response to various orders from customers regarding different diameters of pin parts, a local supplier has supported the company. Atorp AB is one of the partner suppliers who collaborate with Laserkraft AB in order to provide machining parts so as to achieve the required flexibility and reliability.

During the study of this particular process, the researcher conducted a non-competitive benchmarking of Atorp AB, who are experts in machining and turning operations, by providing various numbers for facilities and technology in order to identify and compare the challenges in regard to volume flexibility and product-mix flexibility.

During the observations, it was founded that firms could increase both productivity and flexibility outputs by using strategic flexibility approaches and investing on specific operations. This investment could include a high range of facilities and equipment to cope with volume flexibility and product mix flexibility. By focusing on specific operations in order to produce a high range of products, as well as many variants, is the main reason for dealing with flexibility output. Atorp AB could provide more than ten different turning machines in terms of responding to the variety of customer orders. Furthermore, according to the batch production, the closer the machines are position to each other, the more advantages arise. Besides better utilisation of space, the number of man hours can be reduced because one operator can set up or program two or more machines at the same time. Therefore, this method would increase flexibility and ease in material handling due to reducing the amount of products travelling on the shop floor (Figure 16).

Figure 16: Exemplification of how volume flexibility and product mix flexibility can be achieved through large investment on specific process (Atorp AB shop floor).

4.3.3 Welding

The welding process plays an important role in Laserkraft AB since it is the finalising process for the product under study. The welding department was divided in ten manual stations and five robotic welding cells. The welding cell was capable of welding components of up to 500 kg in weight and with a maximum length of 2.500*1.500 mm on the fixture table. The difference between manual and robot welding is that the manual process can be faster than the robot welding for the lower output numbers. However, welding robots are more accurate in terms of position tolerance of ± 0.1 mm. Consequently, while the manual welding cycle time is less than in the robot welding process, the productivity is lower (head of welding department).

Because this project focuses on fluctuation in volume and the verity of articles and standardisation process, automated cell and robot welding is also another important issue of this study at the welding station. Furthermore, the researcher discovered that among all the processes, welding needs to be taken into more consideration when identifying challenges. As the welding process is compared with two other processes, it requires more human involvement in order to adjust a welding table, design the fixtures, clamping and so on - which will be described later in this report.

Choosing the right type of welding in order to join a component based on the material properties is the primary decision for the welding of product families. Moreover, in order to investigate a welding process, there are some input parameters such as welding speed, material thickness and properties, which have direct influence on the production flexibility output.

The main element in a welding process consists of the welding power source, twin robot welding with 6 axis movement abilities, multi-task operator responsible for programming the robot, work piece station - which includes a symmetric welding table, fixtures, positioning, clamping and unclamping the component, and at the end, unloading finished products onto the pallet. In general, during the observation and interviews with the welding department, the researcher realised that there are many challenges that need to be taken in consideration.

4.3.3.1 Challenges in Welding operation

In order to identify the critical challenges, there are some aspects to be noted on increasing the cycle time. Fixture is an important element in the welding sequence. It uses a clamping system to position the components accurately together. In this case, each article of a different size and diameter requires certain fixture systems in place. Designing the fixture for each article is costly and to increase the lead-time it takes up to two weeks; in consequence this reduces the flexibility to respond to the variety of products. In order to cope with this challenge, after receiving the drawing of the component from the customer, the company then needs to involve the suppliers to design a number of appropriate fixtures and clamps for the various articles.

The next step is to install the fixtures on the welding tables, after which the components must be placed and clamped in small batches. The advantage of a symmetric table is that when the robot performs on one side of the table, there is generally an opportunity for the operator to command the other side. While the first batch is welded, the welding table rotates 180º in order to prepare for the next batch welding and unloading from the other side. This process keeps be performed until all of the orders are welded. The difficulty in unloading the finished product is the high temperature of the finished products when the operator wants to unload the product from the fixtures. Basically, the waiting time for cooling is a non-value added action when the next batch is waiting to be loaded onto the fixture.

4.3.4 Material Handling and Flexibility Output

In order to investigate the effect of volume flexibility and product mix flexibility on material handling, there are some aspects that should be taken into consideration. The first point is to analyse the material transport equipment between different processes. According to chapter 2.3.3, cellular production layout typically requires less floor space and parts are moved within a machine cell rather than within the entire factory. Therefore, material handling between processes is reduced. However, the complexity of material handling could increase due to volume flexibility and product mix flexibility. In this case, the company has designed the semi-storage shelf close to the next scheduled machines in order to control and transfer the materials at the right time for the next process. Furthermore, many different products require a large storage place to keep track of all the different materials and fixtures and to quickly get them to production when needed.

4.3.5 Labor and Flexibility Output

Although the production system of major processes in the company are automated, there are still some tasks such as programming, setting up the machinery, and positioning and unloading the parts which are performed as manufacturing support systems. During the observation, it was noticed that in each specific process, one multi-skilled worker can undertake many tasks. For instance, one operator in the welding operation could firstly program the robot-welding machine, then position the parts and also unload the finished products. Moreover, multi-skilled employees provide many advantages for the company by way of performing multitasks, as well as decreasing labor costs and increasing planning efficiency.

4.4 Production Planning and Control

In order to investigate product mix flexibility and volume flexibility, the production planning and control needs to be considered.

4.4.1 Pull System of Production Control

After coding each batch of parts, the pull system determines how different parts shall be transported to the different workstations in the production sequence. Thereafter, the upstream station approves production of the needed parts in the next station. A production Kanban allows the upstream station to produce a batch of parts. Each batch is then transported to the next station based on the bar codes on each pallet (Kanban cards). To reduce any bottlenecks during this flow, this transportation occasionally stops at semi-storage shelves when the next machine is running with other parts. In effect, this production discipline pushes parts to a better flow in the system and consequently upstream and downstream stations operate according to the Kanban pull system. Computer-based systems for planning, scheduling, and controlling the resources, materials, and supporting activities are implemented in order to control and balance the production process planning within the company.

4.4.2 Capacity Planning and Slack Capacity

Basically, capacity planning in this study could be analysed in terms of facility size, economies of scale and scope through flexibility in both volume and product mix.

Historically, the company was mainly using a strategy in pace with the market. When there was a decline in incoming orders a few years ago, they decreased their capacity. However, when the incoming orders increased again, they also increased their capacity, again. When customer demand temporarily increases they try to manage this by acquiring extra personnel or by working extra hours.

In general, according to Hallgrena & Olhager, (2009) there are a number of strategies for changing the capacity available to the manager to meet uncertain demands. This company adopted capacity change in a few different ways (Figure 17)

In order to deal with volume flexibility over time, subcontracting has been highly rated among other strategic capacity choices. In fact, demand comprising different annual volumes requires more set up time and consequently more batch sizing. Thus, by over timing the plant up to two or three work shifts can help the company handle this difficulty. On the contrary, according to interviews with the managerial teams, it was found that additional equipment and facilities are the highest rated strategic capacities to improve the product mix flexibility. However, subcontracting is the second rated solution for handling the product mix flexibility. For instance, in order to produce pins with complicated turning processes more economically, the company can use subcontracting strategies either with Far East suppliers or with higher quality locally located suppliers to handle the product mix flexibility. The latter, hiring or laying off workers has the lowest rate among other strategic capacity choices in the company. Perhaps, the company prefers to use other alternative capacities, which are economically and logically feasible to handle volume and product mix flexibility.

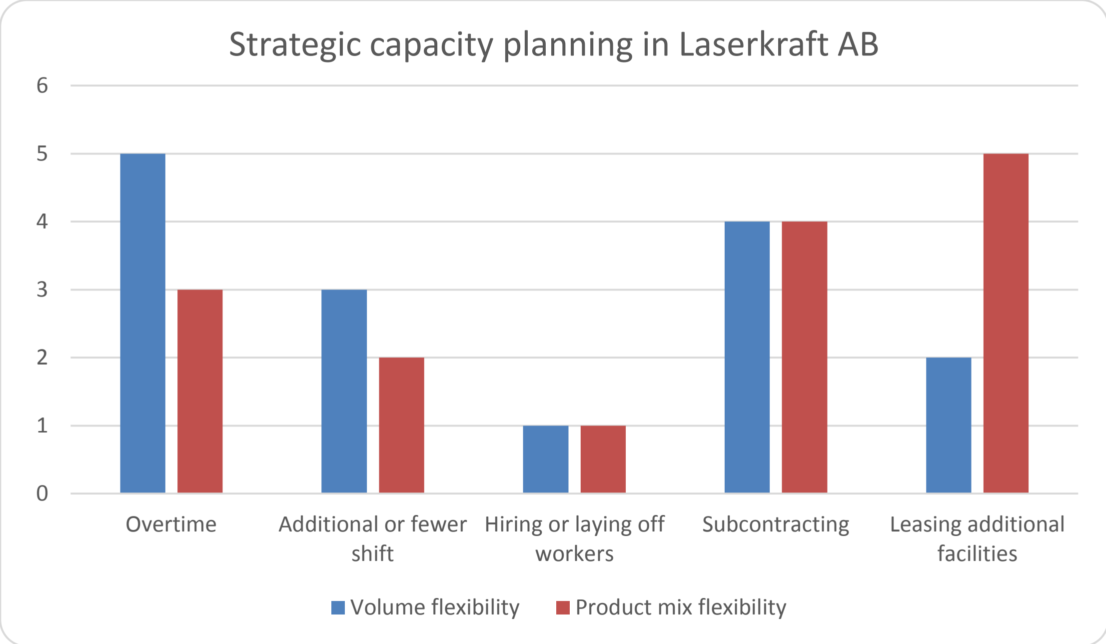

Figure 17: Strategic capacity planning in Laserkraft AB.

*Rank between 1 to 5

4.5 Analysis

This chapter presents an analysis of the comparison between the literature review and empirical data for the case company in order to realise the possible consequences of research for Laserkradt AB. The analysis of source drivers between the volume flexibility and product mix flexibility was conducted in order to answer the first research question. Then in order to fulfill the second research question, those common source drivers were then examined in the case company production system to point out how volume flexibility and product mix flexibility will be achieved in batch production.

4.5.1 Analysis of company results regarding RQ1

In order to analyse the first research question, the collected articles were grouped and broken down in order to identify the important source drivers among the volume flexibility and product mix flexibility. Then, a synthesis of the collection of outcomes was drawn as a framework of source drivers to answer the first research question.

In the literature studied, it was found that volume flexibility and product mix flexibility are the two most widely cited flexibilities of all flexibility types. They are also the most two important flexible manufacturing capabilities, which have a crucial influence on customer satisfaction. Volume flexibility refers to the ability of firms to quickly adjust production volume according to customer demand. Mix flexibility refers to the ability to efficiently switch between producing different products without penalty to cost or performance. As Zhang et al (2006) argued, flexibility in a production subsystem is the foundation for flexible manufacturing capabilities. His argument determines how flexibility in the whole value chain of firms can have positive effects on manufacturing capabilities. For instance, labor flexibility, material handling flexibility and machinery flexibility have a direct influence on volume flexibility and product mix flexibility (Zhang, et al., 2003).

Since the contribution of analysing the literature was to identify the common source drivers between volume flexibility and product mix flexibility, this was narrowed down to specific aspects related to various manufacturing practices and technical aspects of batch production. As a matter of fact, the focus of the first research question is to investigate the common source drivers which have a relationship with the case company production subsystem.

Furthermore, Suarez et al (1991) identified flexibility source drivers through implementation of volume flexibility and product mix flexibility based on the impact of internal and external aspects. Consequently, these source drivers could be categorised from a strategic flexible approach such as: level of automation, production management techniques (e.g. JIT), slack capacity, labor policies (e.g. labor skills) and relationships with the supplier (e.g. subcontractor). Strategic sourcing is referred to as a way to obtain manufacturing capabilities without capital investment (Carter & Narashihan, 1990). Moreover, Hallgrena & Olhager (2009) divided the internal common source drivers between volume flexibility and product mix flexibility in terms of a proactive and adaptive strategic point of view. Their work mainly contributes to identifying the source drivers based on the objectives of the operational performance of the firms. For instance, their model in Figure 7 indicates which specific types of strategic flexibility approaches could be accomplished in order to achieve the objective of the firm's operational performance. This approach could be a good guideline for flexibility development in manufacturing operations. In general, their empirical findings and analysis conclude to the top three common source drivers between volume flexibility and product mix flexibility, such as: *set-up time reduction, multi-trained employees and advanced manufacturing technology.*

Despite strategic flexibility approaches, the significance of FMC has a great impact on realising the common source drivers between volume flexibility and product mix flexibility (Zhang, et al., 2003). They believe that FMC, which includes machine, labour, material handling, and routing flexibilities, have a direct and positive impact on volume flexibility and product mix flexibility. However, they could cover their research and suggest the effects of AMT and OIP on FMC (Figure 6). In general, their study empirically approves the support of manufacturing capabilities (volume flexibility and product-mix flexibility) with FMC principles. These principles include details such as: *product and process design, manufacturing planning and control, integration between function and process, set-up time reduction, cellular layout, pull production, preventive maintenance, and continuous improvement.*

This analysis highlighted the sorts of common source drivers between volume flexibility and product mix flexibility, which are recognised through a combination of empirical and theoretical researches. However, the aim of the analysis of the first research question is to investigate the effect of the common source drivers through the case company production subsystem, and determine the most relative common source drivers between volume flexibility and product mix flexibility.

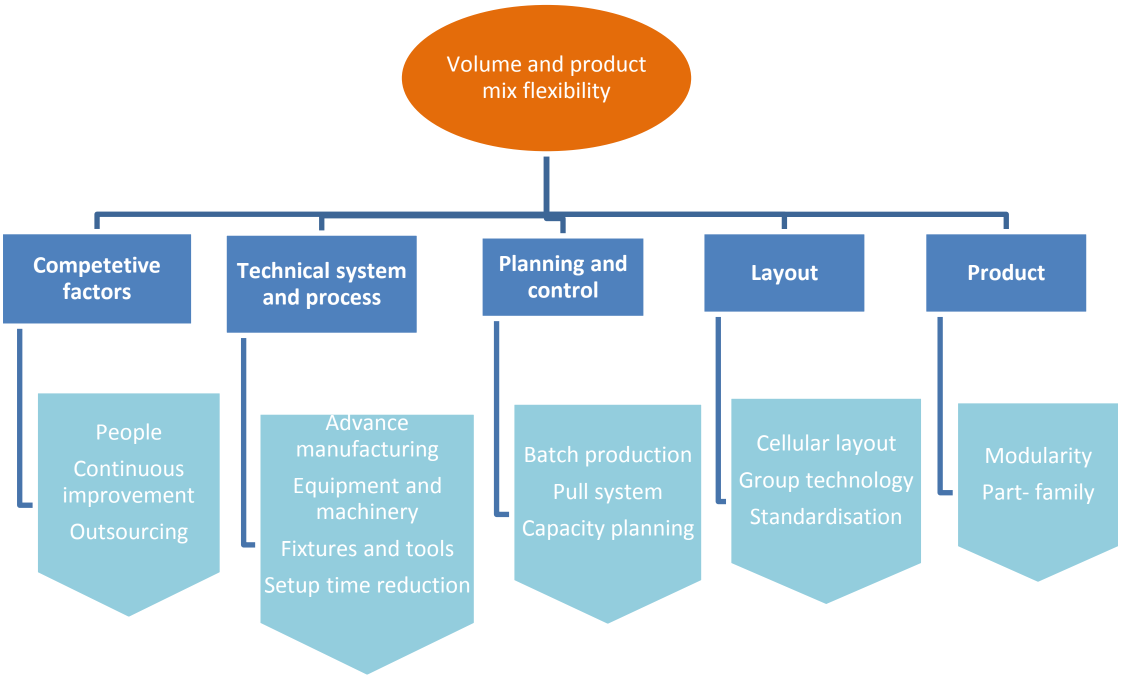

Figure 18: Essential common source drivers between volume flexibility and product mix flexibility in case company

During the case study research, the most crucial aspect of the production subsystem was considered in order to find the common source drivers between volume flexibility and product mix flexibility. The outcome of data collection on the case study revealed that competitive factors, technical systems and processes, planning and control, layout and product specification have essential roles to play in identifing the source drivers (Figure 18).

Competitive factors consist of human resources, operational improvement practices and advance manufacturing technology. For instance, it was realised that multi-skilled employees provide many advantages for the company such as performing multi-tasks as well as decreasing labour costs and increasing planning efficiency. Furthermore, continuous improvement and preventive maintenance are the competitive source drivers that Laserkraft AB has capability to consider when faced with volume flexibility and product mix flexibility in their production system.

Moreover, in order to improve technical systems and improve processes the company has this opportunity to invest on the new equipment and facilities required. However, investment on the new machinery is reliant on the manager's decisions based on the level of automation, size and capacity of production. For instance among different processes and equipment in Laserkraft AB, the machining department has a better chance to invest and improve in terms of reducing setup time, loading and unloading the products.

Cellular layout is one of the strong cited source drivers in both theoretical and empirical findings in order to achieve volume flexibility and product mix flexibility. Cellular layout eases material handling and leads to better utilisation of resources. The combination of a cellular layout with the pull system allows Laserkraft AB to enjoy a continuous transportational flow of small batches of products between different stations.

One of the challenges in cellular layout is to identify the family parts that require the same group of machines. Some cells may have a high volume of production at times and at others a very low level. To prevent poor balance between cells, Laserkraft AB has been using different capacity planning strategies. In fact, it has discovered that capacity planning is important for fulfilling the cellular layout. In this case supplier networks, using multi-skilled employees and duplicated machinery in different cells are the most cited strategies identified throughout the literature review in terms of enhancement in volume flexibility and product mix flexibility. However, it has been detected that it is difficult to balance the flow of work through a cellular layout compared with other physical layout types. This is because part families may follow different sequences through the cell that need different machines or processing times. Also, capital investment on additional machinery and the cost of moving existing machinery are other issues that must be considered before any changes in capacity are realised.

In addition, the design characteristics of products in terms of size, shape and function contribute to identifying families of parts with similar processing requirements. This categorisation in the primary process has benefits for planning and controlling capacity as well. For instance, based on documented data in chapter 4.2, Laerkraft AB has been outsourcing some items that they are not efficient or capable of producing in-house.

Figure 18, displays the framework of common source drivers between volume flexibility and product mix flexibility in the case company production system, which allows it to adapt the conditions in which volume flexibility and product mix flexibility develop.
The researcher grouped the common source drivers as a framework in order to create a guideline for the company. Furthermore, aside from answering the first research question, this analysis meets the same result as Salvador et al, (2007) suggested regarding how volume flexibility and product mix flexibility may be synergistically achieved. In fact it has been extracted that the combination of source drivers has a positive effect on both volume flexibility and product mix flexibility. However, this does not mean that all factors that have an impact on successful volume and product-mix flexibility were presented in this framework.
Since these source drivers were identified based on the case firm's operational performance and customer satisfaction, other firms with different business strategies and objectives might have use for different drivers to achieve volume flexibility and product-mix flexibility.

4.5.2 Analysis of archived volume flexibility and product mix flexibility in batch production.

The combination of empirical findings and first research question outcomes gave a basis for analysing the second research question. The analysis of the production subsystem in Laserkraft AB with regards to the specification of batch production, and also the product family under the study, has contributed to investigating which source drivers are most suitable in order to achieve volume flexibility and product mix flexibility in batch production here.

First, the specification of batch production by focusing on each process determined by promotion in the standardisation of tooling, fixtures and setups, plays a crucial role in order to achieve output flexibility in batch production. Therefore, it is crucial to analyse the machinery in terms of its flexibility and ability to handle volume flexibility and product mix flexibility (Zhang, et al., 2003). For instance, according to chapter 4.3, Laserkraft AB has a better level of flexibility in its laser cutting process due to the advanced automation technology used and the availability of a wide range of facilities to cut different sheet metal thicknesses. On the other hand, the turning department needs more investment on machinery to handle output flexibility. Not only that; but standardisation in welding fixtures is another factor affecting volume and product-mix flexibility in this process. For instance, the time for designing a new fixture in the welding process for each product - here, flexible family fixtures could reduce the lead times by up to three weeks, which is economically beneficial for the company.

In addition, production planning in the batch shop relies more on the actual demand. This means that the pull production system and inventory control are the most suitable approaches to transporting the products to different workstations in the production sequence. Obviously, production planning and scheduling play a key role in coping with flexibility output, especially when the product mix is highly varied (Zhang, et al., 2006).

According to Groover (2001) in section 2.2.3, increasing up to two or three working shifts is one adaptive strategic flexibility approach that can contribute to an increase in production to cope with higher demand, or to deal with product mix flexibility. In fact, using more working shifts gives more opportunities to firms for a more intensive use of their facilities and equipment, besides the optimal usage of energy and/or other resources. On the other hand, challenges such as additional administrative costs, complexity and difficulty in ensuring adequate supervision and potential negative effects on health and safety are issues that the company needs to deliberate.

The term 'economy of scale' refers to the earning of lower unit costs through the use of larger facilities (Meredith & Shafer, 2001). Therefore, the unit output cost and consequently volume and variety of output have a significant influence on capacity planning. However, to avoid any risk in regards to increasing the facilities, managers must examine more closely where the economies are expected to come from. Sometimes the economies stem from higher volumes or new technology in order to produce new products.
Similarly, the use of many advanced and flexible technologies such as programmable robots lean towards the economies of scope (Meredith & Shafer, 2001). By providing flexible facilities and equipment, the case company has grown its capacity in order to offer a high variety output, instead of only volume flexibility. In this case, economies of scope are driven from the same economies as those of scale, which are obtained over many small batches of a wide variety of outputs. For instance, installing new laser cutting machines on the shop floor with fibre technology expands the capacity of sheet metal products through the wide range of materials, especially on a low range of thicknesses more economically and rapidly. Also, the way that the machinery can be positioned in close proximity has many advantages in batch production, such as better utilisation of space, reducing manpower, and increasing flexibility and ease in material handling.

The results from the observation of different process reveal that reduced set-up times make it more efficient to produce small batch sizes. Thus, small batch production reduces the work-in-process and lead-times, and consequently increases the firm's product mix flexibility. Setup time reduction is one of the most crucial source drivers to achieving volume flexibility and product mix flexibility, a conclusion which resonated strongly in the empirical findings of the case company and literature analysis. This is because of the largest influence compared with other source drivers. According to what (Salvador, et al., 2007) argued, since product mix flexibility implies less time wasted in switching production from one item to another one, reduction of setup times not only leads to an increase in volume flexibility, but also improves the product mix flexibility too. In the case study, it was found that the company considered small batch sizing to minimise work-in-progress inventories in manufacturing and also increase their flexibility output. According to Groover (2001) the setup time reduction is essential in order to produce smaller batches. Section 4.3 describes how the case company implements different methods in order to improve setup time reduction across different processes. Nevertheless, it was found that the case company still has opportunities to improve their setup time reduction in their production system. For instance, in the welding process, they can use a quick-acting clamping system instead of bolts. Not only that, but they can also use modular fixtures, which can be quickly changed for each new part style and for different volumes of products.

5 Discussion and Conclusions

In this chapter, the discussion and conclusion of this work are provided based on the analysis in the previous chapter. The chapter starts with the evaluation of the methodology that was used in this study. Then the empirical findings of the research are evaluated in order to recover the research question answers. Furthermore, some contributions will be presented to develop the implementation of flexibility output in batch production for the case company. Further study in the area of this research is suggested in the 'future study' section. Finally, the last section covers the optimal conclusion of this research.

5.1 Discussion of Method

In this thesis, both theoretical and empirical findings were used to answer the research questions. In the deductive approach, the answer to the first research question was developed with theoretical consideration (Saunders, et al., 2009). In other words, this research began with a literature review in order to seek out different areas of interest with regards to the identification of common drivers between volume flexibility and product mix flexibility which may contribute towards answering the first research question. These solutions were then verified by empirical investigation on a single case study of one company through interviews, observations and the analyses of internal documents.

Regarding the different methods and techniques used in order to gather a better understanding of the subject of thesis work, a single case study was conducted to verify the problem in a real life context (Yin, 2003). During the case study investigation, various data collection techniques such as interviews, observations and calculation were used. It is important to recognise that a single case study does not provide a valid method in other research contexts. Therefore, the researcher believed that it would have been better to use multi-case study research in terms of comprising and analysing theoretical findings among a group of competitors, even in different countries. This could also have increased the validity of the research as well.

One of the problematic issues that occurred during the interview data collection was that sometimes some of the questions required more pre-study about previous data. The interviewee could not answer some of the questions immediately. However, semi-structured interviews were carried out in a more discussion-like manner with the managerial team in the case company, such as the direct manager, production manager and production engineer, who were all aware of the project. The idea of performing semi-structured interviews was to enable the creation of an environment where the interviewees could have the possibility to openly express their own thoughts; while the researcher could be more flexible and form subsequent questions based on their previous answers.

Observation and distance measurement on the shop floor and discussion with the operators about different challenges regarding different processes were all opportunities for the researcher to identify gaps in the literature and present those main findings in order to come closer to a conclusion and answer the research questions. The focus of the observations were on technical matters in the subsystem of production such as human factors, machinery and process technology. The difficulty in this case was to compare the current production system facility in Laserkraft AB with the latest machinery available in the market. For this purpose, the opportunity to visit the Hannover Fair in Germany (the world's most important industrial show) was a great means to benchmark the competitors and best practice companies. This approach enabled the comparison and evaluation of new technology and machinery with the current situation of the case company. As a conclusion, all these techniques allowed the company to gain more information and knowledge on the market, industry, and competitors in order to make a better decision with regards to investment allocation and new technology.

Moreover, the researcher believed that if he could have created a simulation platform to visualise how volume flexibility and product mix flexibility can be achieved through batch production in real life, it would contribute to an increase in the reliability of the research within the accurate techniques, and also help to evaluate the source drivers for the case company. However, due to the limited time and complexity involved in visualising each process, it was decided to send this topic to the area of possible future studies.

5.2 Discussion of Findings

During this research the literature review started by broadly covering manufacturing flexibility and was then narrowed down to explanations on how previous work has attempted to realise the relationship between volume flexibility and product mix flexibility in terms of mutual source drivers. In contrast, the discussions started by analysing the empirical results to explain what the outcomes of this thesis were to be. Finally, it ended by branching out to explain how these results might relate to achieving volume flexibility and product mix flexibility in batch production.

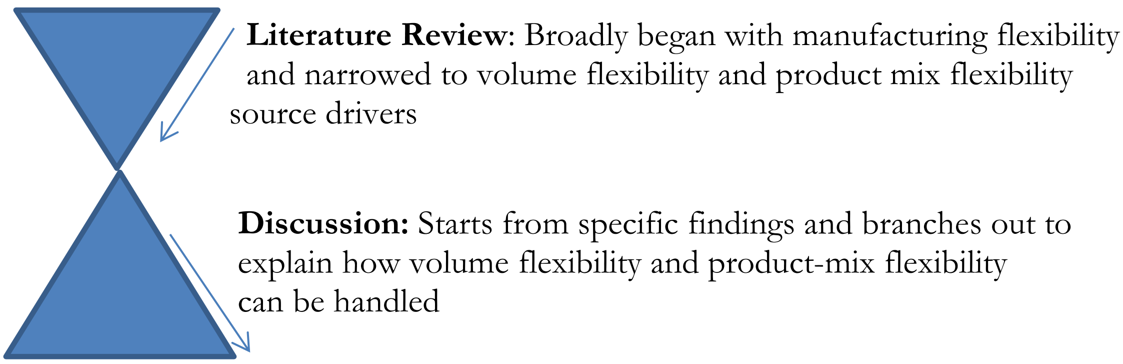

Figure19: Research process

In this chapter, the findings from the previous chapter and the linkage to the objects of the study will be discussed. The research problem, which was broken down into two specific research questions, will be answered.

Primarely, Salvador, et al (2007) argued that the number of methods typically used to increase volume flexibility have a negative effect on product mix flexibility and vice versa. Nonetheless, some empirical evidence also advocates that there are some techniques which may contribute to volume flexibility and product mix flexibility which are to be achieved synergistically. This claim has been the motivation behind this study to realise the interrelation between volume flexibility and product mix flexibility.

5.2.1 Discussion of RQ1

This research question was answered through the literature review. However, tests and evaluations of each source factor were examined through the empirical research of the case company. In this section, the source drivers from the literature were grouped and formulated as illustrated in Figure 8.
This model shows the fundamental roots and most of the sited source drivers in the literature studied regarding flexible manufacturing competencies and the strategic flexibility point of view. According to the literature, these two elements support the manufacturing capabilities in order to handle both volume flexibility and product mix flexibility. For instance, Gerwin (1993) suggested some flexibility source drivers, which are characteristically associated with adoptive and proactive strategic approaches.

During the literature review, the researcher found similar work (Hallgrena & Olhager, 2009) which empirically studied the relation between volume flexibility and product mix flexibility. In contrast, Hallgrena & Olhager (2009) used the survey questionnaire to collect empirical data from the high performance manufacturing study, including three industries such as electronics, machinery and auto suppliers, which clarified the great external validity and generalisation of their work. In their research, they realised that different levels of volume flexibility and product mix flexibility represent different impacts, both in terms of emphasis into different flexibility source drivers and in terms of influence on operational performance. In general, the result of their empirical research implies that volume flexibility requires high levels of all adoptive source factors, and that DFM and modular designs are the most significant source drivers for product mix flexibility. Lastly, to support the judgement of Salvador et al (2007), they suggested that setup time reduction, advanced manufacturing technology and multi-trained employees are the top mutual source drivers of volume flexibility and product mix flexibility.

On the other hand, Zhang et al (2006) proposed that the source drivers stem from flexible manufacturing competence, which includes the use of advanced manufacturing technology and operational improvement practices. In general, analysing the literature was narrowed down to the fundamental source drivers, which connect volume flexibility and product mix flexibility as stated below.

The focus from the beginning was to identify the mutual source drivers of volume flexibility and product-mix flexibility from the literature review. All of the identified factors were analysed, however, this does not mean that all factors that have an impact on successful volume flexibility and product mix flexibility are presented in this thesis work. The purpose was to identify the most important technical aspects regarding production subsystems. By answering the first research question, the basis for answering the second research question was made.

5.2.2 Discussion of RQ2

The analysis of the empirical findings are presented in chapter 4, which shows that some source drivers within Laserkraft AB are the same as the findings from the literature review. For instance, according to the empirical findings in chapter 4.3, both setup time reduction and advanced manufacturing technology have a significant impact on achieving volume flexibility and product mix flexibility in the case company. Empirical findings on the firm reveal that slack capacity and multi-trained employees have a lower impact on flexibility output compared to adoptive strategic flexibility approaches. Furthermore, the researcher believed that aspects related to proactive strategic flexibility to control uncertainty through advanced manufacturing planning such as total preventive maintenance, statistical process control and design for manufacturing, were carefully implemented in the case company. This essentially means that the company has the potential to focus on adoptive source drivers.

However, some other findings are more specific to Lasekraft AB in regards to the specification of batch production and also the product family under the study. First of all, referring to chapter 2.1.1, one of the advantages of batch production is cellular layout and group technology. These elements are significantly enhanced with the achievement of volume flexibility and product mix flexibility due to the promotion classification of batch sizes, standardisation of equipment and fixtures, reduction in material handling and consequently, reduction in setup time (Groover, 2001). Moreover, the evidence in the analysing section indicates that advanced manufacturing technology plays a key role in handling the flexibility output due to the ease in programming the machinery, which thereby reduces setup times.

It was found that setup time reduction is the most crucial source factor towards achieving volume flexibility and product mix flexibility; this was strongly collaborated in both the literature studies and the case study. This was due to the largest influence compared with other source drivers. According to what Salvador et al (2007) argued, since product mix flexibility implies less time wasted in switching production from one item to another one, the reduction of setup times not only leads to an increase in volume flexibility, but also improves the overall product mix flexibility too.

Lastly, flexibility output was not achieved through a single driver; rather it was formed through a group of source drivers at the same time. Each organisation and industry must refer to their own product, process and type of layout etc., which then requires a group of practices to achieve volume flexibility and product-mix flexibility.

5.3 Contributions

This section includes academic recommendations for analysing volume flexibility and product mix flexibility, as well as industrial recommendations to Laserkraft AB and their consequences, which can even support the relevance of small companies based on the analysis of empirical findings and the literature review.

This research has developed a contrivance to be used by small and medium enterprise (SME) managers to improve the volume flexibility and product mix flexibility of their manufacturing systems. This research can be applied to the decisions of changes that are required to achieve these flexibility capabilities. Using historical data of the type and volume of products demanded by clients, SME managers can foresee the mixture and the quantity of products that should be produced in a scheduled period. With this information, operational flexibility can be improved by using the model developed in chapter 4.5.1. This research specifies the type of framework that is more beneficial to volume flexibility and product mix flexibility. As it can be seen, figure 8 indicates the combination of source drivers based on the internal and external sources of flexibility. This information can be used by managers to decide what decision should be prioritised. For instance, what machines they need to purchase and when to do so. Managers can also have information about how to train their employees and reorganise them from one process to another.

The originality of this research is found a) in the common source drivers of volume flexibility and product mix flexibility, which considers the existing relationship between them and also b) in the application of the batch flow production as a type of process and cellular manufacturing as a physical layout.

Despite general contributions, this research recommends the sort of academic aspects required for Laserkraft AB to be able to analyse the consequences of development based on empirical findings:

- Setup time reduction

Setup time reduction is one of the most crucial source drivers to achieve volume flexibility and product mix flexibility to be found in the observation and empirical findings of the case company. There are a number of industrial engineering methods that could be determined as academic contribution as well in order to improve the setup time reduction:

1. Identify and separate internal and external setup procedure elements.

2. Organise various parts into families.

   Parts coding and classification of products based on geometrics, size and the like. In this case, several of the parts can be organised into part families. And since the output is all-similar, the equipment can be set up in one pattern to produce an entire family and does not need be to set up again.

3. Schedule and categorise the batches of similar parts in sequence to minimise the change required in the setup procedure (e.g. categorise all sheet parts with 3 mm thicknesses in the laser cutting process).

4. Design modular fixtures and standardise the manufacturing process.

   The term standardisation means less variety and customisation in the methods and equipment employed. Therefore, the methods and equipment that can perform a variety of tasks under volume flexibility and product mix flexibility conditions are contributed. For instance, a flexible fixture to be used for clamping components with different geometries could be an efficient solution to welding materials with different lengths, heights and thicknesses. In this case, the cost for designing specific fixtures for each type of product will dramatically decrease. Moreover, a flexible fixture method can reduce the fixture preparation time for the design and can then draw up a new fixture. The researcher offers the solution of using permanent magnetic clamping technology to the company, with consideration to ensuring a highly effective setup time killer and a flexible solution for the welding process.

- Advanced manufacturing technology.

Automation in welding and turning in terms of loading and unloading the product's parts is recommended in order to increase output flexibility, reduce or eliminate routine tasks, and reduce manufacturing lead times.

5.4 Future Approach

This research has some issues which are worthy of future investigation. The result of this research could have been practiced by using the simulation technique. In fact, simulation can help to optimise the design of production subsystems when flexibility output is required. Furthermore, simulation contributes to the firms that want to reduce the risk of investment by the testing of physical equipment. Therefore, to perform such a future study, this research could be evaluated using simulation tools, which will then give a better result with higher external validity.

The mutual source drivers between volume flexibility and product mix flexibility, which are presented in this paper, could also be investigated in other industry branches. It could prove important to test whether or not the theories presented in this report are relevant and valid in other industrial segments. This might then also contribute to new findings that are relevant in subcontractor manufacturing.

Finally, the development of a framework of theoretical results could be extended to a more complex product and industry.

5.5 Conclusions

Fulfilling the objective of industry to gain a competitive advantage through complexity of market demand, combination of source drivers in terms of volume flexibility and product mix flexibility has been the main focus of this research. The main objective of this research has been to provide a framework that contributes to investigating source drivers and the ways to achieve volume flexibility and product mix flexibility in batch production.
To accomplish this objective, a theoretical framework and single case study were conducted for this thesis.

The main characteristics of the relationship between volume flexibility and product mix flexibility were investigated. Two sub drivers of internal and external factors were considered as the foundation of volume flexibility and product mix flexibility and as a support for manufacturing flexibility. Furthermore, strategic flexibility and FMC were used to identify the source drivers through the set of internal abilities of firms such as machines, labour and material handling. Supplier networks and relationships are the set of external source drivers for achieving volume flexibility and product mix flexbility.
Based on the knowledge gleaned from the literature review and empirical analysis, the source drivers between volume flexibility and product mix flexibility, with respect to the characteristics of the batch production system from the case company, were identified. Accordingly, the framework in the analysing chapter was develeoped to determine the source drivers, which were needed to improve.

Lastly, as a result, it was recognised that the common source factors of (i) setup time reduction, (ii) advanced techonlogical manufacturing and (iii) standardisation of equipment, have a higher influence on the case company's production system.

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7 Appendices

Appendix 1

7.1 Interview questions

1- Approximately how many different articles does Laserkraft produce in a year?

2-What is the approximate volume range (lowest to highest) that Laserkraft produces annually?

3-How do you compare the ability of Laserkraft to handle volume and product mix flexibility compared with your competitors in the industry?

4-Which other flexibility type proves more demanding in Laserkraft AB? How does the company generally define manufacturing flexibility?

5-What are the flexibility source factors that the company has more focus on?
6-What are the most and least important strategic adoptive source factors when the company needs to handle volume and product mix flexibility?

- Setup time reduction
- Slack capacity
- Advanced manufacturing technology
- Multi-trained employees

7-In what way does slack capacity contribute to coping with volume and product mix flexibility? What are the advantages and challenges? How can multi-skilled employees affect production capacity?

8-In what way does advanced manufacturing technology contribute to coping with volume and product mix flexibility?

9-In what way does production planning and control contribute to coping with volume and product mix flexibility?

10-What are the most effective solutions that the company has used in order to reduce setup times?

11-What is the company's approach regarding advanced manufacturing control?

12-What are the main focuses of the company in respect to operational improvements practices in order to handle volume and product mix flexibility? Please give an example of some recent improvements?

Appendix 2

7.2 Observation Criteria

- Machine setup time and cycle time calculations
- Characteristics of machines that can perform many types of operations
- What different tools can a typical machine effectively use?
- Can machine tools be changed quickly?
- Can workers perform many types of operations effectively?
- Can cross-trained workers perform a broad range of manufacturing tasks effectively in the organisation?
- Can workers be transferred between different departments?
- How does the material handling system handle different part types?
- Can a typical material handling system link different processing centers?

Appendix 3

7.3 Questions for Marketing Interview

The aim of this questionnaire is to understand the business dynamics with regards to "Locking-Shaft" as well as to aid the investigation of volume and product mix variety from customer point of view.
The result will contribute to identifying the product generic as well as appropriate production planning for this particular product.
Please notice that some of the questions require more consideration based on prior purchasing data.
Thank you for your collaboration.

How many different article numbers do you have for locking-shafts?
1-9
10-29
30-59
60-99
More than 100

What is the most common approximate size of the locking-shafts purchased?
⌀diameter < 10mm

10<⌀<30

30<⌀<50

50<⌀<80

Other:

What is the most common approximate length of the locking-shafts purchased?
L<30mm
30<L<50
50<L<80
80mm<L
Other:

From 1 (least important) to 5 (most important), which of the following factors do you consider important to your purchasing strategy? (Remember, two factors cannot have the same valuation)
PRICE
1 2 3 4 5
least important /most important
QUALITY (from a product perspective)
1 2 3 4 5
least important /most important
DELIVERY (time)
1 2 3 4 5
least important/ most important
FLEXIBILTY (response to changing demands)
1 2 3 4 5
least important/ most important
SERVICE
1 2 3 4 5
least important /most important

Please mention if there is any other important factor you consider!

What is your annual purchasing value of “locking-shafts”?
Less than 100 tSEK
Up to 500 tSEK
Up to 1.000 tSEK
Up to 5 MSEK
Above 5 MSEK

Of the annual purchasing, quantify in % the split between
Low volume up to 1000 pcs/year
Medium volume – up to 10.000 pcs/year
High volume – 10.000 pcs and more

Maximum week(s) expected from order to delivery of the goods?
(without considering forecast time)
Less than 1 week
1-2 weeks
2-3 weeks
More than 3 weeks

Which of the following delivery methods do you usually rely on for this type of product?
Use of own truck
Supplier delivery service
Other logistic companies

How would you like the products to be delivered?
Pallets
Cardboard boxes
Plastic boxes
Other:

Number of expected/desired boxes in one pallet?
5
10
20

Number of suppliers you do business with today?
Single supplier
From 2 to 5
From 6 to 10
More than 10

Please name the top 3 suppliers you do business with today regarding this product.
Specify for each supplier: Company name; Location; Production type (high,medium,low); Purchase value per year

End