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Mikael Ollikainen

ORIGINS OF PRODUCTION ERRORS AND SIGNIFICANCE OF EMPLOYEE EMPOWERMENT IN REDUCING PRODUCTION ERROR AMOUNT IN SHEET METAL FABRICATING INDUSTRY

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium of the Student Union House at Lappeenranta University of Technology, Lappeenranta, Finland on the 19th of December, 2003, at noon.

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ABSTRACT

Ollikainen, Mikael

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The market place of the twenty-first century will demand that manufacturing assumes a crucial role in a new competitive field. Two potential resources in the area of manufacturing are advanced manufacturing technology (AMT) and empowered employees. Surveys in Finland have shown the need to invest in the new AMT in the Finnish sheet metal industry in the 1990's. In this run the focus has been on hard technology and less attention is paid to the utilization of human resources. In many manufacturing companies an appreciable portion of the profit within reach is wasted due to poor quality of planning and workmanship.

The production flow production error distribution of the sheet metal part based constructions is inspected in this thesis. The objective of the thesis is to analyze the origins of production errors in the production flow of sheet metal based constructions. Also the employee empowerment is investigated in theory and the meaning of the employee empowerment in reducing the overall production error amount is discussed in this thesis.

This study is most relevant to the sheet metal part fabricating industry which produces sheet metal part based constructions for electronics and telecommunication industry. This study concentrates on the manufacturing function of a company and is based on a field study carried out in five Finnish case factories.

In each studied case factory the most delicate work phases for production errors were detected. It can be assumed that most of the production errors are caused in manually operated work phases and in mass production work phases. However, no common theme in collected production error data for production error distribution in the production flow can be found. Most important finding was still that most of the production errors in each case factory studied belong to the "*human activity based errors-category*". This result indicates that most of the problems in the production flow are related to employees or work organization. Development activities must therefore be focused to the development of employee skills or to the development of work organization. Employee empowerment gives the right tools and methods to achieve this.

Keywords: *sheet metal part fabricating, defective sheet metal part, employee empowerment*

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Lappeenranta, December 2002

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LIST OF ACRONYMS

AMT	Advanced Manufacturing Technologies. A generic term for a group of integrated hardware-based and software-based manufacturing technologies (e.g. Henry et al., 1998; Udo and Ehie, 1996; Mechling et al., 1995; Boyer, 1994)
FMEA	Failure Model and Effects Analysis
FMS	Flexible Manufacturing System
LELA	Quality control of sheet metal products (Levytotteiden laadunvalvonta in Finnish) - research program carried out by LUT between 12/2000 and 8/2002
LUT	Lappeenranta University of Technology
NC	Numerical Control

1 INTRODUCTION

Constructions based on fabricated sheet metal parts are used in a wide range of different types of products. Typically, these constructions can for example be found in consumer goods (e.g. white brand products), means of transportation (e.g. cars and elevators), mechanical engineering (e.g. machine cabinets and covers) and electronic equipment, such as telecommunication cabinets and computer housings. One typical product, a telecommunication cabinet, is featured in figure 1 - 1.

FIGURE 1 - 1 Telecommunication cabinet (Source: NOKIA Networks Ltd.)

Sheet metal has a number of important properties according to Bitzel et al. (1996). For example, sheet metal can be cut or punched, sheet metal can be formed or bent, sheet metal can be deep-drawn, and sheet metal can be joined with numerous methods. Also continuous development of the process and processing machinery makes sheet very inexpensive to produce.

Many of the properties listed above make it clear why sheet metal is the ideal material for many different types of products listed in the first paragraph. In some products sheet metal only takes up a small proportion of the load as, for example, in the case of a machine cover. There are also many products in which the sheets not only have a covering function but also a supportive one, e.g. a telecommunication cabinet (Bitzel et al., 1996).

Production flow is often very complex and it includes both manual and automated process phases. Due to this complex production flow and several various process phases, sheet metal part fabricating industry is quite unique compared to other manufacturing branches. Direct comparison between branches is therefore quite often very difficult to put into practice.

Increasing market turbulence and customer demands compel manufacturing companies to manufacture high-quality and customized products within short lead-times and at condescending expenses. These competition requirements are important for customer loyalty and long-term survival but they can eat deep into profits. The solution for stable profits and long-term survival, therefore, lies in the continuous development of manufacturing resource performance and the elimination of threats amongst them. Improved production efficiency and flexibility are the keywords for most manufacturing companies. Two potential resources in the area of manufacturing are AMT (e.g. Adeleye et al., 2001; Mital et al., 1999; Udo and Ehie, 1996; Mechling et al., 1995; Trainfield et al., 1991) and empowered employees (e.g. Adeleye et al., 2001; Mital et al., 1999; McEwan and Sackett, 1998; Johnson and Thurston, 1997).

Surveys in Finland (e.g. Ollikainen, 1990; Varis, 1988) have shown the need to invest in the new AMT in the Finnish sheet metal industry in the 1990's. The need to produce growing amount of customized products within short lead-times and at condescending expenses mainly for the electronics and telecommunication industry has driven the metal fabricating industry to find new ways of improving production through advanced manufacturing technology, such as NC machine tools, industrial robotics, flexible manufacturing systems (FMS´s) and automated storage and retrieval systems.

In this run the focus has been on hard technology and less attention is paid to the employees (Ollikainen and Varis, 2001). Because of that, not much attention has been paid to production flow in wholeness and quality assurance.

It is extensively accepted that human intelligence and human beings in an organization are the key factors in manufacturing systems and for their success (e.g. Zhou and Chuah, 2000; McEwan and Sackett, 1998; Cook and Cook, 1994; Hammer, 1992; Williams, 1992; Yoshikawa, 1992; Kidd, 1991; Grant et al., 1991; Tranfield et al., 1991). Bohnhoff et al. (1992) and Mital et al. (1999) point out that the design of a technical system will always be the design of a human-machine system. They also believe that the unmanned factory appears to be impossible to implement. Corbett (1998) states that the unmanned factory will not become widespread reality due to inability of most companies to manage the complexities of system integration. He also comments that the operation and maintenance of a complex manufacturing system requires skilled and trained personnel.

In many manufacturing companies an appreciable portion of profit within reach is wasted due to a poor quality of planning and workmanship (e.g. Ollikainen, 2001; Porter and Rayner, 1992). In many cases potential savings are high and assuring quality should reach the same importance as improving efficiency and flexibility.

In some papers employee empowerment and empowered work organization are seen as a method to improve production on final product quality (e.g. Harris and

Sohal, 2002; Hammuda and Dulaimi, 1997; Sykes et al., 1997). Empowerment offers an efficient way to improve quality without investing in new machinery.

Information about the production flow and errors of constructions based on sheet metal parts and used by electronics and telecommunication industry is very limitedly available in published papers. There is much information to collect about production errors in the production flow in manufacturing companies. Such data can be used as a tool when production flow performance and revenue improvement activities are planned. This requires systematic data collection and proper tools to analyze collected data.

1.1 Theoretical review

The aim of this chapter is to find out what has been discovered in earlier research. Focus has been in the production flow of constructions based on fabricated sheet metal parts, errors in the production flow of sheet metal part based constructions and in the employee empowerment.

1.1.1 Production flow of constructions based on fabricated sheet metal parts and errors in production flow

Few papers can be found in literature about the production flow of constructions based on fabricated sheet metal parts. A literature review exposed no published papers handling the production flow of constructions used in electronics and telecommunication industry. Following papers concentrating on the frame of reference has been presented:

Bitzel et al. (1996) describe the sheet metal process flow in general in their book (Figure 1.1.1 - 1 a)). Also, the production chain of a sheet metal parts based cross member of a flatbed laser machine is described as an industrial example.

Berkhahn and Miyakawa (1993) show general sheet metal fabrication processes in their paper. They also show examples of sheet metal parts used in a machine tool. The process flow of elevator car constructions is showed in a paper of Kanamouri et al. (1995). Two examples (Bitzel et al., 1996; Berkhahn and Miyakawa, 1993) of described sheet metal processes are showed in figures 1.1.1 - 1 a) and b).

Ollikainen (2000a) has listed production activities in sheet metal part fabricating industry in his paper. According to Ollikainen activities include following work phases in manufacturing function of the company:

- NC-programming.
- Part fabricating operations; 2D-parts, bending, joining, assisting work phases.
- Surface treatment operations; pre-treatments, surface treatments, after-treatments.
- Assembly operations.
- Packing and transportation arrangements.
- Warehousing operations.

In electronics and telecommunication industry products have become more global and very much attention is paid for product usability, durability and quality. Many standards must be fulfilled. The production chain can therefore be very complicated in individual sheet metal parts. Ollikainen (2001) has described the production chain (figure 1.1.1 - 3) of a front panel of telecommunication cabinet plug-in unit (figure 1.1.1 - 2).

Sheet metal process flow descriptions were found out to be too inaccurate to be used in this thesis. Own definition is developed in chapter 2.2.1 and 2.2.2 later on in this thesis.

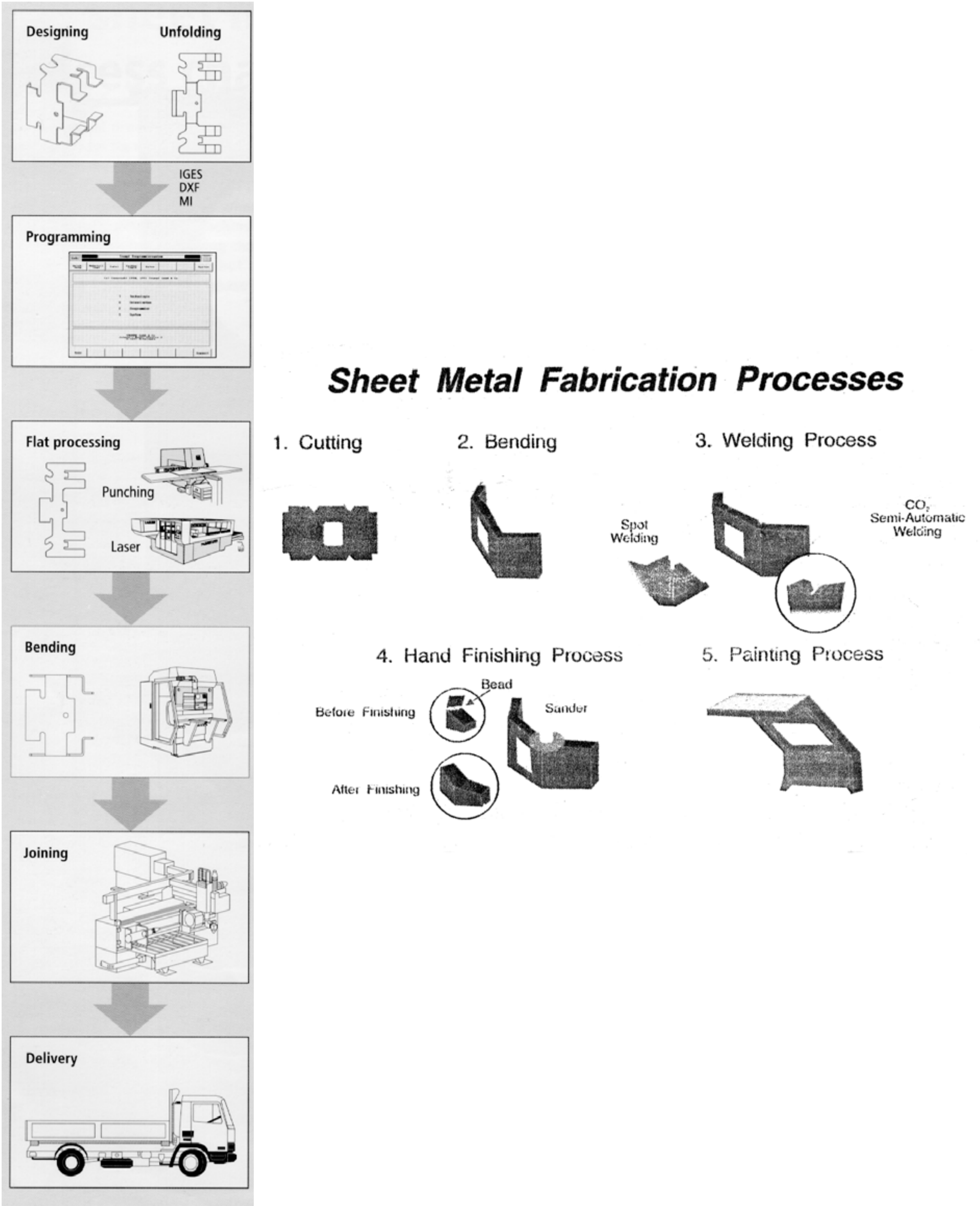
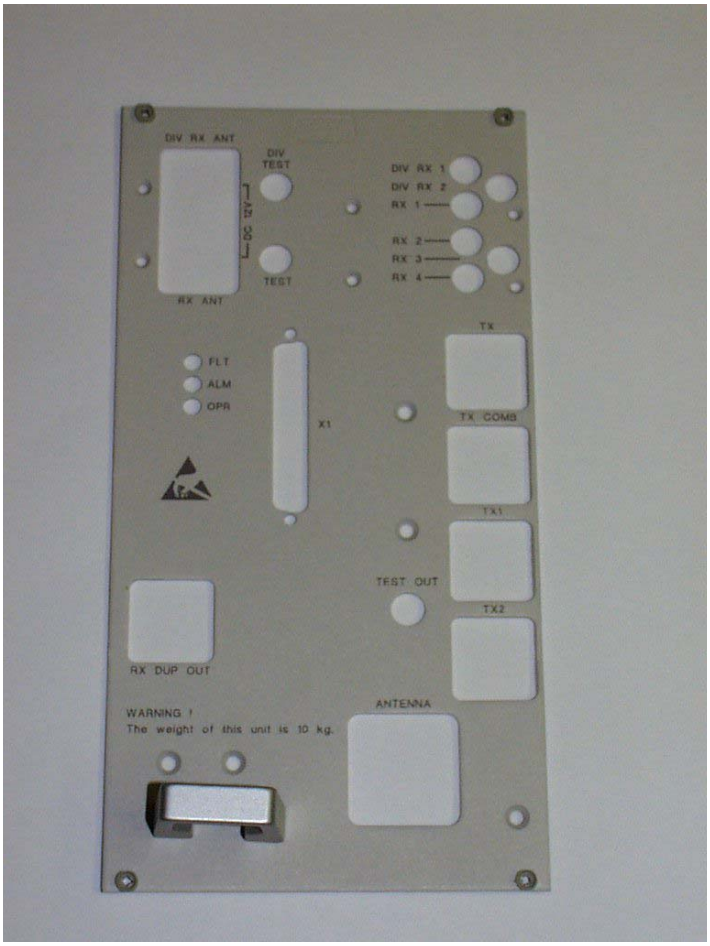


FIGURE 1.1.1 - 1 a) and b) Two sheet metal processes described (Bitzel et al., 1996; Berkhahn and Miyakawa, 1993)



Material	Al 99.5
Thickness	2.5 mm
Finish	Yellow chromate DIN 50939 Al/C
Coating	Painting, film thickness 35 µm
Printing	Texts according to drawing, one color
Embedding	1 piece, front side, depth 0.3 mm
Countersinks	*Size 1*; 5 pieces, front side *Size 2*; 2 pieces, back side *Size 3*; 6 pieces, front side
Size	137 x 262 mm
Punched holes	37 pieces
Nibbled holes	2 pieces
Notes from drawing	Rise caused of embedding has to be removed from the backside. No paint allowed on back surface.

FIGURE 1.1.1 - 2 The front panel of a telecommunication cabinet plug-in unit and technical specifications used in drawing (Ollikainen, 2001)

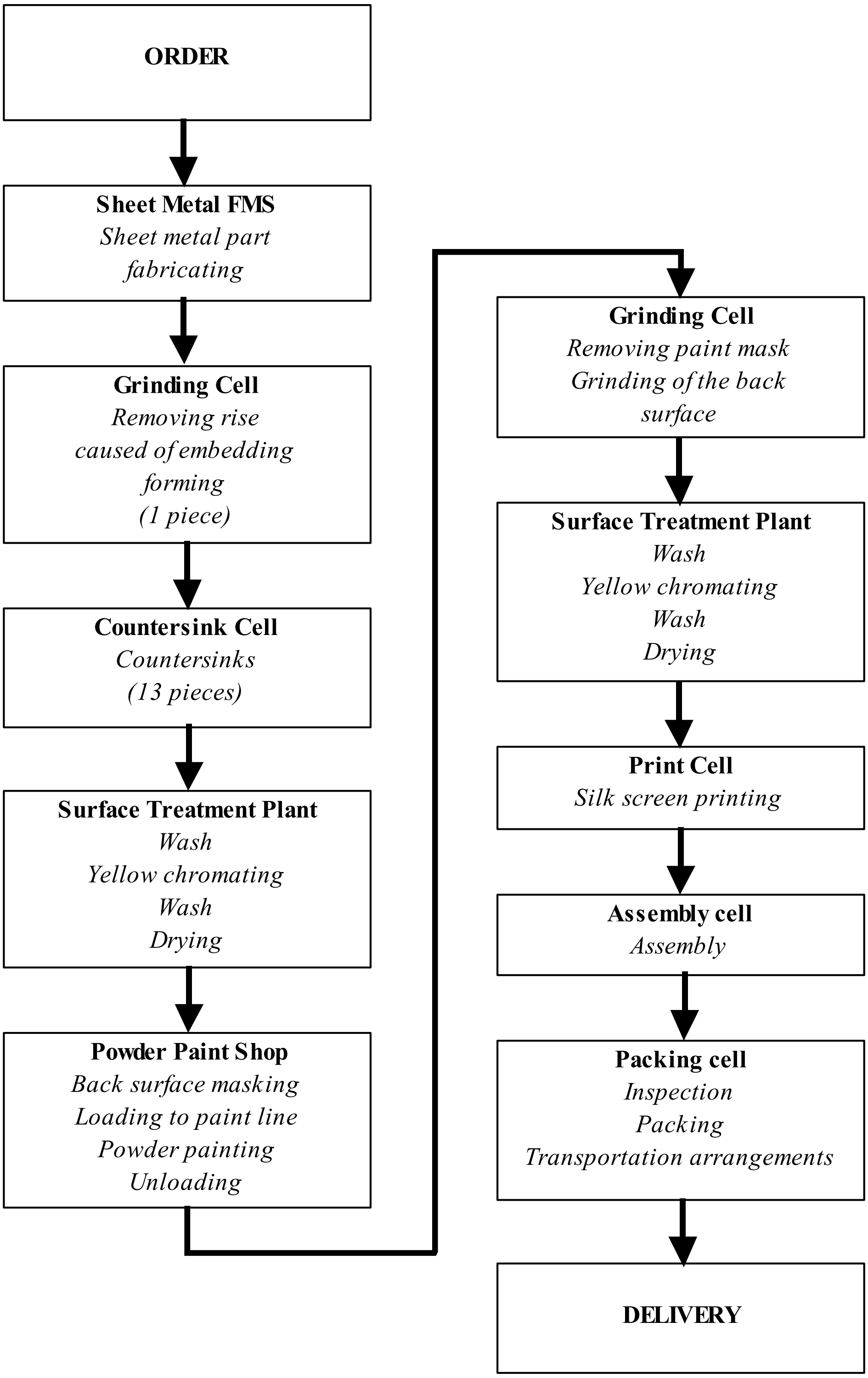


FIGURE 1.1.1 - 3 The production chain of the front panel of a telecommunication cabinet plug-in unit (Ollikainen, 2001)

Noticeable is that in literature review no published papers could be found about error distribution or origins of production errors in the production flow of constructions based on fabricated sheet metal parts.

1.1.1.1 Cost structure of sheet metal parts and value-adding time in sheet metal part fabricating

Only a small amount of time spent in sheet metal part fabricating is value-adding. One example can be found in literature, where Berkhahn and Miyakawa (1993) states that only 7 per cent of the whole fabricating time is value-adding while 93 per cent is wasted in various auxiliary activities and waiting (figure 1.1.1.1 – 1) in sheet metal part production. These auxiliary activities include time used for tool set and change, programming and program downloading, work piece transfer and checking processing. Also, the waiting time can be considered notable because a single sheet metal part spends a lot of time waiting other parts in a batch to be fabricated before it is possible to transfer the whole batch from the current work phase to the proceeding work phase.

Ollikainen (2000a) has studied the time spent from the order to the delivery in sheet metal part fabricating industry in his paper and the handling time of the order can be very long when compared to the total time of delivery (up to 55.7 per cent of the total time of delivery in that study). This makes the percentage of the value adding time in order-delivery chain even smaller than presented by Berkhahn and Miyakawa (1993) in figure 1.1.1.1 – 1 (see also “sheet metal fabrication processes” in picture 1.1.1 – 1 b)).

The cost structure of sheet metal parts can vary considerably depending on the amount and quality of raw materials used in fabricating and also, on the complexity of the work phases required in the process. The cost of a single component increases if expensive and multi-phased surface treatment processes are needed as often in sheet metal components used in telecommunication and electronics industry.

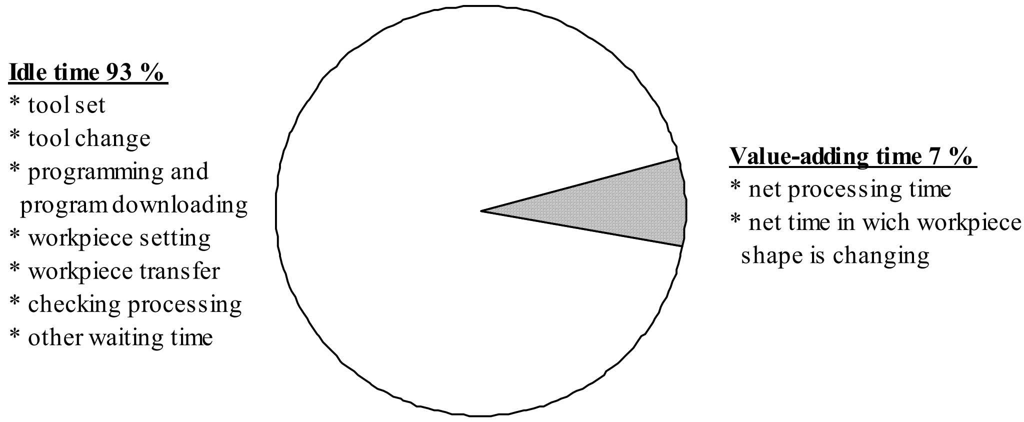


FIGURE 1.1.1.1 – 1 Value-adding time in sheet metal part fabricating (Berkhahn and Miyakawa, 1993)

The cost structure and value adding time in sheet metal part fabricating industry will be presented by an industrial example from a real situation in Finnish sheet metal part fabricating industry. The objective of the example is the front panel of a telecommunication cabinet plug-in unit presented in figure 1.1.1 – 2. The figures presented in the table 1.1.1.1 – 1 are rounded off and the cost structure presented is from a certain period of time. The source cannot be disclosed because of confidential information.

The raw material cost of the front panel is 30 per cent of the total manufacturing cost excluding the parts (handle, screw sleeves and screws) needed for the final assembly phase. The cost of the raw material is not mentioned in the table 1.1.1.1 – 1. Other material cost, e.g. powder paint, is included in each work phase in the table 1.1.1.1 – 1.

The front panel was fabricated in batches of 500 pieces during the examined period of time. The fabricating time of a batch is 32 hours, which means four full 8 hours working shifts. The handling time of the orders is not included in these 32 hours. The customer demands 100 % reliability of the delivery, which means that notable buffer store is needed.

Table 1.1.1.1 – 1 Cost structure of the front panel, excluding raw material.

Work phase	Cost [%]
Sheet metal part fabricating	12
Removing rise caused of embedding forming	3
Countersinks	12
Wash, yellow chromating, wash and drying	13
Back surface masking, loading to paint line, powder painting and unloading	22
Removing paint mask and grinding of the back surface	3
Wash, yellow chromating, wash and drying	13
Silk screen printing	8
Assembly	12
Inspection, packing and transportation arrangements	2

1.1.2 Learning organization and employee empowerment

The idea of organizational learning has been present in the management studies literature for decades, but it has only become widely recognized in 1990's (Easterby-Smith and Araujo, 1999). The notion of organizational learning is essentially based on individual learning, and it is hypothesized that organizational learning and applications of organizational learning will benefit the long-term performance of the organization. Through learning, organizations adapt to change, avoid repeating past mistakes, and retain critical knowledge that would otherwise be lost (Pegels, 1998).

Mabey and Salaman (1995) suggest that the learning organization is often a piece of shorthand to refer to organizations which try to make a working reality of such desirable attributes as flexibility, teamwork, continuous learning and employee participation and development. Popular management techniques that are often associated to learning organization are for example quality circles, re-engineering, total quality management and empowerment (Staw and Epstein, 2000).

Employee involvement is a strategy that firms use to give employees more responsibility and accountability in performing their jobs. It is based on the principle that people will support ideas or decisions that they helped form, and that people who actually perform the work have valuable insight into the inner workings of operations that are not always known to managers. One technique of employee involvement is the use of empowerment. Empowerment involves pushing the authority to make decisions down to the first level of qualified people in the organization. (Pegels, 1998)

Empowerment evolved because of technological advances, increased global competition, and better-educated employees. Technology allowed the supervision and control once maintained by managers to be exercised by lower-level employees having access to systems, knowledge, and information. New global economics has created the need for managers to be more involved in strategic planning. It has also called upon the firms as a whole to be responsive to cultural factors, which empowerment facilitates. (Pegels, 1998)

In the literature the term *empowerment* is generally used to refer to the autonomy on the job, education and training of different skills, support and information sharing as well as pay system that link pay with performance (e.g. Maurer, 2000; Civerolo, 1992; Adeleye et al., 2001). All those are important factors strongly related to learning organization.

At its simplest, according to Wilkinson (1998), empowerment would commonly be associated with the redistribution of power, but in practice empowerment is usually seen as a form of employee involvement, designed by management and intended to generate commitment and enchain employee contributions to the organization (Wilkinson, 1998).

Maurer (2000) expresses that people are empowered when they are given the authority and responsibility to make decisions affecting their work with a minimum for interference and second-guessing by others. When people are empowered they bring their minds to work and they are engaged in making decisions that affect their part of the business. They take responsibility for their actions and work free from the petty bureaucratic hassles that diminish value and waste time. They also add value to the organization by embracing the principles of quality and service as well as search for ways to make a difference.

Smith (1997) writes that to empower is to give power, open up and to release potential of people. In Smith's terms it can be viewed as a commonsense activity. Typically, it embraces job involvement, job enrichment and participation of people in various forms, including suggestion schemes. Essentially, the main trust of empowerment is through having greater autonomy on how jobs are done, carrying with it immense potential for improving productivity.

According to Adeleye et al. (2001), empowerment means providing employees with the dynamic knowledge and skills required in manipulating and operating advanced machines, as well as increasing employee relevance.

Shannon's (1991) definition for empowerment is "the personal potential of employees and the cultural climate for employees to co-create a workplace they personally believe in and thrive in". Empowerment:

- Is the function of two variables: potential and opportunity.
- Is the process of people working together to co-create quality of work life and work output.
- Touches one at ones core, allowing one to co-create something one personally believes in.

With empowerment not existing as a single unified entity, it can cover a very wide range of schemes, which in turn may involve a variety of diverse management motivations. However, sharing a common assumption that employees and employers interests are inextricably connected unites them. They can range from the mechanistic (i.e. structural change) to the more organic (connected with attitude/culture). (Wilkinson, 1998)

Empowerment is no quick fix according to Smith (1997). It is about significant cultural change, which requires time and real commitment. For many organizations the introduction of empowerment will both require and ultimately cause a major cultural shift. It can only be effective when it is linked to the organization's values; values for which people need to feel a large measure of ownership.

This paper identifies five most important themes related to employee empowerment as found in published papers. These themes and references are described in Table 1.1.2 - 1.

Table 1.1.2 - 1 Five main types of themes in employee empowerment

Theme	**Reference (e.g.)**
Multifunctional team structure	Adeleye et al., 2001
	Civerolo, 1992
	Duncombe et al., 1993
	Karlsson and Åhlström, 1996
	Maurer, 2000
	Pegels, 1998
	Randolph, 1995
	Shannon, 1991
	Smith and Mouly, 1998
	Smith, 1997
	Wilkinson, 1998
	Willis, 1997
Information sharing	Civerolo, 1992

	Greif, 1991 Hammuda and Dulaimi, 1997 Karlsson and Åhlström, 1996 Maurer, 2000 Pegels, 1998 Randolph, 1995 Smith and Mouly, 1998 Willis, 1997
Upward problem solving	Bessant and Caffyn, 1997 Civerolo, 1992 Karlsson and Åhlström, 1996 de Leede and Looise, 1999 Pegels, 1998 Willis, 1997
Education and training	Adeleye et al., 2001 Civerolo, 1992 Duncombe et al., 1993 Karlsson and Åhlström, 1996 Pegels, 1998 Randolph, 1995 Smith and Mouly, 1998 Smith, 1997 Willis, 1997
Reward system	Born and Molleman, 1996 Civerolo, 1992 Milner et al., 1995 Smith and Mouly, 1998 Smith, 1997 Willis, 1997

Multifunctional team structure

A multifunctional team is a group of employees who are able to perform many different tasks. These teams are often organized along a cell-based part of the production flow. Thus, each team is given responsibility of performing all the tasks along this part of the production flow meaning that the number of tasks in the group increases. (Karlsson and Åhlström, 1996)

Teams make it possible for people to participate in decision-making and implementation that directly affects them. Teams help all members of the organization feel responsible for co-creating a workplace they can believe in and thrive in (Shannon, 1991).

One consequence of the use of multifunctional teams is that the number of job classifications decreases. Instead of having different employees performing only a limited number of tasks, the aim is to have employees who are able to perform more than one task in the team. Tasks previously performed by indirect departments are now responsibility of the team. These tasks can include material handling, material control, maintenance and quality control (Karlsson and Åhlström, 1996).

Sykes et al. (1997) have listed many positive results achieved by the use of multifunctional teams. These results are based on the studies in Norway and Sweden. Most important results are that autonomous working groups (teams) often result in rising product quality and work groups (teams) can have improved problem-solving abilities. Work groups (teams) can also have greater worker motivation, increased participation and more power equalization.

Information sharing

The organization must clearly communicate the company's vision, strategy, objectives, goals and directions (Civerolo, 1992). People who are closest to the work must have immediate access to the tools and information they need in their work (Maurer, 2000). Information is important in order for the multifunctional teams to be able to perform according to the goals of the company. The objective is to provide timely information continuously, directly to the production flow. (Karlsson and Åhlström, 1996)

Empowered individuals need to be given frequent and constructive feedback on their performance (Smith, 1997). They need to be reminded where they started, where they have been and how far they have come. Baselines must be agreed upon, to define success and provide milestones for monitoring progress. To avoid confusion later on, it is important to define these up front, as well as knowing how the measurements will be taken. Visions can serve as the context for feedback. A clear sense of vision and mission allows us to have humility to recognize that we need other's perspective to improve those areas where we are not perfect (Willis, 1997).

The means of visual communication can and must be used. They offer effective tool for company to communicate with employees. Visual communication can be used for example in documentation, production control, quality control, process indicators and making the progress more visual (Greif, 1991).

Upward problem solving

There is the old paradigm that says, "Workers work and managers think". This paradigm must be replaced with a new paradigm where everyone is a problem solver. People who have been doing their job for years know the problems best. (Civerolo, 1992)

Everyone should be involved in the work of improvement and problem solving. (Karlsson and Åhlström, 1996) Employees have to know and accept that it is their turn to be creative in solving problems and finding better ways of doing things. This includes accepting the responsibility to govern ourselves as individuals and as parts of teams in harmony with agreements we have made, holding people accountable for results, and being a source of help to them in achieving those results. (Willis, 1997)

Tools that can be used in upward problem solving scheme are continuous improvement (e.g. de Leede and Looise, 1999; Bessant and Caffyn, 1997) and formal suggestion schemes (e.g. Karlsson and Åhlström, 1996).

A quality circle is an activity where operators gather in a group to come up with suggestions on possible improvements. An elaborate scheme for implementing suggestions, rewarding employees and feeding back information on the status of the suggestions is tied to this. This can be contrasted with the traditional suggestion scheme where individual employees are encouraged to leave suggestions in a suggestion-box. (Karlsson and Åhlström, 1996)

Education and training

The number of tasks in which employees receive training should increase. Training should be given in statistical process control, quality tools, computers, performing set-ups, carrying out maintenance, etc. Also, the employees should be trained in a number of functional areas. Tasks previously performed by indirect departments should now be the responsibility of the team. Training in such areas as material handling and control, purchasing, maintenance, and quality control should become essential. (Karlsson and Åhlström, 1996)

Training should become an ongoing event, not a once a year course (Willis, 1997). Knowledge and sight of the "bigger picture" is an essential requirement of empowerment. Obvious thought it may seem, each individual need to have a clear understanding of his or her job and how it relates to the organization's mission. Coupled with mission is the need for inspiring visions, which can help raise expectations of success. (Smith, 1997)

Problem solving tools and techniques are important instruments in quality control. These tools and techniques include for example flow charts, cause and effect diagrams, control charts, run charts, brainstorming, histograms and check sheets.

Without understanding these tools and techniques, the teams and individuals will be unable to separate the symptoms of the problems from the root causes of the problems. (Civerolo, 1992)

Reward system

The cornerstone of empowerment is to congratulate, to reward (non financially) and to recognize people for a job well done and also, to promote their specific accomplishments. This has to be done in such a way that people throughout the organization can see the results that were achieved. This positive action will help defuse the perception that performance measurements are only to be used to catch the people doing something wrong. (Civerolo, 1992)

Non-financially reward system (Civerolo, 1992; Milner et al., 1995; Willis, 1997) and financially reward system (Born and Molleman, 1996) are both supported in published papers. Yet, the importance is in non-financially reward systems.

1.1.2.1 Results of empowerment - an industrial case study

Sykes et al. (1997) present a case study of an optical fiber manufacturer *Eurotec* in England that was taken over by a German company *TBL* in 1991. The company was a traditional manufacturing organization, hierarchical and functional, characterized by tension between management, supervisors and workforce. Despite a healthy order book and low labor costs management perceived a threat from European competitors who provided faster delivery and higher quality.

The company realized that a major change in operations was necessary. The problems in production were so serious that the survival of the company was threatened. It was apparent that incremental change would not provide the necessary solutions. In order to solve these major problems without increasing costs of labor and supervision, a fresh start was needed.

First production work teams were introduced and employees were split into groups, with one person in each group as the team leader. The composition of each team was decided on the basis of trying to achieve the right mix of skills within each team using a skill matrix. The team leaders were selected on the basis of the senior managers´ assessment of their leadership ability and this was purely subjective.

This change moved the company from large batch production methods, where operators often performed the same short-cycle and repetitive job all day, every day, to one where every member of each team performs every task. Production throughput time needed to be reduced and team working helped the company to achieve this. However, the company structure did not yet provide for fast communication, so the management then took a layer out of the organization by removing the supervisors. This actually exacerbated the span of control problems since the team leaders now reported directly to the production director. It was thus imperative that responsibility now be delegated to these team leaders who had become crucial to the effective operation of the company. The team leaders and the shop floor employees were therefore empowered to deal with:

- Allocation of all work within their team: who does what, and when.
- Control of all working hours within the team.
- Purchasing of tools, basic equipment and protective clothing.
- Communication: the team leaders are encouraged to hold regular meetings between themselves and their teams in order to improve communication and to provide a forum for solving problems and making improvements.

- Monitoring of their team's performance in the area of quality, efficiency, delivery and absenteeism. Results are posted on their own notice boards.
- Operator recruitment.

Training became a real issue on the appointment of the team leaders. Training has also been expanded at all levels. Training has covered all necessary skills needed in different positions in the company and it has made employees feel more involved as well as enhanced their technical and communication skills.

Table 1.1.2.1 - 1 shows the results that have been achieved in the operations of the company from the takeover of *TBL* in 1991, introduction of work teams in 1991/1992 and the period of emphasis on training since then. Noticeable is the problem of absorbing the new products from the takeover of *TBL*. Though performance in 1995 does not look superior to that in 1991, in fact it is, because many more units were sold in 1995.

Table 1.1.2.1 - 1 Performance at Eurotec

	1991	**1993**	**1995**
Sales per employee (ratio)	1	1.1	1.6
Quality: units rejected at final inspection	160	510	140
Quality: units returned by customers	170	920	240

1.2 Objective and scope of the study

The objective of the thesis is to analyze the origins [(1] of production errors [(2] in the production flow of the sheet metal based constructions. The production error distribution in the production flow of the sheet metal part based constructions is inspected in this thesis. Also, the employee empowerment is investigated in theory and the meaning of the employee empowerment in reducing the overall production error amount is discussed. However, the main focus in this thesis is in the origins of production errors.

This study is most relevant to the sheet metal part fabricating industry which produces sheet metal part based constructions for electronics and telecommunication industry. This study concentrates on the manufacturing function of a company and the focus is in Finnish based companies.

1.3 Limitations

There are several ways to view the effects of production errors on the production flow. Any production error causes extra activities and impairs the production flow control. These activities raise production costs and make the production flow less fluent and efficient. In this thesis the major focus is in the origins of the production errors and how the production errors are distributed in the production flow. Therefore, a functional approach has been chosen. The functional approach reveals the total sum of production errors in each functional work phase and reasons for the production errors.

[(1] By the word ***origins*** in this thesis is meant the factor that causes the production error, e.g. malfunction in production machinery, human error or defective raw material.

[(2] The term ***production error*** in this thesis means a deflection from a planned production flow where the customer demands are not met. Because of that deflection various repairing operations are needed. The term ***production error*** is more precisely explained later in this thesis in chapter 2.2.3.

How efficiently the production process is utilized in each case factory is not studied in this thesis. Also, quality costs caused by the production errors are not studied in this thesis. The assumption is that there will always be extra cost for repair and rework activities. It is also noticeable that this extra cost rises in proportion to the amount of completed work phases. However, the effect of the production errors on the business activities of the studied companies has been studied theoretically on the basis of the results presented in this thesis.

Product design plays very remarkable role in product manufacturing. Incorrect product design appreciably can increase possibilities to production errors. In this thesis errors in product design are therefore included in the production flow in so far as production errors are caused by defective product design.

This study is based on a field study carried out in five Finnish case factories which produce sheet metal part based constructions, mainly for electronics and telecommunication-related industry. In this study these factories are called as Factory A, Factory B, Factory C, Factory D and Factory E.

Case Factories B, C and D are direct competitors in some product groups. Therefore results are presented in a form where key figures in separate factories are not recognizable. Only the distribution of all production errors in each factory studied is presented.

1.3.1 Case factories

All case factories are well known Finnish based factories. It is generally accepted that these factories represent advanced activities in their manufacturing operations. Factories A, C, D and E are parts of larger consolidated companies. All case factories manufacture products for global distribution. The turnover of the consolidated companies is representing a remarkable part of the annual Finnish turnover in sheet metal part fabricating industry.

Branches of manufacturing activities in case factories are listed below:

- Factory A manufactures electromechanical locking systems.
- Factory B manufactures sheet metal parts based constructions for electronics, telecommunication and automotive industry.
- Factory C manufactures custom outdoor and indoor enclosures for telecom applications such as wireless base stations, switching systems and network access equipment.
- Factory D manufactures sheet metal parts based constructions for electronics, telecommunications, networking and automotive industry.
- Factory E manufactures sheet metal components, e.g. electronics cabinets and NC-cabinets, for machine tool constructions.

The production flow in each case factory is different. Different fabricating methods are used. Also batch sizes and annual production figures are different in each case factory. Common factors for every factory are mechanical constructions based on sheet metal parts and used in electronics and telecommunication industry.

1.4 Statement of this thesis

The production flow of a sheet metal part fabricating factory can be seen as a sum of four elements, presented in figure 1.4 – 1. These elements include materials, manufacturing technology, human work and supporting elements. Materials consist of raw materials, subcontracted components and purchased standard parts and also, chemicals etc. needed in different manufacturing processes. Manufacturing technology contains all production machinery needed in various manufacturing activities, tooling for production machinery, software needed in manufacturing processes and also, different chemical processes needed in e.g. surface treatment processes. Human work consists of direct work needed in manufacturing activities and also, indirect human activities needed to support manufacturing activities, such as maintenance activities, quality control activities and production planning activities. Supporting elements contain production facilities and warehousing operations as well as logistics arrangements.

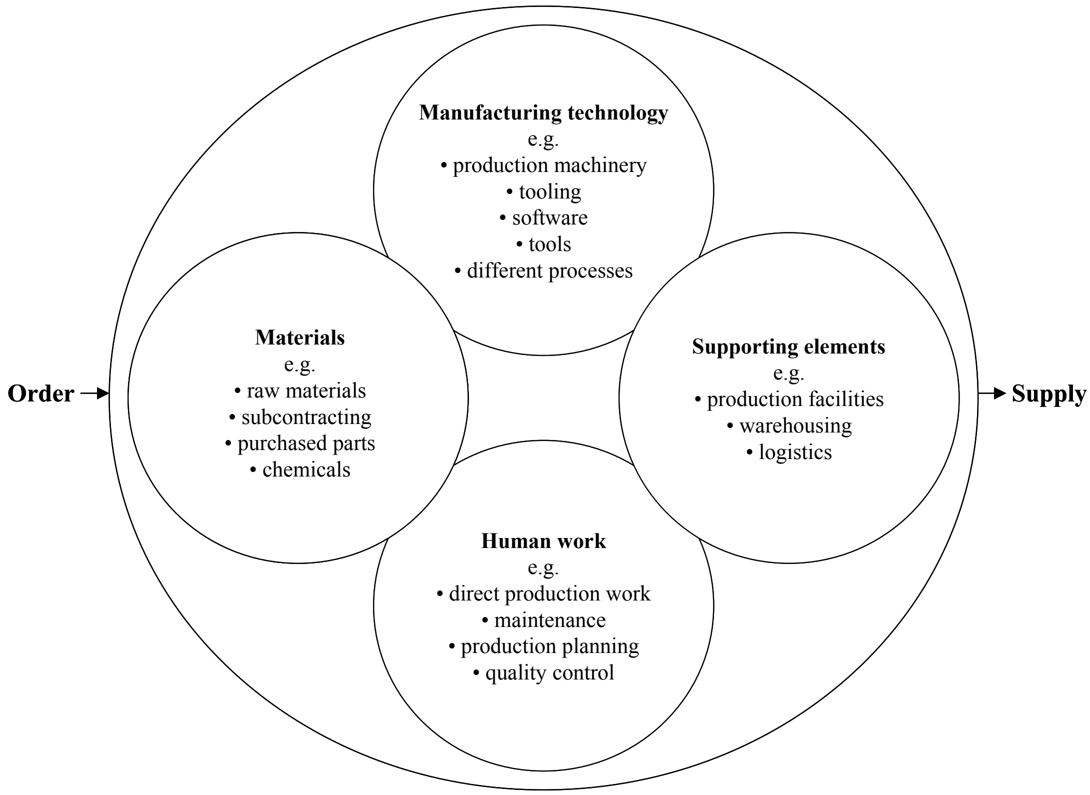


FIGURE 1.4 – 1 Four elements in production flow

Considering these four elements, objective and scope of the study and limitations described earlier, the statement of this thesis can be presented as:

"Human activity based errors cause most of the production errors in the production flow of the sheet metal part fabricating industry."

2 METHODS

Three different study methods were used in this thesis. Those study methods are literature search, field study and empowerment survey. The literature search is described in chapter 2.1, the field study is described in chapter 2.2 and the empowerment survey is described in chapter 2.3.

2.1 Literature search

The aim of the literature search was to find as much information as possible about the production flow of constructions based on fabricated sheet metal parts and errors in a production flow such as caused by the employee empowerment. A comprehensive literature study was carried out, which included a thorough search for relevant publications in the major databases at the Lappeenranta University of Technology (LUT) library. An Internet search was also carried out. Also chained references were used. Many (well over 2000) article references were found and more than 200 articles were ordered or printed for closer inspection.

2.2 Field study

The field study was a part of LELA -research program (Ollikainen et al., 2003) carried out by Lappeenranta University of Technology (LUT) between 12/2000 and 8/2002. LELA-research program was concentrating on reducing the quality costs in Finnish sheet metal companies. LELA-research program participants were LUT, Tekes and seven Finnish companies. Five of these companies are manufacturing sheet metal part based constructions, one is manufacturing machine tools for the needs of sheet metal industry and one is an end-user of constructions based on sheet metal parts.

The aim of the field study was to collect data from the production error distribution and origins of production errors in the production flow of the sheet metal part based constructions. No existing model for a similar or comparable field study could be found in published papers. Some case factories are using own methods to collect the production data. These methods were observed to be too rough to be used in the analysis of the origins of production errors. Also, it is impossible to have a comparable data if different methods are being used. Therefore, own study methods had to be developed. The study method is based on background information (fabricated products, used work phases, production machinery, different production processes e.g.) collected from the case factories and long time experience from sheet metal part fabricating industry.

The principle used in this field study is presented in figure 2.2 - 1. Background information was collected from the case factories. Most of this information was received from the LELA-project management group in a management group meeting. It was also possible to visit some of the factories in this point of study.

After receiving sufficient background information, a production flow partition was done and production error charts were formulated. Factories were asked to appraise formulated charts and to give feedback from the charts. The production error charts were finalized using that feedback.

Every factory was asked to select some products to be tracked in this field study. The tracked products are typical products in daily basis for each factory and they form a daily production flow in each factory.

A training occasion was arranged in each factory studied. The training occasion included following information:

- General information about changing competitive requirements.
- Background of the field study.
- Aim of the field study.

- Production flow partition used in the field study.
- Production error charts used in the field study.
- Filling instruction for error charts used in the field study.

Following personnel participated in the training occasion:

- Company management.
- Supervisors.
- Team leaders.
- Machine tool operators.

After the training occasion an internal training period was arranged in every factory studied. During this period necessary information was shared among all shop floor personnel and they were trained to collect error data.

Following that internal training period a production error data collection was arranged for selected products. As an entirety the field study was performed between the time period of March 2001 - November 2001. Field studies in each case factory endured from two to three months. Noticeable is that conditions of the production flow stayed unchangeable in each case factory during that period of time.

All completed production error charts were collected and necessary error data was delivered to LUT. Production error databases were generated from this delivered data.

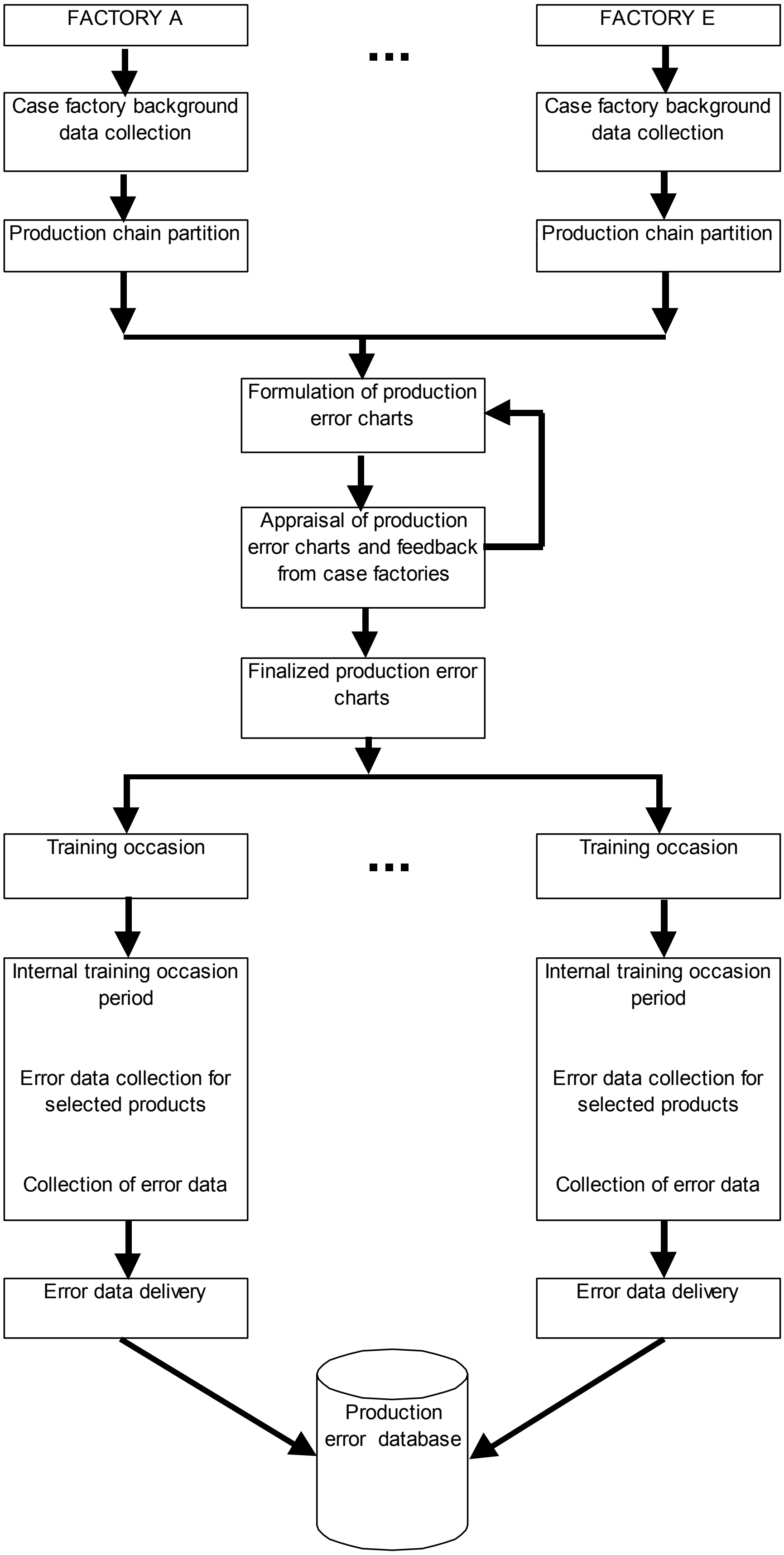


FIGURE 2.2 - 1 Principle used in the field study

2.2.1 Product categories

The sheet metal part fabricating industry mainly produces components in different levels to be used in final products. A component can be a single sheet metal part used as e.g. heat shield or it can be more complex component including some kind of assembly work, e.g. cabinet door assembly. Based on this fact, the products have been divided into three main categories in the field study. These three main categories are:

- Part category.
- Subassembly category.
- Assembly category.

The principle of the product categories and the partition used in this study is showed in figure 2.2.1 - 1.

In Part category parts are manufactured. Single parts are fabricated of sheet metal. Producing single parts can contain joining, surface treatments and different assisting work phases. A single part can be a final product alone or it can be used in a larger construction.

Subassembly category is, as its name says, the phase where subassemblies are made. Subassemblies are based on the part category parts and non-sheet metal parts. The subassemblies can contain different assembly phases as well as surface treatments and different assisting work phases. A single subassembly can be a final product alone or it can be used in a larger construction.

In Assembly category constructions are assembled. The assemblies are based on the part category parts and the subassembly category subassemblies. The assemblies can contain assembly phases and assisting work phases.

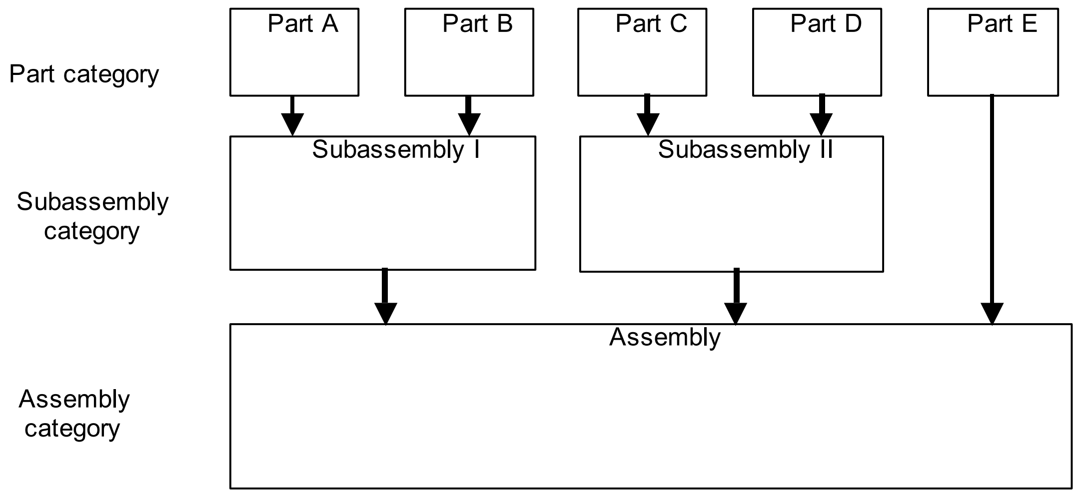


FIGURE 2.2.1 - 1 Principle of product partition used in this study

2.2.2 Production flow partition

In this study the production flow has been shared into functional phases. These functional phases have then been shared into work phases. This partition and numeration is featured in Table 2.2.2 - 1. This partition and numeration is used in the production error charts and in the production error database later on in this study. Every factory studied has different production machinery. Therefore, every functional phase or work phase does not necessarily exist in the production flow of every factory studied.

Table 2.2.2 - 1 Production flow partition used in this study

	FUNCTIONAL PHASE		WORK PHASE
1	Fabrication of blank parts	11	Mechanical cutting
		12	Punch press
		13	Deep drawing
		14	Forming
		15	Laser cutting
2	Bending	21	Press brake

		22	Panel bender
		23	Folding machine
		24	Eccentric press
		25	Hydraulic press
3	Joining	31	Welding
		32	Spot welding
		33	Riveting
		34	Other joining method
4	Surface treatments	41	Cleaning
		42	Pretreatment
		43	Surface treatment
		44	Painting
		45	Printing
5	Unspecified work phases	51	Threadning
		52	Forming
		53	Marking
		54	Grinding
		55	Countersinking
		56	Nut inserting
		57	Assembly of non-sheet metal parts
		58	Bonding
		59	Hardening
		60	Heat treatments
		61	Deburring
7	Assembly	71	Welding
		72	Riveting
		73	Screwing
		74	Spot welding
		75	Bonding
9	Assisting work	91	Transportation
		92	Handling

93	Packing
94	Transportation arrangements
95	Warehousing

2.2.3 Definition for production error

Many experts have defined the word *quality* in a slightly divergent way. For example Crosby (1979) has defined quality as "conformance to requirements" and Feigenbaum (1983) "the total composite product and service characteristics of marketing, engineering, manufacture and maintenance through which the product and service in use will meet the expectations of the customer". According to Juran (1988) the word quality has multiple meanings. Two of those meanings dominate the use of the word:

1. Quality consists of those product features that meet the needs of customers and thereby provide product satisfaction.
2. Quality consists of freedom from deficiencies.

Practitioners have proposed several phrases but none has achieved universal acceptance (Juran, 1988).

A planned and optimal production flow can only be achieved when manufactured products are fault free and meet a customer expectation in every stage of the production flow. In this study the production error can be seen as a deflection from a planned production flow. Because of that deflection, various operations are needed depending on the situation:

- Defective products must be adjusted.
- Defective products must be completed.
- Defective products must be scrapped and new products must be fabricated.

This deflection may be exposed in the same point of the production flow where it is caused or it can progress in the production flow and it may be exposed later on in the production flow.

In this study production errors are classified into fourteen production error types and numbered as follows:

1. Human errors
2. Machine tool related errors
3. Tool related errors
4. Organizational errors
5. External errors
6. Preceding work phase related errors
7. Design errors
8. Surface treatment process related errors
9. Surface treatment equipment related errors
10. Warehousing errors
11. Transportation device related errors
12. Lifting device related errors
13. Raw-material related errors
14. Other unclassified errors

This classification and numeration is used in the production error charts and in the production error database later on in this study. The production errors are specified. This specification is presented in Table 2.2.3 - 1.

Table 2.2.3 - 1 Error specification used in this study

	PRODUCTION ERROR		**ERROR SPECIFICATION**
1	Human errors	11	Work error
		12	Interpretation error
		13	Setup error

		14	Incorrect NC-program
		15	Incorrect drawing
		16	Undefined error
2	Machine tool related errors	21	Error in NC-control unit
		22	Machine tool failure
		23	Operating error
		24	Insufficient maintenance
		25	Indefinable error
3	Tool related errors	31	Tool break
		32	Insufficient maintenance
		33	Setup error
		34	Indefinable error
4	Organizational errors	41	Old drawing
		42	Old instruction
		43	Defective drawing
		44	Defective work instruction
		45	Wrong work method
		46	Indefinable error
5	External errors	51	Defective purchase
		52	Defective subcontracting
		53	Water damage
		54	Convulsion of nature
		55	Indefinable error
6	Preceding work phase related errors	61	Work error in preceding work phase
		62	Product out of tolerances
		63	Handling error in preceding work phase
		64	External error in preceding work phase
		65	Indefinable error
7	Design errors	71	Defective construction
		72	Product impossible to manufacture
		73	Functional error

		74	Indefinable error
8	Surface treatment process related errors	81	Defective bath
		82	Soiled bath
		83	Wrong bath temperature
		84	Defective work instruction
		85	Indefinable error
9	Surface treatment equipment related errors	91	Wrong program
		92	Wrong hanging method
		93	Functional error
		94	Indefinable error
10	Warehousing errors	101	Dents / scratches
		102	Water damage
		103	Convulsion of nature
		104	Dirt in product
		105	Indefinable error
11	Transportation device related errors	111	Functional error
		112	Wrong work instruction
		113	Falling
		114	Indefinable error
12	Lifting device related errors	121	Functional error
		122	Wrong work instruction
		123	Falling
		124	Indefinable error
13	Raw-material related errors	131	Wrong material delivery
		132	Water damage
		133	Dents / scratches
		134	Indefinable error
14	Other unclassified errors	141	Write comments other side

2.2.4 Production error charts used in field study

In this study three different production error charts were formulated:

- Chart 1 (appendix I)
- Chart 2 (appendix II)
- Chart 3 (appendix III)

Chart 1 for the part category includes following functional phases:

1 Fabrication of blank parts
2 Bending
3 Joining
4 Surface treatments
5 Unspecified work phases
9 Assisting work

Chart 2 for the subassembly category includes following functional phases:

4 Surface treatments
5 Unspecified work phases
7 Assembly
9 Assisting work

Chart 3 for the assembly category includes following functional phases:

5 Unspecified work phases
7 Assembly
9 Assisting work

All charts include functional phase related work phases. Also, production error specification is included in all charts (appendix IV).

All charts have a table for production error notes. The table includes columns for following notes:

- Work phase / production error classification.
- Error specification.
- Amount of defective products.
- Amount of acceptable products delivered to the next work phase.
- Comments.

All charts have also cells for product identification markings and production flow description. Also cells for batch size markings and production date information are included.

2.2.5 Presented results from field study

Separate production flow error databases are formed for each case factory. These databases are presented in tables 3 - 2 (Factory A), 3 - 3 (Factory B) and 3 - 4 (Factory C). The databases formed are published in this paper. Also, a number of traced parts and a number of detected errors are published in this paper.

All information in the databases is analyzed and following tables and figures are published later on in this study:

- Production error distribution by functional phases in each factory studied, figure 3.1 - 1.
- Production error distribution by work phases in each factory studied, table 3.2 - 1.
- Production error distribution by error type in each factory studied, table 3.3 - 1.

- Production error distribution in each work phase by error type in each factory studied, figures 3.4 - 1 to 3.4 - 27.
- Production error distribution by error specification in each factory studied, table 3.5 - 1.

2.2.6 Reliability of field study method

The production error data collection presented in this thesis includes a lot of manual work. This asks a certain commitment by the work organization and employees who perform the data collection. However, human mistakes can happen. Possible factors of uncertainty are listed below:

- Some markings are missing.
- Wrong codes are used.
- Number of the production errors caused is marked incorrectly in the chart.
- Incorrect assessment of the situation and, as a result of that, wrong codes are used.
- The production error chart is missing or destroyed.

In some cases it is possible that the production error data collection faced resistance from some employees. The perception can be that the data collection was put into practice only to catch people doing something wrong. In such cases data is not collected by some of the employees and the data remains imperfect.

All cases described above weaken the results. The assumption is that the total amount of errors is less than actually caused in the production flow.

Positive feedback of the field study methods and the error charts was received from the case factories. The study methods used were applicable in each factory studied and the error charts used did cover the whole production flow in each factory studied. Also, the error charts used were detailed enough to be used in every factory studied. Presumably, the methods and the error charts used give reliable results from each factory studied.

All procedures and production error charts are described in this paper. This ensures that the production error data collection can be repeated in any sheet metal parts based constructions manufacturing company fulfilling criteria set in this paper.

2.3 Empowerment survey

To estimate what is the level and the state of the empowerment in the case factories, an empowerment survey was completed. Sixteen questions (Q1 - Q16) were asked from a representative of every case company. Those questions are based on five main types of themes in employee empowerment (table 1.1.2 – 1) and the content of different types of themes presented in chapter 1.1.2. Those sixteen questions are:

Multifunctional team structure:

Q1: *Is a multifunctional team organization in use?*

Q2: *Is supervisor-level in use in the organization or is there a team leader system?*

Q3: *Is task rotation in use? How often does this happen?*

Q4: *Are different functions integrated in the tasks of the teams? (Purchasing of articles, quality control, control of all working hours etc.)*

Information sharing:

Q5: What is the content of the information communicated with the employees? (Vision, strategy, objectives, goals and directions etc.)

Q6: Are public performance indicators in use?

Q7: How and where is the information displayed?

Q8: Are the means of visual communication in use?

Upward problem solving:

Q9: Who is responsible for developing the production activities?

Q10: Is formal suggestion scheme in use?

Q11: Is a continuous improvement program in use?

Education and training:

Q12: Are continuous training and education methods and activities in use?

Q13: What is the content of the training?

Q14: Are problem solving techniques taught to the staff?

Reward system:

Q15: Is a reward system in use?

Q16: What performance meters are used in the reward system?

Results from the empowerment survey are presented in table 3-5 later on in this thesis.

3 RESULTS

Field study

The error data collection was started in five case factories (Factories A to E). Information was received from three case factories out of five. Information was received from factories A, B and C and not received from factories D and E. Factory D did not inform any cause why the collection of the error data was not completed. Factory E informed that the collection of the error data faced resistance from employees and was ended unproductive.

The number of the parts traced in the field study was 732724 pieces. A total of 84011 production errors were reported. Key figures of this field study are summarized in table 3 - 1.

Table 3 - 1 Summary of key figures in the field study

Number of reported case factories	3
Parts traced in the field study	732724 pieces
Production errors reported	84011 pieces

The production flow error databases are presented in Tables 3 - 2, 3 - 3 and 3 - 4. Each table has 5 columns. The first column identifies the functional phase where a production error is caused or observed. The second column identifies the work phase where a production error is caused or observed. The functional phase numeration and the work phase numeration are presented in Table 2.2.2 - 1 in chapter 2.2.2 Production flow partition.

The third column identifies the production error classification. The fourth column identifies the production error classification. The numeration for production error classification and the numeration for production error specification are presented in Table 2.2.3 - 1 in chapter 2.2.3 Definition for production error.

The fifth column states the total amount of defective products. Rows with the corresponding production error numeration has been added and the total number of defective products during the tracking period is presented. For example, the first row (1, 12, 2, 23 and 10) in table 3 - 2 specify production error as follows:

- The production error has been caused in the functional phase *1 Fabrication of blank parts* and in the work phase "*12 Punch press*".
- The production error is of type "*2 Machine tool related errors*" and error specification is "*23 Operating error*".
- The total amount of defective products in this stage is 10 pieces.

Code <26> in the work phase column signifies indefinable notes in the production error charts. Code <76> in the work phase column is added to signify the general assembly work phase in an assembly phase of an electromechanical product.

Table 3 - 2 Production error database, Factory A

Functional phase	**Work phase**	**Production error type**	**Error specification**	**Number of defective products**
1	12	2	23	10
1	12	2	22	630
1	12	2	23	54
1	12	3	34	12
1	12	14	141	72
1	15	2	21	80
1	15	2	23	7
2	21	6	63	2
2	21	6	61	5
2	21	14	141	5
2	24	14	141	5
3	33	1	11	1

3	33	5	51	5
3	33	6	61	69
3	33	14	141	15
4	43	9	94	54
4	43	9	93	5
4	43	14	141	145
5	54	6	65	9
5	54	6	63	5
5	55	3	34	28
5	55	6	62	25
5	55	6	65	29
5	55	6	61	28
5	55	6	65	9
5	55	14	141	12
5	59	4	45	2077
5	61	14	141	15
7	<76>	2	24	1
7	<76>	2	25	26
7	<76>	3	34	123
7	<76>	6	61	106
7	<76>	6	63	115
7	<76>	6	65	657
7	<76>	7	71	130
7	<76>	7	72	16
7	<76>	8	81	5
7	<76>	9	94	4
7	<76>	10	101	5
7	<76>	13	133	24
7	<76>	14	141	154
Sum				**4779**

Table 3 - 3   Production error database, Factory B

Functional phase	Work phase	Production error type	Error specification	Number of defective products
1	11	1	11	393
1	11	1	13	165
1	11	1	14	1682
1	11	3	31	2165
1	11	3	32	313
1	11	3	34	2999
1	11	7	72	5717
1	13	1	13	200
2	21	1	11	360
2	21	3	34	1060
2	21	4	45	22
2	24	1	11	1290
2	24	1	13	174
2	24	1	14	7159
2	24	3	32	12265
2	24	3	33	10216
2	24	3	34	122
2	24	4	41	11
2	24	7	72	17386
3	31	1	11	8
3	31	1	12	305
3	31	1	13	165
3	31	3	33	300
3	31	3	34	50
3	31	7	72	697
3	33	1	13	4761
4	41	7	72	461

4	43	5	52	2734
4	44	1	12	232
4	44	9	93	588
4	44	9	94	640
5	51	1	11	1020
5	51	5	51	216
5	52	5	52	136
5	53	1	14	46
5	54	1	11	1118
5	57	5	52	124
5	58	5	51	100
5	58	7	72	60
5	61	5	52	977
7	72	1	13	10
7	73	1	11	16
9	91	11	113	350
9	95	10	105	13
Sum				**78826**

Table 3 - 4 Production error database, Factory C

Functional phase	**Work phase**	**Production error type**	**Error specification**	**Number of defective products**
1	11	6	141	2
1	12	1	12	45
1	12	1	14	1
1	12	2	23	45
1	12	2	25	12
1	12	3	34	1
1	12	5	141	23

1	12	6	141	34
1	12	13	133	12
1	12	14	141	10
2	21	1	11	122
2	21	2	25	7
2	24	1	13	2
2	<26>	1	11	1
3	33	6	61	1
5	54	1	12	10
5	54	4	43	45
5	57	5	52	10
9	92	6	63	23
Sum				**406**

Empowerment survey

Results of the empowerment survey are presented in table 3 - 5. The survey results are presented from Factory A, Factory B and Factory C.

Table 3 - 5 Results of the empowerment survey

	Factory A	Factory B	Factory C
Q1	no; workgroups / cell production	yes; three separate work teams in use + functional organization	no; workgroups
Q2	supervisor-level	supervisor-level	supervisor-level
Q3	some tasks, e.g. machine tool operator tasks, are rotated	yes; daily basis	no

Q4	no; some tasks, e.g. purchasing of gas and sheet materials, are performed by turret punch press operators	quality control, control of working hours	no
Q5	both strategic and operative type information	both strategic and operative type information	daily matters
Q6	yes	yes; quality feedback	some indicators in workgroup level
Q7	notice board, information leaf	info session once a week, notice board	e-mail, notice board
Q8	no	no	no
Q9	everyone in the company	supervisors	supervisors
Q10	yes; very active use	yes; poor activity	yes; poor activity
Q11	no	no	no
Q12	no; education is based on needs	yes; training program	no; basic training, education is based on needs
Q13	based upon to professional needs	based upon to professional needs	based upon to professional needs
Q14	no	no; FMEA + Pareto-methods are used by supervisors	yes; FMEA-method
Q15	yes	yes	yes
Q16	Working time per calculated working time based on invoicing	machine tool operators cycle time	economic results, quality

Questions:

Q1: Is a multifunctional team organization in use?

Q2: Is supervisor-level in use in the organization or is there a team leader system?

Q3: Is task rotation in use? How often does this happen?

Q4: Are different functions integrated in the tasks of the teams? (Purchasing of articles, quality control, control of all working hours etc.)

Q5: What is the content of the information communicated with the employees? (Vision, strategy, objectives, goals and directions etc.)

Q6: Are public performance indicators in use?

Q7: How and where is the information displayed?

Q8: Are the means of visual communication in use?

Q9: Who is responsible for developing the production activities?

Q10: Is formal suggestion scheme in use?

Q11: Is a continuous improvement program in use?

Q12: Are continuous training and education methods and activities in use?

Q13: What is the content of the training?

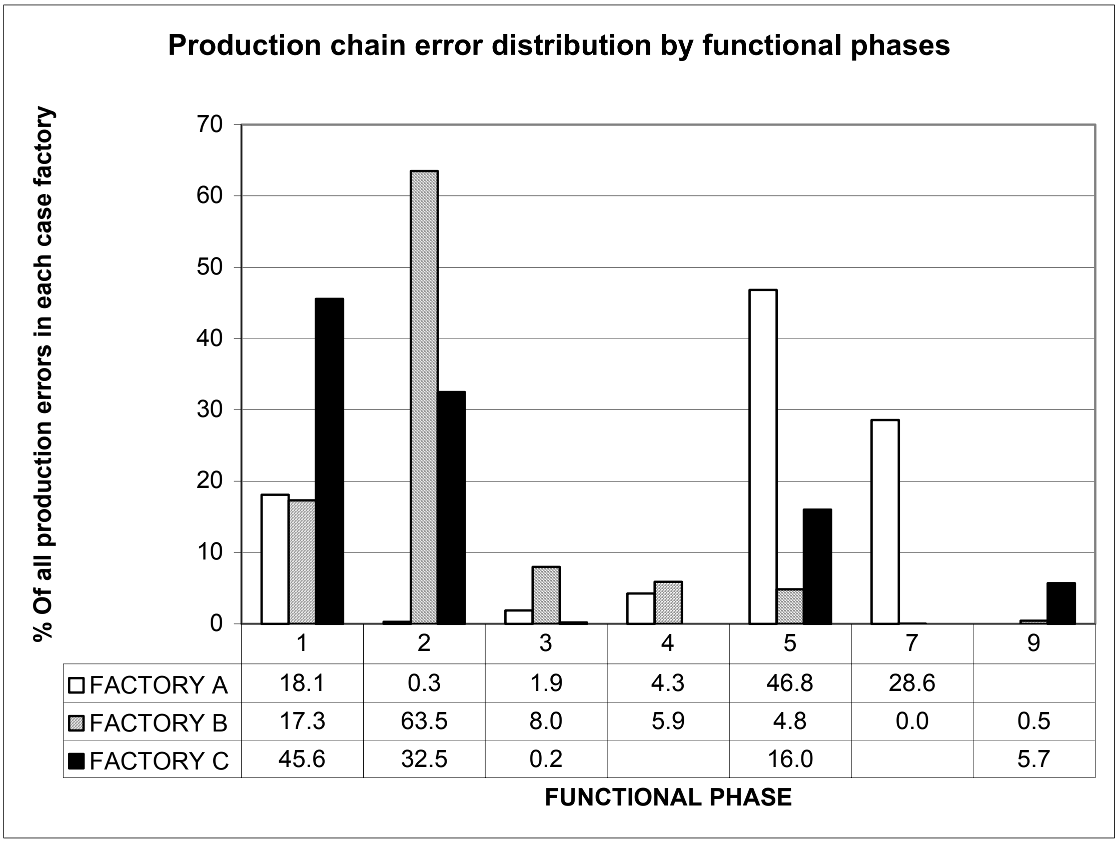
Q14: Are problem solving techniques taught to the staff?

Q15: Is a reward system in use?

Q16: What performance meters are used in the reward system?

3.1 Production error distribution by functional phases

The production error distribution by functional phases in each factory studied is presented in figure 3.1 - 1. Figures shown in figure 3.1 - 1 are presenting the percentage distribution of all production errors in each factory. In some cases figure 0.0 is used. This figure expresses that a production error exists but the share is zero.



Functional phase:

1. Fabrication of blank parts
2. Bending
3. Joining
4. Surface treatments
5. Unspecified work phases
7. Assembly
9. Assisting work

FIGURE 3.1 - 1 Production error distribution by functional phases

3.2 Production error distribution by work phases

The production error distribution by the work phases in each factory studied is presented in Table 3.2 - 1. Figures shown in the table are presenting the percentage distribution of all production errors in each factory. In some cases figure 0.0 is used. This figures does express that a production error exists but the share is zero. Grey color in a table cell expresses that no production error exists in that work phase.

Table 3.2 - 1 Production error distribution by work phases in each factory studied [%]

	Work phase	Factory A	Factory B	Factory C
11	Mechanical cutting		17.0	0.5
12	Punch press	16.3		45.1
13	Deep drawing		0.3	
14	Forming			
15	Laser cutting	1.8		
21	Press brake	0.2	1.8	31.8
22	Panel bender			
23	Folding machine			
24	Eccentric press	0.1	61.7	0.5
25	Hydraulic press			
<26>				0.2
31	Welding		1.9	
32	Spot welding			
33	Riveting	1.9	6.0	0.2
34	Other joining method			
41	Cleaning		0.6	
42	Pretreatment			
43	Surface treatment	4.2	3.5	
44	Painting		1.9	
45	Printing			
51	Threadning		1.6	
52	Forming		0.2	
53	Marking		0.1	
54	Grinding	0.3	1.4	13.5
55	Countersinking	2.7		
56	Nut inserting			
57	Assembly of non-sheet metal parts		0.2	2.5
58	Bonding		0.2	

59	Hardening	43.5		
60	Heat treatments			
61	Deburring	0.3	1.2	
71	Welding			
72	Riveting		0.0	
73	Screwing		0.0	
74	Spot welding			
75	Bonding			
<76>		28.6		
91	Transportation		0.4	
92	Handling			5.7
93	Packing			
94	Transportation arrangements			
95	Warehousing		0.0	

3.3 Production error distribution by production error type

The production error distribution by the production error classification in each factory studied is presented in Table 3.3 -1. Figures shown in the table are presenting the percentage distribution of all production errors in each factory. Grey color in a table cell expresses that no production error exists in that work phase.

Table 3.3 - 1 Production error distribution by error classification in each factory studied [%]

Production error	FACTORY A	FACTORY B	FACTORY C
1	0.0	24.2	44.6
2	16.9		15.8
3	3.4	37.4	0.2

4	43.5		11.1
5	0.1	5.4	8.1
6	22.2		14.8
7	3.1	30.9	
8	0.1		
9	1.3	1.6	
10	0.1		
11		0.5	
12			
13	0.5		2.9
14	8.8		2.5

Production error:

1 Human errors

2 Machine tool related errors

3 Tool related errors

4 Organizational errors

5 External errors

6 Preceding work phase related errors

7 Design errors

8 Surface treatment process related errors

9 Surface treatment equipment related errors

10 Warehousing errors

11 Transportation device related errors

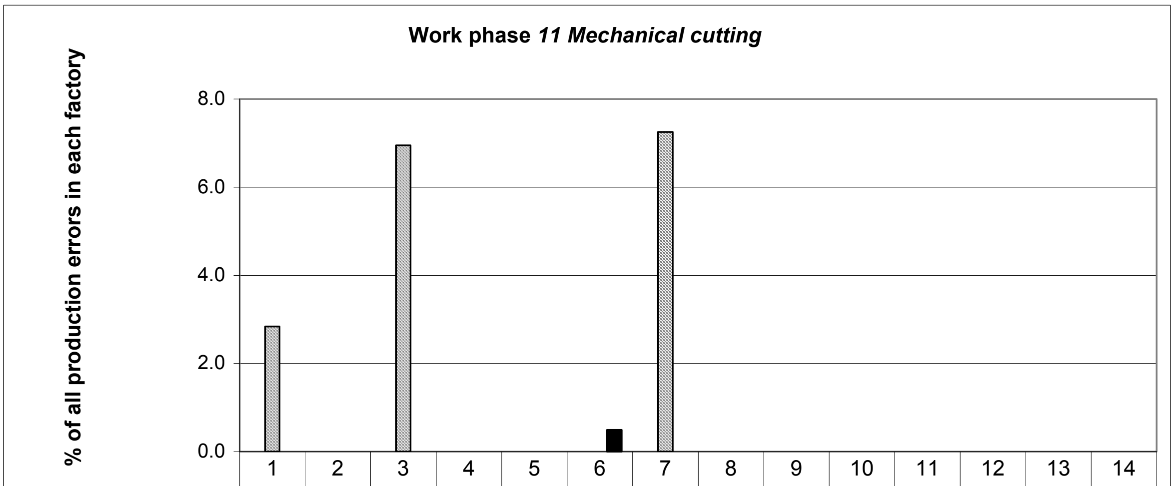
12 Lifting device related errors

13 Raw-material related errors

14 Other unclassified errors

3.4 Production error distribution in each work phase by error type

The production error distribution in each work phases by the error classification (* in each factory studied is presented in figures 3.4.1 - 1 to 3.4.1 - 27. The figures shown in the tables are presenting the percentage distribution of all production errors in each factory. In some cases figure 0.0 is used. This figure expresses that a production error exists but the share is zero.

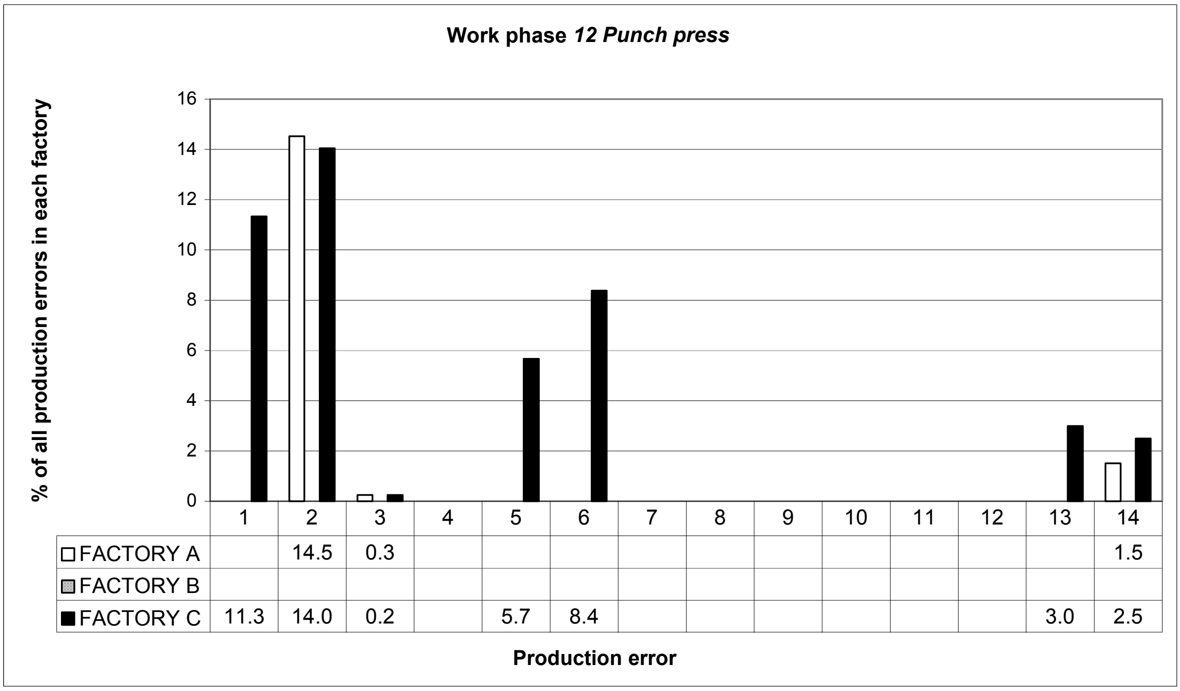


	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A														
FACTORY B	2.8		6.9				7.3							
FACTORY C						0.5								

FIGURE 3.4 - 1 Percentage distribution of all production errors in each factory studied by error classification. Work phase 11

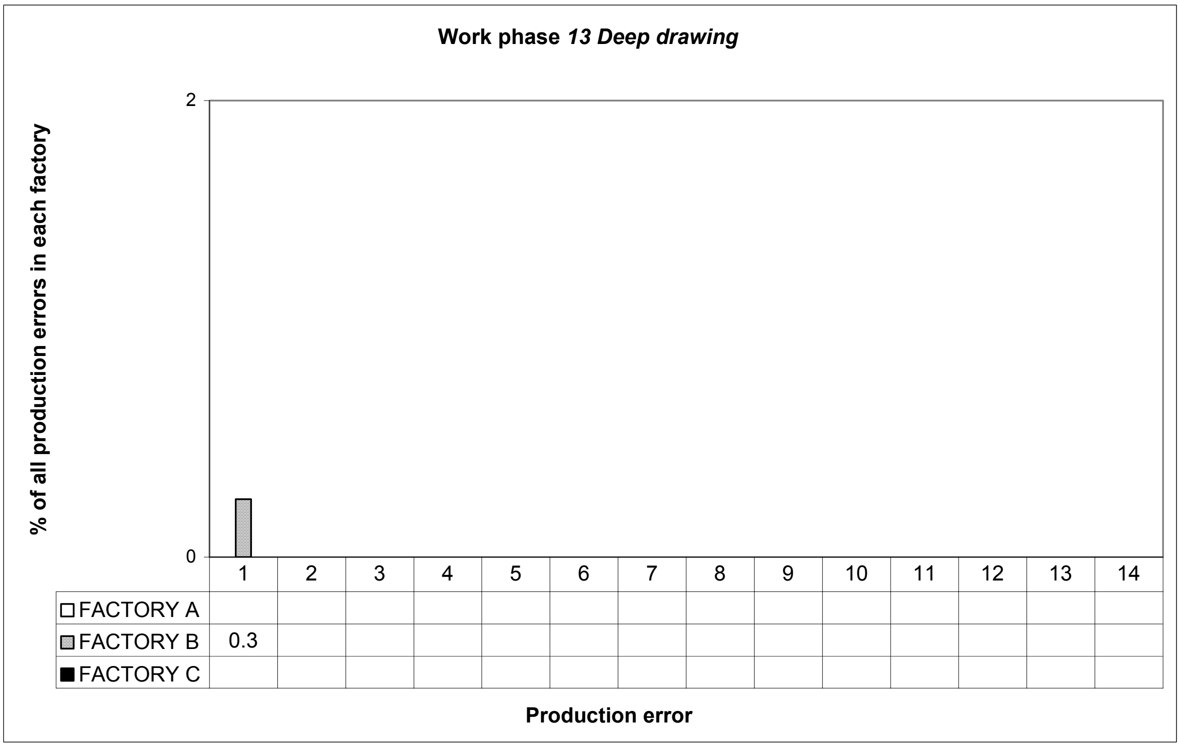
(*

1 Human errors
2 Machine tool related errors
3 Tool related errors
4 Organizational errors
5 External errors
6 Preceding work phase related errors
7 Design errors
8 Surface treatment process related errors
9 Surface treatment equipment related errors
10 Warehousing errors
11 Transportation device related errors
12 Lifting device related errors
13 Raw-material related errors
14 Other unclassified errors



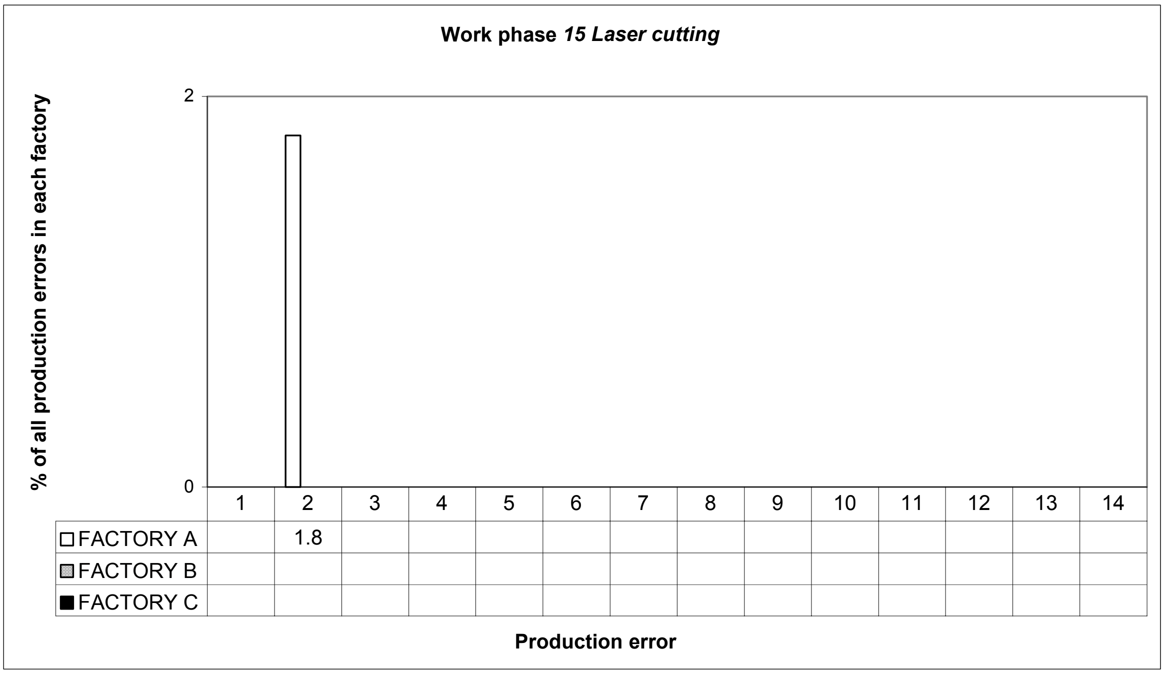
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
□ FACTORY A		14.5	0.3											1.5
▒ FACTORY B														
■ FACTORY C	11.3	14.0	0.2		5.7	8.4							3.0	2.5

FIGURE 3.4 - 2 Percentage distribution of all production errors in each factory studied by error classification. Work phase 12



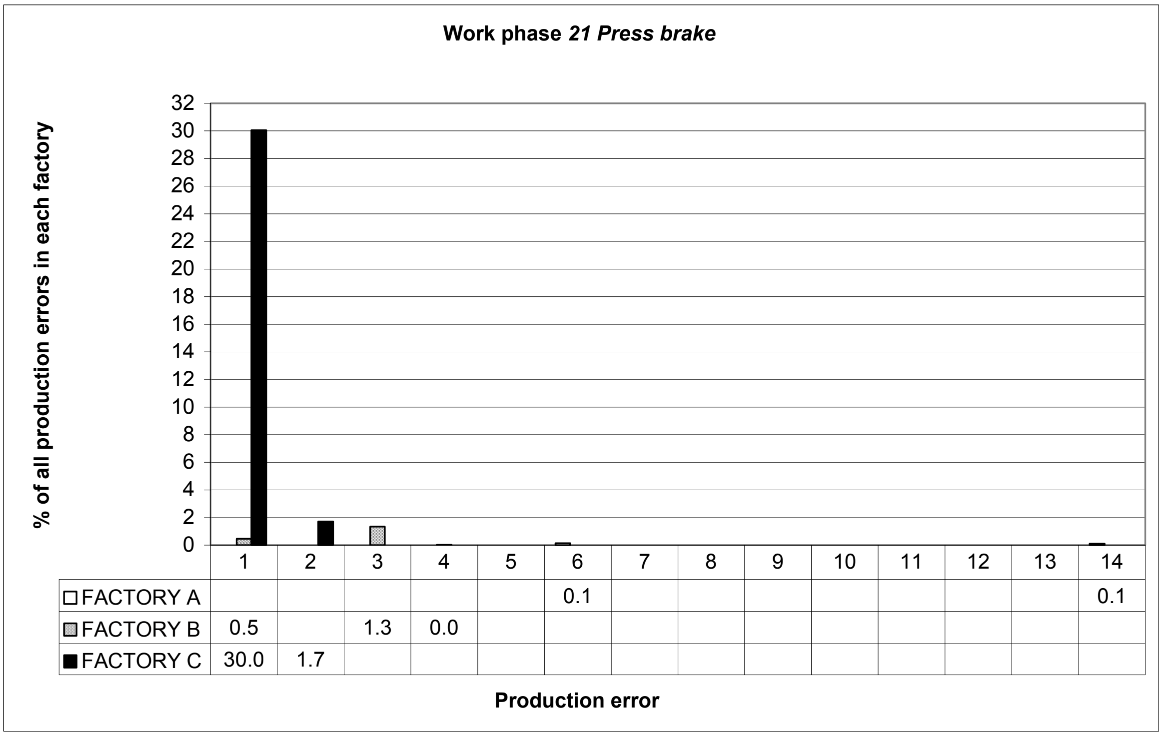
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
□ FACTORY A														
▒ FACTORY B	0.3													
■ FACTORY C														

FIGURE 3.4 - 3 Percentage distribution of all production errors in each factory studied by error classification. Work phase 13



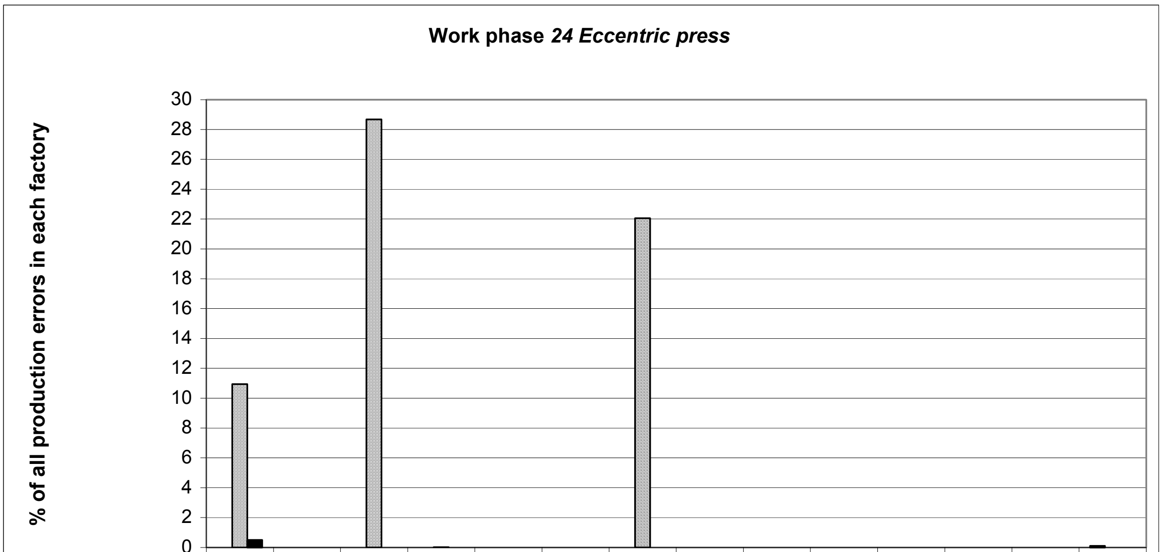
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A		1.8												
FACTORY B														
FACTORY C														

FIGURE 3.4 - 4 Percentage distribution of all production errors in each factory studied by error classification. Work phase 15



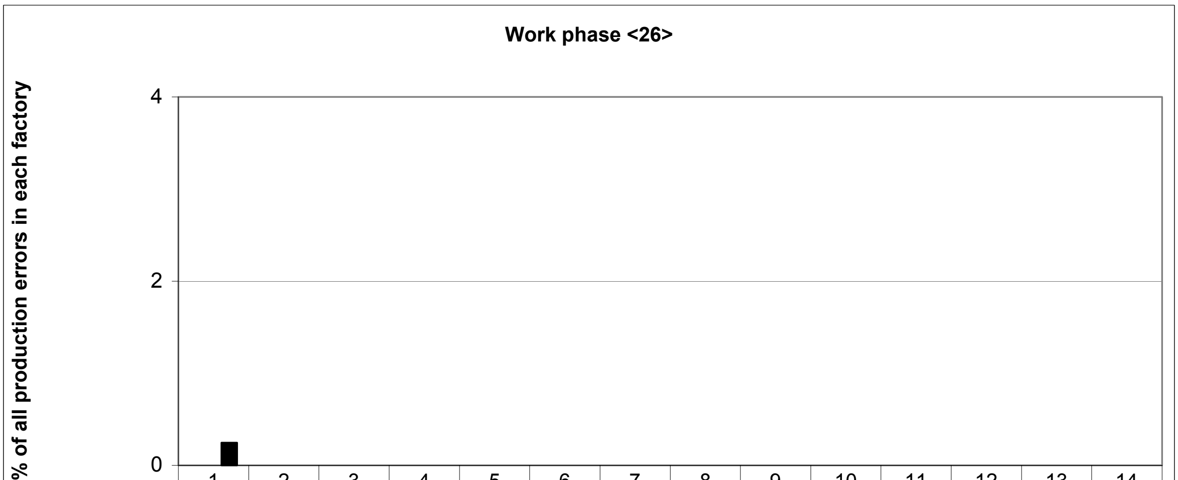
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A						0.1								0.1
FACTORY B	0.5		1.3	0.0										
FACTORY C	30.0	1.7												

FIGURE 3.4 - 5 Percentage distribution of all production errors in each factory studied by error classification. Work phase 21



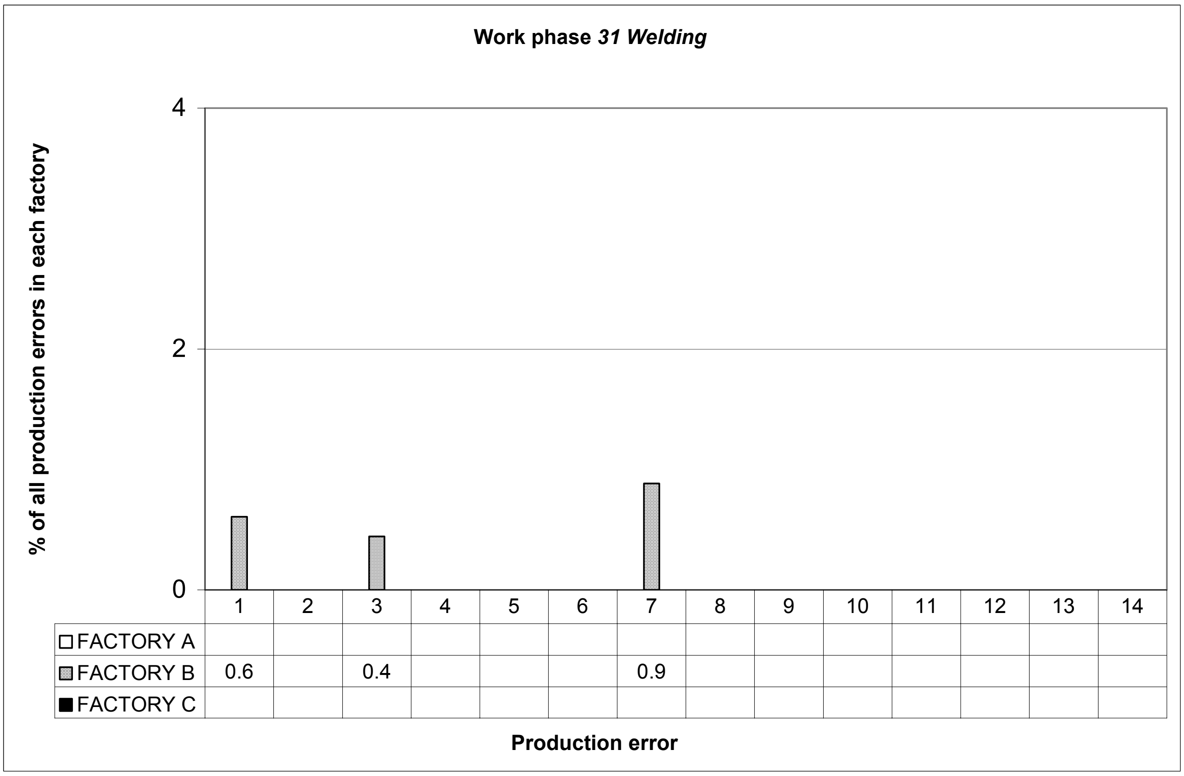
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A														0.1
FACTORY B	10.9		28.7	0.0			22.1							
FACTORY C	0.5													

FIGURE 3.4 - 6 Percentage distribution of all production errors in each factory studied by error classification. Work phase 24



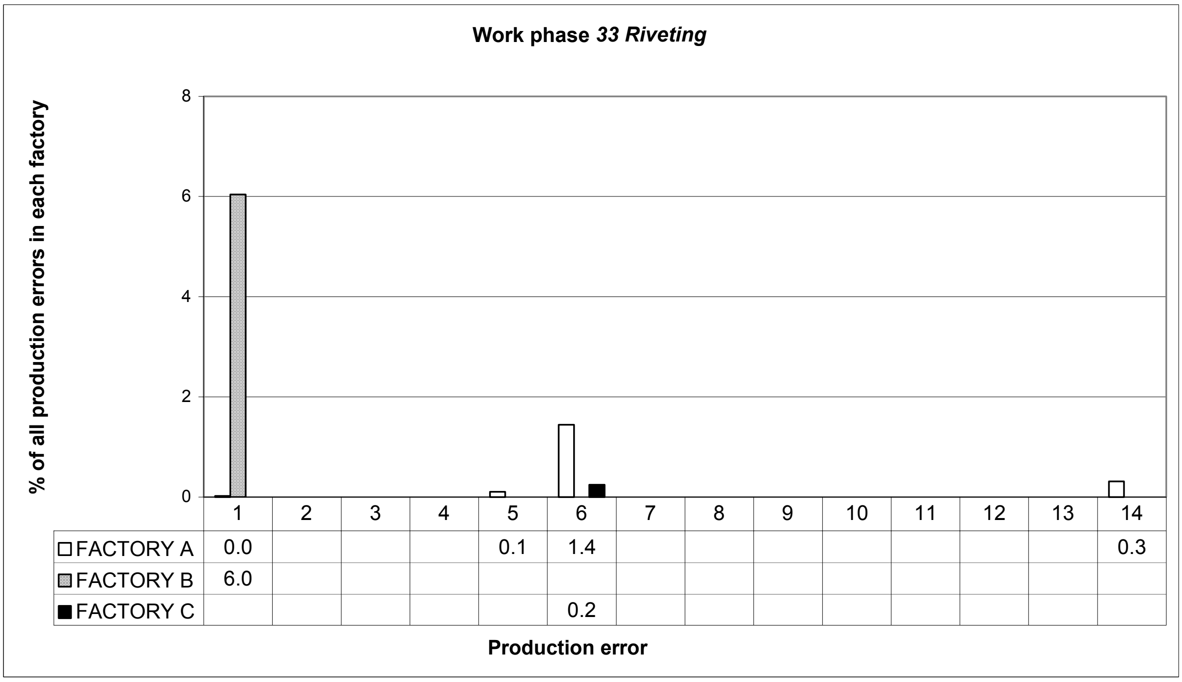
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A														
FACTORY B														
FACTORY C	0.2													

FIGURE 3.4 - 7 Percentage distribution of all production errors in each factory studied by error classification. Work phase <26>



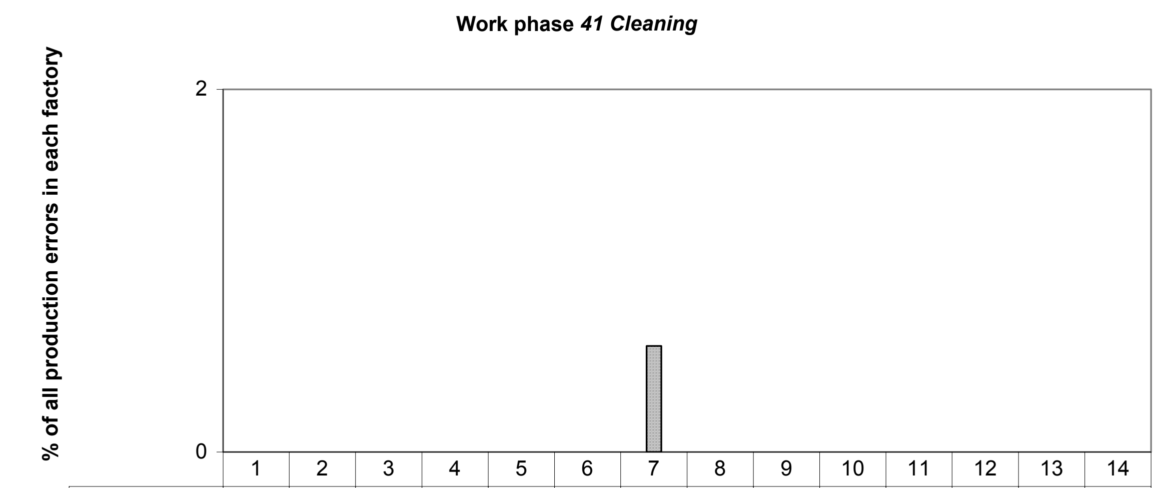
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A														
FACTORY B	0.6		0.4				0.9							
FACTORY C														

FIGURE 3.4 - 8 Percentage distribution of all production errors in each factory studied by error classification. Work phase 31



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A	0.0				0.1	1.4								0.3
FACTORY B	6.0													
FACTORY C						0.2								

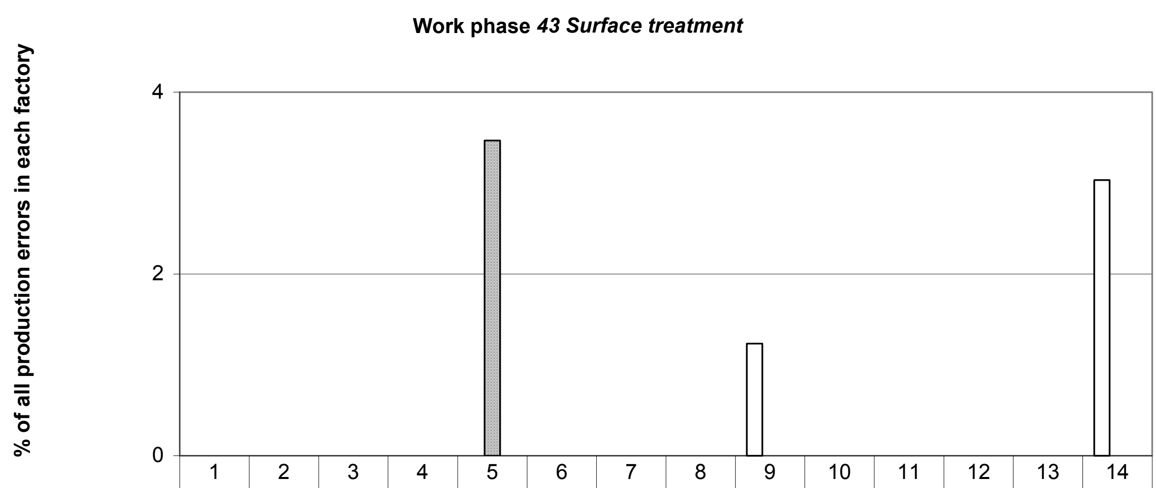
FIGURE 3.4 - 9 Percentage distribution of all production errors in each factory studied by error classification. Work phase 33



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A														
FACTORY B							0.6							
FACTORY C														

Production error

FIGURE 3.4 - 10 Percentage distribution of all production errors in each factory studied by error classification. Work phase 41



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A									1.2					3.0
FACTORY B					3.5									
FACTORY C														

Production error

FIGURE 3.4 - 11 Percentage distribution of all production errors in each factory studied by error classification. Work phase 43

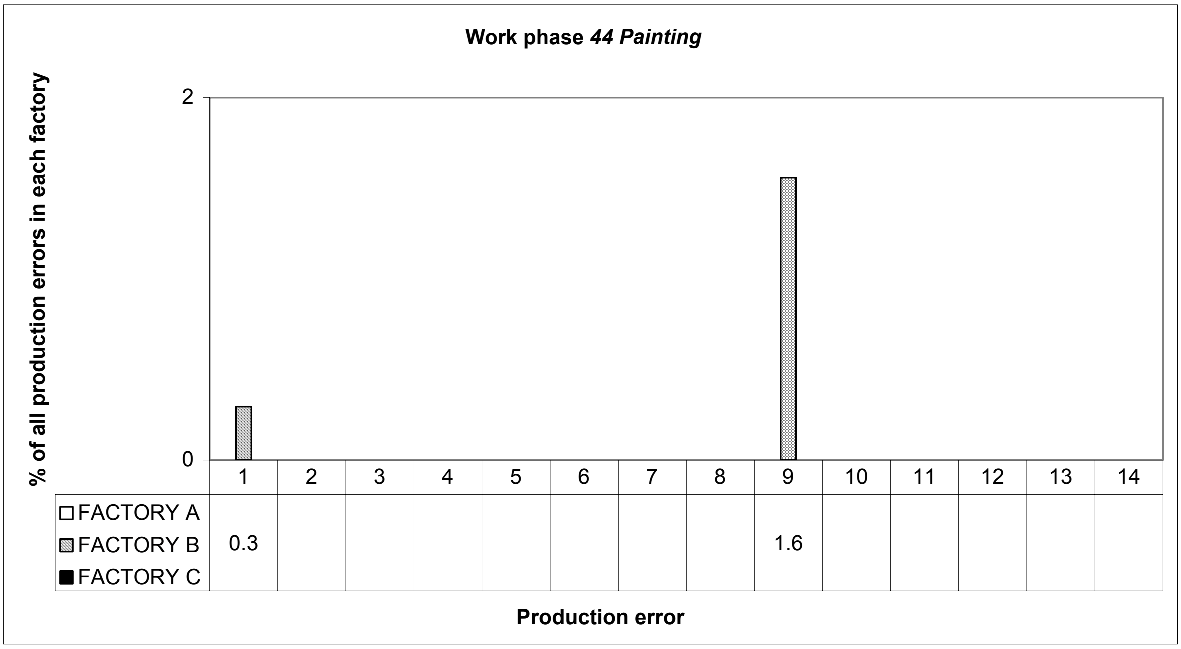


FIGURE 3.4 - 12 Percentage distribution of all production errors in each factory studied by error classification. Work phase 44

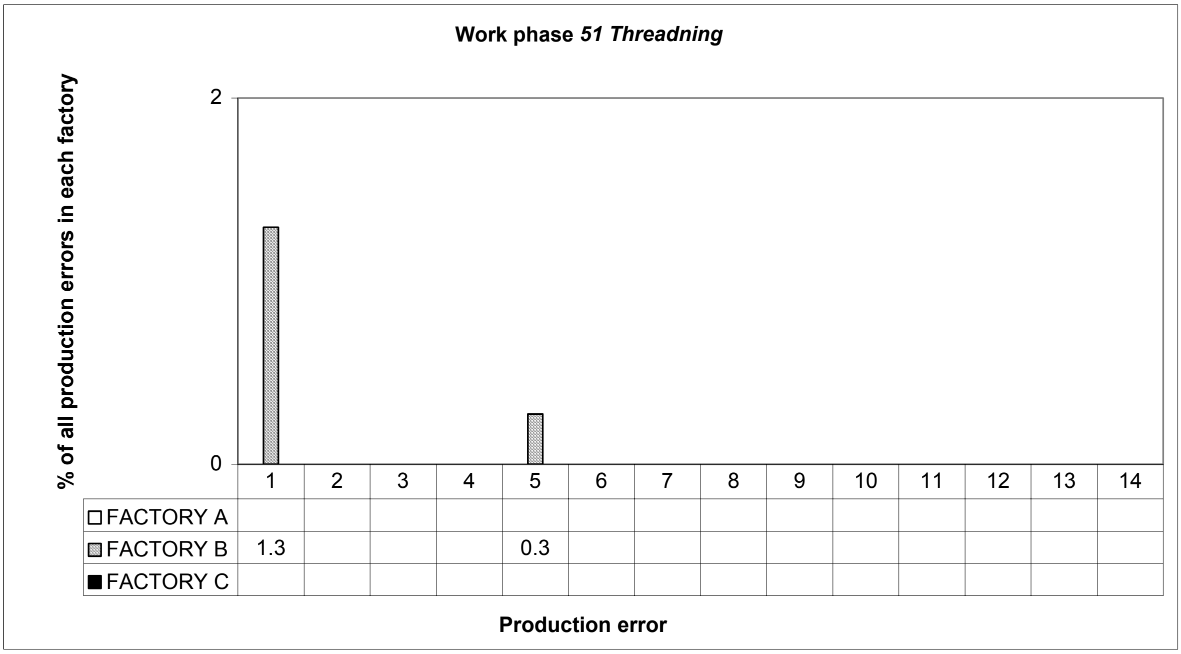


FIGURE 3.4 - 13 Percentage distribution of all production errors in each factory studied by error classification. Work phase 51

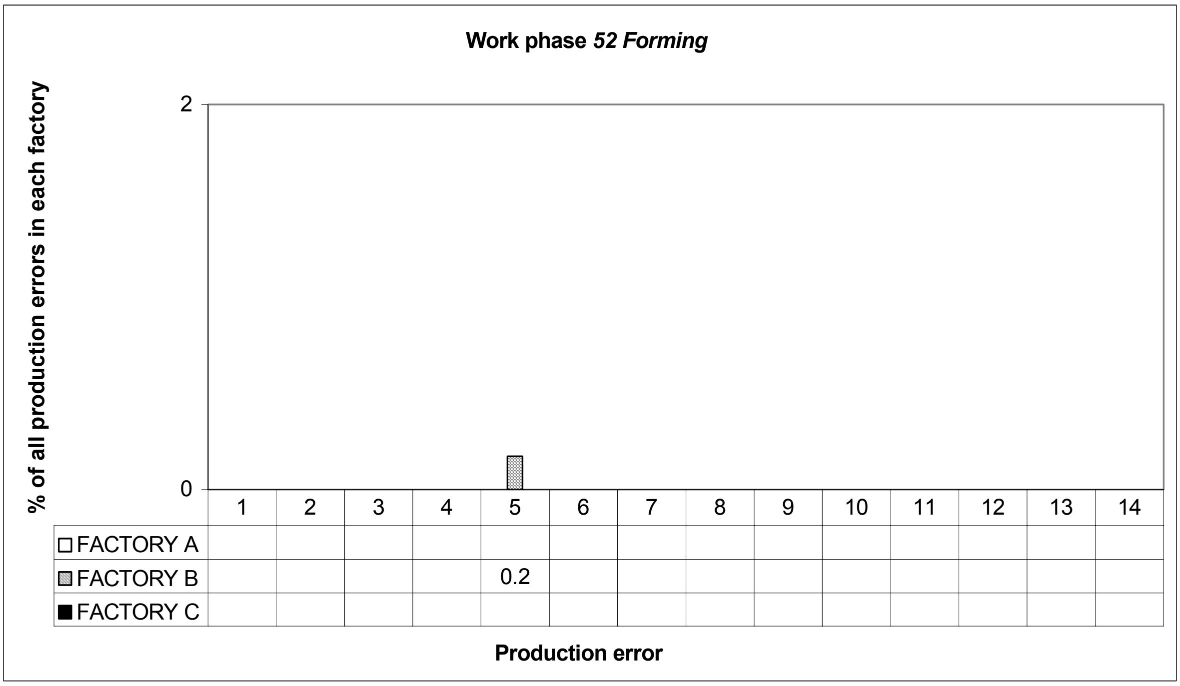


FIGURE 3.4 - 14 Percentage distribution of all production errors in each factory studied by error classification. Work phase 52

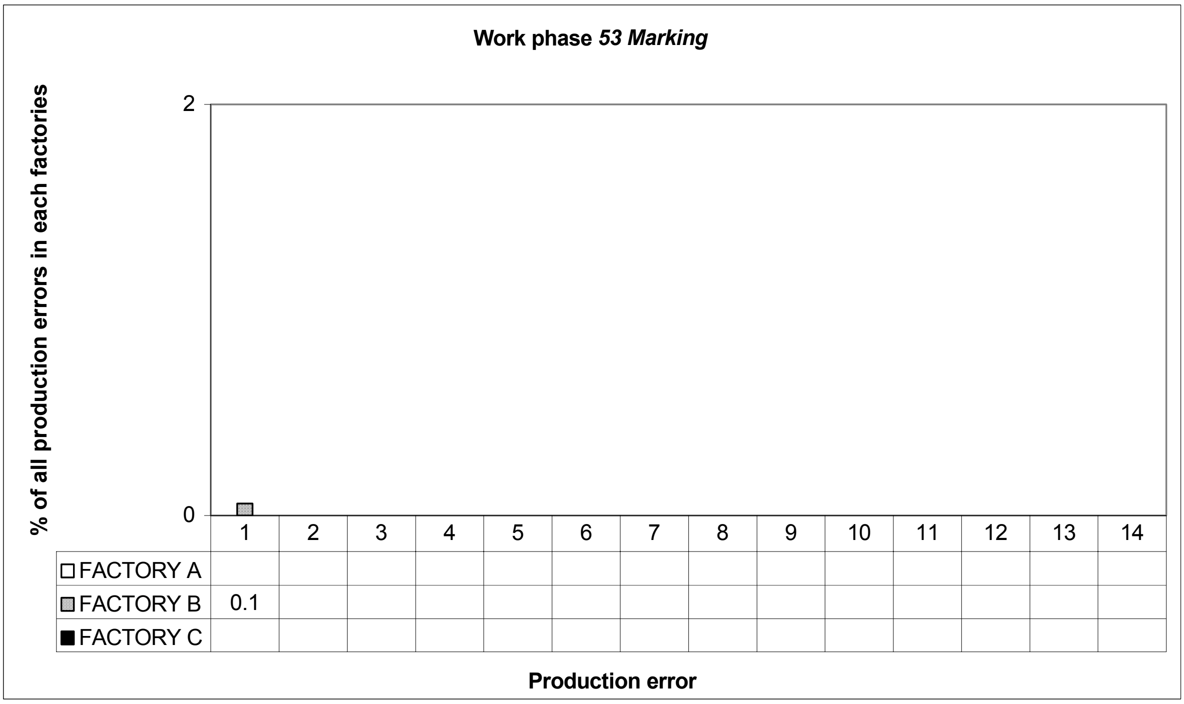
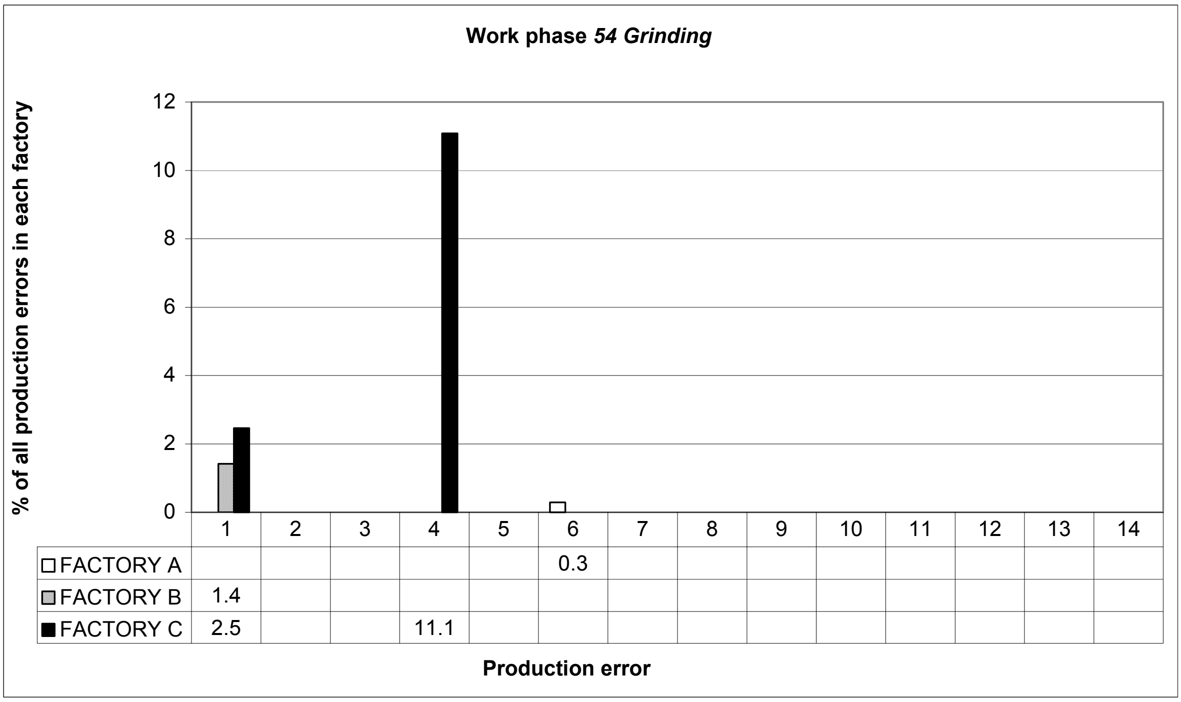
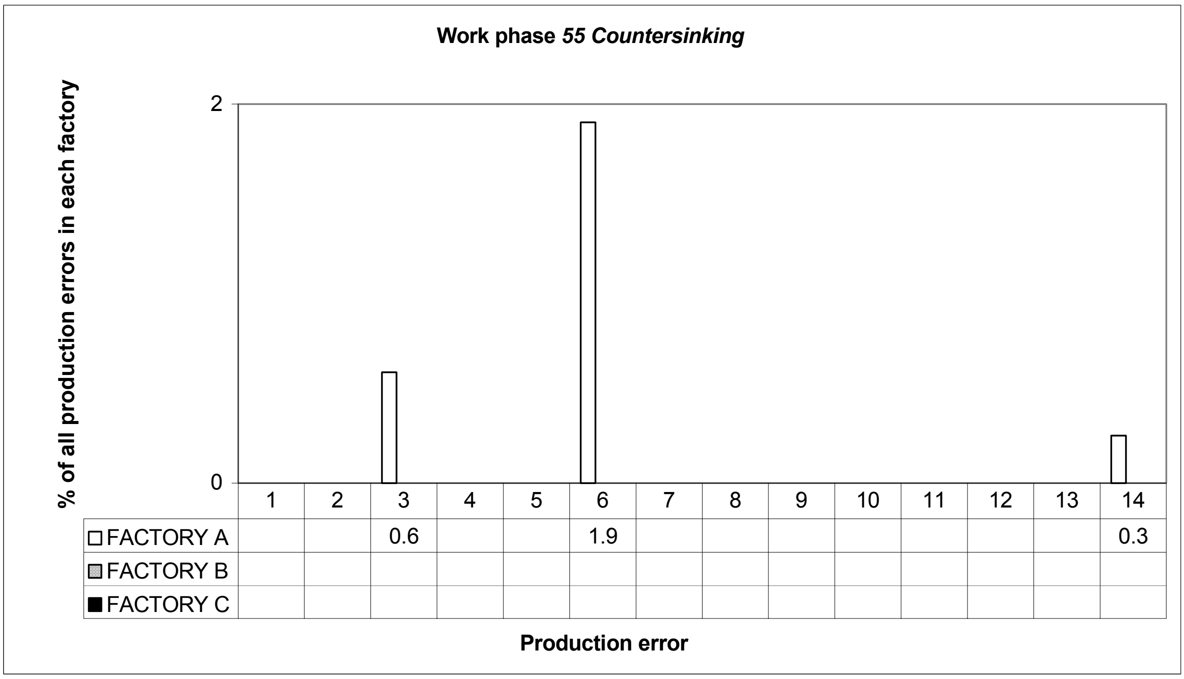


FIGURE 3.4 - 15 Percentage distribution of all production errors in each factory studied by error classification. Work phase 53



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A						0.3								
FACTORY B	1.4													
FACTORY C	2.5			11.1										

FIGURE 3.4 - 16 Percentage distribution of all production errors in each factory studied by error classification. Work phase 54



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A			0.6			1.9								0.3
FACTORY B														
FACTORY C														

FIGURE 3.4 - 17 Percentage distribution of all production errors in each factory studied by error classification. Work phase 55

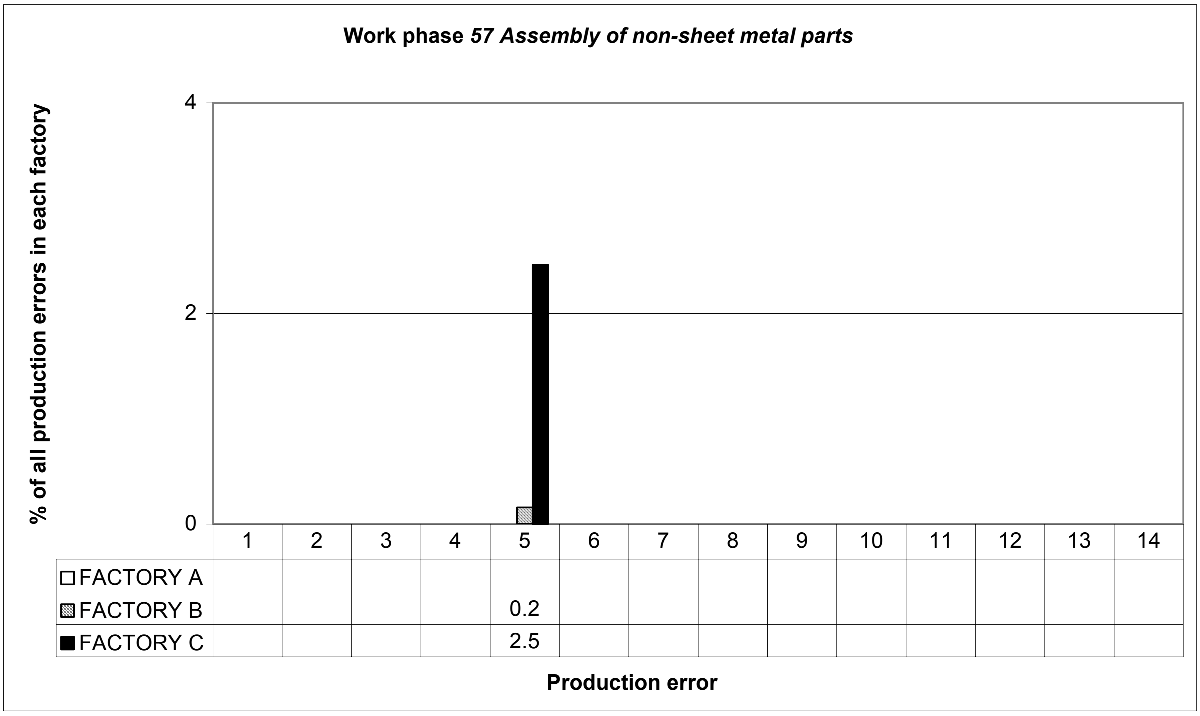


FIGURE 3.4 - 18 Percentage distribution of all production errors in each factory studied by error classification. Work phase 57

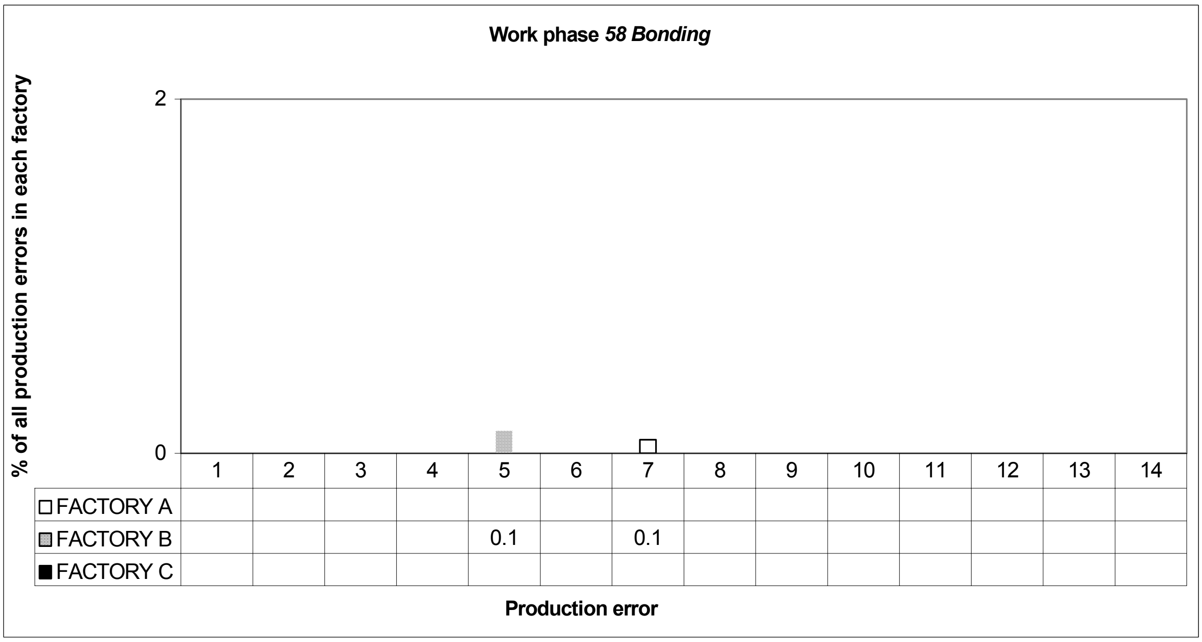


FIGURE 3.4 - 19 Percentage distribution of all production errors in each factory studied by error classification. Work phase 58

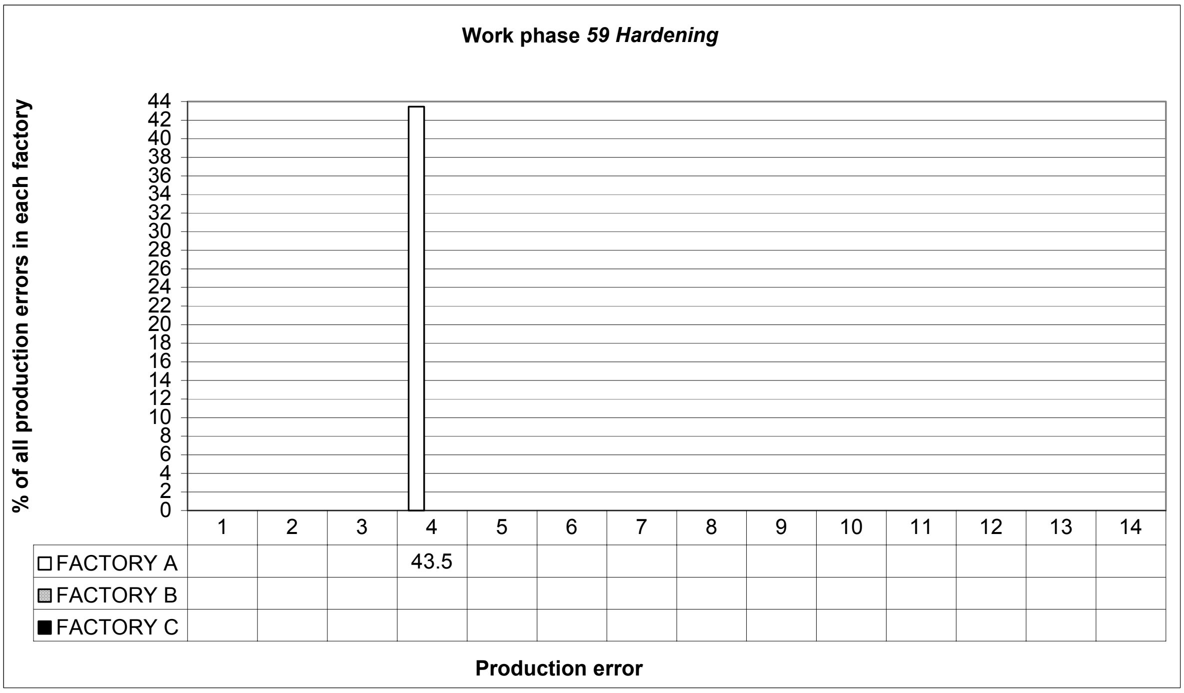


FIGURE 3.4 - 20 Percentage distribution of all production errors in each factory studied by error classification. Work phase 59

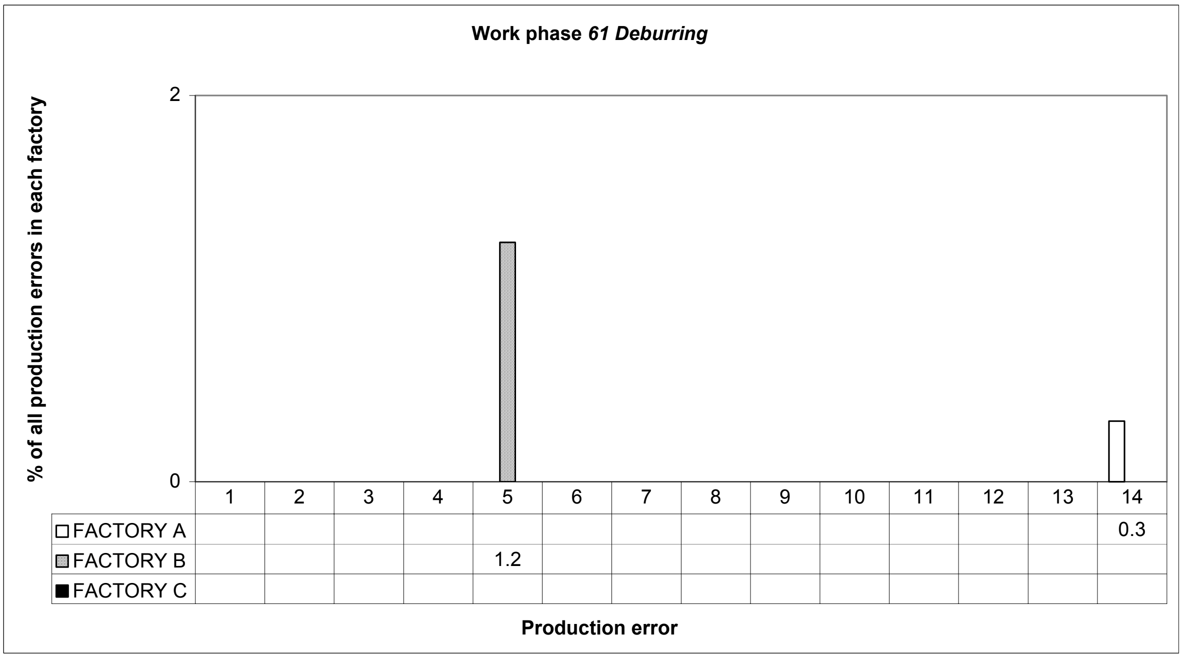


FIGURE 3.4 - 21 Percentage distribution of all production errors in each factory studied by error classification. Work phase 61

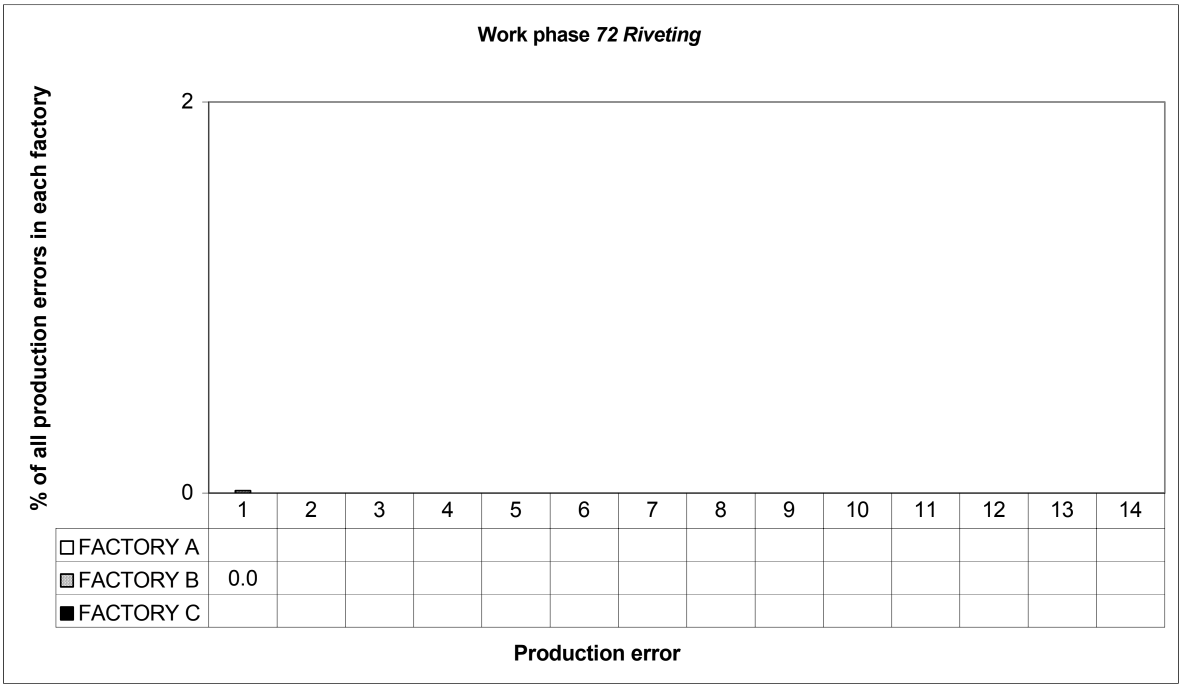


FIGURE 3.4 - 22 Percentage distribution of all production errors in each factory studied by error classification. Work phase 72

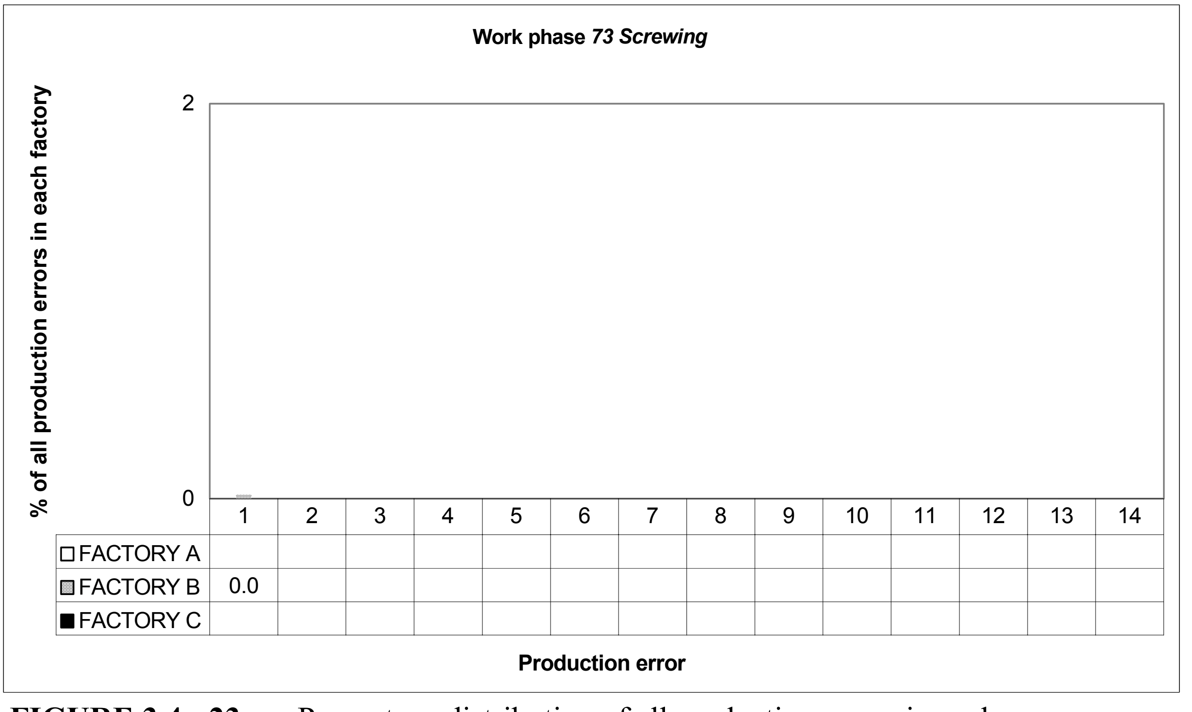
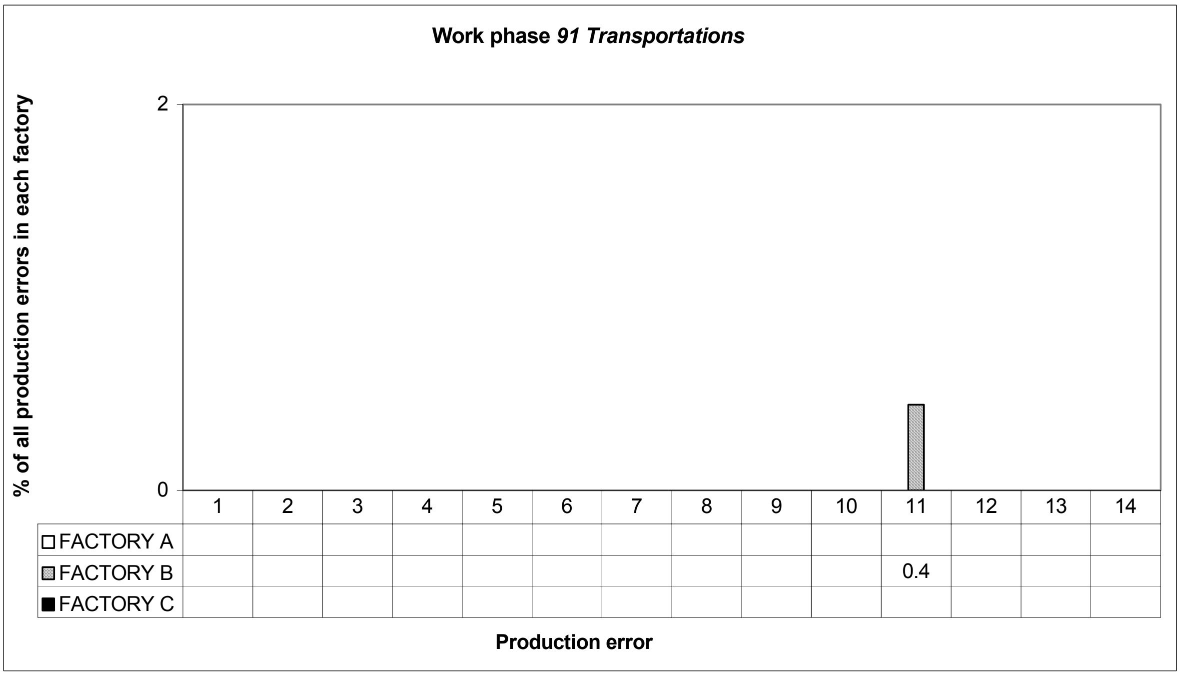


FIGURE 3.4 - 23 Percentage distribution of all production errors in each factory studied by error classification. Work phase 73

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A		0.6	2.6			18.4	3.1	0.1	0.1	0.1			0.5	3.2
FACTORY B														
FACTORY C														

FIGURE 3.4 - 24 Percentage distribution of all production errors in each factory studied by error classification. Work phase <76>



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FACTORY A														
FACTORY B											0.4			
FACTORY C														

FIGURE 3.4 - 25 Percentage distribution of all production errors in each factory studied by error classification. Work phase 91

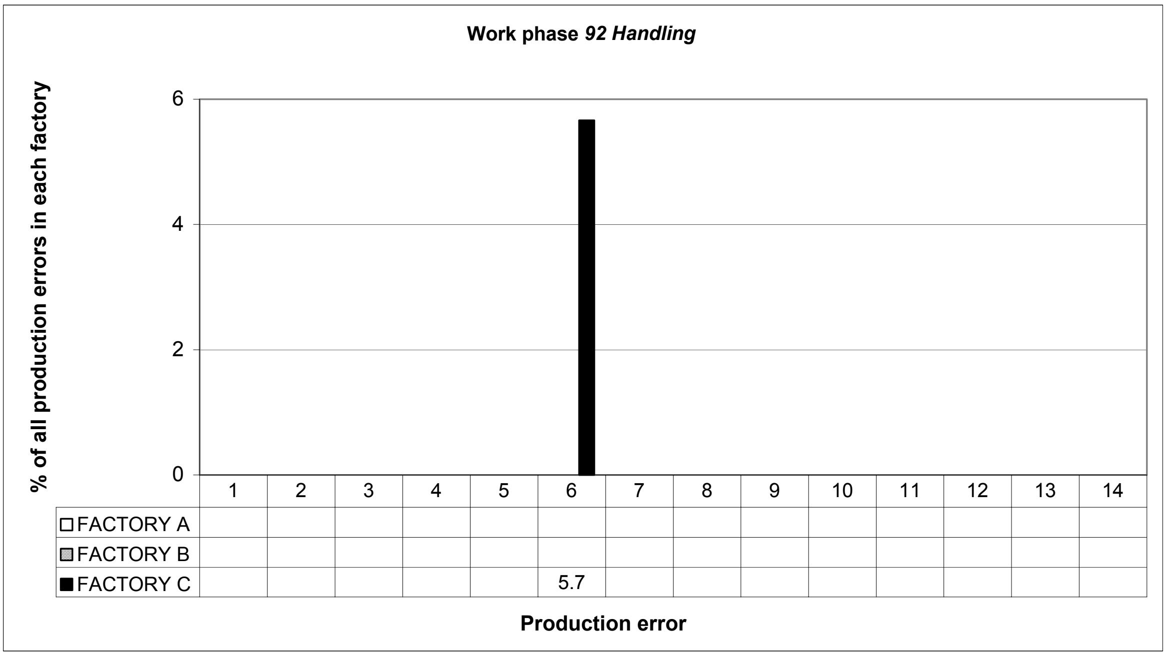


FIGURE 3.4 - 26 Percentage distribution of all production errors in each factory studied by error classification. Work phase 92

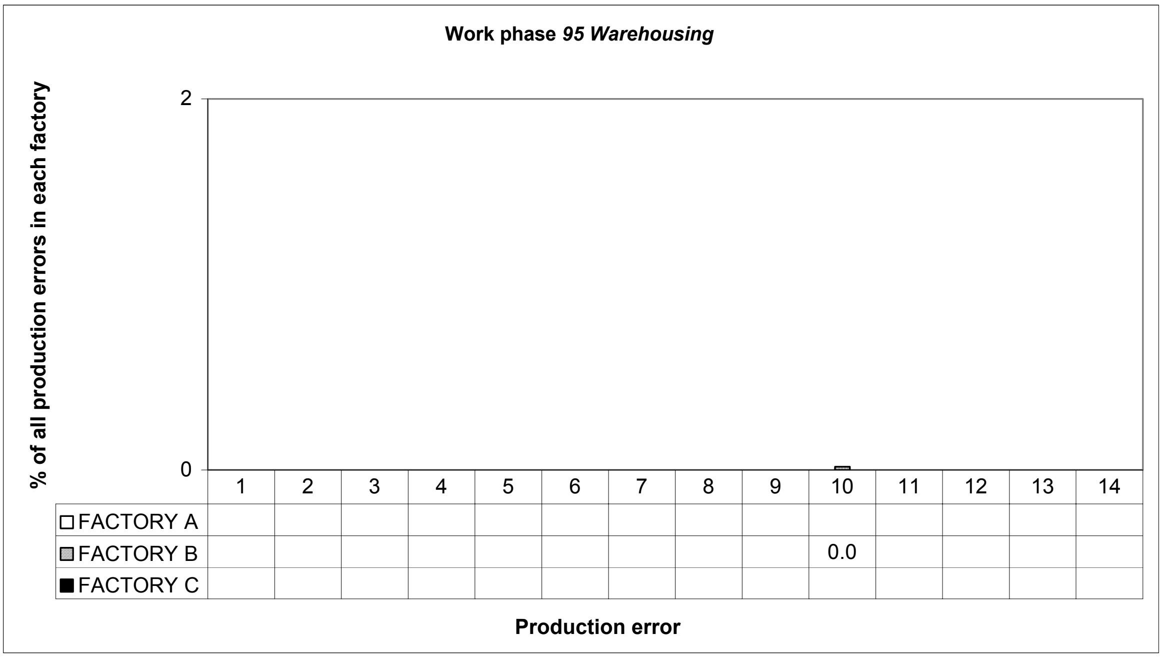


FIGURE 3.4 - 27 Percentage distribution of all production errors in each factory studied by error classification. Work phase 95

3.5 Production error distribution by error specification

The production error distribution by the production error specification in each factories studied is presented in Table 3.5 - 1. Figures shown in the table are presenting the percentage distribution of all production errors in each factory. In some cases figure 0.0 is used. This figure does express that a production error exists but the share is zero. Grey color in a table cell expresses that no production error exists in that error specification. Rows with no markings have been left out.

Table 3.5 - 1 Percentage distribution of all production errors by error specification in each factory studied [%]

	ERROR SPECIFICATION	Factory A	Factory B	Factory C
11	Work error	0.0	5.3	30.3
12	Interpretation error		0.7	13.5
13	Setup error		7.0	0.5
14	Incorrect NC-program		11.3	
16	Indefinable error			0.2
21	Error in NC-control unit	1.7		
22	Machine tool failure	13.2		
23	Operating error	1.5		11.1
24	Insufficient maintenance	0.0		
25	Indefinable error	0.5		4.7
31	Tool break		2.7	
32	Insufficient maintenance		16.0	
33	Setup error		13.3	
34	Indefinable error	3.4	5.4	0.2
41	Old drawing		0.0	
43	Defective drawing			11.1
45	Wrong work method	43.5	0.0	
51	Defective purchase	0.1	0.4	
52	Defective subcontracting		5.0	2.5

55	Indefinable error			5.7
61	Work error in preceding work phase	4.4		0.2
62	Product out of tolerances	0.5		
63	Handling error in preceding work phase	2.6		5.7
65	Indefinable error	14.7	0.0	8.9
71	Defective construction	2.7		
72	Product impossible to manufacture	0.3	30.9	
81	Defective bath	0.1		
93	Functional error	0.1	0.8	
94	Indefinable error	1.2	0.8	
101	Dents/Scratches	0.1		
105	Indefinable error		0.0	
113	Falling		0.4	
133	Dents/Scratches	0.5		3.0
141	Write comments other side	8.9		2.4

4 ANALYSIS AND DISCUSSION

The results presented earlier are analyzed and discussed in this chapter. Also the starting point in case factories is discussed and analyzed. Conclusions and key findings based on the analysis and the discussion are made later in this thesis.

4.1 Starting point in case factories in the beginning of the study

It was possible to discuss the current situation in the production errors, their significance and costs during the first visits in each company. These discussions gave impression of a situation where there was no exact knowledge of the bigger picture. It was unclear where and when the production errors occurred and what was their influence in the total cost and their effects on the production flow. There was an attempt to find out the cost of the production errors during the LELA – research program as a separate study. Only minor results were achieved and the situation seemed to be very challenging in case factories.

The current situation can partly be explained by examining the boom in the sheet metal part fabricating industry in Finland during 1990´s. The boom started in the first part of the 90´s and it was boosted mainly by the telecommunication and electronics industry. There are several estimations about the rate of growth and one of them is presented in figure 4.1 – 1 (Ollikainen, 2000b).

In the situation of the time, sheet metal part based products were produced at increasing pace and the most important factor became that there were enough production. Huge investments were made in the production machinery and human and organizational factors were considered as secondary matters. Enough cover was provided even with the higher production costs caused e.g. by the production errors. The efficiency of the production system was not used as a competitive weapon.

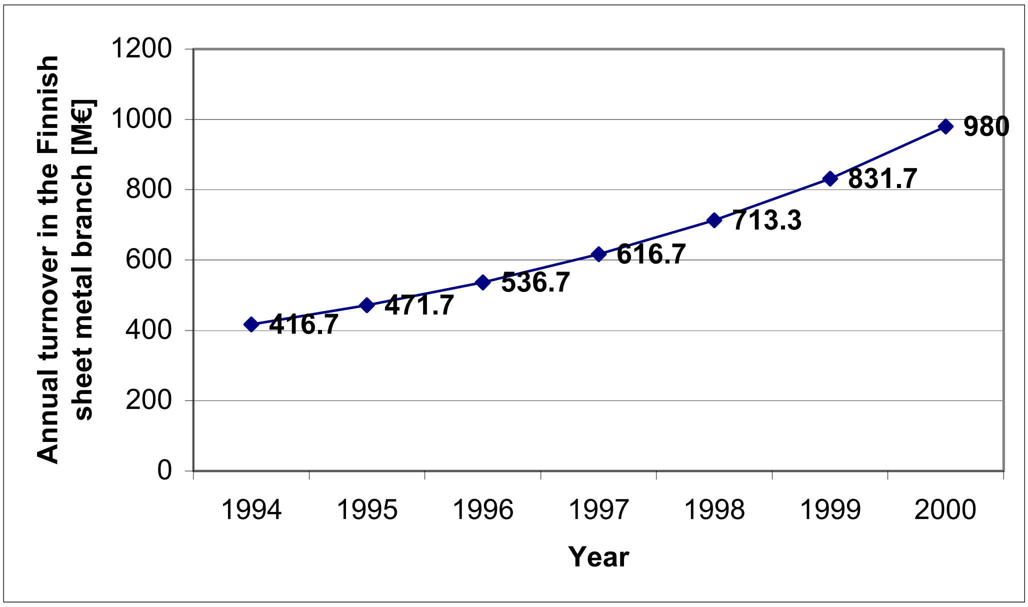


FIGURE 4.1 – 1 Estimation about the rate of growth in the Finnish sheet metal branch (Ollikainen, 2000b)

4.2 Field study

The field study was started in five case factories and information was received from three of the companies. This indicates that a production performance information measurement is a tender spot in many organizations.

Employees can easily feel that results from the performance measurements are only used to catch people doing something wrong. In such a case it can sometimes be seen that management has failed to communicate the vision strategy of the company, objective goals and directions. Such situation also indicates lack of education and training in the organization. Employees do not have a clear understanding of their job and how it relates to the mission of the organization. Employees have not received enough education, either, about problem solving tools and techniques. Without understanding how these tools and techniques work and are used, individuals will be unable to separate the symptoms of the problems from the root causes of the problems.

If a company wants to improve the production performance, the measurement of the performance is necessary to be done to understand the prevailing situation. A systematic information collection is therefore needed. One systematic method of a study is presented in this thesis. It can be used to collect production error information in the shop floor level of a factory. This information can be used to determine sensitive phases in the production flow and to eliminate production errors in these sensitive phases.

4.3 Production flow error distribution

The production flow error distribution is analyzed and discussed in each factory studied in chapters 4.3.1 to 4.3.3. Figures and verbal analysis are used in this analyze.

4.3.1 Factory A

Factory A manufactures electromechanical locks. The electromechanical locks contain many sheet metal components, e.g. lock body, front shield and counterparts. The production flow of the sheet metal components used in locks includes many work phases. A punch press and a laser-combination machine is used in the fabrication of blank parts. The production flow includes many manually operated phases. These manually operated phases are grinding phases of visible surfaces, heat treatment in some lock components, inserting different inserts, special work phases and final assembly. Surface treatment processes are used extensively. The production strategy in Factory A is a medium volume production.

The three most problematic functional phases are emphasized in figure 4.3.1 - 1. In the figure we can see that production errors are mainly caused in "*5 Unspecified work phases*" (46.8% of all production errors) and in "*7 Assembly*"

(28.6% of all production errors). The third problematic functional phase is “*1 Fabrication of blank parts”* (18.1 % of all production errors). A total of 93.5 % of all production errors are caused in the three most problematic functional phases. Manually operated work phases are mainly performed in unspecified work phases and in assembly. This indicates that manually operated work phases are the most sensitive sources for production errors in factory A.

The three most problematic work phases are presented in figure 4.3.1 - 2. In the figure we can see that production errors are caused mainly in “*59 Hardening”* (43.5 % of all production errors), “*<76> Assembly”* (28.6 % of all production errors) and in “*12 Punch press”* (16.3 % of production errors). A total of 88.4 % of all production errors are caused in the three most problematic work phases. Work phases hardening and assembly are mainly operated manually. This supports the observation made above; that manually operated work phases are the most sensitive sources for the production errors in factory A. Also, the punch press related production is very sensitive source for production errors in factory A.

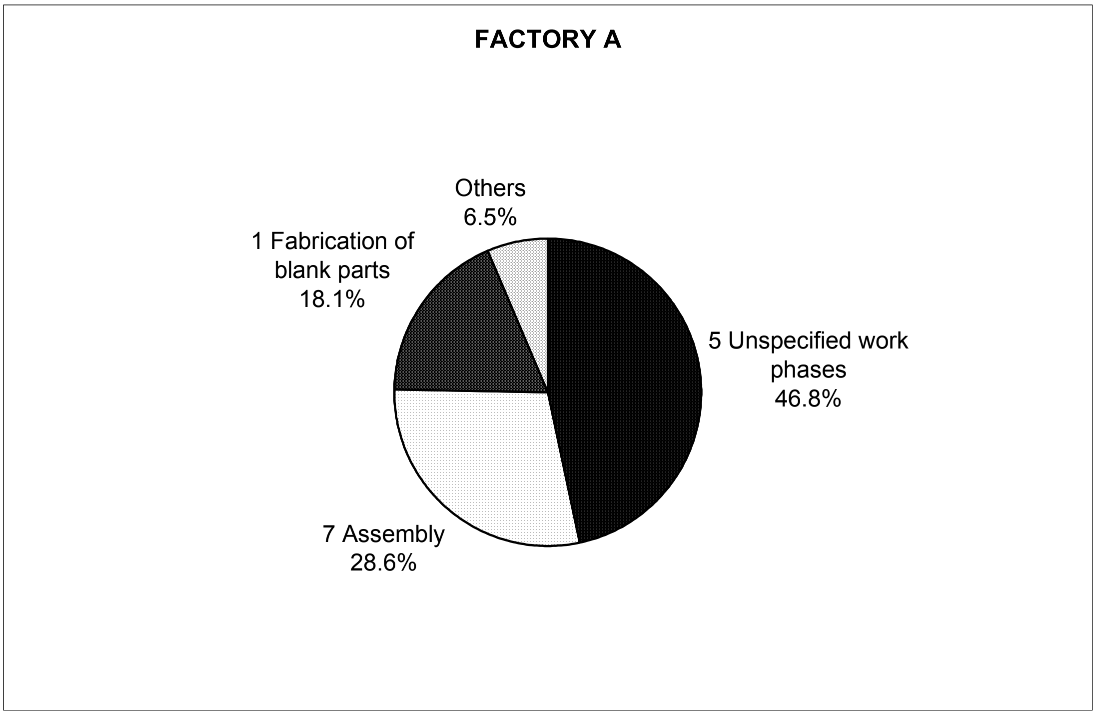


FIGURE 4.3.1 - 1 The most problematic functional phases in factory A

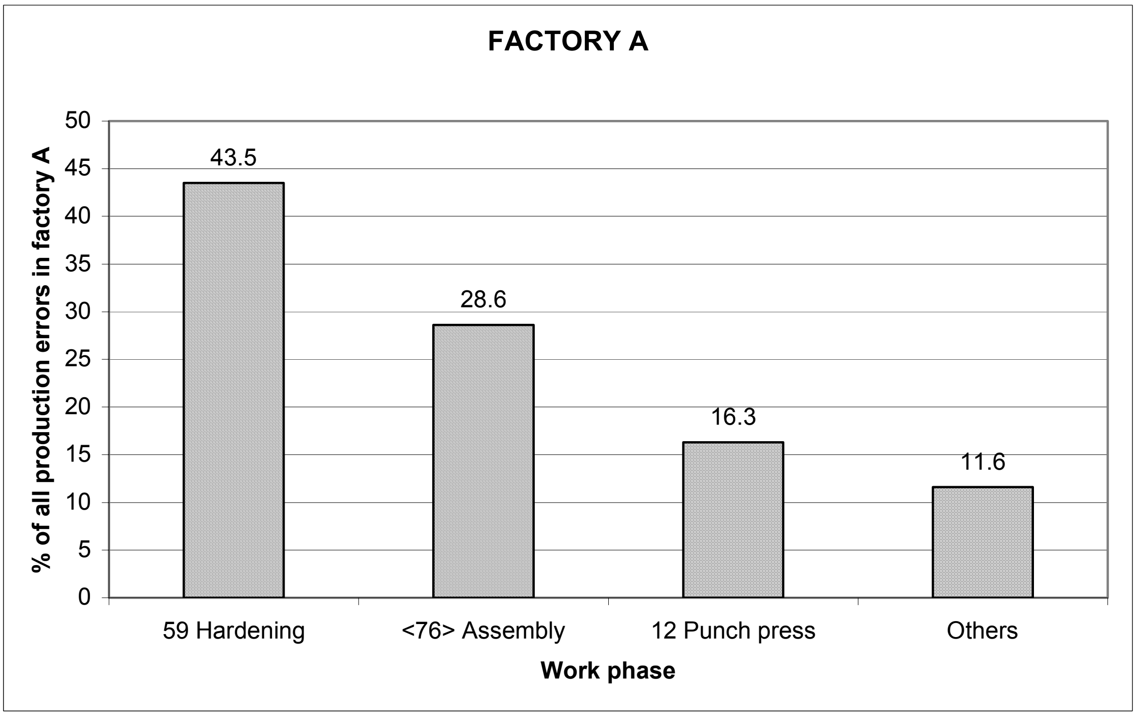


FIGURE 4.3.1 - 2 The most problematic work phases in factory A

4.3.2 Factory B

Factory B manufactures sheet metal based constructions for the electronics, telecommunication and automotive industry. Mass production methods, such as automated eccentric presses, are used extensively in the production. Most of the bending and fabrication of blank parts-phases are done by these eccentric presses. The production flow includes some manually operated phases. These manually operated phases include the riveting. Surface treatment processes are used extensively. The production strategy in factory B is a high volume production.

The three most problematic functional phases are emphasized in figure 4.3.2 - 1. In the figure we can see that the production errors are mainly caused in "*2 Bending"* (63.5 % of all production errors) and in "*1 Fabrication of blank parts"* (17.3 % of all production errors). The third problematic functional phase is "*3 Joining"* (8.0 % of all production errors). A total of 88.8 % of all production errors is caused in the three most problematic functional phases. The mass production methods are used extensively in the bending. The joining is operated mainly manually. This indicates that the mass production methods are the most sensitive sources for the production errors in factory B.

The three most problematic work phases are presented in figure 4.3.2 - 2. In the figure we can see that production errors are mainly caused in "*24 Eccentric press*" (61.7 % of all production errors) and in "*11 Mechanical cutting*" (17.0 % of all production errors). A total of 84.7 % of all production errors in factory B is caused in the three most problematic work phases. This supports observation made above; that the mass production methods are the most sensitive for the production errors in factory B.

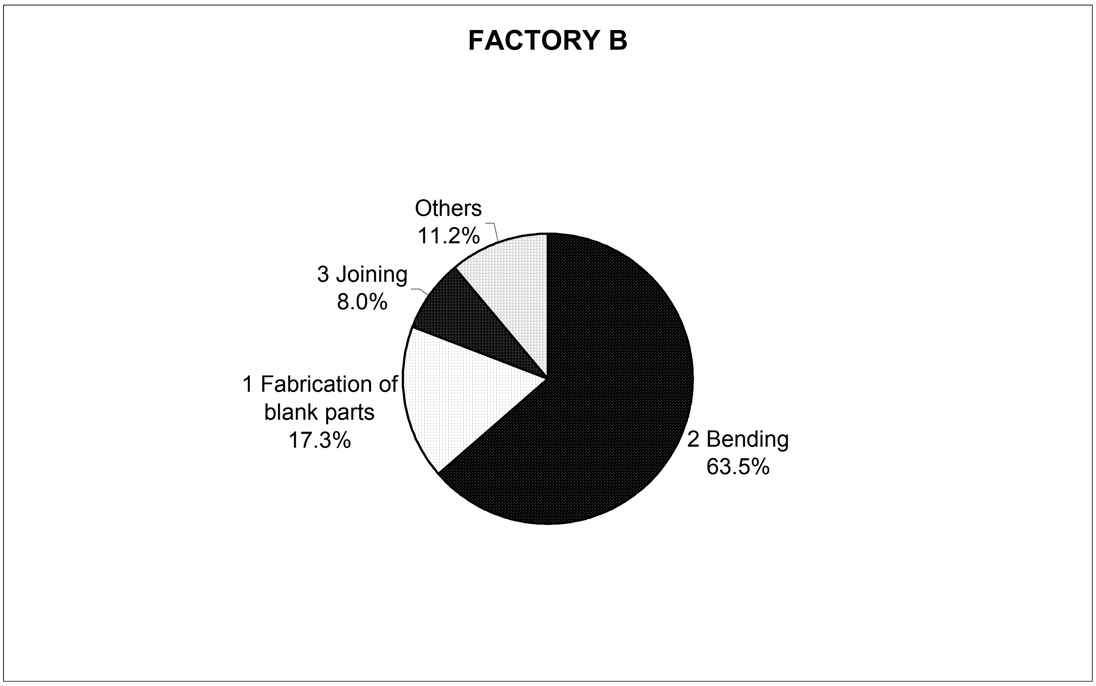


FIGURE 4.3.2 - 1 The most problematic functional phases in factory B

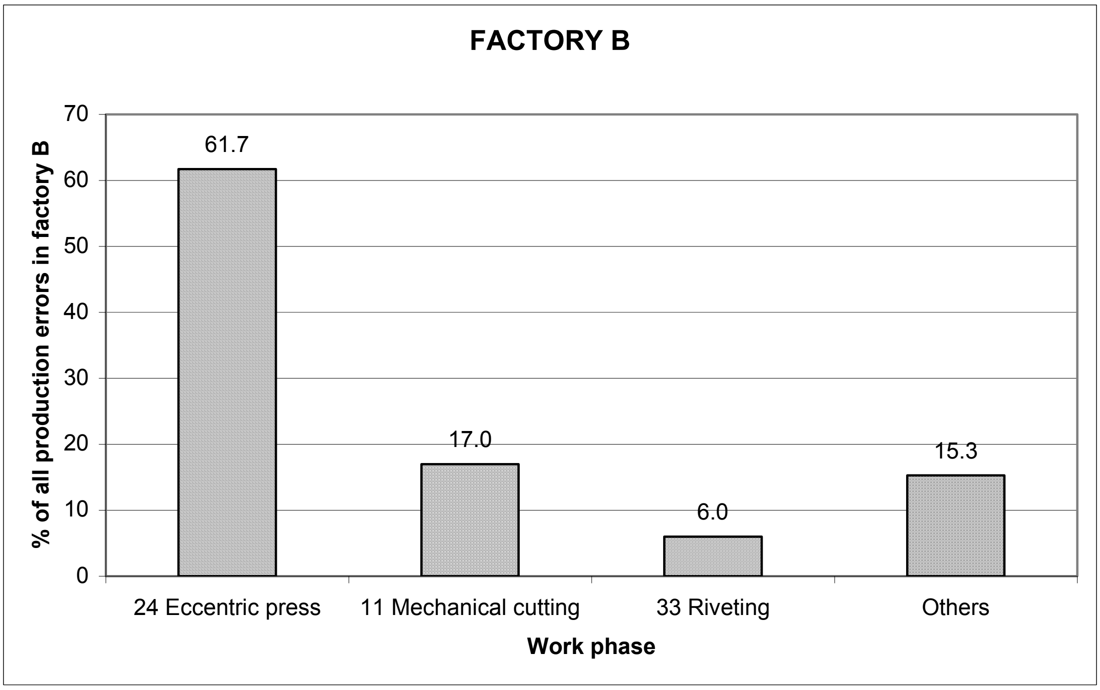


FIGURE 4.3.2 - 2 The most problematic work phases in factory B

4.3.3 Factory C

Factory C manufactures custom outdoor and indoor enclosures for telecom applications such as wireless base stations, switching systems and network access equipment. The production includes a wide range of sheet metal part based constructions. The production flow includes many automated work phases, such as punch press operations. Many work phases are operated manually. Manually operated work phases include press brake phases, joining phases and grinding phases. Surface treatment processes are used extensively. The production strategy in factory C is a medium volume production.

The three most problematic functional phases are emphasized in figure 4.3.3 - 1. In the figure we can see that production errors are mainly caused in "*1 Fabrication of blank parts*" (45.6 % of all production errors), in "*2 Bending*" (32.5 % of all production errors) and in "*5 Unspecified work phases*" (16.0 % of all production errors). A total of 94.1 % of all production errors in factory C are caused in the three most problematic functional phases.

The three most problematic work phases are presented in figure 4.3.3 - 2. In the figure we can see that production errors are mainly caused in "*12 Punch press*" related operations (45.1 % of all production errors), in "*21 Press brake*" related operations (31.8 % of all production errors) and in "*54 Grinding*" (13.5 % of all production errors). A total of 90.4 % of all production errors in factory C are caused in the three most problematic work phases. The result indicates that in factory C there are problems related to both automated work phases and manually operated work phases. It can be said that the most sensitive work phases for the production errors are the punch press related operations and the press brake related operations.

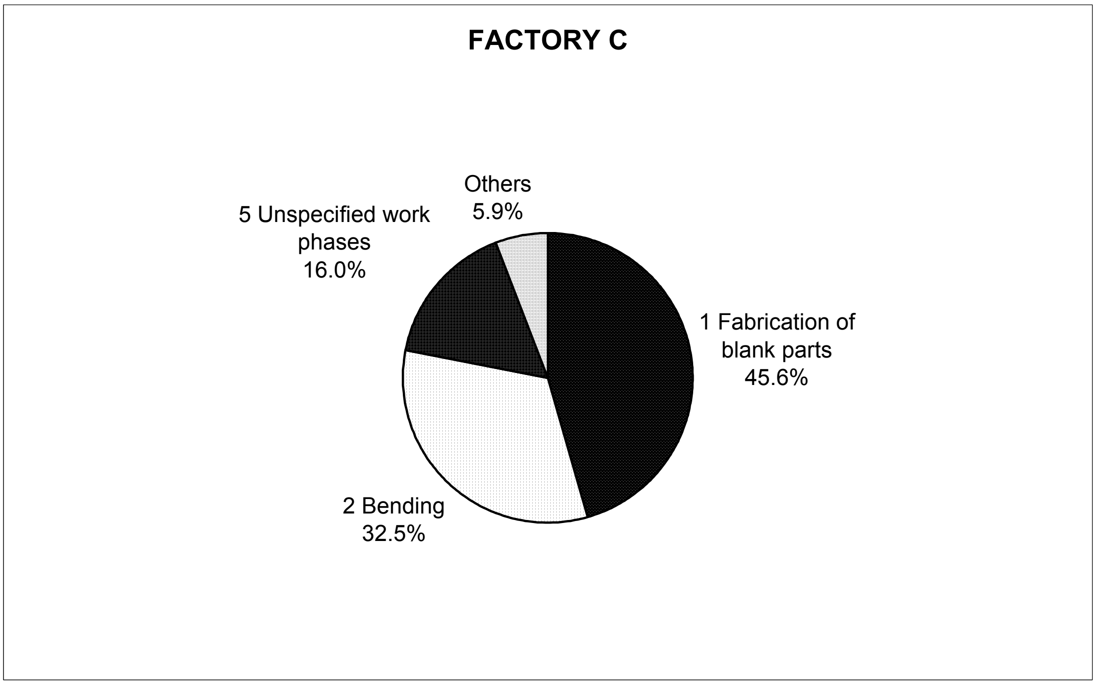


FIGURE 4.3.3 - 1 The most problematic functional phases in factory C

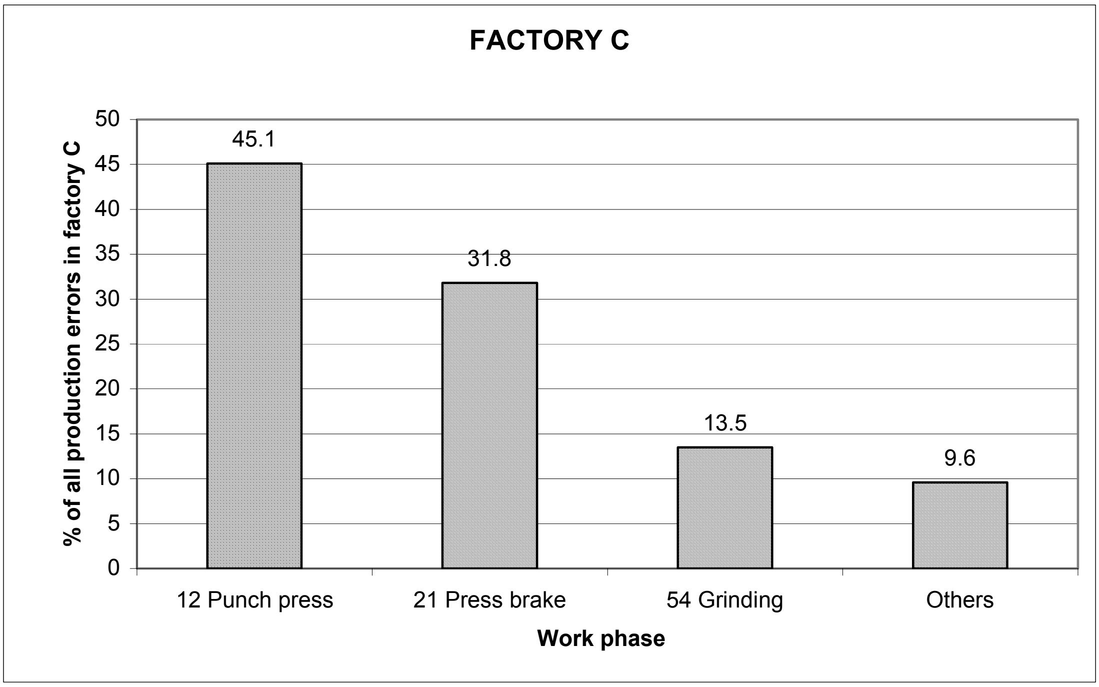


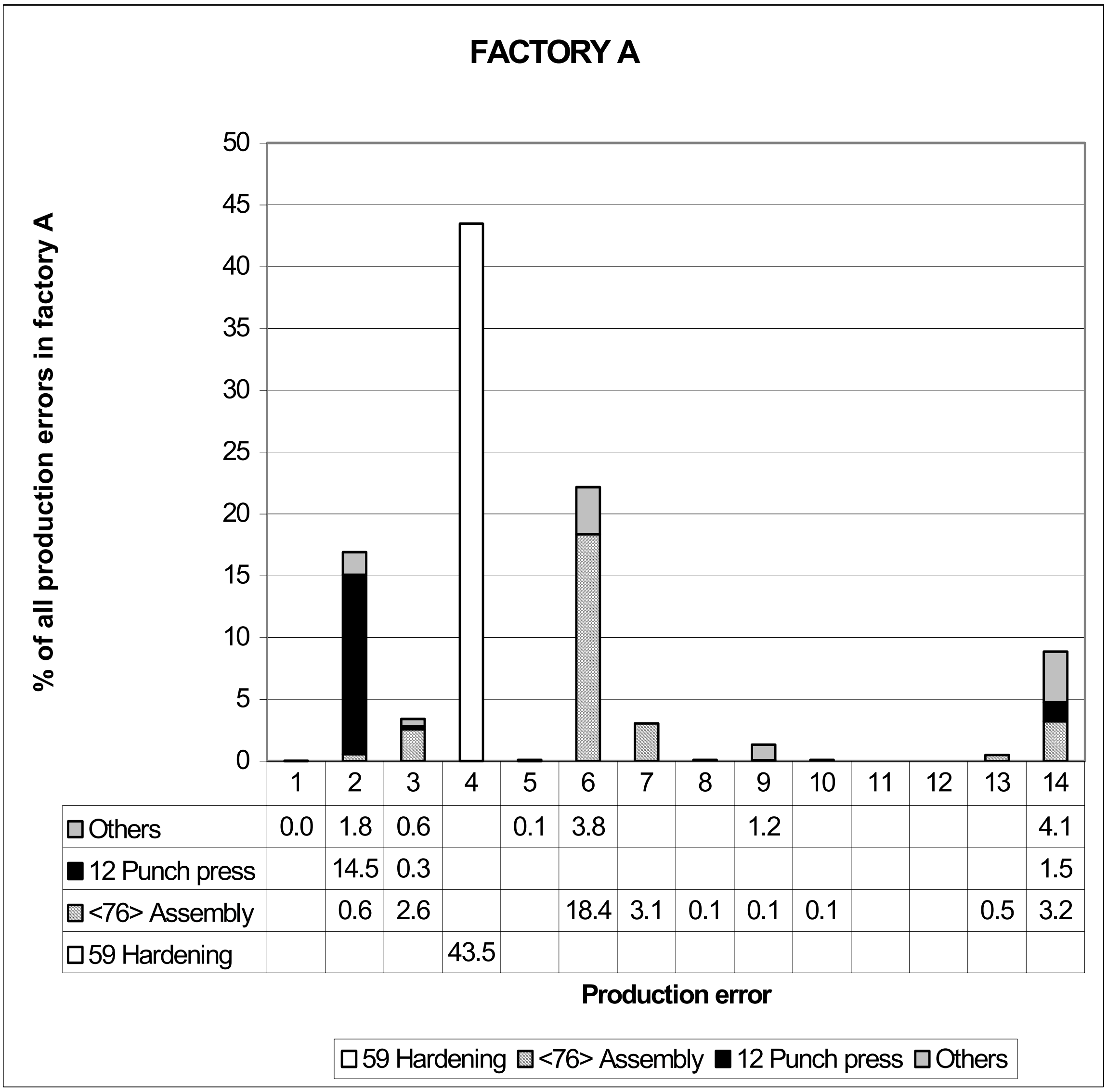
FIGURE 4.3.3 - 2 The most problematic work phases in factory C

4.4 Production error distribution by production error types

The production flow error distribution by the production error types is analyzed and discussed in each factory studied in chapters 4.4.1 to 4.4.3. Figures and verbal analysis are used in this analyze.

4.4.1 Factory A

Production error types in the three most problematic work phases are presented in figure 4.4.1 - 1. In the figure we can see that all production errors in work phase "*59 Hardening*" (43 % of all production errors) are type "*4 Organizational errors*" type production errors. Most of the production errors (18.4 % of all production errors) in work phase "*<76> Assembly*" are type "*6 Preceding work phase related errors*" type production errors and most of production errors



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Others	0.0	1.8	0.6		0.1	3.8			1.2					4.1
12 Punch press		14.5	0.3											1.5
<76> Assembly		0.6	2.6			18.4	3.1	0.1	0.1	0.1			0.5	3.2
59 Hardening				43.5										

Production error:

1 Human errors

2 Machine tool related errors

3 Tool related errors

4 Organizational errors

5 External errors

6 Preceding work phase related errors

7 Design errors

8 Surface treatment process related errors

9 Surface treatment equipment related errors

10 Warehousing errors

11 Transportation device related errors

12 Lifting device related errors

13 Raw-material related errors

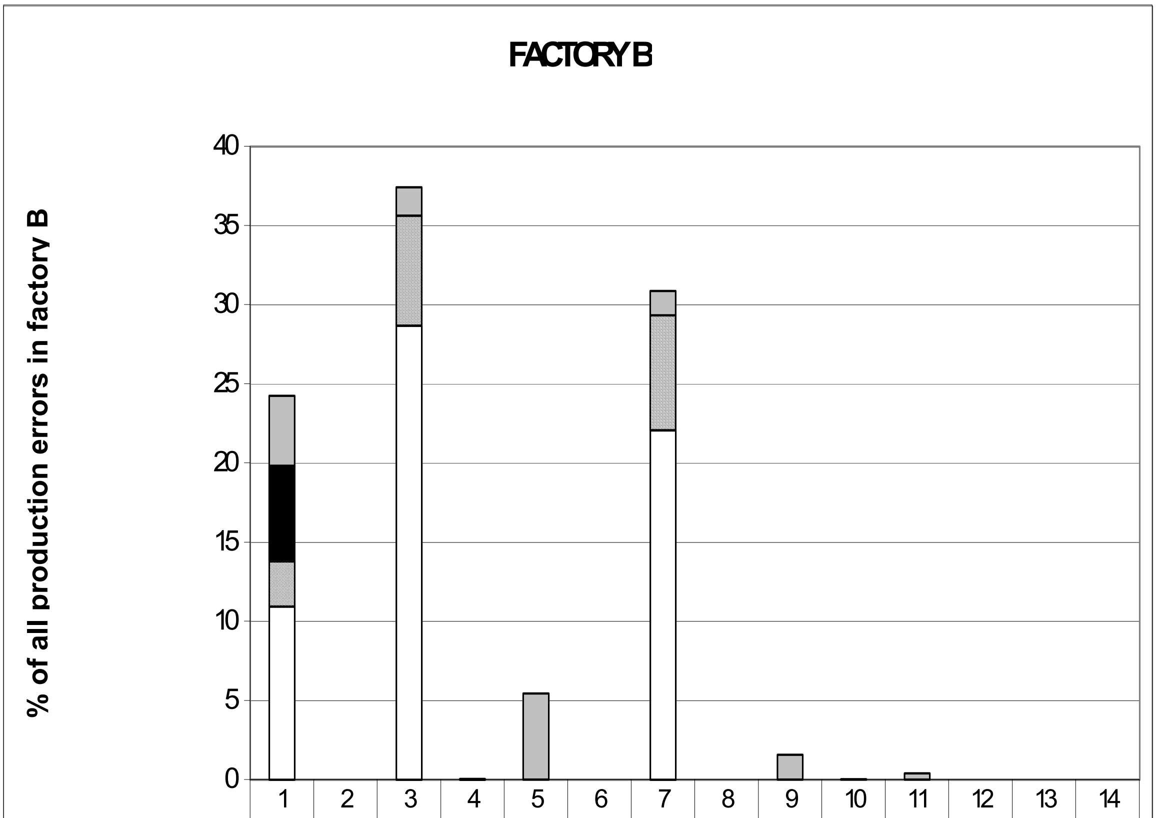
14 Other unclassified errors

FIGURE 4.4.1 - 1 Production error types in the most problematic work phases, factory A

(14.5 % of all production errors) in work phase "*12 Punch press*" are type "*2 Machine tool related errors*" type production errors. A total of 82.6 % of all production errors are caused by type "*4 Organizational errors*", type "*6 Preceding work phase related errors*" and type "*2 Machine tool related errors*" types of production errors.

4.4.2 Factory B

Production error types in the three most problematic work phases are presented in figure 4.4.2 - 1. In the figure we can see that most (50.8 % of all production errors) of the production errors in work phase "*24 Eccentric press*" are type "*3 Tool related errors*" type production errors (28.7 % of all production errors) and type "*7 Design errors*" type production errors (22.1 % of all production errors). Most (14.2 % of all production errors) of the production errors in work phase "*11 Mechanical cutting*" are type "*7 Design errors*" type production errors (7.3 % of all production errors) and type "*3 Tool related errors*" type production errors (6.9 % of all production errors). All production errors in work phase "*33 Riveting*" (6 % of all production errors) are type "*1 Human errors*" type production errors. A total of 92.4 % of all production errors are caused by type "*3 Tool related errors*", type "*7 Design errors*" and type "*1 Human errors*" types of production errors.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Others	4.4		1.8	0.0	5.4		1.5		1.6	0.0	0.4			
33 Riveting	6.0													
11 Mechanical cutting	2.8		6.9				7.3							
24 Eccentric press	10.9		28.7	0.0			22.1							

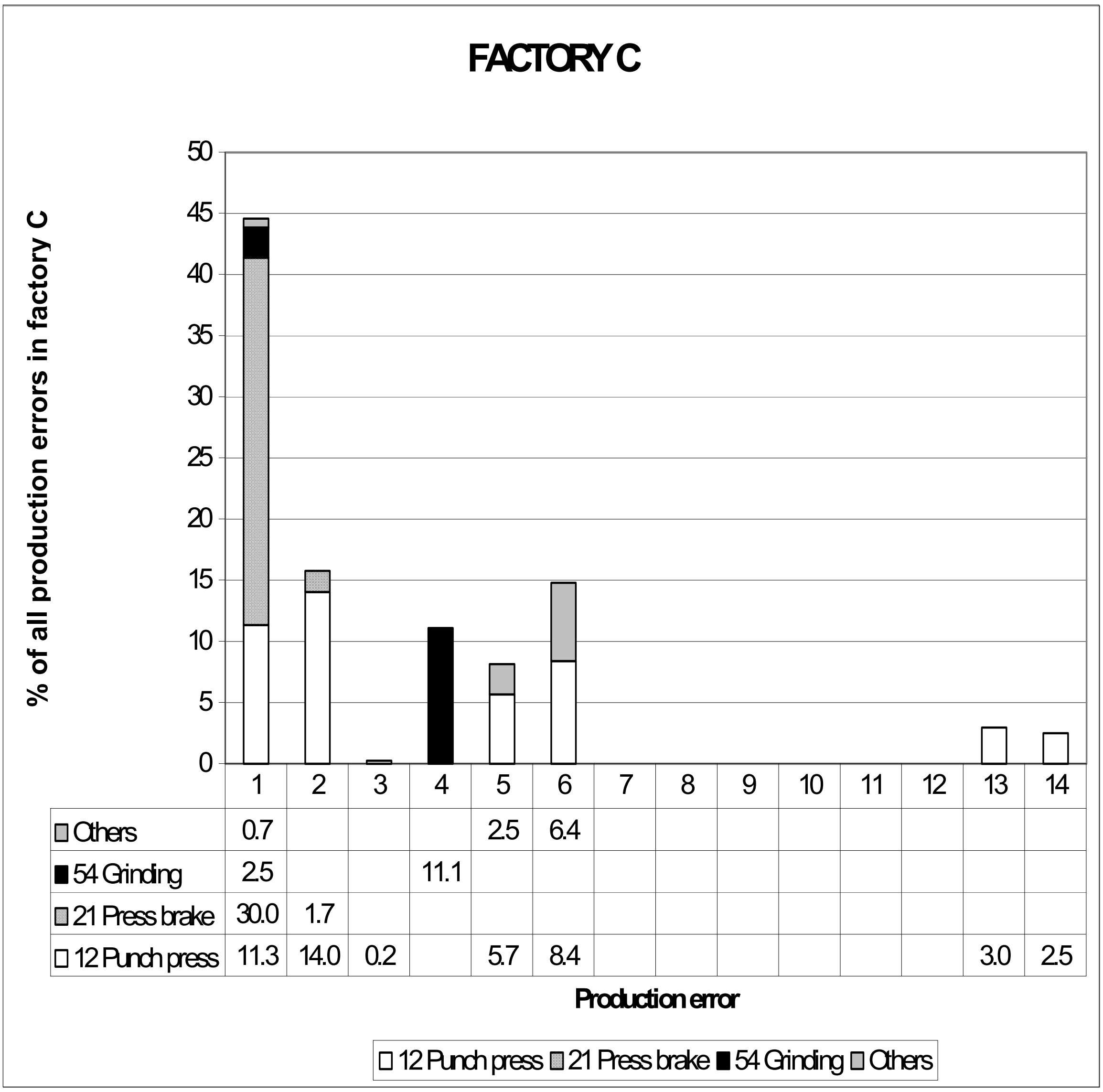
Production error:

1 Human errors
2 Machine tool related errors
3 Tool related errors
4 Organizational errors
5 External errors
6 Preceding work phase related errors
7 Design errors
8 Surface treatment process related errors
9 Surface treatment equipment related errors
10 Warehousing errors
11 Transportation device related errors
12 Lifting device related errors
13 Raw-material related errors
14 Other unclassified errors

FIGURE 4.4.2 - 1 Production error types in the most problematic work phases, factory B

4.4.3 Factory C

Production error types in the three most problematic work phases are presented in figure 4.4.3 - 1. In the figure we can see that most of the production errors in work phase "*12 Punch press*" are type "*2 Machine tool*" related errors (14.0 % of all production errors), type "*1 Human errors*" (11.3 % of all production errors) and type "*6 Preceding work phase related errors*" (8.4 % of all production errors) types of production errors. Most of the production errors in work phase "*21 Press brake*" (30.0 % of all production errors) are type "*1 Human errors*" type of production error and most of production errors in work phase "*54 Grinding*" are type "*4 Organizational errors*" (11.1 % of all production errors) type of production error. A total of 75.0 % of all production errors are caused by type "*1 Human error*", type "*2 Machine tool related errors*" and type "*6 Preceding work phase related errors*" types of production errors.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Others	0.7				2.5	6.4								
54 Grinding	2.5			11.1										
21 Press brake	30.0	1.7												
12 Punch press	11.3	14.0	0.2		5.7	8.4							3.0	2.5

Production error:

1 Human errors
2 Machine tool related errors
3 Tool related errors
4 Organizational errors
5 External errors
6 Preceding work phase related errors
7 Design errors
8 Surface treatment process related errors
9 Surface treatment equipment related errors
10 Warehousing errors
11 Transportation device related errors
12 Lifting device related errors
13 Raw-material related errors
14 Other unclassified errors

FIGURE 4.4.3 - 1 Production error types in the most problematic work phases, factory C

4.5 Origins of production errors

The origins of the production errors will be shared into four categories in this thesis to analyze the origins of the production errors. This share is based on the four elements in the production flow mentioned earlier in chapter 1.4 in this thesis. In this chapter a closer look is taken at different types of production error origins. These four categories are "*human activity based errors –category"*, "*manufacturing technology-based errors –category"*, "*material based errors –category"* and "*other errors –category"*. In this share the following criteria of evaluation has been used:

In the "*human activity based errors –category*" the production errors are based e.g. on:

- Work error.
- Interpretation error.
- Faultiness of work instruction, drawing e.g.
- Forgetting of matter.
- Lack of interest.
- Careless mistake.
- Unskilled work force.
- Design error.

In the "*manufacturing technology based errors –category"* the production errors are based e.g. for:

- Malfunction of machine tool, NC-control unit e.g.
- Tool breakage or malfunction.

In the "*material based errors –category"* the production errors are based e.g. on:

- Defective purchase of external part.
- Defective subcontracting part.
- Defective raw material supply.

"*Other errors-category"* includes all other production errors not mentioned above.

The production error share described above is presented in Table 4.5 - 1. An error specification classification has been used in this share.

Table 4.5 - 1 Production error share in to four categories by error specification

CATEGORY	ERROR SPECIFICATION	
Human activity based errors-category	11	Work error
	12	Interpretation error
	13	Setup error
	14	Incorrect NC-program
	15	Incorrect drawing
	16	Undefined error
	24	Insufficient maintenance
	32	Insufficient maintenance
	33	Setup error
	41	Old drawing
	42	Old instruction
	43	Defective drawing
	44	Defective work instruction
	45	Wrong work method
	46	Indefinable error
	61	Work error in preceding work phase
	62	Product out of tolerances
	63	Handling error in preceding work phase
	64	External error in preceding work phase

	65	Indefinable error
	71	Defective construction
	72	Product impossible to manufacture
	73	Functional error
	74	Indefinable error
	84	Defective work instruction
	91	Wrong program
	92	Wrong hanging method
	101	Dents / scratches
	112	Wrong work instruction
	113	Falling
	122	Wrong work instruction
	123	Falling
Manufacturing technology based errors-category	21	Error in NC-control unit
	22	Machine tool failure
	23	Operating error
	25	Indefinable error
	31	Tool break
	34	Indefinable error
	81	Defective bath
	82	Soiled bath
	83	Wrong bath temperature
	85	Indefinable error
	93	Functional error
	94	Indefinable error
Material based errors-category	51	Defective purchase
	52	Defective subcontracting
	131	Wrong material delivery
	132	Water damage
	133	Dents / scratches
	134	Indefinable error

Other errors-category	53	Water damage
	54	Convulsion of nature
	55	Indefinable error
	102	Water damage
	103	Convulsion of nature
	104	Dirt in product
	105	Indefinable error
	111	Functional error
	114	Indefinable error
	121	Functional error
	124	Indefinable error
	141	Write comments other side

The share of the origins of the production error categories is presented in figure 4.5 - 1. This share is based on the calculated value from the production error database in each case factory. In this figure we can see that most of the production errors in each factory belong to the "*human activity based errors –category*". The figures are 68.8 % of all production errors in factory A, 84.9 % of all production errors in factory B and 61.6 % of all production errors in factory C.

The second largest category is the "*manufacturing technology based errors – category*". The figures are 21.7 % of all production errors in factory A, 9.7 % of all production errors in factory B and 16.0 % of all production errors in factory C.

"*Material based errors –category*" is the smallest in factory A (0.6 % of production errors) and the second smallest in factory B (5.4 % of all production errors) and in factory C (5.4 % of all production errors).

There are some differences in the results between each studied factories. The differences can partly be explained by different manufacturing strategies and different level of factory automation used in the production flow. These differences are analyzed and discussed later in this thesis in chapter 4.7.

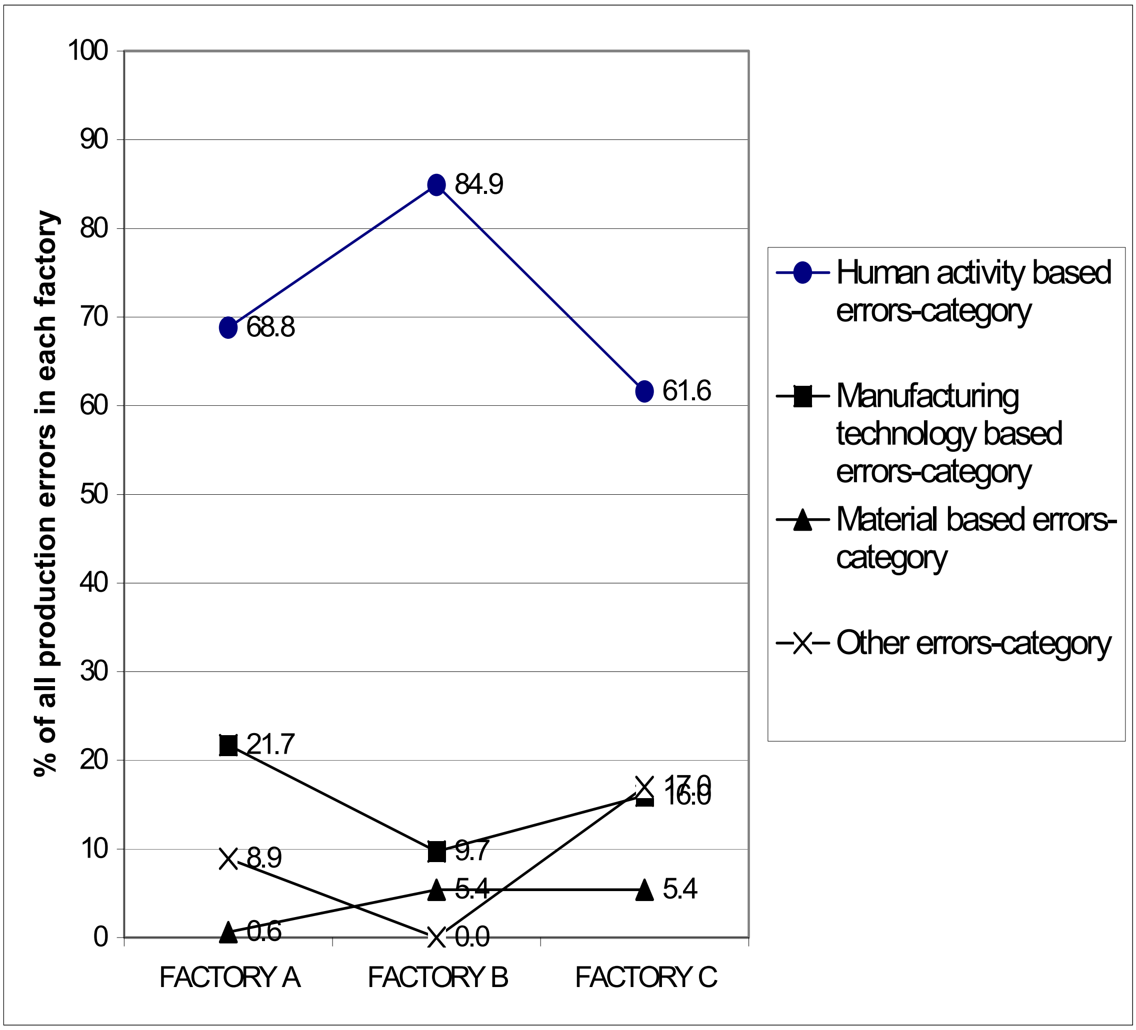


FIGURE 4.5 - 1 Percentage distribution of production error categories based on calculated value from the collected database in each studied case factories

4.5.1 Validity of origins of production errors

In order to be able to evaluate the reliability of the results presented in figure 4.5 – 1, possible sources of errors interfering the results have to be examined more closely. The possible sources of errors include missing production error data, missing markings in production error charts, selecting wrong kind of products to be tracked in the field study and mistakes in interpreting the production errors during error observation phase.

Missing production error data

The production error data collection includes a lot of manual work and human mistakes can happen. However, it is assumed that the amount of the missing markings is minor compared to the collected data as a whole. This assumption is supported by the fact that if employees had not wanted to collect the production error data, as in one case factory, it would have been seen in the results of the whole field study. Presumably, the employees have been motivated enough to collect production error data carefully.

On the other hand, it is supposed that the missing markings divide evenly between all categories. Therefore, it can be assumed that missing markings have no significance in the final results.

Missing markings in production error charts

There have been a few insufficiently filled lines in the production error charts. In this case the classification has tried to be done during the analysis phase based on available information and other markings in the production error charts. Unsolved markings have been classified under "*14 Other unclassified errors*" and "*141 Write comments other side*". The amount of unsolved markings is such small that it does not have any effect on the final results.

Selecting wrong kind of products

Every factory was asked to select some products to be tracked in the field study. The products to be tracked were asked to be typical products for each factory.

This selection may not have been correct in all respects but the effect of this on the presented results is very difficult to verify.

Mistakes in interpreting the production errors during error observation phase

Mistakes in interpreting the production errors during error observation phase are assumed to be the biggest error-causing factor in the field study. It is presumed that the employee who observed the production error knew in which functional phase and work phase the production error was caused or detected and therefore, these markings are correctly done. The real errors have occurred when the employee has decided the type of the production error and the type of error specification. Because of this, the possible errors in the presented origins of production errors have to be examined from this point of view.

In the first place it is essential to study the mistakes in interpreting the production errors that reduce the share of human activity based errors. There are no mistakes in interpreting the production error in the production error types "*1 Human errors*", "*4 Organizational errors*", "*5 External errors*", "*7 Design errors*", "*8 Surface treatment process related errors*", "*9 Surface treatment equipment related errors*", "*11 Transportation device related errors*", "*12 Lifting device related errors*" and "*13 Raw- material related errors*".

In the production error type "*2 Machine tool related errors*" interpreting mistakes can easily happen. An error interpreted to be caused by a human error and placed under "*24 Insufficient maintenance*" may in reality be caused by faulty operating manufacturing technology and should therefore be classified under "*manufacturing technology based errors-category*".

Also, in the production error type "*3 Tool related errors*" interpreting mistakes often can happen. An error interpreted to be caused by a human error and placed under "*32 Insufficient maintenance*" and "*33 Setup error*" may, too, in reality be caused by faulty operating manufacturing technology and should therefore be classified under "*manufacturing technology based errors-category"*.

In the production error type "*6 Preceding work phase related errors"* there is a great possibility to make interpreting mistakes. An error can faultily be interpreted to belong to "*human activity based errors –category" "61 Work error in preceding work phase"*, "*62 Product out of tolerances"*, "*63 Handling error in preceding work phase"* and "*64 External error in preceding work phase"* even though the reason can be in defective material and it belongs to "*material based errors-category"*.

Furthermore, in the production error type "*10 Warehousing errors"* there is a possibility to make interpreting mistakes. An error can incorrectly be interpreted to belong to "*human activity based errors-category" "101 Dents/scratches"* even though the reason can be in dented and scratched raw material and it should be included in "*material based errors-category"*.

In the second place, it is essential to go through other categories in error specification and examine the influence of the interpreting mistakes on "*human activity based errors-category"*. In the production error type *"2 Machine tool related errors" "22 Machine tool failure"* and "*23 Operating error"* there is a possibility to make interpreting mistakes. An error can incorrectly be interpreted to belong to "*manufacturing technology based errors-category"* even though in reality it is caused by a human error, for example lack of maintenance, and should be placed into "*human activity based errors-category"*.

Also, in the production error type "*3 Tool related errors"* the interpreting mistakes can easily happen. An error interpreted to be caused by tools and placed under "*31 Tool break"* may in reality be caused by lack of tool maintenance and should therefore be classified under "*human activity based errors-category"*.

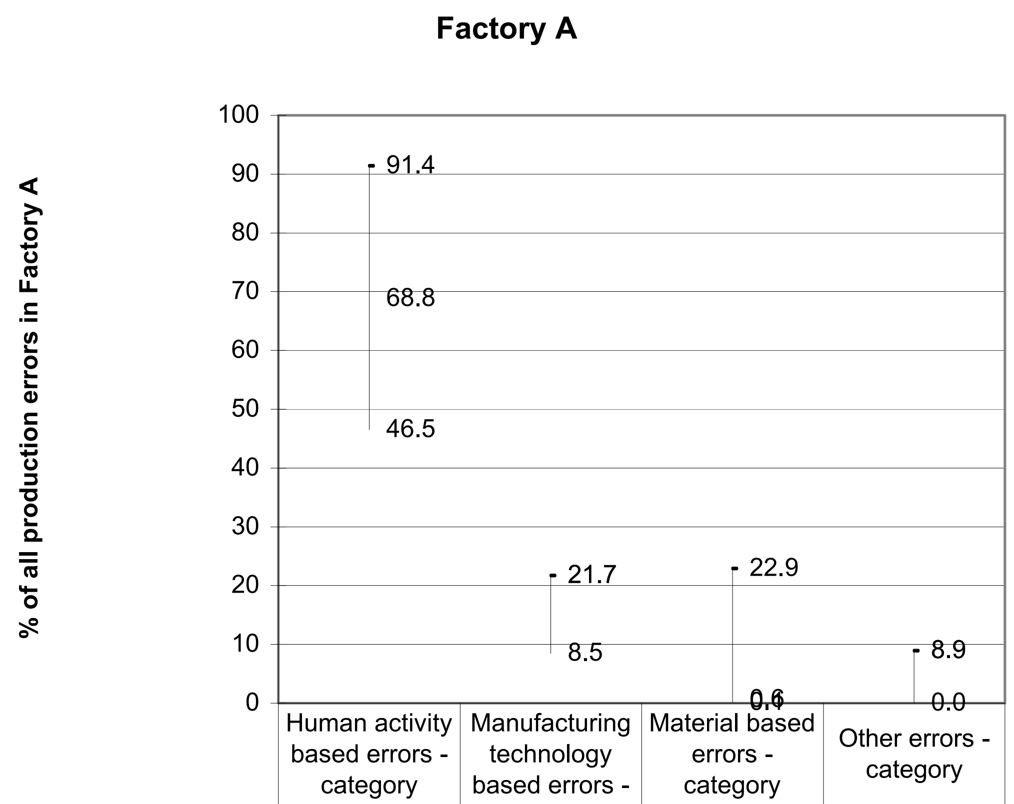
In the production error type "*8 Surface treatment process related errors*" it is also easy to make interpreting mistakes. Wrong bath temperature selection can be seen as a manufacturing technology based error but in reality it is caused by a human error. Therefore, "*83 Wrong bath temperature*" should be included in "*human activity based errors-category*".

Furthermore, in the production error type "*13 Raw-material related errors*" the interpreting mistakes can happen. An error interpreted to be caused by raw material and placed under "*133 Dents/scratches*" may in reality be caused by wrong handling of raw materials and should therefore be classified under "*human activity based errors-category*".

Finally, in the production error type "*14 Other unclassified errors*" "*141 Write comments other side*" is the most questionable category because all the unsolved markings are classified under it. Because the production errors included in this category can be caused by human errors the situation should be examined from the point of view where these errors are placed under "*human activity based errors-category*".

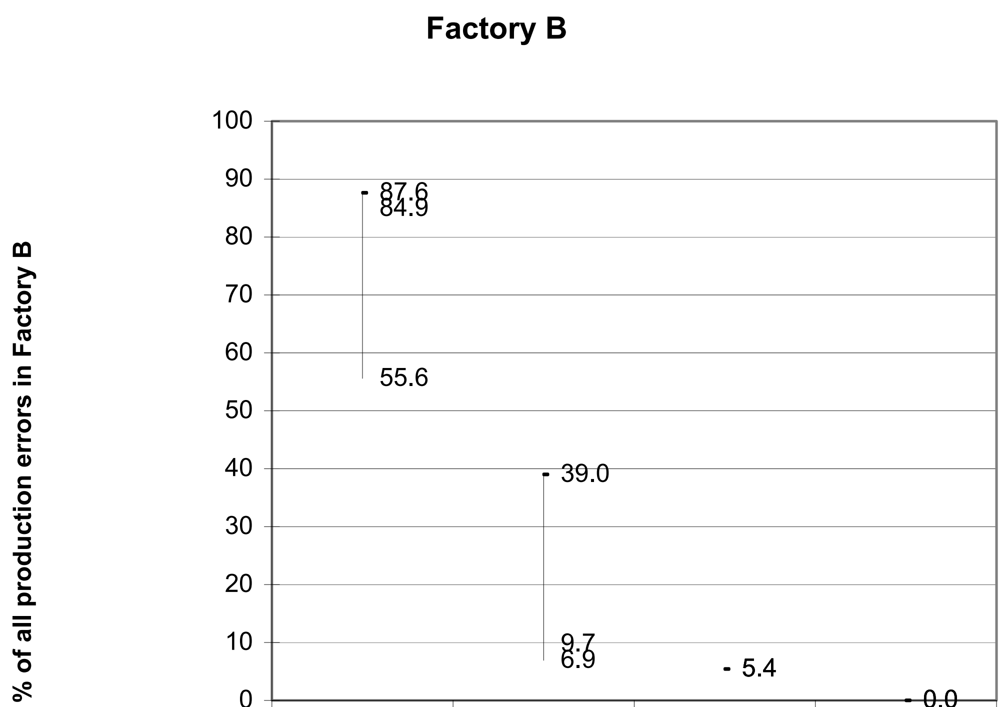
The figures 4.5.1 – 1, 4.5.1 – 2 and 4.5.1 – 3 show origins of the production errors in each factory taking into account possibilities of interpreting errors. In each figure the calculated value from production error database as presented in figure 4.5 – 1 is shown and minimum and maximum values considering the possibilities of interpreting errors as mentioned above are presented.

As a result the figures 4.5.1 – 1, 4.5.1 – 2 and 4.5.1 – 3 display that "*human activity based errors-category*" is clearly the largest production error category in each case factory and therefore, it can be argued that human activity based errors cause most of the production errors in the case factories.



	Human activity based errors - category	Manufacturing technology based errors -	Material based errors - category	Other errors - category
Min	46.5	8.5	0.1	0.0
Calculated value	68.8	21.7	0.6	8.9
- Max	91.4	21.7	22.9	8.9

FIGURE 4.5.1 – 1 Origins of the production errors in factory A taking into account possibilities of interpreting errors



	Human activity based errors - category	Manufacturing technology based errors -	Material based errors - category	Other errors - category
Min	55.6	6.9	5.4	0.0
Calculated value	84.9	9.7	5.4	0.0
- Max	87.6	39.0	5.4	0.0

Error -categories

FIGURE 4.5.1 – 2 Origins of the production errors in factory B taking into account possibilities of interpreting errors

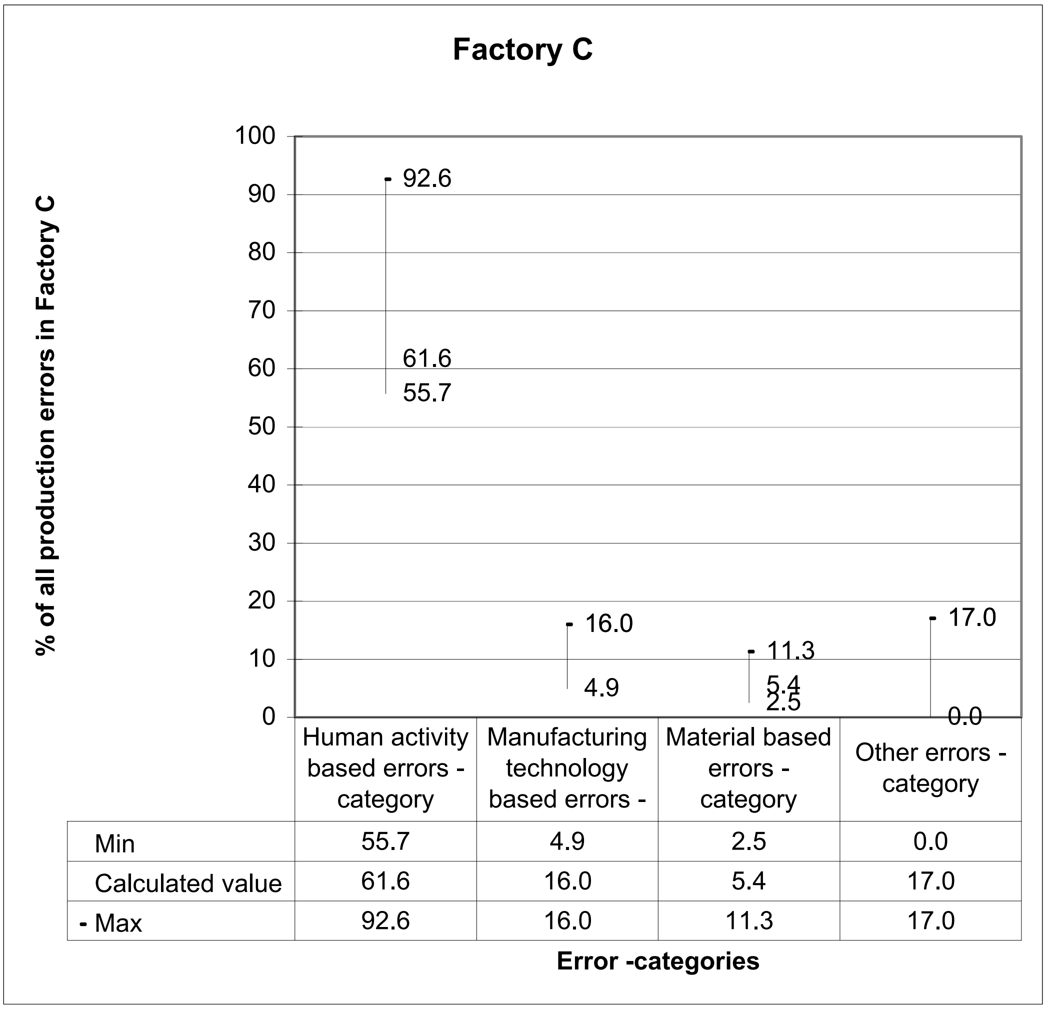


FIGURE 4.5.1 – 3 Origins of the production errors in factory C taking into account possibilities of interpreting errors

4.5.2 Comparability of results

It would have been very useful to be able to compare the results achieved in this thesis to any previous empirical work in the area of manufacturing engineering but none such could be found. To get comparable data from the area of manufacturing industry more research on this area must be done. That would also give better comparison material between different branches of manufacturing. This observation and suggestion is also written in suggestions for further research in this thesis.

In published papers there is still some information available from different branches to compare the results achieved in this thesis to existing results. For example Halevy and Naveh (2000) state in their paper that an appreciable portion (some 30 %) of the national product in Israel is wasted due to poor quality of planning and workmanship. Furthermore, Barber et al. (2000) developed a methodology to measure the cost of the quality failures in two major road projects in England and the finding was that the cost of failures is a “significant” percentage of the total costs. Most important feature in this case is that it was estimated that up to 50 % of the errors resulted from design errors. Finally, Porter and Rayner (1992) have collected some examples of the costs of the quality in the England. Examples show remarkably high values in some cases (British Airways Technical workshop 49 %, Computer equipment 22 % and Metal processing, 12 %). All quality costs mentioned are expressed as a percentage of sales value. Results from different authors cannot be compared directly to the results presented in this thesis but they confirm that results presented in this thesis are truthful.

4.6 Empowerment in case factories and suggested empowerment actions to reduce overall error amount

Production teams are used only in factory B, where three separate teams are formed alongside the functional organization. In these teams every member performs every task and task rotation is used in daily basis. Team leaders are not used, however. Supervisor-level is still in use. Some functions are integrated in to the tasks of the teams. These functions include the control of working hours within the teams and quality control functions.

Production in factory A and factory C is very traditional and functional, although some machine tool operator tasks are rotated and some functions are integrated in the tasks of turret punch press operator operations in factory A. Noticeable is that the supervisors play a remarkable role in the operations of all the case factories.

Information is shared in very different ways in the case factories. In factory A and factory B both strategic and operative information is shared, while information shared in factory C is more linked to daily production operations. Various methods for information sharing are used in the case factories. In factory A a notice board and an information leaf are used, in factory B info sessions are arranged once a week and in factory C e-mail and a notice board are used. Every factory is using some public performance meters, but the means of visual communication are not in use in any of the case factories.

The development of production activities is in response of supervisors in factory B and factory C. Only in factory A the development of production activities is in response of everyone in the factory.

A formal suggestion scheme is in use in every case factory. Only in factory A the use of a suggestion scheme is conceived active. In factory B and factory C the use of a suggestion scheme is in very low level. A continuous improvement program is not in use in any of the case factories.

In every case factory training and education is based on professional needs. Only in factory C problem solving technique (FMEA) is taught to the employees.

A reward system is in use in every case factory. Various performance meters are used. Noticeable is the minor amount of different meters in the reward system (see table 3 – 5). In factory A and factory B only one meter is used.

This thesis suggests that main problems are related to the organization model, absence of visual communication and absence of proper production development tools that involve everyone in the factory to the development process. This thesis also suggests that real multipurpose training and education is missing in case factories and meters used in a reward system are not supportive enough to production development activities.

It can be claimed that real employee empowerment is in comparatively low level in the case factories. Every case factory has both good and less good sectors when empowerment is inspected as entirety. All sectors must, however, be taken into consideration when totally empowered employees are aimed at.

Comparable results have been published earlier. Ollikainen and Varis (2001) have studied employee empowerment in the Finnish sheet metal industry in their paper. Their study is based on case studies performed in three Finnish case factories utilizing AMT in their production flow. The paper indicates that the employee empowerment is not in use in or is in very low level in the case factories studied in their paper. Their paper suggests that the main problems are associated with a failure in organizational adoption. The organizational models in the studied companies are very rigid and the foreman level is clearly in use. In most cases employees perform only one task in the production flow, performance measurement indicators and customer feedback are not used as tools and there are few continuous improvement activities in all the factories studied.

The human activity based error -category in the production flow can presumably be affected with the employee empowerment. The role of the employee empowerment in reducing production errors is presented in table 4.6 - 1. The table has two columns. The first column indicates error specification and the second column some means that can be used to reduce production errors. The means are arranged by the employee empowerment themes mentioned earlier on this thesis. In addition, a truthful reward system is needed to support the production error reduction.

Table 4.6 - 1 Employee empowerment in reducing production errors

Error specification	Themes in employee empowerment and means to reduce production errors
Work error	***Education and training;*** basic training improves working skills, knowledge and sight of the "bigger picture" improve performance, each individual has a clear understanding of his or her job and how it relates to the mission of the organization.
Interpretation error	***Education and training;*** basic training improves working skills, the number of tasks in which employees receive training increases. **Information sharing;** people who are closest to the work have immediate access to the information they need in their work. ***Multifunctional team structure;*** improved problem-solving abilities.
Setup error	***Education and training;*** the number of tasks in which employee receive training increases, basic training improves working skills. ***Information sharing;*** people who are closest to the work have immediate access to the information they need in their work, constructive feedback is given on employees' performance. ***Multifunctional team structure;*** improved problem-solving abilities.
Incorrect NC-program	***Education and training;*** basic training improves working skills, knowledge and sight of the "bigger picture" improve performance, each individual has a clear understanding of his or her job and how it relates to the mission of the organization. ***Information sharing;*** people who are closest to the work

	have immediate access to the information they need in their work, constructive feedback is given on employees' performance.
Insufficient maintenance	***Education and training;*** basic training improves working skills, knowledge and sight of the "bigger picture" improve performance, each individual has a clear understanding of his or her job and how it relates to the mission of the organization. ***Information sharing;*** constructive feedback is given on employees' performance, visual process indicators are used. ***Multifunctional team structure;*** team is able to perform maintenance tasks.
Old drawing	***Information sharing;*** people who are closest to the work have immediate access to the information they need in their work, constructive feedback is given on employees' performance.
Old instruction	***Information sharing;*** people who are closest to the work have immediate access to the information they need in their work, constructive feedback is given on employees' performance.
Defective drawing	***Education and training;*** basic training improves the working skills of designers, knowledge and sight of the "bigger picture" improve performance, each designer have a clear understanding of his or her job and how it relates to the mission of the organization. ***Upward problem solving;*** feedback from the employees to the designers.
Defective work instruction	***Education and training;*** basic training improves the working skills of designers, knowledge and sight of the "bigger picture" improve performance, each designer has a

	clear understanding of his or her job and how it relates to the mission of the organization. ***Upward problem solving;*** feedback from the employees to the designers.
Wrong work method	***Education and training;*** basic training improves working skills. ***Information sharing;*** people who are closest to the work have immediate access to the information they need in their work. ***Upward problem solving;*** feedback from the employees to the designers.
Work error in preceding work phase	***Education and training;*** basic training improves working skills, knowledge and sight of the "bigger picture" improve performance, each individual has a clear understanding of his or her job and how it relates to the mission of the organization, quality tools are trained. ***Information sharing;*** constructive feedback is given on employees' performance, visual process indicators are used. ***Multifunctional team structure;*** team performs many different tasks, quality control is in response of the teams.
Product out of tolerances	***Education and training;*** basic training improves working skills, knowledge and sight of the "bigger picture" improve performance, each individual has a clear understanding of his or her job and how it relates to the mission of the organization, quality tools are trained. ***Information sharing;*** constructive feedback is given on employees' performance, visual process indicators are used. ***Upward problem solving;*** feedback is given on employees, performance. Feedback from the employees to the

	designers.
Handling error in preceding work phase	***Education and training;*** basic training improves working skills, knowledge and sight of the "bigger picture" improve performance, training in material handling. ***Information sharing;*** constructive feedback is given on employees' performance, visual process indicators and instructions are used, people who are closest to the work have immediate access to the information they need in their work.
External error in preceding work phase	***Information sharing;*** subcontractors have immediate access to the information they need in their work, constructive feedback is given on subcontractors' performance,
Defective construction	***Education and training;*** basic training improves the working skills of designers, knowledge and sight of the "bigger picture" improve performance, each designer has a clear understanding of his or her job and how it relates to the mission of the organization ***Information sharing;*** designers have immediate access to the information they need in their work. ***Upward problem solving;*** feedback from the employees to the designers.
Product impossible to manufacture	***Education and training;*** basic training improves the working skills of designers, knowledge and sight of the "bigger picture" improve performance, each designer has a clear understanding of his or her job and how it relates to the mission of the organization ***Information sharing;*** designers have immediate access to the information they need in their work. ***Upward problem solving;*** feedback from the employees to the designers.

Functional error	***Education and training;*** basic training improves the working skills of designers, knowledge and sight of the "bigger picture" improve performance, each designer has a clear understanding of his or her job and how it relates to the mission of the organization. ***Information sharing;*** designers have immediate access to the information they need in their work. ***Upward problem solving;*** feedback from the employees to the designers.
Wrong program	***Education and training;*** basic training improves the working skills, knowledge and sight of the "bigger picture" improve performance, each individual has a clear understanding of his or her job and how it relates to the mission of the organization. ***Information sharing;*** people who are closest to the work have immediate access to the information they need in their work, constructive feedback is given on employees' performance.
Wrong hanging method	***Education and training;*** basic training improves working skills. ***Information sharing;*** people who are closest to the work have immediate access to the information they need in their work.
Dents/scratches	***Education and training;*** basic training improves working skills, knowledge and sight of the "bigger picture" improve performance, training in material handling. ***Information sharing;*** visual process indicators and instructions are used, people who are closest to the work have immediate access to the information they need in their work.
Falling	***Education and training;*** basic training improves working

	skills, knowledge and sight of the "bigger picture" improve performance, training in material handling. ***Information sharing;*** visual process indicators and instructions are used, people who are closest to the work have immediate access to the information they need in their work.

The percentage distribution of all production errors is presented in the "*human activity based errors-category"* in each factory in table 4.6 - 2. In some cases figure 0.0 is used. This figure expresses that a production error exists but the share is zero. Grey color in table cell expresses that no production error exists in that work phase. Rows with no markings have been left out.

In Table 4.6.1 - 2 we can see that most of the production errors in "*human activity based errors –category"* are error specification *"45 Wrong work method"* type production errors in factory A (43.5 & of all production errors), error specification "*72 Product impossible to manufacture"* type production errors in factory B (30.9 % of all production errors) and error specification "*11 Work error"* type production errors in factory C (30.3 % of all production errors). These figures in each factory are greater than figures summarized in all the other production error categories (31.2 % of all production errors in factory A, 15.2 % of all production errors in factory B and 29.6 % of all production errors in factory C).

In factory A "*65 Indefinable error"* related to the production error type "*6 Preceding work phase related errors"* and "*61 Work error"* in the preceding work phase are also remarkable production error specification types. In factory B "*32 Insufficient maintenance"* and "*33 Setup error"* are also remarkable production error specification types. In factory C "*12 Interpretation error"* and "*43 Defective drawing"* are also remarkable production error specification types.

To reduce the overall production error amount in the production flow the sources of production errors mentioned above must be affected. The employee empowerment gives proper tools for that action. As mentioned earlier by Smith (1997) empowerment is no quick fix. It is about significant cultural change, which takes time and real commitment. Therefore, it is important to take it in use step by step. Themes *information sharing*, *upward problem sharing* and *education and training* as mentioned earlier in chapter 1.1.2 Learning organization and employee empowerment are good starting activities on the way to a totally empowered workplace. The theme *multifunctional team structure* takes more time to adopt and requires basic skills produced by themes mentioned above. Therefore, the goal in an empowerment program should be in the multifunctional team structure. A truthful reward system is needed to support the change in every stage. With a real commitment a great success can be achieved.

Table 4.6 - 2 Percentage distribution of production error in human activity based errors -category by error specification in each case factory studied [%]

ERROR SPECIFICATION	Factory A	Factory B	Factory C
11	0.0	5.3	30.3
12		0.7	13.5
13		6.9	0.5
14		11.3	
16			0.2
24	0.0		
32		16.0	
33		13.3	
41		0.0	
43			11.1
45	43.5	0.0	
61	4.4		0.2

62	0.5		
63	2.6		5.7
65	14.7	0.0	8.9
71	2.7		
72	0.3	30.9	
101	0.1		
113		0.4	
TOTAL	**68.8 %**	**84.8 %**	**70.4 %**

11 Work error
12 Interpretation error
13 Setup error
14 Incorrect NC-program
16 Indefinable error
24 Insufficient maintenance
32 Insufficient maintenance
33 Setup error
41 Old drawing
43 Defective drawing
45 Wrong work method
61 Work error in preceding work phase
62 Product out of tolerances
63 Handling error in preceding work phase
65 Indefinable error
71 Defective construction
72 Product impossible to manufacture
101 Dents / Scratches
113 Falling

4.6.1 Feedback from suggested repairing actions from case factories

In the feedback meeting it was possible to discuss the results of the field study and suggested repairing actions with shop floor employees, supervisors and designers of factory A. The results were considered surprising and expectations had been much more positive than the reality. The great amount of the production errors was surprising and also, the conjectures of where the production errors will most often take place were not correct.

The great amount of production errors in the work phase "*59 Hardening*" was a real surprise to designers and supervisors in the feedback meeting. The feedback from the shop floor employees stated that a construction of one particular sheet metal component was sensitive to errors in a hardening process. The component was narrow and long and because of this structure it was easily bent in the required hardening process. The designers got this piece of information first time in the feedback meeting and they were able to start planning new solutions. This showed that means of employee empowerment (information sharing and upward problem solving) are working and if there had been proper and working feedback system information about this problem would have reached the designers much earlier.

Problems in assembly were realized. The field study revealed that problems in assembly were related to the preceding work phases. Most of the problems occurred in inserting press where process parameters were very difficult to maintain. It resulted in faulty joints between lock frame parts that were detected only in the assembly phase. The feedback reached the supervisors and actions were taken to purchase a modern inserting press. The inserting press was taken into production during LELA –research program and as a result of it the errors decreased dramatically. This indicates that feedback from shop floor employees is important and the means of employee empowerment are working also in this case.

The amount of production errors in work phase "*12 Punch press*" was also a total surprise to everyone. The reason for errors in this work phase were tried to be revealed after the feedback meeting but no single reason was found. Anyway, this indicates the importance of a systematic production information collection when problematic work phases are spotted.

Obviously, in factory A the problematic work phases in the production flow can be affected by the means of the employee empowerment. The themes that are working best in factory A are upward problem solving and information sharing. Also, other themes of the employee empowerment can be applied as long as suitable ground is formed.

4.6.2 Validity of suggested production error reducing actions

A number of investigators have shown in theory that worker skill levels are a direct determinant of levels of quality performance (Flynn et al., 1995; Hackman and Wageman, 1995). Also, many published papers about the learning organization and the employee empowerment can be found. However, one observation is that there is very little detailed discussion about the real scores of a success achieved with the employee empowerment and learning organizations particularly in the manufacturing engineering (notice Sykes et al., 1997) and most of the papers are based on literary surveys.

Some comparable and trendsetting information can however be found. Significant improvements in productivity (through improvements in quality, reduction in scrap and waste, reduction in throughput time and greater flexibility to respond to needs) and a competitive advantage of employers and the nation as a whole have been reported as an economic benefits of training organizations (Carnevale and Goldstein, 1990; Mincer, 1988; Denison, 1984). The United States Department of Labor (1993) has further reported that formal worker training introduced in 180 manufacturing firms in the United States increased overall productivity by 17 % in three years when compared to industries that did not introduce any training program. The department of Labor also reported that another survey of 157 small manufacturers observes a drop of 7 % in scrap and increase of 20 % in the productivity of production workers. Also comparable information can be found from the results of empowerment mainly in the specific area of health care industry (Koberg et al., 1999; Hill et al., 2000) but these cases cannot be generalized in the area of manufacturing engineering.

A book by Easterby-Smith and Araujo (1999) backs up this observation of the lack of real empirical results in the field of learning organization. Easterby-Smith and Araujo (1999) report in their book that many authors including Fiol and Lyles, 1985; Huber, 1991; Miner and Mezias, 1996 have bemoaned the shortage of empirical work in the field of organizational learning for a long time. Even recently there are no signs of the pattern changing. As an example, Easterby-Smith and Araujo (1999) have studied 150 papers on the learning organization abstracted in ABI Inform during 1997 and found out that only 15 (10 per cent) were based on new empirical data collected by the authors, and of these, ten were based on investigations carried out by the authors themselves.

There is also some disbelief about the promises of learning organization and however, it is understandable, following some documented failures in implementing such desired changes as self-managed teams, high commitment work systems, total quality management or organizational learning (e.g. Roth and Kleiner, 2000; Beer and Spector, 1992; Turner and Crawford, 1998).

This thesis cannot adequately verify the efficiency of the employee empowerment on reducing the production errors especially in the case factories but it will stay as a matter of belief. However, it can be assumed that it has no negative influences on the amount of production errors. Mital et al. (1999) also back this opinion by finding that the skills of the employees determine the effectiveness and the efficiency of the process of manufacturing and the quality of goods produced.

To gain empirical results in the area of the employee empowerment particularly in the manufacturing engineering it is necessary to start a documented development project that concentrates on collecting empirical data from the results of empowerment activities. Only after doing this it will be possible to verify the influence of the empowerment activities. This observation is also written as a suggestion for further research in this thesis.

4.7 Influence of manufacturing strategy, employee empowerment and automation level on human activity based errors –category

When factories A and C are examined it can be observed that the production strategy in both factories is medium volume production and the production flow is a mixture of automated production machinery and manually operated work phases. Also, the results presented in figure 4.5 – 1 are similar in factories A and C when human activity based errors –category is observed.

Factory B differs from factories A and C when manufacturing strategies and automation level is investigated. The production strategy in factory B is high volume production and the production flow is highly automated. However, the figure of "*human activity based errors –category"* is clearly highest in factory B (68.8 % in factory A and 61.6 % in factory C compared to 84.9 % in factory B).

When the results are examined it seems that employee empowerment is most advanced in factory B despite the fact that the *"human activity based errors –category"* is most dominant in factory B. This situation can be explained by results achieved earlier in this thesis. In factory B, a lot of production errors are made not only in direct human production work but also in set up production machinery and maintenance of tools and production machinery. Also, a lot of product or tool design errors are made in factory B. In a highly automated factory and in a high volume production a lot of defective products will be produced before the error is observed and corrective actions can be taken. In fact, the situation could be much worse in factory B without few employee empowerment actions adapted to the production flow.

The inference of what is mentioned above is that increasing factory automation will not directly decrease the amount of human activity based errors in sheet metal part fabricating industry. The effect can even be the opposite. When the efficiency and automation level is increased, a lot more is required of the rest of the supporting functions, e.g. quality control and preparing functions such as set up activities. The situation can be observed through an imaginary example where there is an automated and efficient punch press FMS that is capable of using unmanned production periods. If an error is made in the tool set up phase, e.g. wrong tools are used in set up and the FMS is left alone during an unmanned production period the result is a lot of faulty punched sheet metal parts because of the wrong tool.

4.8 Effects of production errors on business activities of companies

The production errors have various effects on the business activities of the companies. Mainly, they affect the timetable and the cost structure.

The production errors in sheet metal part fabricating industry are seldom repaired because of the nature of the sheet metal part fabricating. It is impossible to repair a part that has been punched with a wrong tool or bended in a wrong way. Instead, a new part is fabricated. Only errors in surface treatment and assembly can be repaired in some cases, and because of strict demands especially in telecommunication and electronics industry these are usually not repaired. If e.g. a wrong countersink or defective grinding occurs in the front panel presented earlier in figure 1.1.1 – 2 a new panel will be fabricated instead of repairing the defective one. Because of this, the cost caused by defective parts is surprisingly high, in some cases it can be claimed that the real cost caused by defective parts is up to 20 – 30 per cent of the turn over of the manufacturing activities. Also, the high number of the production errors reported in this study in table 3 - 1 supports the mentioned figures. It is possible to repair some of the parts with production errors reported in this study but still a large number of them are wasted because of the production error.

The production errors also affect the timetable and the reliability of the delivery. The later in the production chain the error occurs the more it delays the delivery and weakens the reliability of the delivery.

As an example, figure 4.8 – 1 is presented. The figure shows increase of the processing value and the time spent in manufacturing the front panel presented earlier in figures 1.1.1 – 2 and 1.1.1 - 3. The figure 4.8 - 1 includes raw material costs excluding parts needed in assembly phase.

It can be seen in the figure 4.8 – 1 that the later the production error occurs the more money and production time is wasted. Because of the production error, the raw material is wasted in any case and all the work done in previous work phases has been unprofitable. Also, the fabricating capacity could have been used in fabricating proper parts. All the wasted work phases cause extra work and weaken the material flow control because replacement parts have to be fabricated within the normal fabricating schedule. This decreases the reliability of the delivery of the whole factory and all the products.

At this point it is important to notice the price erosion in sheet metal parts that is generally 10 per cent a year in sheet metal parts used in telecommunication and electronics industry. The price erosion means yearly reduction in prices that customers are willing to pay for sheet metal components. This is caused by continuous development of the final products, which means that the price of the more developed new final products is lower. It is also remarkable that the life cycle of such products is relatively short.

In order to estimate how the production errors affect the economic efficiency in business activities in different types of manufacturing companies, the companies have to be divided into two types. The first type of a company is solely a sub-deliverer of sheet metal components whose main business is in sheet metal part fabricating. In this thesis case factories B and C are representing this type of companies. The second type company fabricates sheet metal part based components to be used in its manufacturing process. The fabricating of sheet metal parts is clearly secondary process in the whole manufacturing flow. In this thesis case factory A represents this type of a company. This examination is presented in chapters 4.8.1 and 4.8.2.

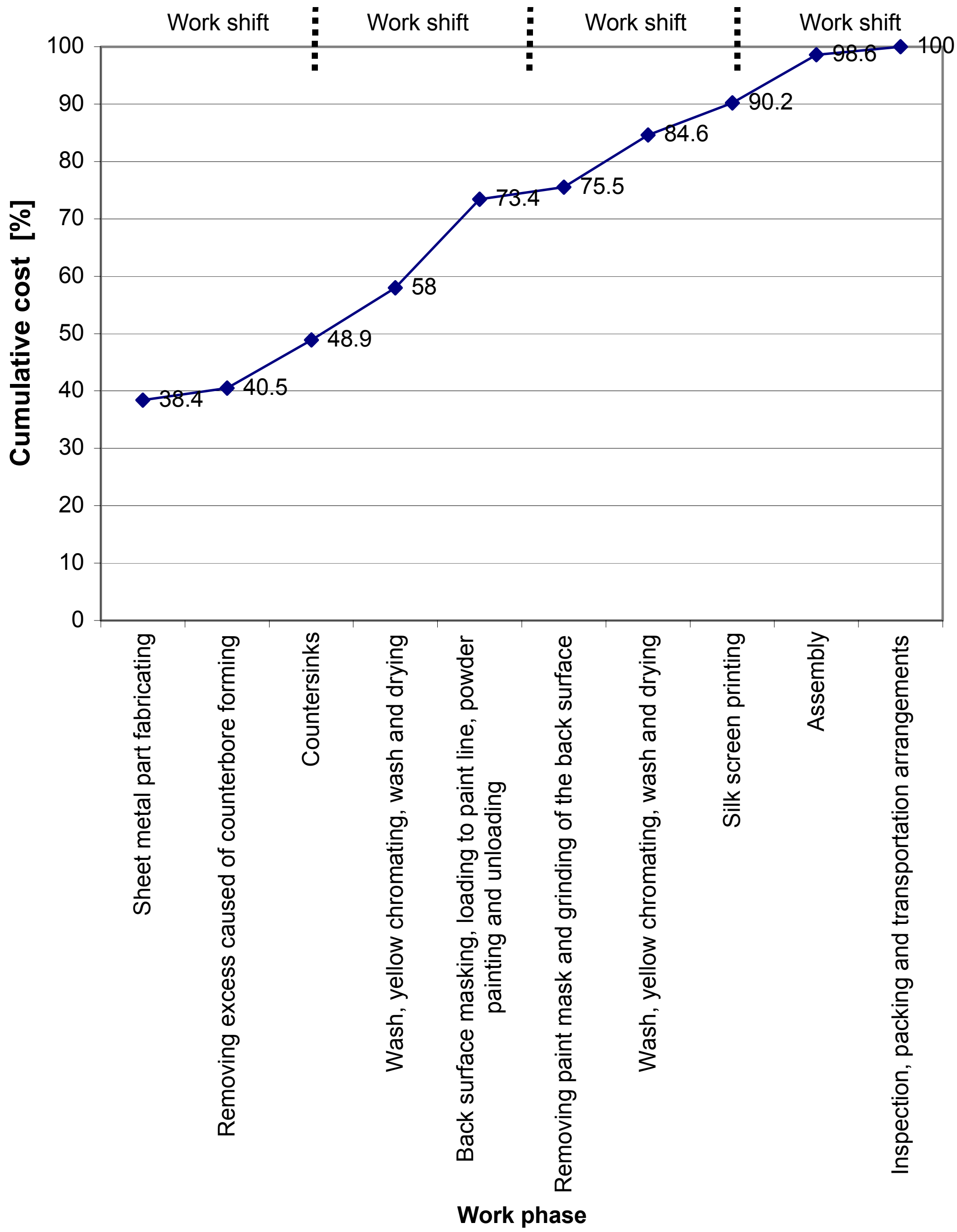


FIGURE 4.8 – 1 Increase of the processing value and the time spent in manufacturing the front panel.

4.8.1 Company as a sub-deliverer

The final product of the company is a sheet metal parts based component (e.g. custom outdoor enclosure for telecom application) where all the coverage of the whole business consists mainly of the gap between sales price and fabricating costs. This type of a situation is presented in figure 4.8.1 – 1. In this figure the black continuous line indicates the sales price with 10 per cent annual price erosion. The dotted line in this figure represents unchanged production costs during the production period and dotted dashed line displays the production costs that have been able to be reduced by 5 per cent annually by decreasing the number of production errors. The grey continuous line shows the unchanged production costs excluding the cost caused by production errors. In this case the cost caused by production errors is estimated as 25 per cent of the production costs.

If the production cost cannot be reduced the sales price -curve and unchanged production costs -curve cross and the coverage will be negative in some point of the production period (in this case about 2.8 years). Because of this it is essential to reduce production costs during the production period in order to keep the coverage positive during the whole production period. The costs can be reduced even more if the efficiency of the manufacturing flow is developed as a whole and if the price of the raw materials can be decreased.

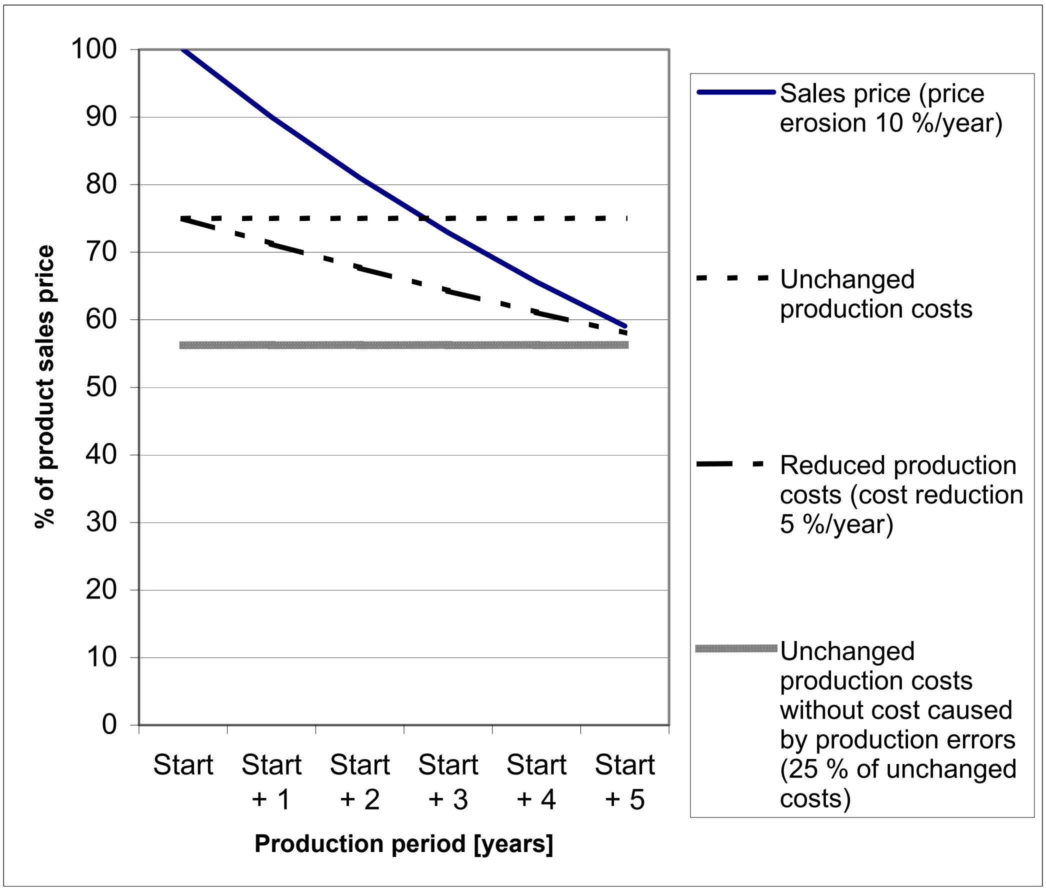


FIGURE 4.8.1 – 1 Sales price – production cost curves in sub-delivering company

4.8.2 Company with own final product manufacturing

The final product of the company is a more developed product or system (e.g. electromechanical locking system for a block of flats) where the sheet metal parts are in a secondary role and the coverage of the whole business consists mainly of the sales of the final product or system. The effect of the sheet metal parts can be as low a few percent of the price of the final product or system. There is no large price erosion pressure in a situation like this and the products are transferred from one production unit to another with internal uncovered transfers. This type of a situation is presented in figure 4.8.2 – 1. In this figure the dotted line indicates both unchanged production costs and uncovered transfer price during the production period and dotted dashed line displays the production costs that have been able to be reduced by 5 per cent annually by decreasing the number of production errors. The grey continuous line shows the unchanged production costs excluding the cost caused by production errors. Also, in this case the cost caused by production errors is estimated as 25 per cent of the production costs.

In a company with own final product manufacturing the production cost of the sheet metal parts can be reduced, but the effect on the covered price of the final product is only infinitesimal because the coverage comes from other values than sheet metal part fabricating.

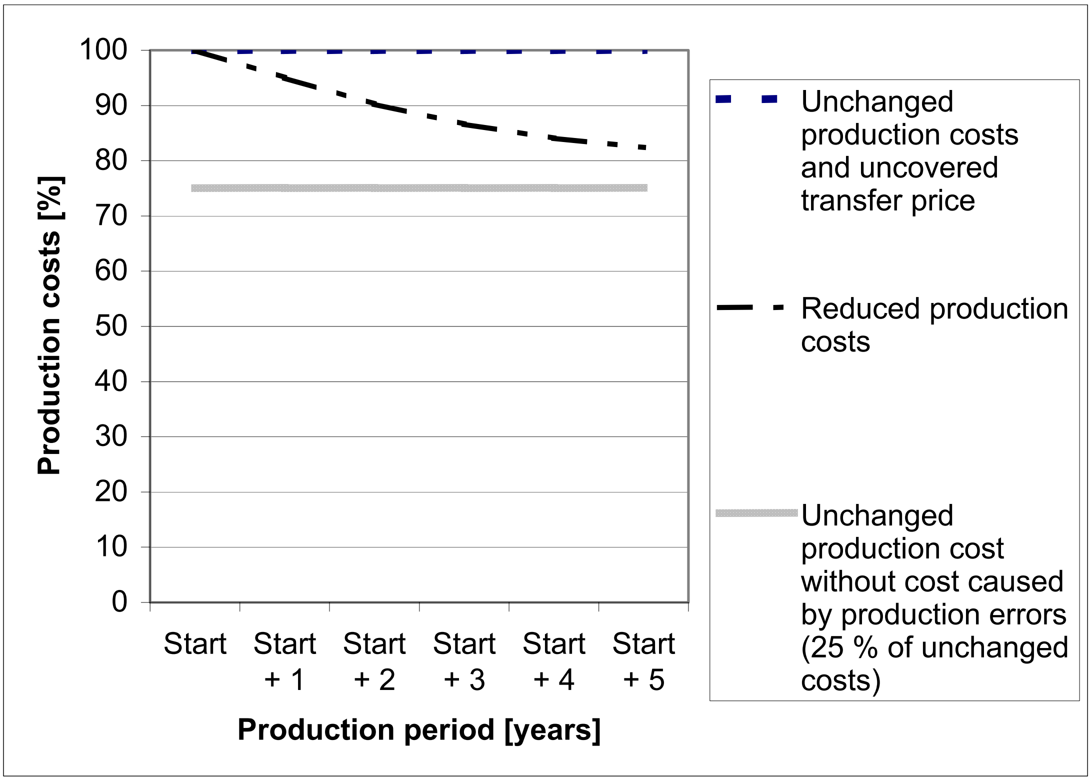


FIGURE 4.8.2 – 1 Unchanged production costs – reduced production costs curve in a company with own final product manufacturing

5 CONCLUSIONS

The production error distribution of the production flow of sheet metal part based constructions is studied in this thesis. The objective of the thesis is to present the origins of the production errors and to estimate the role of the employee empowerment in reducing the overall production error amount in the production of sheet metal based constructions.

The original statement of this thesis is that human activity based errors cause most of the production errors in the production flow of the sheet metal part fabricating industry. It is also claimed that there are a group of activities in personnel management and in changing organizational structure that can be used as a tool when efforts are made to reduce the total amount of production errors.

Case factories were used in this thesis. The production flow in each case factory studied is different. Different fabricating methods are used and also batch sizes and annual production figures are different in each case factory. A common factor for every case factory is mechanical constructions based on fabricated sheet metal parts and used in electronics and telecommunication industry. This makes this thesis most relevant to the sheet metal fabricating industry which produces sheet metal part based constructions for electronics and telecommunication industry.

A number of conclusions can be traced back to the results and analysis presented earlier in this thesis:

A systematic method for collecting production error data

The field study was started in five case factories and the production error data was received from three case factories. In one of the case factories the collection of the error data faced resistance from employees and was ended unproductive. This indicates that a production performance information measurement is a tender spot in some organizations. Also, it indicates that performance measurement work is not put into practice in this scale in many companies.

In the starting point it was unclear where and when the production errors occurred. This indicates that a systematic production performance measurement is needed when development activities are considered. The production error data collected can be used as a tool when the production flow performance and revenue are improved in each case factory. Without knowing the real problematic areas it is impossible to start any improvement activities.

In this thesis a systematic and functional method is developed to collect production error data. As a result the total amount of the production errors is collected and the share of these errors can be divided into different work phases. It can be used in all sheet metal fabricating industry where criteria set in this thesis is fulfilled.

Production error distribution of production flow

In each case factory the most delicate work phases for the production errors were detected with methods used in this thesis. In each factory three work phases could clearly be found where most of the production errors were caused. These figures were 88.4 % in factory A, 84.7 % in factory B and 90.4 % in factory C. In each case factory this observation can be used when development activities are planned. The development activities can be focused to the real problematic areas, where great improvement is within reach.

From the collected production error data it can be identified that most of the production errors are caused in manually operated work phases and in mass production work phases. However, no common theme can be found in the production error data collected in production error distribution of the production flow of sheet metal part based constructions in different case factories because the production errors are divided into different work phases in each factory.

<u>Origins of production errors</u>

The origins of the production errors are shared into four categories in this thesis. These categories are “*human activity based errors –category”*, “*manufacturing technology -based errors –category”*, “*material errors –category”* and “*other errors –category”*.

Most of the production errors in the case factories studied belong to the “*human activity based errors –category”*. A smaller part of the production errors belongs to the “*manufacturing technology -based errors –category”*, the “*material based errors –category”* and “*other errors –category”*. The differences in the “*human activity based errors –category”* can be explained by different manufacturing strategies and automation level in each factory.

The result indicates that most of the problems in the production flow are related to employees or work organization. Development activities must therefore be focused to the development of employee skills or to the development of work organization. The employee empowerment gives the right tools and methods to achieve this.

The result also indicates that production machinery is working at an acceptable level and materials are useful for common production of sheet metal part based constructions.

<u>Significance of employee empowerment in reducing overall production error amount</u>

With the employee empowerment the “*human activity based error –category”* in the production flow can be affected. The employee empowerment functions mentioned earlier in this thesis can be used in each case factory to improve the existing situation. It can be expected that the employee empowerment make reductions in the overall amount of the production errors in the production flow of constructions based on fabricated sheet metal parts possible. It can be claimed that more can be done by investing in the employee empowerment than investing in a new manufacturing technology in the case factories studied.

Validity of the statement

The original statement of this thesis is that human activity based errors cause most of the production errors in the production flow of the sheet metal part fabricating industry. It is also claimed that there are a group of activities in personnel management and in changing organizational structure that can be used as a tool when efforts are made to reduce the total amount of production errors.

In this thesis the statements have been proven valid by analyzing the production errors. This analyze shows indisputably that human activity based errors dominate production errors and there are employee empowerment –related methods that can be used to reduce the amount of production errors when limitations shown earlier in this thesis are considered.

In addition, a number of other conclusions can be drawn:

The effect of automation level on human activity based errors

This study reveals that the higher automation level not always decreases the amount of human activity based errors. In fact, it can be vice versa. Higher volumes of production and risks in set-up stage and production and quality control in highly automated partially unmanned production systems can explain this. It can take longer time to notice the defective set-up and it can result in a lot of faulty products.

The significance of reducing production errors to business activities of sheet metal part fabricating companies

Reducing of the production errors in sheet metal part fabricating companies lowers the time between the order and the delivery and increases the reliability of the delivery in all the cases. However, the financial effects have to be observed with a wider scope. The financial effects are remarkable in a business where sheet metal parts are the main product or if their production cost forms a considerable part of the sales price.

The financial effects are minor in a business where sheet metal parts are only secondary in the whole production flow of a company. In such cases possible savings are infinitesimal compared to the sales price of the final product or system.

Study method

The selected functional approach is useful when production errors are studied from a quantitative point of view or when the distribution of production errors is examined. However, this approach does not give information about the effects of the production errors on total costs of the products. Any production error causes extra costs and disturbance into a production system and it can be said that by reducing production errors the whole production flow can be made more effective and therefore, this chosen approach gives proper tools for improvement activities.

Miscellaneous conclusions

In this thesis the product design is included in the production flow. In some case factories design errors are a remarkable source for production errors. This indicates problems in the work organization. Because of that the employee empowerment should be extended to cover the whole work organization, not only factory floor-level operations. This extension is a requirement for a totally empowered work organization.

5.1 Suggestions for further research

This study is most relevant to the sheet metal fabricating industry that produces constructions of sheet metal part for electronics and telecommunication industry. More production error data are needed from sheet metal fabricating industry producing sheet metal part based constructions for different types of industry. That information makes it possible to expand the production error database collected in this thesis, which makes the results more general in the sheet metal fabricating industry. It also makes it possible to compare the production error data between different branches of the manufacturing activities.

The potential of the employee empowerment is clear. However, there is very little detailed discussion about the real scores of the success achieved with the employee empowerment particularly in the manufacturing engineering. At least one employee empowerment pilot project should be put into practice in Finnish sheet metal part fabricating factories to find out the potential of the employee empowerment in a shop floor level in manufacturing activities. Especially, this should be put into practice in case factories studied in this thesis. This requires that training and development plans are prepared and put into practice. It also requires that a regular, periodic performance measurement is carried out. The performance indicator output from this procedure indicates the real potential of the employee empowerment.

This study could be better applied to practice if the costs of production errors and the disturbance to the production flow were included. However, the chosen functional approach does not make it possible to take them into consideration. Therefore, a completely new study would be needed to investigate their influence in Finnish sheet metal fabricating industry. The results from such a study would compliment the results of this study.

In addition, one possible suggestion for further research is a study with feedback about the content of the education given in schools. If real scores of success are achieved with the employee empowerment, results from individual factories could be used as a guiding principle when developing the training in basic empowerment skills at schools in order to make their curriculum to correspond to demands of the modern business world.

6 KEY FINDINGS

The key findings in this thesis can be summarized as follows:

- Most production errors in case factories studied belong to "*human activity based errors-category"*. A smaller part of production errors belong to the "*manufacturing technology based errors –category"*, the "*material based errors –category"* and "*other errors –category"*.

- No common theme can be found in the production error data collected of the production error distribution of the production flow of sheet metal part based constructions. However, it can be assumed that most of the production errors are caused in manually operated work phases and in mass production work phases.

- It can be claimed that the real employee empowerment is in comparatively low level in case factories. Every case factory has both good and less good sectors when empowerment is inspected as entirety. All sectors must however be taken into consideration when totally empowered employees is aimed at.

- A higher automation level not always decreases the amount of human activity based errors. In fact, it can be vice versa. This can be explained by higher volumes of production and risks in set up stage and production and quality control in highly automated and partially unmanned production systems.

7 SUMMARY

The market place of the twenty-first century will demand that the manufacturing assume a crucial role in a new competitive field. Increasing market turbulence and customer demands compel manufacturing companies to manufacture high-quality and customized products within short lead-times and at lowering expenses.

The solution for stable profits and long-term survival, therefore, lies in the continuous development of manufacturing resource performance and the elimination of threats amongst them. The improved production efficiency and flexibility are the keywords for most of the manufacturing companies. Two potential resources in the area of manufacturing are AMT (advanced manufacturing technologies) and empowered employees.

Surveys in Finland have shown the need to invest in the new AMT in the Finnish sheet metal industry in the 1990's. The need to produce a growing amount of customized products within short lead-times and at lowering costs mainly for the electronics and telecommunication industry has driven the metal fabricating industry to find new ways of improving production through advanced manufacturing technology. In this run the focus has been on hard technology and less attention is paid to the utilization of human resources. Because of that, not much attention has been paid to the wholeness of the production flow and quality assurance.

In many manufacturing companies an appreciable portion of profit within reach is wasted due to the poor quality of design and workmanship. In many cases the potential savings are high and assuring quality should reach the same importance as improving efficiency and flexibility.

The production error distribution of the production flow of sheet metal part based constructions is inspected in this thesis. The objective of the thesis is to analyze the origins of the production errors in the production flow of sheet metal based constructions. Also, the employee empowerment is investigated in theory and the significance of the employee empowerment in reducing the overall production error amount is discussed in this thesis.

The original statement of this thesis is that human activity based errors cause most of the production errors in the production flow of the sheet metal part fabricating industry. It is also claimed that there are a group of activities in personnel management and in changing organizational structure that can be used as a tool when efforts are made to reduce the total amount of production errors.

This study is most relevant to the sheet metal part fabricating industry which produces sheet metal part based constructions for electronics and telecommunication industry. This study concentrates on the manufacturing function of a company. The focus is in Finnish based companies.

Not many published papers can be found on the production flow of constructions based on fabricated sheet metal parts. Instead, a number of published papers about the employee empowerment can be found. There are several problems with the existing papers on the empowerment. First, the term is used very loosely and various researchers have looked at the dimensions of the empowerment from very different perspectives. Second, there is very little detailed discussion about the real scores of a success achieved with the employee empowerment particularly in the manufacturing engineering.

This thesis identifies five main types of themes in the published papers:

- Multifunctional Team structure.
- Information sharing.
- Upward problem solving.
- Education and training.
- Reward system.

This thesis is based on a field study carried out in five Finnish case factories which produce sheet metal part based constructions mainly for electronics and telecommunication related industry. Background information was collected from the case factories. After receiving sufficient background information, a production flow partition was done and production error charts were formulated. Factories were asked to appraise formulated charts and to give feedback about the charts. The production error charts were finalized using that feedback.

Every factory was asked to select some products to be tracked in this field study. The products tracked are typical products for each factory. In this study the products have been divided into three main categories:

- Part category.
- Subassembly category.
- Assembly category.

In this thesis the production flow has been shared into functional phases. These functional phases have then been shared into work phases.

In this study the production error can be seen as a deflection from a planned and optimal production flow. Because of that deflection, various operations are needed depending on the situation:

- Defective products must be adjusted.
- Defective products must be completed.
- Defective products must be scrapped and new products must be fabricated.

This deflection may be exposed in the same point of production flow where it is caused or it can progress in the production flow and it may be exposed later in the production flow.

In this study production errors are classified into fourteen production error types. The production errors are specified.

In this study three different production error charts were formulated:

- Chart 1 for part category.
- Chart 2 for subassembly category.
- Chart 3 for assembly category.

Separate production flow error databases were formed for each case factory. To retain anonymity of the case factories all data concerning one recognizable factory is presented as a percentage distribution of all production errors in each factory. All databases are published in this paper. Also, the number of traced parts and the number of detected errors are published in this paper.

Information in each separate database is analyzed and the following tables and figures are published:

- Production error distribution by functional phases.
- Production error distribution by work phases.
- Production error distribution by error type.
- Production error distribution in each work phase by error type.
- Production error distribution by error specification.

The field study was started in five case factories and information was received from three companies, which indicates that a production performance information measurement is a tender spot in many organizations.

In each case factory the most delicate work phases for production errors were detected with methods used in this thesis. In each factory three work phases could be found where most of the production errors were caused.

No common theme can be found on the production error data collected to the production error distribution of the production flow of sheet metal part based constructions. However, it can be assumed that most of the production errors are caused in manually operated work phases and in mass production work phases.

The origins of the production errors are shared into four categories in this thesis. These categories are "*human activity based errors –category*", "*manufacturing technology -based errors –category*", "*material errors –category*" and "*other errors –category*".

Most of the production errors in case factories studied belong to the "*human activity based errors-category*". A clearly smaller part of the production errors belongs to "*manufacturing technology based errors-category*", "*material based errors –category*" and "*other errors –category*".

With the employee empowerment the "*human activity based error –category*" in the production flow can be affected. Five themes in the employee empowerment have been identified in this thesis. The themes mentioned above can be used in each case factory. Based on the analysis, the employee empowerment makes reductions in overall production error amount in the production flow of constructions based on fabricated sheet metal parts possible.

This study also reveals that a higher automation level not always decreases the amount of human activity based errors. In fact, it can be vice versa. Higher volumes of production and risks in set-up stage and production and quality control in highly automated partially unmanned production systems can explain this. It can take longer time to notice the defective set-up and it can result in a lot of faulty products.

In addition, this thesis indicates that reducing of the production errors in sheet metal part fabricating companies lowers the time between the order and the delivery and increases the reliability of the delivery in all the cases. However, the financial effects have to be observed with a wider scope. The financial effects are remarkable in a business where sheet metal parts are the main product or if their production cost forms a considerable part of the sales price.

The financial effects are minor in a business where sheet metal parts are only secondary in the whole production flow of a company. In such cases possible savings are infinitesimal compared to the sales price of the final product or system.

The original statement of this thesis is that human activity based errors cause most of the production errors in the production flow of the sheet metal part fabricating industry. It is also claimed that there are a group of activities in personnel management and in changing organizational structure that can be used as a tool when efforts are made to reduce the total amount of production errors. In this thesis the statements have been proven valid by analyzing the production errors. This analyze shows indisputably that human activity based errors dominate production errors and there are employee empowerment –related methods that can be used to reduce the amount of production errors when limitations shown earlier in this thesis are considered.

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LIST OF APPENDICES AND APPENDICES

Appendix I

Osan numero:	Liittyy osakokoonpanoon:	Sarjakoko kpl:	Valmistus alkoi:
			/ .2001 pp.kk.vv
Osan nimi:	Osan reitti:		

	VAIHE	TYÖNVAIHE	VIRHE	TYÖN-VAIHE/ VIRHE	NO (OHJE)	KPL	TYÖ-PISTEELTÄ LÄHTI KPL	KOMMENTIT
1	Osanvalmistus	11 Mek. leikkaus	1 Inhimillinen virhe	/				
		12 Levytyökeskus	2 Työstökone	/				
		13 Syväveto	3 Työkalu	/				
		14 Muovaus	4 Organisatoorinen virhe	/				
		15 Laserityöstö	5 Ulkoinen virhe	/				
			6 Edellinen työnvaihe					
2	Taivutus	21 Särmäyspuristin	7 Suunnitteluvirhe	/				
		22 Taivutusautomaatti	8 Pintakäsittelykylpy	/				
		23 Taivutuskone	9 Pintakäsittelylinja	/				
		24 Epäkeskopuristin	10 Varastointivirhe	/				
		25 Hydraulipuristin	11 Siirtoväline	/				
			12 Nostoväline					
3	Liittäminen	31 Hitsaus	13 Materiaalivirhe	/				
		32 Pistehitsaus	14 MUU	/				
		33 Niittaaminen		/				
		34 Muu		/				
4	Pintakäsittely	41 Pesu		/				
		42 Esikäsittely		/				
		43 Pintakäsittely		/				
		44 Maalaus		/				
		45 Painatus		/				
5	Muut työnvaiheet	51 Kierteytys		/				
		52 Muovaus		/				
		53 Merkkaus		/				
		54 Hionta		/				
		55 Upottaminen		/				
		56 Niittimutterit		/				
		57 Ulkoiset osat		/				
		58 Liimaus		/				
		59 Karkaisu		/				
		60 Lämpökäsittely		/				
		61 Jäysteenpoisto		/				
9	Aputoimet	91 Siirrot		/				
		92 Käsittely		/				
		93 Pakkaus		/				
		94 Lähetys		/				
		95 Varastointi		/				

Appendix II

Osakokoonpanon numero:	Liittyy koonpanoon:	Sarjakoko kpl:	Valmistus alkoi: / .2001 pp.kk.vv
Osakokoonpanon nimi:	Osakokoonpanon reitti:		

	VAIHE	TYÖNVAIHE	VIRHE	TYÖN-VAIHE/ VIRHE	OHJE NO	OHJE KPL	TYÖ-PISTEELTÄ LÄHTI KPL	KOMMENTIT
7	Kokoonpano	71 Hitsaus	1 Inhimillinen virhe	/				
		72 Niittaminen	2 Työstökone	/				
		73 Ruuvaaminen	3 Työkalu	/				
		74 Pistehitsaus	4 Organisatoorinen virhe	/				
		75 Liimaus	5 Ulkoinen virhe	/				
			6 Edellinen työnvaihe					
4	Pintakäsittely	41 Pesu	7 Suunnitteluvirhe	/				
		42 Esikäsittely	8 Pintakäsittelykylpy	/				
		43 Pintakäsittely	9 Pintakäsittelylinja	/				
		44 Maalaus	10 Varastointivirhe	/				
		45 Painatus	11 Siirtoväline	/				
			12 Nostoväline					
5	Muut työnvaiheet	51 Kierteytys	13 Materiaalivirhe	/				
		52 Muovaus	14 MUU	/				
		53 Merkkaus		/				
		54 Hionta		/				
		55 Upottaminen		/				
		56 Niittimutterit		/				
9	Aputoimet	91 Siirrot		/				
		92 Käsittely		/				
		93 Pakkaus		/				
		94 Lähetys		/				
		95 Varastointi		/				

HAVAINNOT:

Appendix III

Kokoonpanon numero:	
Kokoonpanon nimi:	

Sarjakoko kpl:	Valmistus alkoi:	Valmis:
	/ .2001 pp.kk.vv	/ .2001 pp.kk.vv

	VAIHE	TYÖN VAIHE	VIRHE	TYÖN-VAIHE/VIRHE	OHJE NO	OHJE KPL	TYÖ-PISTEELTÄ LÄHTI KPL	KOMMENTIT
7	Kokoonpano	**71** Ruuvaaminen	**1** Inhimillinen virhe	/				
		72 Niittaminen	**2** Työstökone	/				
		73 Liimaus	**3** Työkalu	/				
			4 Organisatoorinen virhe	/				
			5 Ulkoinen virhe	/				
			6 Edellinen työnvaihe					
5	Muut työnvaiheet	**51** Kierteytys	**7** Suunnitteluvirhe	/				
		53 Merkkaus	**10** Varastointivirhe	/				
		56 Niittimutterit	**11** Siirtoväline	/				
			12 Nostoväline	/				
			13 Materiaalivirhe	/				
			14 MUU					
9	Aputoimet	**91** Siirrot		/				
		92 Käsittely		/				
		93 Pakkaus		/				
		94 Lähetys		/				
		95 Varastointi		/				

HAVAINNOT:

Appendix IV

OHJE

1 **TYÖNVAIHE/VIRHE**-sarake: Täydennä numerokoodit TYÖNVAIHE ja VIRHE kohdista.

2 Tarkenna virhe **NO**-sarakkeeseen. Numerokoodit alla olevasta listasta. **KPL**-sarakkeeseen virheellisten osien määrä

3 Merkitse sarakkeeseen **TYÖPISTEELTÄ LÄHTI KPL** kuinka monta työkappaletta toimitit eteenpäin

4 Lisää mahdolliset kommentit **KOMMENTIT**-sarakkeeseen

5 Toimita lomake seuraavaan työpisteeseen tuotantoerän yhteydessä !

1 Inhimillinen virhe	11 Työvirhe
	12 Tulkintavirhe
	13 Asetusvirhe
	14 Väärä ohjelma
	15 Väärät piitustukset/ohjeet
	16 MUU, erittele kommenttiriville
2 Työstökone	21 NC-ohjaimen häiriö
	22 Työstökonerikko
	23 Toimintahäiriö, muu kuin työkaluista johtuva
	24 Puutteelisen huollon aiheuttama häiriö
	25 MUU, erittele kommenttiriville
3 Työkalu	31 Työkalurikko
	32 Huollon puutteesta aiheutunut häiriö
	33 Asetusvirhe
	34 MUU, erittele kommenttiriville
4 Organisatoorinen virhe	41 Vanha piirustusrevisio
	42 Vanhat ohjeet
	43 Puutteelliset piirrustukset
	44 Puutteelliset ohjeet
	45 Väärät työmenetelmät
	46 MUU, erittele kommenttiriville
5 Ulkoinen virhe	51 Virheellinen osto-osa
	52 Virheellinen alihankintatyö
	53 Vesivahinko
	54 Luonnonmullistus
	55 MUU, erittele kommenttiriville
6 Edellinen työnvaihe	61 Työvirhe edellisessä työnvaiheessa
	62 Toleranssit ulkona määritellyistä
	63 Käsittelyvirhe edellisessä työnvaiheessa
	64 Ulkoinen virhe edellisessä työnvaiheessa
	65 MUU, erittele kommenttiriville
7 Suunnitteluvirhe	71 Virheellinen suunnitelma
	72 Mahdoton valmistaa nykyisillä menetelmillä
	73 Toiminnallinen virhe
	74 MUU, erittele kommenttiriville
8 Pintakäsittelykylpy	81 Virheellinen kylpy
	82 Likainen kylpy
	83 Väärä lämpötila
	84 Väärä ohjeistus
	85 MUU, erittele kommenttiriville
9 Pintakäsittelylinja	91 Väärä ohjelma
	92 Väärä ripustus
	93 Laitehäiriö
	94 MUU, erittele kommenttiriville
10 Varastointivirhe	101 Kolhuja/naarmuja
	102 Vesivahinko
	103 Luonnonmullistus
	104 Likaa pinnoilla
	105 MUU, erittele kommenttiriville
11 Siirtoväline	111 Laitevika
	112 Ohjeistus
	113 Putoaminen
	114 MUU, erittele kommenttiriville
12 Nostoväline	121 Laitevika
	122 Ohjeistus
	123 Putoaminen
	124 MUU, erittele kommenttiriville
13 Materiaalivirhe	131 Väärä mateeriaalitoimitus
	132 Kosteusvirhe
	133 Kolhuja/naarmuja
	134 MUU, erittele kommenttiriville
14 MUU	141 ERITTELE KOMMENTTIRIVILLE

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