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Applying Six Sigma Statistical Control to Managing Manufacturing

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Abstract

Six Sigma is known as a useful methodology for analyzing production efficiency and establishing statistical control as well as for ideation of process improvements. If a factory decides to implement Six Sigma statistical control at its production site, it will require a thorough plan and preparation. However, little has been written about how to do it step-by-step and how to obtain the most of it for the factory and the business.

In order to create such a clear and practice-based plan for Six Sigma implementation, different theoretical concepts were studied. They included descriptions of manufacturing strategies, of Six Sigma and relevant methodologies as well as Six Sigma tools analyses and the Six Sigma mathematical concept explanation. All these theoretical elements were acquired from different authoritative sources and discussed based on their relevance to the topic.

The above information was then utilized to generate a new Six Sigma implementation plan. The steps of this plan were implemented at a case company in the city of Chelyabinsk, Russia. It was a case study of a specific production line. The study process included quantitative and qualitative data collection with further analysis. The results of this study were: established working tools for statistical control, thorough analysis of the current state of the production line and proposals for improvements.

Hence, the Six Sigma implementation plan was a combination of information acquired from both theoretical and practical research. Although it was tested only at a single industry-specific factory, the plan is supposed to be a general how-to-do scenario for all the companies that want to implement Six Sigma.

In conclusion, Six Sigma is a useful methodology and tool that can significantly improve the control and understanding of a production site as well as create a process where improvement ideas can be generated on a constant basis.

Keywords/tags (subjects)
Six Sigma; Lean Management; TQM; statistical control; managing manufacturing; Manufacturing Strategy

Miscellaneous

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1 Introduction

This chapter describes the nature and motivation of this work, the objectives that the research was trying to reach, the characteristics of the research topics and description of the study company.

1.1 Motivation

Despite being a part of the education curricula in the International Business Program and thus being necessary to write for students, this thesis also represents a rather exploratory interesting and practically significant topic. The overall interest comes from two facts – the topic is rather well discussed in the scientific engineers' community, though for business students and managers that do only administrative tasks, not the engineering ones, this topic is not an easy one to be implemented on ground without a proper preparation. (Tjahjono et al. 2010, 223; Schulte 2016, 5.)

The thesis' idea rose from the researcher's attempts to implement several effectivity analysis concepts from Six Sigma methodology, especially Six Sigma tool, on a factory in Russia. Due to the lack of theoretical knowledge available in common access, these attempts were not very successful. At the same time, though, the practical material gathered during these attempts occurred to be rather promising for a further research. This all was reinforced by discussions with lecturers and specialists in JAMK University of Applied Sciences.

1.2 Research objectives and questions

The research consists of three parts – three main objectives of this thesis work. They are presented below.

1. Explore the topics of Manufacturing Strategy concepts, Six Sigma concepts and statistical control concepts.

2. Elaborate on general guidance on how to use and establish such statistical control tools as Six Sigma tool, Control chart and others using a practical case context.

3. Draw a proper plan for a production manager on how to use the tools of Six Sigma methodology in order to establish Six Sigma statistical control.

Having these three objectives set, it becomes easier to formulate the research questions for this study. These questions are presented below.

1. What Manufacturing Strategy concepts need to be considered on a production line in order to conduct a proper production effectivity analysis?

2. How to use the statistical tools (Six Sigma tool, Pareto diagram, Control chart, Fishbone diagram) of Six Sigma methodology to evaluate the current level of defected products and statistical control at the production line of research?

3. How to get the results from these statistical control tools, how to act on these results and how to define the best strategy for improving these in the future?

1.3 Importance and usability of the study

Results of the thesis can be used both theoretically and practically. There is quite a lot of sources about Six Sigma methodology from the engineering point of view, though not from the business administration side at the moment (Tjahjono et al. 2010, 223). Therefore, additional material aimed at easing managers' understanding of this phenomena could be helpful. This way, the research could be useful not only theoretically for business administration managers and students, but it could also be helpful practically – for implementing statistical control on production lines.

The thesis' findings could help to easier overcome misunderstandings between management departments that have different responsibility areas like product development and manufacturing. According to Boone and Hendriks, lack of information exchange between top managers as well as lack of their qualifications lead to misunderstandings and possible losses. (Boone et al. 2009, 169.)

Moreover, as it will be seen later in this research, many authoritative sources and authors state that Six Sigma methodology and Lean Management methodology represent rather interesting topics for today’s supply chain industry. These methodologies are implemented in many big companies, and the proper knowledge of them is in demand today. (Hopp et al. 2008, 409-414; Tjahjono et al. 2010, 223; Hilton et al. 2012, 54-56.)

1.4 Description of the case company

The study company is called “Heraeus Electro-Nite Chelyabinsk”. “Heraeus Electro-Nite” is a company inside a big technology group called Heraeus Holding with headquarters in Houthalen-Helchteren, Belgium (Heraeus Electro-Nite Locations & Contacts 2018). Its core business products include “components to coordinated material systems which are used in a wide variety of industries, including the steel, electronics, chemical, automotive and telecommunications industries” (Sensors for Molten Metals 2018).

“Heraeus Electro-Nite Chelyabinsk”, in turn, is the company’s branch in a remote industrial city of Chelyabinsk close to Russia-Kazakhstan border. There they produce measuring systems, including immersion probes, recording instruments and auxiliary equipment (Heraeus Electro-Nite Locations & Contacts 2018). The company is not big – it includes around 10 white-collar managers working in sales, accounting, manufacturing management, administration, about 10 people working as middle managers at the production site, and around 20 people working as blue-collar workers. Most of the products at the company are being produced with a fully manual or semi-manual labor, little of the operations is mechanized. Sometimes, the company holds visits of representatives from the headquarters in Belgium. In Russia, “Heraeus Electro-Nite” also has sales representatives in Moscow.

2 Literarure review

Literature review is carried in a classical way of exploring and studying different information sources using multiple ways of acquiring information, such as books and articles available offline in the university libraries and online in electronic university libraries and in the internet.

The first part of the literature review is dedicated to examining different concepts of Manufacturing Strategy. The second part includes the study of some of some relevant logistics methodologies and Six Sigma concept. The third part summarizes previous chapters and includes the ideated Six Sigma statistical control implementation plan.

2.1 Manufacturing Strategy and its concepts

“A company’s business strategy is the sum of the individual strategies of its component functions – manufacturing, marketing, finance, research and development (R&D) and so on” (Miltenburg 2005, 1). This citation describes well what this chapter is going to be about. It is going to be about a one component of a company’s business strategy – about the Manufacturing Strategy.

As any other business function strategy, the Manufacturing Strategy is based on rather obvious questions. It is based on customer requirements, competitive strategy, manufacturing capabilities, opportunities to grow and the outputs of manufacturing that need to be optimized (Miltenburg 2005, 2-3; Lee et al. 2014, 118-119). All these elements are going to be thoroughly discussed in the next subchapters.

Manufacturing Strategy formulation process is an important action, which a company has to consider firmly. According to Lee, Rhee and Oh, correctly established Manufacturing Strategy helps to affect positively the manufacturing-marketing integration, as well as Manufacturing Strategy implementation and a level of plant performance (Lee et al. 2014, 121-130). More than that, Fine and Hax discuss that Manufacturing Strategy affects all business functions and may actually be the most difficult one to plan. They argue, “Manufacturing has to interact with all the remaining managerial functions of the firm in developing integrated business strategies and in monitoring the basic external markets” (Fine et al. 1985, 28-30).

The whole picture of how to define and build a Manufacturing Strategy is presented by Miltenburg in a form of a scheme, and is also added as the first appendix in this research. This model allows to see how the Manufacturing Strategy concepts are implemented in a company by choosing what Manufacturing Strategy concepts are applied in the company and how. It gives a clear and full schematic picture of a company's current Manufacturing Strategy state, and also gives ideas of how this state can be changed.

Knowing the right manufacturing concepts which need to be taken into account on a production site will ease further production development planning and will help in defining what statistical tools to use as well as where to use them.

2.1.1 Competitive Strategy and Network Types

Competitive Strategy is the first step that needs to be clarified in order to proceed with Manufacturing Strategy formulation process. After choosing one of the Competitive Strategies, all other concepts or elements of Manufacturing Strategy will be chosen accordingly. At the same time, these elements are mutually dependent, hence, each aspect affects another and the full answer of which Manufacturing Strategy to choose only comes after identifying all of its elements. (Miltenburg 2005, 6-7.)

The prerequisites and premises for understanding the company's Competitive Strategy are the company's competitive advantage, company's products' competitive advantage, marketing and manufacturing goals and competitive scope (here scope means the range of products' categories a company produces, the distribution channels it uses, the geographic areas and target markets it aims at). (Miltenburg 2005, 12-17.)

According to Chapman, market drivers for the product or service significantly affect design and management of the Competitive Strategy planning. He mentions that there are 4 most important competitors' dimensions, which are price, quality, delivery (speed and reliability of the delivery processes) and flexibility (volume and variety of the products' range). Therefore, these Chapman's customer dimensions may bring several additional competitive issues. For example, Customer Learning (when a competitor offers something better, so a customer starts to expect the same level of service from all other competitors) or Competitor Moves (when competitors decide to concentrate on some specific competitor dimension). Other examples include Multiple Markets (if a company has a product range, then there is a certain need to keep a hand at pulse of each market) or Product Design Changes (when the design of a product changes, a company has to simultaneously adapt to the changes). These things may be rather important to reconsider before choosing a Competitive Strategy as Stephen Chapman mentions, and it might also be important to choose what competitive dimensions are Order Qualifiers (criteria that qualifies a product with competitors) and which are Order Winners (criteria that helps a product bypass the competitors) and where the competitive issues are the least dangerous. (Chapman 2006, 7-10; Miltenburg 2005, 43.)

The choice of Competitive Strategy is also dependent upon aforementioned competitive scope. According to Miltenburg, the two most popular types are narrow and broad, where narrow means Focused Cost strategy or Focused Differentiation strategy (concentrating on a one or several product categories and product characteristics), and broad means Cost Leadership or Differentiation strategies (different product categories and their characteristics). There is also a competitive scope “in the middle”, which is the Best Value strategy (this one is trying to aim at both). (Miltenburg 2005, 16.)

Thus, after identifying the emphasis of a company in terms of competitors’ attitude, it will be possible to choose its strategy. According to Miltenburg, there are 4 main Generic Competitive Strategies: Cost Leadership, Differentiation, Best Value and Focused Cost and Focused Differentiation. Each strategy has its own features and is supposed to be chosen by managers upon company’s marketing aspirations. These 4 strategies and their features are presented in the table below. (Miltenburg 2005. 17-22.)

Table No 1. Features of Generic Competitive Strategies (adapted from Miltenburg 2005, 17)

Feature	**Cost Leadership**	**Differentiation**	**Best Value**	**Focused Cost and Focused Differentiation (Market Niche)**
Competitive advantage	Lower costs than competitors	Ability to offer customers something different from competitors	Better products at same price or same products at lower price	Lower cost than competitors or something different from competitors in a market niche
Competitive Scope	Broad market	Broad market	Value conscious customers	Narrow market where customer needs are distinctively different
Products	Good quality, basic product	Superior products that create value for customers; many product variations	Good product with several upscale features	Features that appeal to needs of customers in market niche
Manufacturing Emphasis	Continuous search for cost reduction without sacrificing quality and essential features	Build features customers are willing to pay for; charge premium price to cover costs of differentiating features	Build product with several upscale features at low cost	Customize product to meet needs of customers in market niche
Marketing Emphasis	Good product at low price	Communicate key differentiating features to create reputation and brand image	Build reputation for value; underprice rival products with comparable features, or match price of rival products and provide better features	Communicate how product features meet special needs of customers in market niche
Strategy Summary	Manage costs down in every area of the business	Consistent improvement in product; use innovation to stay ahead of competitors	Develop capability to simultaneously manage costs down and add new, upscale features	Remain dedicated to serving niche customers better than competitors; do not dilute image by adding products to appeal to broad market

After defining the Competitive Strategy, it is also increasingly important to identify beforehand the type of Manufacturing Network (which is also a type of business model at some point) as it affects the manufacturing characteristics quite a lot. Miltenburg defines 9 types of Manufacturing Networks. (2005, 161-167.)

1. Domestic (operating in a single country),
2. Domestic Export (operating with export orientation) or International (operating while having overseas facilities),
3. Multidomestic (operating with overseas subsidiaries),
4. Multinational (operating with overseas divisions),
5. Global Product (operating with overseas full companies concentrated on several products),
6. Global Function (operating with overseas full companies concentrated on several functions),
7. Global Mixed (mixed Global Function and Global Product),
8. Transnational (having full companies overseas),
9. Keiretsu (Japanese word for a large, vertically integrated group of companies that work together closely).

After understanding the overall Generic Competitive Strategy and Manufacture Network Type, it will be possible to dive deeper into the other elements of Manufacturing Strategy, which are tightly interconnected.

2.1.2 Manufacturing Outputs and Layouts, Production System Types

According to Miltenburg, a factory today may provide 6 main outputs – cost, quality, performance, delivery, flexibility and innovativeness. At the same time, these outputs were partially already mentioned before in this research – Stephen Chapman called only 4 outputs, or competitive dimensions as he called them (price, quality, delivery and flexibility), – this characterizes these outputs mentioned by Miltenburg as purely competitive values. (Miltenburg 2005, 44-51; Chapman 2006, 7-10.)

Continuing the discussion about Manufacturing Outputs, Miltenburg argues that companies today cannot be ideal at each of its outputs – it cannot have the least cost, while giving the best quality and so on. Thus, companies today aim at performing the best at their chosen outputs, and marketing only these outputs. Scarcity of resources requires wiser allocation and wiser approach towards identifying the best company’s Manufacturing Strategy. Each output requires its own share of the resources. The best cost requires cuts in resources used to produce a product; the best quality requires the best extent to which materials and activities conform to specifications and customer expectations. The best performance requires the best extent to which the product’s features outstand other products. The best delivery time and delivery reliability require enough resources allocated to be the best at delivering. The best flexibility requires the best extent to which volumes and characteristics of existing products can be increased or decreased upon market’s demand. The best innovativeness requires the best ability to quickly introduce new products and make significant changes to the existing ones. Therefore, it is impossible to provide all the 6 outputs at the same ideal level, so it is important for a company to determine which outputs are the most important to customers and which will be important in the future. These outputs reflect the customer expectations, thus, meeting and exceeding these expectations will outline the factory’s competitive advantage. Manufacturing Strategy, in turn, specifies the levels at which each Manufacturing Output will be provided and how the factory will accomplish this. (Miltenburg 2005, 44-51.)

Overall, choosing the correct outputs is choosing the correct competitive advantages of a company. Fine and Hax argue that firm’s long-term competitive advantage depends on how it positions its manufacturing skills to its competitors (Fine et al. 1985, 33). According to Wheelwright, in the past, the implicit assumption was that first comes the desired competitive advantage, and only then the Manufacturing Strategy planning tries to fit the desired Manufacturing Outcomes, whereas most of the practical examples show a different picture today. Companies can and should take a more proactive role in Manufacturing Strategy formulation as in the end it may occur to be just a one more competitive advantage of the company (Wheelwright 1984, 88).

Hence, Manufacturing Outputs do help in making a proper competitive analysis and choosing the correct emphasis, which will also help in further identification of the other Manufacturing Strategy elements. There are several concrete measures that can help to understand, which Manufacturing Outputs represent competitive advantage or disadvantage of a company. These outputs and measures are presented in the table below. (Miltenburg 2005, 46-47).

Table No 2. Types of Manufacturing Outputs (adapted from Miltenburg 2005, 47)

Output	**Measures**
Cost	• Unit product cost, unit labor cost, unit material cost • Total manufacturing overhead cost • Inventory turnover – raw material, WIP (work in progress products), finished goods • Capital productivity • Capacity/machine utilization • Materials yield • Direct labor productivity, indirect labor productivity
Quality	• Internal failure cost – scrap and rework, percentage defective or reworked • External failure cost – frequency of failure in the field • Quality of incoming materials from suppliers • Percent defective • Warranty cost as a percentage of sales • Rework cost as a percentage of sales
Performance	• Number of standard features and number of advanced features • Product resale price • Number of engineering changes • Mean time between failures
Delivery	• Quoted delivery time • Percentage of on-time deliveries • Average lateness • Inventory accuracy • Order entry time • Master production schedule performance/stability
Flexibility	• Number of products in the product line • Number of available options • Minimum order size • Average production lot size • Length of frozen schedule • Number of job classifications in the factory • Average volume fluctuations that occur over a time period divided by the capacity limit • Number of parts processed by a group of machines • Ratio of number of parts processed by a group of machines to total number processed by the factory • Number of setups • Variations in key dimensional and metallurgical properties that the equipment can handle • Is it possible to produce parts on different machines?
Innovativeness	• Number of engineering changes orders per year • Number of new products introduced each year • Lead time to design • Lead time to prepare customer drawings • Level of R&D investment • Consistency of R&D investment over time

Choosing the correct Manufacturing Outputs will help in identifying what Production System and what Manufacturing Layout to use, which types are the most appropriate and efficient ones in the current “environment” as Ward and Duray call it; moreover, Swamidass and Newell discuss the same ideas. They all argue that both environmental (manufacturing capabilities and resources) and competitive strategies’ variables should be taken into account when designing a Manufactory Strategy model (Ward et al. 2000, 135; Swamidass et al. 1987, 520-523). Therefore, the choice of Production System type and Manufacturing Layout type is highly dependent upon firm's resources available and advantageous manufacturing outputs.

However, before describing all of the Production Systems and their connections with their attributes, it is also important to understand different Manufacturing Layouts' of these Production Systems. Manufacturing Layouts discussed by Miltenburg are presented in the table below; their graphical representation is also presented in the appendices (see Appendix No 1).

Table No 3. Types of Manufacturing Layouts (adapted from Miltenburg 2005, 54)

Type of the Layout	*Functional Layout*	*Cellular Layout*	*Line Layout*
Short Description	• Similar equipment is grouped together • Flow is extremely varied for each product	• One cell (or department) for each product family • Flow is regular for each product family	• One line for each product or product family • Flow is regular

The particular material flow (or Manufacturing Layout) that a factory has, can easily be determined by walking through the factory. Starting from purchasing dock where the raw material is perceived, going through the production or conversion production lines, and ending at the end product and packaging process lines. (Miltenburg 2005, 53-56.)

Following this, different layouts are more appropriate for different Production Systems. Different Production Systems have different type-corresponding and type-dependent attributes, which are product mix and/or product volume, and Manufacturing Layout. These attributes reflect the Competitive Strategy and Manufacturing Outputs raised by the competitors and required by the customers. Most of the known Production Systems types are presented below. (Miltenburg 2005, 50-52.)

Table No 4. Types of Production Systems (adapted from Miltenburg 2005, 52)

Production System	**Product/Volume**	**Layout/Flow**
Job Shop	Very many products / One or a few of each	Functional layout / Flow extremely varied
Batch Flow	Many Products / Low volumes	Cellular layout / Flow varied with patterns
Operator-paced line flow	Several to many products / Medium volumes	Line layout / Flow mostly regular, paced by operators
Equipment-paced line flow	Several products / High volumes	Line layout / Flow regular, paced by the equipment
Continuous flow	One or a few products / Very high volumes	Line layout / Flow rigid, continuous
Just-in-time (JIT)	Many products / Low to medium volumes	Line layout / Flow mostly regular, paced by operators
Flexible Manufacturing System (FMS)	Very many products / Low volumes	Cellular or line layout / Flow mostly regular, paced by the equipment

These Production System Types are also comfortably presented in the summarized Miltenburg’s scheme (see Appendix No 1). As it can be seen from this scheme, in Products/Volumes and Layout/Material Flow matrix there are two Production System types which outstand from the ordinary chain of other 5 Production Systems. These systems are JIT (Just-In-Time) and FMS (Flexible Manufacturing System). The thing with this outstanding is that these Production Systems are relatively new and they represent a one special category of Production Systems, which Miltenburg calls “Lean” Production Systems. These Production Systems allow producing nearly all of the Manufacturing outputs, which is much bigger than in other Production Systems. Production Systems types mentioned above can be categorized into three groups, presented below. (Miltenburg 2005, 57-59.)

Craft Production: Job shop and Batch flow Production Systems. These are mainly the Production Systems that concentrate on tooling and equipment rather than on volumes and efficiency. Job Shop has a functional layout. Material flow varies by the jobs done in different departments. Batch Flow has either a cellular layout, where products are usually categorized into families and produced in batches. Cellular layout is used when it is more efficient to place different equipment in different departments to produce big categories (or families) of products. (Miltenburg 2005, 57-59.)

Mass Production: Operator-paced line flow, Equipment-paced line flow and Continuous flow Production Systems. These Production Systems are characterized by well-established line flows. Equipment and processes are specialized and arranged into a line to produce a small number of different products or product families. These types of Production Systems are appropriate when product design is stable and products' volume is high enough to efficiently dedicate the whole line to this product or product family. Respectively, the choice between Operator-paced or Equipment-paced line flows depends on the variability and complexity of products being produced. At the same time, Continuous flow Production System is characterized by a more automated, specialized, capital intensive and less flexible material flow. (Miltenburg 2005, 57-59.)

Lean Production: JIT and FMS Production Systems. Just-in-time Production System is a result of JIT methodology, which will be discussed later. This Production System, in turn, is characterized by a linear material flow, production of many products in low or medium volumes and continuous improvement of effectiveness by identifying wastes and compelling itself to waste elimination. As Miltenburg mentions, this Production System is the most difficult to design and operate, but the most efficient one (he gives an example of Toyota company that spent 20 years on designing it, but which is so efficient today). Flexible Manufacturing System is a simple line flow, but which, unlike other production systems, stay unattended most of the time. They usually consist of computer controlled machines and systems, thus they work at the same pace and with the same products. (Miltenburg 2005, 57-64.)

Therefore, identification of the Competitive Strategy and then Manufacturing Outputs leads to the identification of the most suitable and efficient Production System type and Manufacturing Layout. These elements of Manufacturing Strategy, in turn, require taking into account other elements, which are the resources available for manufacture planning or, as John Miltenburg calls them in his book, Manufacturing Levers and Capabilities.

2.1.3 Manufacturing Levers and Capabilities

Each Production System, according to John Miltenburg, includes six main resource types or six main Manufacturing Levers: Human Resources, Organization structure and controls, Sourcing, Production planning and control, process technology and Facilities. These Production Systems' Levers are shown in the table below together with their descriptions.

Table No 5. Manufacturing Levers: Six Subsystems that comprise a Production System (adapted from Miltenburg 2005, 65-67)

Human Resources	• Mix of skilled and unskilled employees • Number of job classifications • Whether employees are multiskilled • Amount of training • Level of supervision • Policy on layoffs • Promotion opportunities • Responsibility and decision making given to employees • Participation of employees in problem solving and improvement activities
Organization Structure and controls	• Whether the Production System is a cost or profit center • Whether the organization structure is flat or hierarchical • Whether the Production System is bureaucratic or entrepreneurial, centralized or decentralized • Relative importance of line and staff • Responsibility and authority at each level of the organization • Measures to evaluate performance of individuals and departments • Who is responsible for quality • How managers are selected • Use of teams
Sourcing	• Amount of vertical integration • Number of suppliers and distributors and their capabilities • Whether supplier and distributor relationships are adversarial or partnerships • Responsibility given to suppliers for design, cost, and quality • Procedure for deciding whether a product will be produced internally or obtained from a supplier
Production planning and control	• Whether systems are centralized or decentralized • Whether a push or pull control system is used • Size of raw material, work-in-progress, and finished goods inventories • How information is gathered and used • When maintenance is done • How to schedule design changes and new products into production
Process technology	• Whether to develop technology internally or purchase it from external sources • Whether technology is new or old • Amount of automation • Whether machines are general purpose or specialized • Whether tooling is low or high volume • Factory layout • Whether layout and technology are static or continuously improving • Quality practices
Facilities	• Whether facilities are large or small • Whether facilities are general purpose or specialized • Location of facilities • Capacity planning • Capabilities of production support departments

According to Miltenburg, aforementioned 6 Manufacturing Levers constitute a Production System – the positions of these levers completely determine which one a company is using now. Miltenburg argues that there are two factors, which may affect how these levers are positioned – top-management's commitment and level of Manufacturing Capability. (Miltenburg 2005, 67-76).

Talking about Manufacturing Capabilities, Hayes and Pisano argue, "Manufacturing Strategy is about creating operating capabilities a company needs for the future" (Hayes et al. 1994, 84-86). Therefore, defining the current capabilities is important, as it will ultimately shape the future results.

Miltenburg defines 4 overall levels of Manufacturing Capabilities at the factories: Infant, Average, Adult and World Class.

1. Infant: Production System barely contributes to the company's success; manufacturing is low-tech and unskilled.
2. Average: Production System keeps up with competitors and maintains the status quo; manufacturing consists of standard, routine activities.
3. Adult: Production System provides market qualifying and order winning outputs at target levels; manufacturing decisions are consistent with manufacturing strategy.
4. World Class: Production System tries to be the best in the industry in each activity in each Manufacturing Lever; Production System is an important source of competitive advantage.

Therefore, top-management needs to take into account many different things when desiring to make a development change, but especially closely managers should look at what Manufacturing Levers they want to change and what Manufacturing Capabilities they have at their disposal. Manufacturing Strategy is thus a way to match internal capabilities with the external ones. (Miltenburg 2005, 80-82.)

2.1.4 Manufacturing Strategy concepts summary

As mentioned before, the interaction of all the elements of Manufacturing Strategy can easily be seen in the Miltenburg's Manufacturing Strategy Worksheet for a Factory (the first Appendix in this research). This sheet shows how tightly each element affects and depends on each other – Manufacturing Outputs on Manufacturing Capabilities, Manufacturing Capabilities on Manufacturing Levers, Manufacturing Levers on Production System, Production System on Manufacturing Layout, Manufacturing Layout on Manufacturing Outputs and vice versa idem.

This is though only a theoretical framework and will be tested in real circumstances in future chapters of this research. At the same time, before coming to the testing part, it is also important to define how testing should be done. Nearly every literature source used in this research was arguing that, in order to conduct a proper development planning, it is necessary to have proper statistical, data-gathering tools in place. Chapman in his book “The Fundamentals of Production Planning and Control” says that “business needs information, systems, and actions required to monitor, prioritize, and control the actions”. Miltenburg argues that there should always be a sequence, in which improvements should be made: “First, manufacturing is focused, then soft technologies are used to improve the focused operations, and finally, hard technologies are added” (where focused manufacturing means a well-defined Production System that produces most, or all, products in a product family; soft technologies are the technologies that improve manufacturing structure only with some methodologies and techniques; and hard technologies are the equipment or computer technologies). Hopp and Spearman argue that manufacturing is a science and, therefore, “to develop a science of manufacturing that enables us to identify and prioritize improvement policies, we must (a) understand the relationships between three buffers and variability, (b) translate this understanding into detailed operational policies. This requires the use of models” (in this citation, the three buffers mean Inventory, Time and Capacity buffers or the three types of resources). (Chapman 2006, 179-180; Miltenburg 2005, 43, 269-291; Hopp et al. 2008, 213.)

Therefore, there will also be an overview of several statistical control methodologies, which could be the best ones for development processes at the production lines. Particularly, the research will concentrate on Six Sigma methodology and its corresponding statistical tools.

Manufacturing Strategy concepts raised in this chapter will be discussed further and applied to the case company during the study part of this research.

2.2 Statistical Control tools to use at a production line

According to Slone, Mentzer, and Dittmann, “powerful process tools such as Lean and Six Sigma are now being applied to the entire supply chain”. These words show how important Six Sigma concept is today. Although, before discussing this concept in a more detail, it is worthy to define what people mean when they say Six Sigma (Slone et al. 2007, 6.)

Six Sigma doesn’t only represent a one specific tool. In turn, it is rather a methodology (which is often called DMAIC) that provides a guidance of which tools to use at which stage. Using this methodology on a production line, a one will be able to act in three improvement directions: setting and adjusting proper control tools for the current processes, development of the current process flows and projecting of the new processes. (Hopp et al. 2007, 171-172.)

2.2.1 Six Sigma methodology

Six Sigma was first introduced by engineers of Motorola, namely Bill Smith and Mikel Harry in 1986. Motorola made the concept its own trademark as it occurred to be rather popular and efficient. General Electric and several other big companies decided to implement it and improved their effectiveness. For example, in 1996-1999 GE reported annual savings of around 1-2 USD billion per year, and Motorola itself attributed over 17 USD billion in 11 years. (Hopp et al. 2008, 176-181; Harry 1998, 62-64; Kwak 2006, 711.)

The idea of Six Sigma is in seeking to improve the quality of process’ output by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes. Some researchers say that Six Sigma implies implementation of TQM and SQC methodologies, but with a stronger customer focus, implementation of additional data analysis tools, improvement of financial results and proper project management. According to Nakhai and Neves, “Six Sigma is not just a way of measuring the level of quality, it is a way of determining weaknesses; where the organization could do better; and how to serve the customer better”. (Kwak 2006, 711; Nakhai et al. 2009, 667-675; Hopp et al. 2008, 401-405.)

The term Six Sigma comes from statistics. Originally, it referred to the ability of manufacturing processes to produce a very high proportion of output within a specification. Processes that operate with six sigma quality over the short period of time are assumed to produce long-term defect levels below 3.4 defects per million opportunities (DPMO). Six Sigma's implicit goal is to improve all the processes, though it is not necessary to achieve 3.4 DPMO level. Organizations need to determine an appropriate sigma level for each of their most important processes and strive to achieve these levels. (Hopp et al. 2008, 409-414.)

Six Sigma projects follow two Methodologies, which bear the acronyms DMAIC and DMADV. DMAIC is used for projects aimed at improving existing business processes. DMADV is used for projects aimed at creating new products or process designs.

The DMAIC methodology has five phases:

- Define the process to be improved;
- Measure current performance;
- Analyze when, where, and why defects occur;
- Improve the process by eliminating defects;
- Control future process performance.

The DMADV methodology, in turn, also features five phases:

- Define the goals of the project;
- Measure and determine customer needs and specifications;
- Analyze the process options to meet the customer needs;
- Design the process to meet customer needs;
- Verify the design performance in terms of its ability to meet customer needs.

The International Organization for Standardization (ISO) has published in 2011 the standard called "ISO 13053" where they defined a Six Sigma process. The introduction to this standard is mentioned below, it gives a better picture of what Six Sigma is supposed to mean.

> *The purpose of Six Sigma is to bring about improved business and quality performance and to deliver improved profit by addressing serious business issues that may have existed for a long time. The driving force behind the approach is for organizations to be competitive and to eliminate errors and waste. A number of Six Sigma projects are about the reduction of losses. Some organizations require their staff to engage with Six Sigma and demand that their suppliers do as well. The approach is project based and focuses on strategic business aims.*
>
> *There is little that is new within Six Sigma from the point of view of the tools and techniques utilized. The method uses statistical tools, among others, and therefore deals with uncertain events in order to provide decisions that are based on uncertainty. Consequently, it is considered to be good practice that a Six Sigma general program is synchronized with risk management plans and defect prevention activities.*
>
> *A difference, from what may have gone before with quality initiatives, is every project, before it can begin, must have a sound business case. Six Sigma speaks the language of business (value measurement throughout the project), and its philosophy is to improve customer satisfaction by the elimination and prevention of defects and, as a result, to increase business profitability.*
>
> *Another difference is the infrastructure. The creation of roles, and the responsibilities that go with them, gives the method an infrastructure that is robust. The demand that all projects require a proper business case, the common manner by which all projects become vetted, the clearly defined methodology (DMAIC) that all*

> *projects follow, provides further elements of the infrastructure. (SFS 13053-1, 2014, 7).*

Taking Six Sigma in use can also include personnel management changes. As stated by the Finnish Standard Association, “An organization seeking to implement Six Sigma should consider the following roles and whether they are applicable to its implementation. Some roles may need to be assigned full time occupation depending upon the size of the organization and the complexity of the projects” (SFS 13053-1, 2014, 26). However, this research will not include a broader description of this concept as its core is in statistical control, not management of personnel.

2.2.2 Explanation of Six Sigma tool

After getting acquainted with the mathematical part of Six Sigma tool, which is discussed below, it becomes clear how to use the graphs of Six Sigma using several formulas and tools in Excel. Excel is chosen as a calculation and graph buildings tool according to its simplicity and availability, moreover it is a convenient tool since most of the managers at the case study factory know how to use it and/or use it in their daily operations.

To give a fuller picture about Six Sigma tool, below is the Six Sigma comparison graph with the random data of defected products.

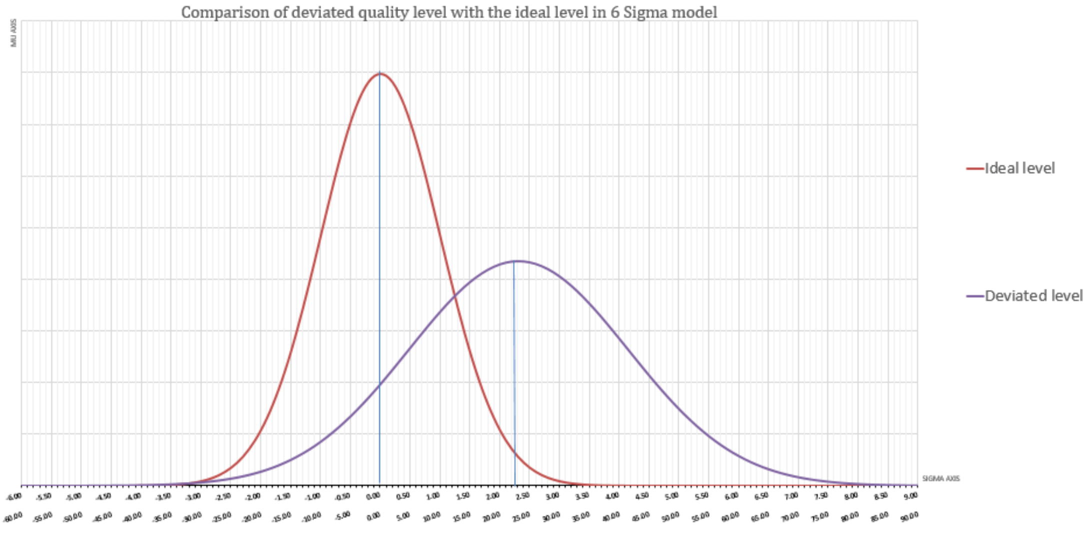


Figure No 1. Six Sigma comparison graph

The graph of the ideal Six Sigma level (the reddish graph above) implies that in its center (that is, from the Sigma axis up to the peak of the ideal graph) there is a straight line (the blue one), which indicates the average value of the selected array of values for an ideal situation. In case of the ideal graph, an average value is *0.00034.* The purple graph is the deviated Six Sigma level (with a big amount of defected products), therefore its average value is much bigger than the ideal one. (according to the Six Sigma mathematical theory). (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487.)

This σ sign (sigma from Greek alphabet) comes from the probability equations and calculations. When performing practical calculations for the deviation unit of a random variable subject to the normal law of mathematical expectation, the standard deviation σ is taken. Then, using the formula for the probability of falling of values of a random variable in a given interval, it is possible to obtain some useful equations in the calculations (Formulas No 1-3). (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487.)

$$P\ (-\sigma<x<\sigma) = \Phi\ (1/\sqrt{2}) = 0{,}683 \tag{1}$$

$$P\ (-2\sigma<x<2\sigma) = \Phi\ (\sqrt{2}) = 0{,}954 \tag{2}$$

$$P\ (-3\sigma<x<3\sigma) = \Phi\ (3/\sqrt{2}) = 0{,}997 \tag{3}$$

These results are shown geometrically in the Figure No 2.

Thus, according to this formula, it is almost certain that the random variable (error) will not deviate from the mathematical expectation in absolute value by more than 3σ. This assumption is called the rule of Three Sigma. (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487.)

When processing various statistical materials, it is useful to know the probability of random variable X to hit the intervals *(0, E), (E, 2E), (2E, 3E), (3E, 4E), (4E, 5E)* (as shown on the Figure No 2). Using the same formula, it becomes possible to calculate the probabilities of various events and analyze the phenomena. Formulas of calculating probabilities falling into different intervals are shown below (Formulas No 4-8). (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487.)

$$P\,(0<x<E) = \tfrac{1}{2}\,\Phi\,(1) = 0{,}2500 \tag{4}$$

$$P\,(E<x<2E) = \tfrac{1}{2}\,[\Phi\,(2) - \Phi\,(1)] = 0{,}1613 \tag{5}$$

$$P^*(2E<x<3E) = \tfrac{1}{2}\,[\Phi\,(3) - \Phi\,(2)] = 0{,}0672 \tag{6}$$

$$P^*(3E<x<4E) = \tfrac{1}{2}\,[\Phi\,(4) - \Phi\,(3)] = 0{,}0180 \tag{7}$$

$$P^*(4E<x<\infty) = \tfrac{1}{2}\,[\Phi\,(\infty) - \Phi\,(4)] = \tfrac{1}{2}\,(1 - 0{,}9930) = 0{,}0035 \tag{8}$$

The results of the calculations in the Formulas No 4-8 can also be easily put on the graph – they represent smaller dimensions of the dispersion areas calculated in the Formulas No 1-3. The graph is shown below, it can also be called Error Dispersion Scale. (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487; Mukhin, lection 25.)

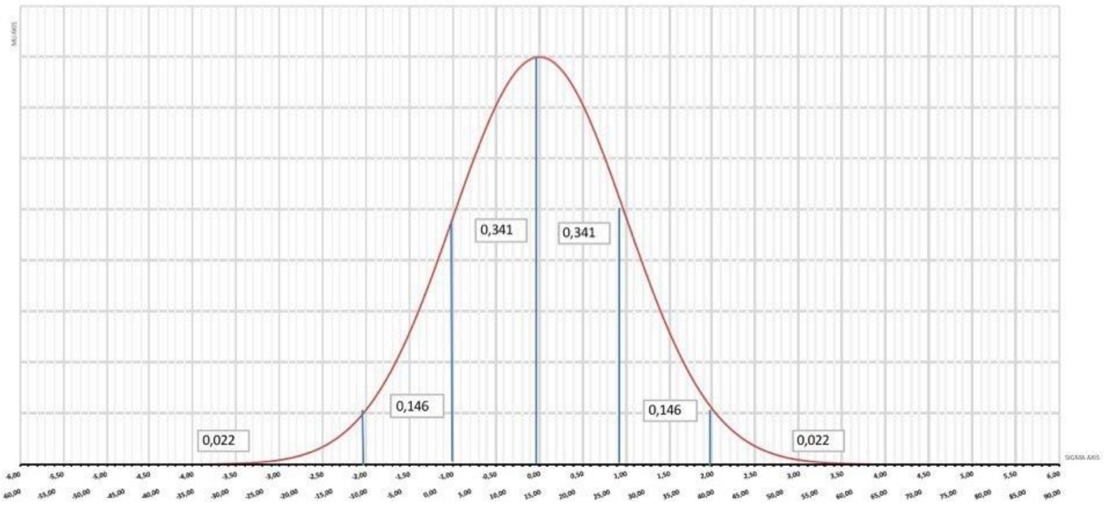


Figure No 2. Error Dispersion Scale

From all these calculations it becomes clear that it is almost certain that the value of the random variable calculated with the Three Sigma rule's formulas falls within the interval *(-4E, 4E)*. The probability that the value of a random variable falls outside this interval is less than *0.01*. (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487.)

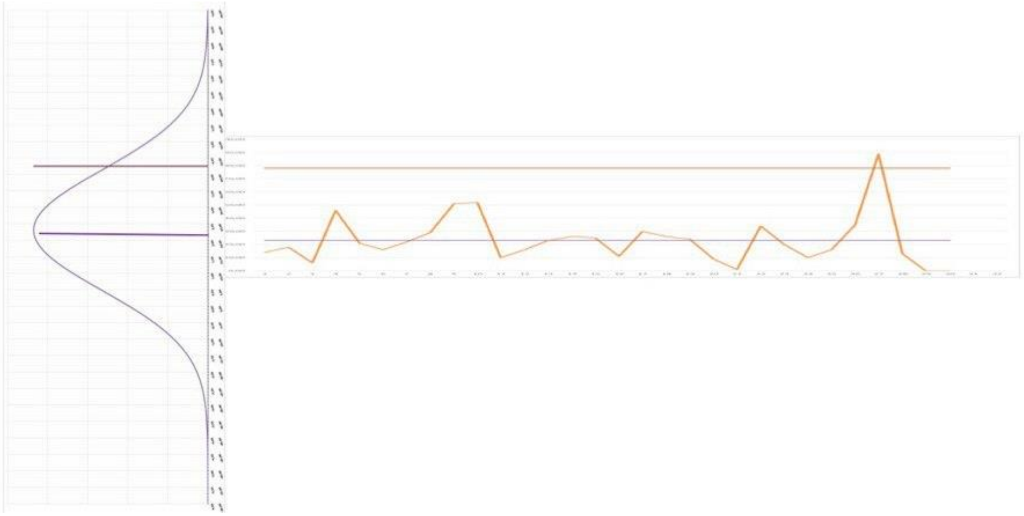


Figure No 3. Six Sigma graph combined with a Control Chart graph

According to Figure No 3, it is possible to see that, in theory, the graph of Six Sigma is simply the continuation of another graph – the Control Chart graph, which simply includes the number of mean value of defected products per a period of time (purple line on the right figure), the calculated upper and lower levels (upper level is a brown straight line on the right figure) and the graph of defected products of every day in a specific period of time (orange fluctuating line on the right figure). That is why Six Sigma graph has a line of mean value (which goes in the middle (on the left figure a dark purple straight line)), upper/lower limits (which go on the sides) (on the left figure – brown line is the upper limit) and the parabola line itself, which includes the area of probable product *X* falls (light purple parabola line which reflects to the orange fluctuating line on the right). (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487; Mukhin, lection 25.)

In turn, the change in the normal distribution parameter *mx* (that is, the change in the mean value) leads to a shift of the curve along the *x*-axis (see Figure No 4). (Hopp et al. 2008, 405-41; Piskunov 1985, 460-4872; Mukhin, lection 25.)

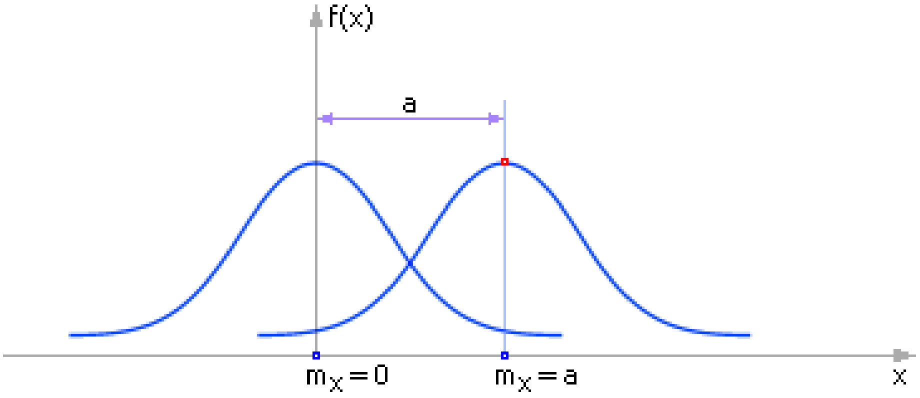


Figure No 4. Six Sigma graph shift (adapted from Mukhin, lection 25)

The less random the process, the less is its standard deviation, the higher the “bell”, or parabola line, on the graph. The change in the normal distribution parameter *σx* leads to the scaling of the shape (see Figure No 5) along the x axis. What is important to mention, is that in any case, always the area under the probability density curve is unchanged and equal to 1 (100 percent). (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487; Mukhin, lection 25.)

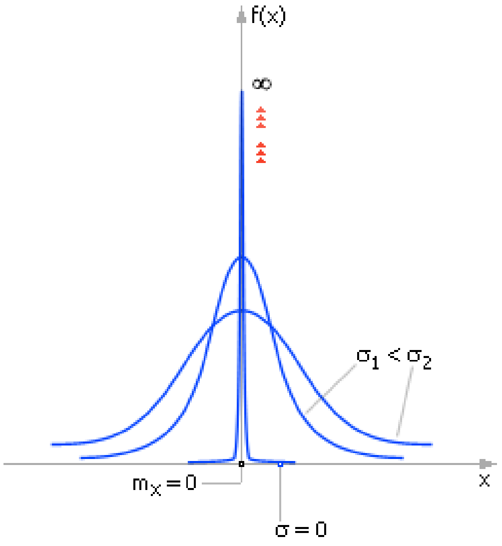


Figure No 5. Six Sigma graph shaping along the *Y* axis with the change of the normal distribution parameter *σx* (adapted from Mukhin, lection 25)

And again, the less random the process, the less is its standard deviation, the higher the bell on the graph. Indeed, the randomness spread relative to the mathematical expectation is becoming increasingly minimal. In the limit, the deterministic process has the form shown in Figure Number 6. (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487; Mukhin, lection 25.)

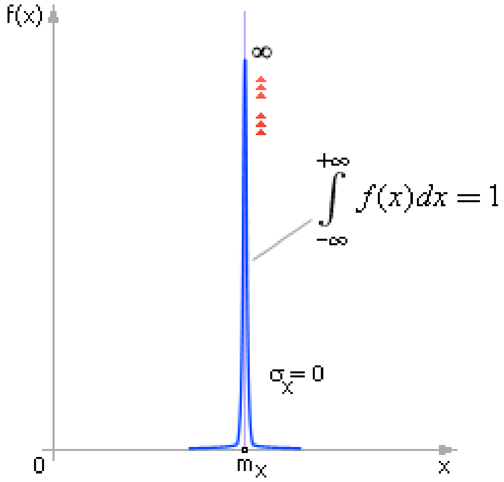


Figure No 6. Six Sigma with a deterministic process shape (adapted from Mukhin, lection 25)

It is easier to study deterministic processes than stochastic proceses. The larger the value of *σx*, the less regular is the behavior of the object studied, since any values of the parameters characterizing it are possible and the spread of the quantities relative to the average expected increases accordingly. Forecasting and controlling the behavior of the object in this case is difficult. (Hopp et al. 2008, 405-412; Piskunov 1985, 460-487; Mukhin, lection 25.)

There is also a one important, though rather contentious thing, namely 1.5 sigma shift. The problem of this phenomena is that the calculated "sigma levels" of some process reflect only short-term, not the long-term performance. Therefore, according to Six Sigma theory, there is needed a so-called “standard error of estimate”, as, for example, Praveen Gupta mentions in his article. He mentions that “sample averages tend to follow a normal distribution irrespective of the distribution of the population… Thus, larger sample size means will be close to one another. In other words, sample-to-sample variation will be less. That’s why sample size matters”. (Gupta 2006.)

More than that, famous Six Sigma researchers Harry and Schroeder, mention in their book the following.

> *By offsetting normal distribution by a 1.5 standard deviation on either side, the adjustment takes into account what happens to every process over many cycles of manufacturing. … Simply put, accommodating shift and drift is our 'fudge factor,' or a way to allow for unexpected errors or movement over time. Using 1.5 sigma as a standard deviation gives us a strong advantage in improving quality not only in industrial process and designs, but in commercial processes as well. It allows us to design products and services that are relatively impervious, or 'robust,' to natural, unavoidable sources of variation in processes, components, and materials. (Harry et al. 2000, 240)*

In any case, Finnish Standard Association state in their description of the standard that it is possible to calculate the Sigma level even with this 1.5 shift. "Sigma score of 6 is actually 4.5 standard deviations from the mean value. Therefore, to determine the proportion of the distribution remaining in the tail of the distribution, z is 4.5, using a standardized normal distribution" (SFS 13053-1, 2014, 23). Hence there will be some formulas needed to calculate the correct level of Sigma.

The formula used to calculate the DPMO is presented below (Formula No 9). (SFS 13053-1, 2014, 21-23).

$$DPMO = 1{,}000{,}000 * (1 - \varphi*(level-1.5)) \qquad (9)$$

The formula can be used to calculate the DPMO by calculating other variables as well. This all can be seen in the table below.

Table No 6. Sigma Levels Calculation with a Formula No 9 with random numbers (adapted from SFS 13053-1, 2014, 21-23)

6 Sigma Calulator for a quality control on Production Lines 1 and 2					
Primary data (November 2017)					
Details made	375080	Production Line 1	183695	Production Line 2	191385
Defected details	693	Production Line 1	301	Production Line 2	392
Results					
Percent of defected	0,18476058441%	Number of Defected Products per Million Opportunities	1847,6		
Percent of good details	99,82 %	Number of defected details per transportation box (there are 1500 details in a transportation box)	2,77		
6 Sigma level for a short period	2,90307243				
6 Sigma level for a long period	**4,403072427**				

The calculated result can be used to compare it with the standards given by the Finnish Standard Association (SFS 13053-1, 2014, 21-23).

Table No 7. DPMO Calculations with a Formula No 9 (adapted from SFS 13053-1, 2014, 21-23)

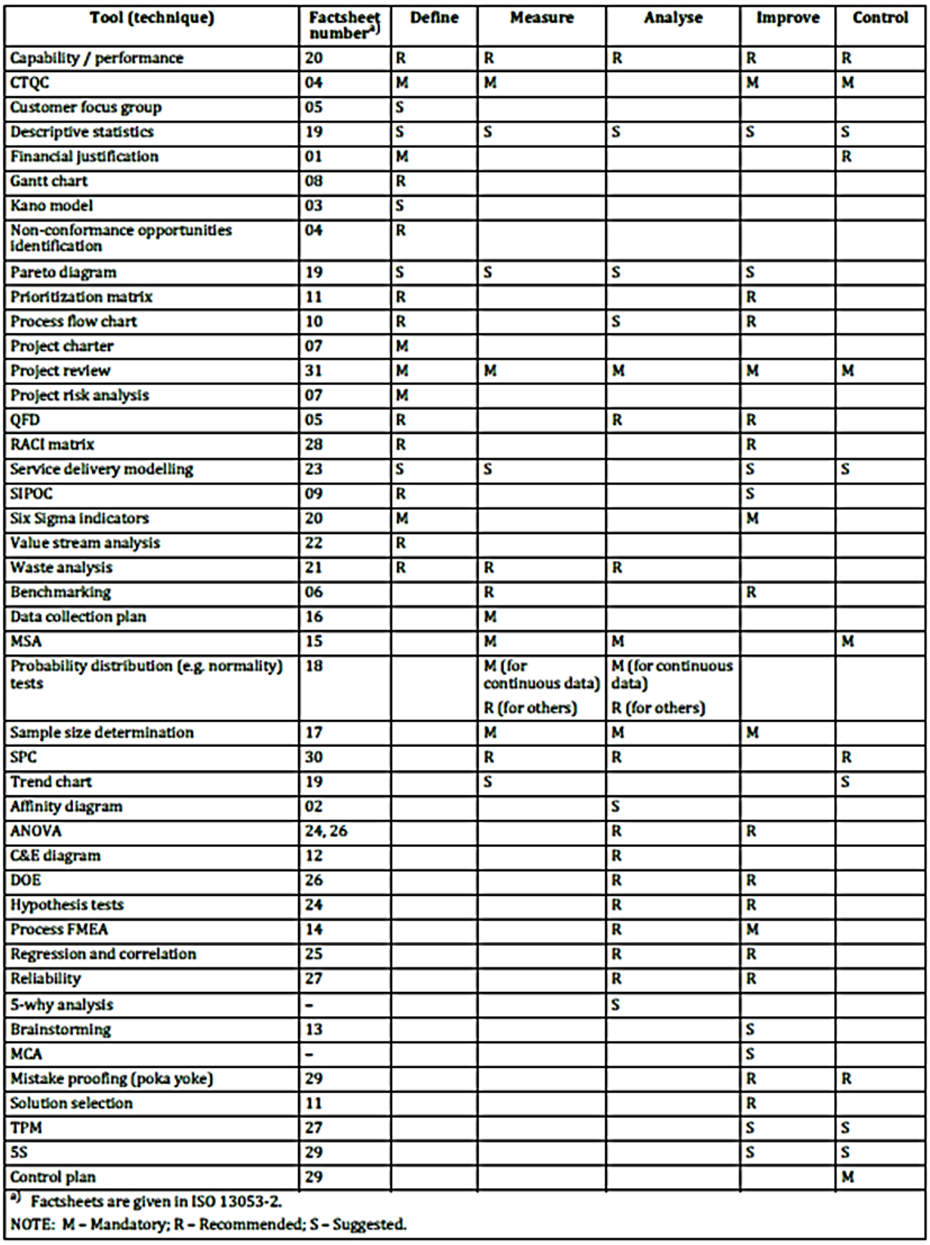
Under the concept of 6 Sigma for a long period			
Sigma number	**Defected product per million opportunities**	**Percent of defected products**	**Quality level**
6σ	3,4	0,00034%	Ideal level
5σ	233	0,023%	World Class level
4σ	6210	0,62 %	Satisfactory level
3σ	66 807	6,68 %	Poor level
2σ	308 537	30,9%	Unsatisfactory level
1σ	691 462	69,1%	

This includes a more-or-less full implementation of Six Sigma. At the same time, this research is aimed at implementing a proper statistical control using different methods, thus, other tools will also be described.

2.2.3 Other analysis tools to use with Six Sigma

Within the individual phases of a DMAIC or DMADV project, Six Sigma utilizes many established quality-management tools that are also used outside Six Sigma. The following table shows an overview of the main methods used, as mentioned by Finnish Standard Association.

Table No 8. Typical Six Sigma tools and techniques mentioned in the ISO 13053 (adapted from SFS 13053-1, 2014, 53)



Tool (technique)	Factsheet number[a)]	Define	Measure	Analyse	Improve	Control
Capability / performance	20	R	R	R	R	R
CTQC	04	M	M		M	M
Customer focus group	05	S				
Descriptive statistics	19	S	S	S	S	S
Financial justification	01	M				R
Gantt chart	08	R				
Kano model	03	S				
Non-conformance opportunities identification	04	R				
Pareto diagram	19	S	S	S	S	
Prioritization matrix	11	R			R	
Process flow chart	10	R		S	R	
Project charter	07	M				
Project review	31	M	M	M	M	M
Project risk analysis	07	M				
QFD	05	R		R	R	
RACI matrix	28	R			R	
Service delivery modelling	23	S	S		S	S
SIPOC	09	R			S	
Six Sigma indicators	20	M			M	
Value stream analysis	22	R				
Waste analysis	21	R	R	R		
Benchmarking	06		R		R	
Data collection plan	16		M			
MSA	15		M	M		M
Probability distribution (e.g. normality) tests	18		M (for continuous data) R (for others)	M (for continuous data) R (for others)		
Sample size determination	17		M	M	M	
SPC	30		R	R		R
Trend chart	19		S			S
Affinity diagram	02			S		
ANOVA	24, 26			R	R	
C&E diagram	12			R		
DOE	26			R	R	
Hypothesis tests	24			R	R	
Process FMEA	14			R	M	
Regression and correlation	25			R	R	
Reliability	27			R	R	
5-why analysis	-			S		
Brainstorming	13				S	
MCA	-				S	
Mistake proofing (poka yoke)	29				R	R
Solution selection	11				R	
TPM	27				S	S
5S	29				S	S
Control plan	29					M

[a)] Factsheets are given in ISO 13053-2.

NOTE: M – Mandatory; R – Recommended; S – Suggested.

According to the table above, Finnish Standard Association suggest that there are tools and techniques, some of which are mandatory to use, some of which are only recommended to be used, and some which are just suggested. Moreover, this comes differently on different stages of DMAIC/DMADV cycle. Out of all, there are 5 tools, which are mandatory at most of the stages, and 9, which are recommended at many stages. Such mandatory tools include: CTQC diagram, Project Review, Six Sigma Indicators, MSA, and Sample Size Determination. At many stages, Finnish Standards Association recommends to use the following tools: Capability/Performance analysis, Gantt chart, Prioritization matrix, Process flow chart, QFD method, RACI matrix, Waste analysis, Benchmarking, SPC, Control chart, Pareto diagram, PDPC method, FMEA analysis.

These tools can complement the realization of each phase of DMAIC process. At the same time the Finnish Standard Association mentions that these tools can be easily “applicable to any sector of activity and any size business seeking to gain a competitive advantage”, therefore, it is up to a concrete case, which tools are going to be used at which stage and how (SFS 13053-2, 2014, 11).

This research, in turn, concentrates only on several Six Sigma tools as suggested by the Finnish Standard Association. It will include (listed in order of implementation):

1) Six Sigma Indicators,
2) Sample Size Determination,
3) Control chart,
4) MSA (Measurement System Analysis),
5) CTQC (Critical To Quality Characteristics) Diagram,
6) Pareto diagram,
7) Fishbone (Isikawa) diagram.

This choice of methods is based on relative simplicity of implementation of the chosen ones and existing time and effort constraints for the research. The choice was influenced mainly by Finnish Standard Association, but also by other sources presented in this research as well as by the researcher’s own experience. Specifically, there is one tool, that wasn’t listed by Finnish Standard Association – namely Fishbone or Isikawa diagram. During the study process, factory managers suggested to use it for analysis, and it seemed very useful, therefore, this study includes this tool. In any case, the choice is subjective and individual and may be widened.

2.2.4 Six Sigma concept summary

Six Sigma is a methodology that implies application of several statistical measurement and analysis tools in a certain order. This research uses the following tools: Six Sigma tool, Control chart, Pareto diagram, Six Sigma Indicators, Sample Size Determination, MSA, CTQC, Pareto diagram, Fishbone diagram. The order of Six Sigma methodology application is summarized in DMAIC cycle.

Correctly established Six Sigma statistical control can significantly improve company’s understanding of defectiveness rate in its production, which, in turn, can lead to big financial wins.

The overall Six Sigma statistical control implementation plan will be ideated in the Results chapter of this research.

3 Empirical study

3.1 Study approach and methodological choices

After having the literature review done it is important to prove the “theory in practice”. Moreover, it is very interesting to try and improve statistical control of the production line of study.

The methodology used in this study is based on the pragmatism research philosophy because, firstly, external view is chosen to answer the research questions, secondly, focus of the research is on practical applied study with different perspectives to help interpret the data, thirdly, this research adopts both subjective and objective points of view, and finally, it uses multiple research methods. The research has inductive approach because in the results chapter there will first be presented the ideated Six Sigma implementation plan, which is tested later on during the single case study. Single case study is used because it seems to be the most convenient and efficient way to prove the theory in practice. This is so because the researcher has agreements with the study case company and because single case study will also show right away whether Six Sigma implementation works or not. This single case study is mixed with action research strategies and is based on the triangulation of different data collection techniques, thus, the acquired data is supposed to give a cross-sectional picture. (Saunders et al. 2009, 108-148; Denscombe 2005, 6-39.)

There are, again, three main objectives in this research. Each objective is questioned and discussed from two points of view – theoretical (literature review chapters) and practical (empirical study and results chapters). There is given text and numerical data derived from different information sources, as well as empirical data derived by the empirical study itself.

In these circumstances, triangulation of methods is used during the study. Both qualitative and quantitative data are studied and analyzed. These data are acquired by semi-structured interviews from non-numerical side, and numerical data is used from primary observations of researcher as a complete participant in action. Interviews are conducted with face-to-face discussions (with the workers of the case study factory related to the production line of study), other data is derived from analysis of documents and observation. Moreover, systematic sampling is used in order to get the best data (systematic sampling of the products manufactured at the production line of study). (Saunders et al. 2009, 108-141; Denscombe 2005, 6-39.)

These methods are the most convenient to use in this research. Moreover, they seem to be the most valid, as they answer the research questions well. They are also the easiest ones to do for this relatively short, light and inexpensive research. The research is of a such “light” nature because that’s what the researcher himself is able to do and what the primary idea of this research is – to see how this Six Sigma methodology works.

3.2 Study design for ethicality, validity and reliability

The study took place at the factory, which was chosen so because, firstly, the managers of this factory have granted the researcher access to their data and inner environment, and secondly, because this factory represents a special interest for this research as it now requires some changes and improvements, according to what managers of the factory said back then.

The researcher signed the Thesis Agreement with this factory. In its end result, the thesis doesn’t include any confidential data, and any sensitive data of the company was changed without harming the study’s findings. These actions ensured that thesis is ethically correct.

This research is also supposed to have objective and unbiased study process, where the results and conclusions generated are not specifically chosen to highlight some presumed point of view. This study can appear to both prove the efficiency and usefulness of Six Sigma implementation at the production site, and it can also disprove it. The researcher doesn’t have any presumptions or hidden aims other than declared here.

Validity and reliability of this paper shall be ensured by the wide range of sources used, and by thorough supervision by the study factory’s managers. Validity and reliability will be discussed in a more depth later in the discussions part of this research, where the research itself will be evaluated on these criteria.

3.3 Limitations

This study has several limitations, specifically at data gathering stage. Due to the lack of resources, the Six Sigma plan ideated in the end of the literature review part was not implemented fully as there were time constraints for data gathering and data analysis, whereas proper Six Sigma plan implementation required a bigger amount of time and effort.

Concretely, the study phase of this research only took several months and the findings of the Six Sigma statistical control plan weren’t implemented. The research only tested whether the ideated plan helps in analysis of the data and finding the root causes of ineffective production process. The research concentrates only on how to establish proper statistical control, how to perceive the results of it by the administration managers, and how to suggest developments based on that. Therefore, this study will not include the Check phase.

3.4 Description of the implementation

The empirical study for this company took place in December 2016. Back then management of the company wanted to update its production processes by heading in a direction of two methodologies – Lean Management and Six Sigma. The factory ended up at having two researchers, where one was concentrated on Lean Management methodology implementation, and another was concentrated on Six Sigma methodology implementation. Consequently, this research is about the latter one.

The management asked to implement Six Sigma statistical control on a single production line. This was completed in March 2017. Thus, overall, the study for this company was done in several steps, mentioned below.

1) December 2016 – Define and Measure phases (done at the factory in Chelyabinsk);
2) January-March 2017 – Analyze and Suggest phases (done remotely by the researcher);
3) October 2017-August 2018 – Writing the research paper.

Therefore, with having a firm plan and literature review, it is now easier to get the correct perception of what the implementation part is about, as well as what results it brings.

4 Results

4.1 Ideated plan for Six Sigma implementation

Literature review phase, and the previous researcher's experience in trials to establish proper Six Sigma statistical control showed that there are several concrete phases, which shall be followed during the study process on the factory. These phases recall the DMAIC cycle – Define, Measure, Analyze, Implement, Control. Below is the answer for the third objective of this research paper – to conclude and draw a proper plan on how to implement Six Sigma statistical control.

First of all, what is needed is to understand the problem that needs to be solved and the main idea of the process that is to be analyzed, and then represent it as fully as possible – visually if needed. Then study the production line of research – look after its problems, find its good sides and bad sides, visualize it if needed. This can be called Define Phase from DMAIC cycle.

Next is the Measure Phase. For Six Sigma statistical control, this includes finding the two measures – number of all products produced at the line, and number of defected products produced. A researcher will need to see where these defected products come from, at which moment of the production process they arise, if these numbers are representative and correct.

The third phase is to analyze the findings (Analyze phase). Using the acquired data, the researcher will need to use the Six Sigma statistical control tools. He will need to create the charts and visualize the data in order to be able to see the patterns, similarities and differences. After finding any interesting peculiarities in statistical part, the researcher will need to make a different analysis – he will need to try and see any patterns between the statistical peculiarities and the company's Manufacturing Strategy. This will, in turn, require a thorough and complete understanding of the Manufacturing Strategy's concepts presented at the company. As mentioned in the Literature review, it includes several "sub-stages" presented below.

1) Get to know the Competitive Strategy and the Network type of a company. This can be done by understanding what core values and type of network a company has.

2) Define the Manufacturing Outputs and Layouts, or in a broader view, define the company's Production System type. This can be done by simply going through the production lines and drawing a way a product fulfils from the raw material phase to the end product phase.

3) Get to know the Manufacturing Capabilities and Levers of a company. Manufacturing Levers described and answered well as they give a broad picture of what potential a company already has for establishing Six Sigma statistical control. After that, defining a type of Manufacturing

Capabilities a company has is simply a process of concluding all the gathered information about the Manufacturing Strategy into one type.

The fourth phase includes making the conclusions. After finding the patterns between data and Manufacturing Strategy, some suggestions concerning improvement of the situation (if needed) shall be in place, as well as analysis of how well is the production operating now. These suggestions should be gathered well and ideated into a step-by-step plan. This phase can also include the implementation part right away, so this can be called Suggest changes phase (similar to Implement phase) in DMAIC cycle.

Making a concluded Six Sigma statistical control plan that is used in this research work, it shall look as following.

1) Define phase. Get the idea of the study problem, also define the process flow, its circumstances and peculiarities. Done at the place.

2) Measure phase. Get and structure the correct data, summarize it and make it look cohesive. Done at the place.

3) Analyze phase. Make the quantitative analysis – analyze patterns in the gathered data. Make the qualitative analysis – analyze correlations between data patterns and the Manufacturing Strategy used in the company. Can be done remotely.

4) Suggest changes phase. Make fair and evidence-based ideas for improvements. Suggest them to management. Can be done remotely.

Therefore, this plan is more like a DMAS (Define, Measure, Analyze, Suggest) and isn’t a real DMAIC or Six Sigma implementation. DMAS is a lighter version for testing and learning. The real plan would include Implement and Check phases (instead of Suggest phase), where real changes are made and evaluated again with DMAIC circle. This is done due to time and financial constraints of the research.

4.2 Define phase

The Define phase was done using some simple observation methods. Firstly, the company’s management defined the production line of study. This line was producing metal sensors by gluing the prefabricated plastic tubes and prefabricated metal sensors. These details were supplied to the company by their partners, stored close to the factory and then delivered to the production line. The end product is presented on the picture below.

Figure No 7. Metal sensor produced at the study line (this stick is 50-60 cm long) (adapted from Sensors for Molten Metals 2018)

After gluing, the end products were packaged into special boxes, put on pallets, and then delivered to shelves right behind the gluing tables. The whole process is graphically shown below.

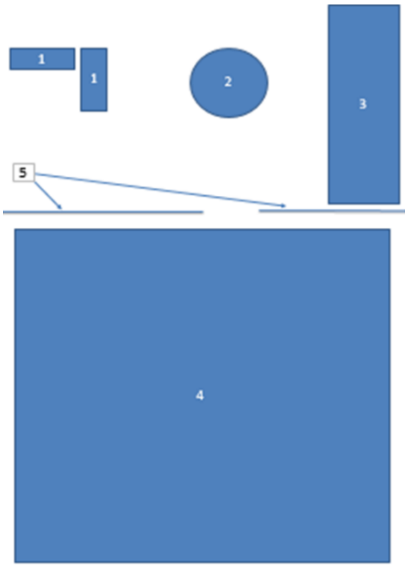


Figure No 8. Scheme of the metal sensor’s process flow, where 1 – gluing tables, 2 – packaging platform, 3 – shelves for keeping the end products, 4 – warehouse premises, 5 – walls

The peculiarities of this process flow included the following.

1) Floor levels between the room of production and warehouse premises were drastically different (up to 2 meters), therefore, the movement of the goods was only done with a help of two forklifts (one above, another below).
2) There were definite shortages of space as often there were idle times because some of the forklifts weren’t able to work something out in time, or because the equipment was broken or because of some other human factor.
3) The gluing tables themselves represented simple tables with small amount of equipment put on them, where most of the work was done by workers. Equipment only played a role of a holder of the raw materials. Equipment itself was always under maintenance or reconstruction.

These were the findings that arose just from observing and watching how the process was working. Next phase was to find the correct data.

4.3 Measure phase

Management stated a clear problem that this process faces – they have a big number of defected products arising throughout the process, and managers want to reduce it with a help of Six Sigma statistical control. Thus, after defining the process flow peculiarities and necessary theoretical issues, the research concentrated on data gathering and structuring.

It was very important to get the qualified and reliable data, therefore, reliability of some given data has also been tested by observation for some shorter period of time. For example, in this research the researcher verified the data by observing and calculating the number of produced products and the number of all the defected products by looking after the production line for several days.

After getting the correct data, it was important to summarize it all, and create the graphs in order to have a more efficient analysis.

Firstly, the tables comprising numbers of all the produced products and only the defected products were created for the months of October 2016 and November 2016 as the ones closest to the actual research period. Extract of such a table is presented in the Appendix No 4.

The data gathering stage was not the most difficult part here, as the factory's management has already introduced data gathering tools by employees before. After some specified period of time (usually a shift), employees count down the number of defected products in their rubbish bins, and then they write them down in the paper book, which is then handed over to the accountants. The calculation of all the products made manufactured by a simple scanner that counts every ready product that goes through it.

Numerical data taken for this phase includes: all the made product parts for the period, all the defective product parts for the period, defective product parts of different types, and different types of defects.

All these summarization and structuration processes of the data was done in Microsoft Excel. Below is the summary table for the data of the two production lines of the study.

Table No 9. Summary tables for October and November 2016

	Calculated data for 30 days of October	**Calculated data for 30 days of November**
Summ of all defected product parts per month	832	693
Summ of all product parts made	371665	375080

These data don't say much by just looking at it, therefore, the analyze phase is needed.

4.4 Analyze phase

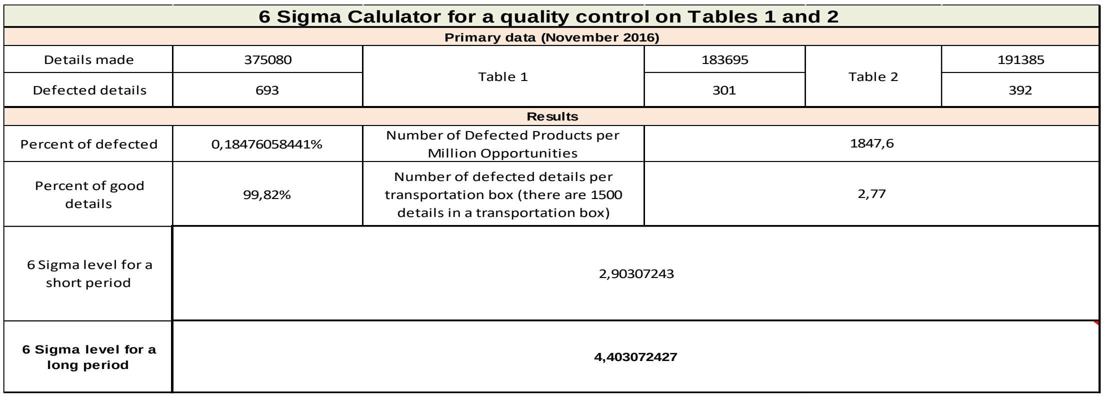
Analysis phase was divided in 2 parts by the type of data that was analyzed – quantitative and qualitative. Quantitative part includes analysis with a help of the aforementioned Six Sigma tools. Qualitative part was based primarily on Manufacturing Strategy concepts analysis.

4.4.1 Quantitative analysis

Six Sigma Indicators

The aforementioned data gives an interesting idea of what is the defects' problem at the production lines of study. Simple calculations give the answer that in October 2016 the defect rate was only approximately 0.22%, and in November 2016 it was even less – only 0.18%. Taking a look back at aforementioned Table No 10, this gives an idea of the existing Sigma level at the production line of study.

Table No 10. Sigma Level Calculation for November 2016



6 Sigma Calulator for a quality control on Tables 1 and 2					
Primary data (November 2016)					
Details made	375080	Table 1	183695	Table 2	191385
Defected details	693		301		392
Results					
Percent of defected	0,18476058441%	Number of Defected Products per Million Opportunities	1847,6		
Percent of good details	99,82%	Number of defected details per transportation box (there are 1500 details in a transportation box)	2,77		
6 Sigma level for a short period	2,90307243				
6 Sigma level for a long period	**4,403072427**				

Then, taking this Six Sigma level for a long period (4.4), it becomes possible to compare the defectiveness rate of the researched production line with the different quality levels that were published by the Finnish Standard Association. This table is presented below.

Table No 11. Sigma Level comparison with the Six Sigma Indicators (adapted from SFS 13053-1, 2014, 21-23)

Under the concept of 6 Sigma for a long period			
Sigma number	**Defected product per million opportunities**	**Percent of defected products**	**Quality level**
6σ	3,4	0,00034%	Ideal level
5σ	233	0,023%	World Class level
The current Sigma level at the production lines of study			
4,4σ	1847,6	0,18%	In between
4σ	6210	0,62 %	Satisfactory level
3σ	66 807	6,68 %	Poor level
2σ	308 537	30,9%	Unsatisfactory level
1σ	691 462	69,1%	

Basically, this seems to be a correct answer, which says that the level is not the worst, it is on the satisfactory level in the ranking of Finnish Standard Association. This result can calm down the management of a factory, though it is not the ideal level, this actually shows that the production effectivity in terms of defect levels is far from perfect. Therefore, further analysis and enlightening of the root causes for defects is needed.

The acquired numbers can act as Six Sigma Indicators that should be followed and used later. This first tool gives the overall picture.

The research then continues with the Six Sigma graph creation. The next part is a rather big one, as it includes implementing several tools in order to create the proper Six Sigma graph. It includes making Sample Size Determination, creating the Control chart, and Measurement System Analysis.

Sample Size Determination

This tool is rather simple as it implies making a correct choice (sample) of data that's going to be used. Out of the two months' data that the research already had, it was decided to use the most current data from November 2016. This data was chosen as the representative one as there were no major changes at the production during this period, therefore it can give a good inter picture – in October 2016, in turn, there were anomalies such as breakdowns at the production lines and forklifts' operational failures (which were later corrected, thus in November the number of details produced is closer to normal). The extract of such a data can be found in the Appendix No 5.

Control chart

After getting the correct data, it was rather important to create a Control chart. In this research this chart was created in Microsoft Excel using several formulas for calculation of the average number and upper control limit. The table with these calculations is presented below.

Table No 12. Control chart data for November 2016

Average number of defected products per day	Upper Control Limit with a standard deviaton percent
23,100000000	78,13237292

This data can be then visualized in the Control chart for November 2016, which is presented below.

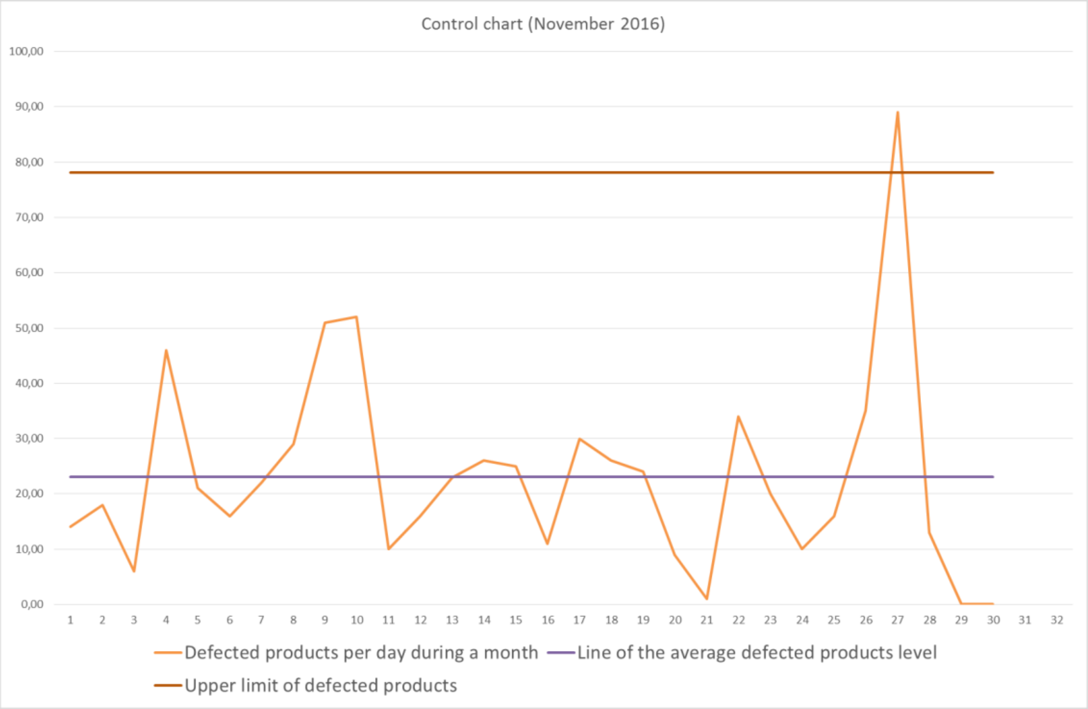


Figure No 9. Control chart for November 2016

From this chart it becomes clear that the number of defected products is stable over the period, it doesn’t usually come out of the limit. In November 2016 it has done so only once – and this research needs to find out why as well.

Measurement System Analysis

Some of the necessary Measurement System Analysis elements have already been done before – when the researcher was checking the correctness of data by first-hand data gathering. Another element of this MAS comes from calculation of the deviations – or, generally, the probabilities of the data to change. These calculations are presented in the table below. They are based on the data given in the Appendix No 5.

Table No 13. Measurement System Analysis for Six Sigma graph with the standard deviation of 10

Criteria	Ideal level	Current level
Average amount	0,0000034	23,1000000
Standard deviation	10	18,34412431
Step of change	10	18,34412431

Following this, the graph Six Sigma was created. To give a better understanding of the current level, the ideal Six Sigma graph can also be created and given in the table. This graphs is also based on the data given in the Appendix 5.

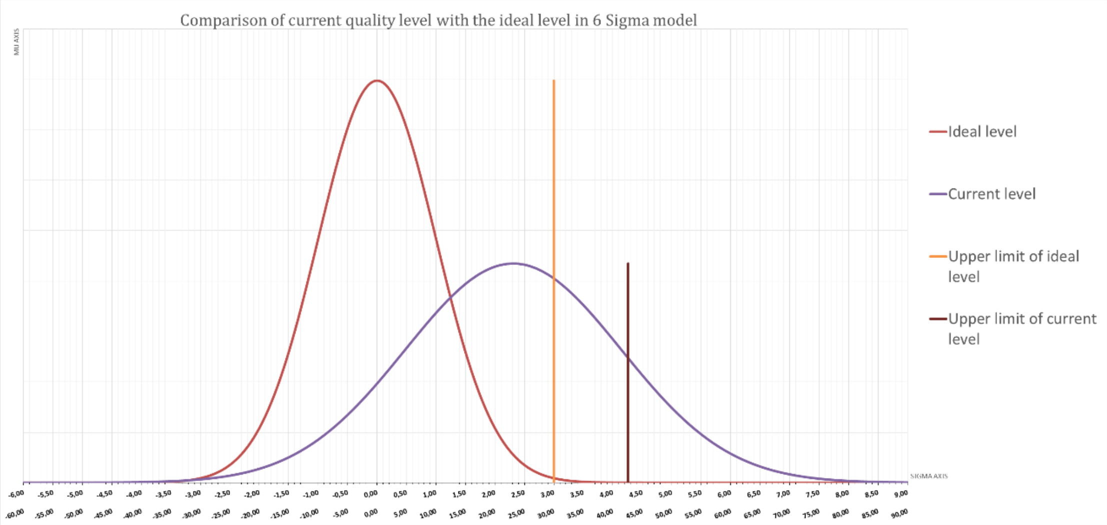


Figure No 10. Six Sigma graph for November 2016 with standard deviation of 10

In the table No 13 it can be seen that the standard deviation for the ideal level is not 1, but 10. It was done with a purpose to have the graphs in the same flat, otherwise it could only be possible to see the ideal level graph and only the beginning of the current level graph, as can be seen below in the Table No 14 and then Figure No 11.

Table No 14. Measurement System Analysis for Six Sigma graph with the standard deviation of 1

Criteria	Ideal level	Current level
Average amount	0,0000034	23,1000000
Standart deviation	1	18,34412431
Step of change	1	18,34412431

This data is then applied in the Six Sigma graph presented in Figure No 11.

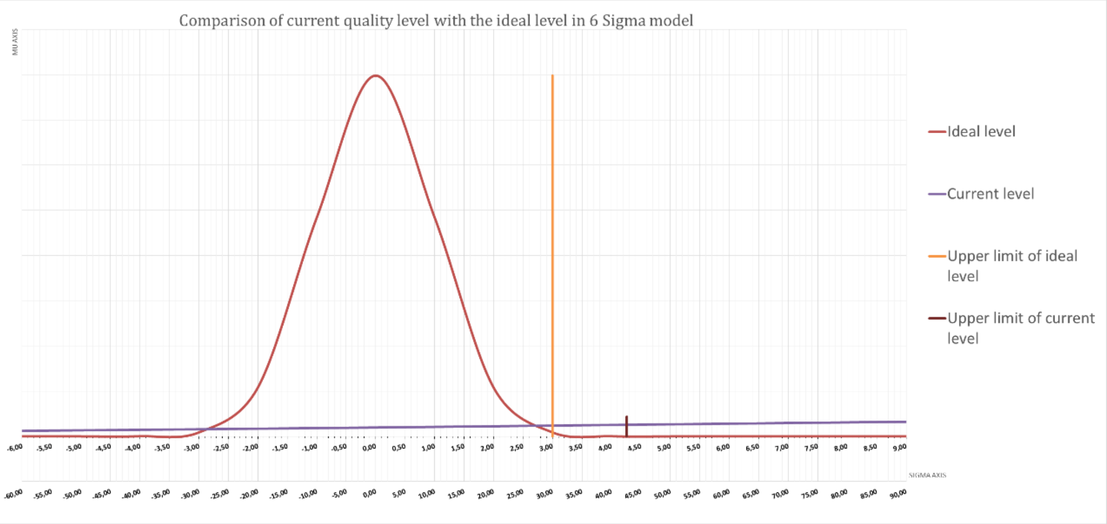


Figure No 11. Six Sigma graph for November 2016 with standard deviation of 1

This Six Sigma graph, presented in Figure No 10, as well as all the tools used above, does not give a new answer on what is the root cause of the defected product parts. It basically has a descriptive and visualizing role as after the implementation of the tools used above, there now can be done the following conclusions.

1) Approximately 2-3 parts per batch are defective; 0.18% of all the product parts made a month are defective; 23 product parts every day are defective.

2) The Sigma level at the production lines of study is not the worst, nor is it at the ideal level. Usually the number of defected product parts goes

around the average level. Sometimes though this number goes beyond the limit – and that is a very unusual thing that needs to be analyzed further.

3) The standard deviation for the defected product parts is rather high, therefore the Six Sigma graph for the production lines of study is much wider than it should be in the ideal case because the probability of falling out of the limit sis bigger. Moreover, the current situation graph is shifted along the *x*-axis, which means that the average of the defected products is drastically higher than it should be in ideal.

CTQC (Critical To Quality Characteristics)

What is also very important to understand, are the “Critical To Quality Characteristics”. For the production line of study, these characteristics include the following characteristics.

1) The end product is working as should – the metal sensor is able to check the temperature correctly.
2) The plastic tube doesn’t have any defects on it – no scratches, no scraps, no dents, and no ends broken.
3) The product should be glued well – there shouldn’t be too much of glue on the tube, nor should there be too less of it so that the product parts fall apart.

Pareto diagram

The next tool that’s going to be used is Pareto diagram. After the defining the Critical To Quality Characteristics it becomes clear what types of defects should the research look after. Below are the tables that show what are the types of defects and it also can give an idea of what defect types are the most common.

Table No 15. Control chart data for November 2016

Defect type		Table 1	Table 2	All per type
Scraps	October	30	35	65
	November	48	39	87
Ends broken	October	75	52	127
	November	63	122	185
Dents	October	243	397	640
	November	190	231	421
All		October		832
		November		693
In percentage relation				
Start		0		
Scraps	October	7,81		
	November	12,55		
Ends broken	October	15,26		
	November	26,70		
Dents	October	76,92		
	November	60,75		
All		100		

These tables are also needed to create a proper Pareto diagram that comes next.

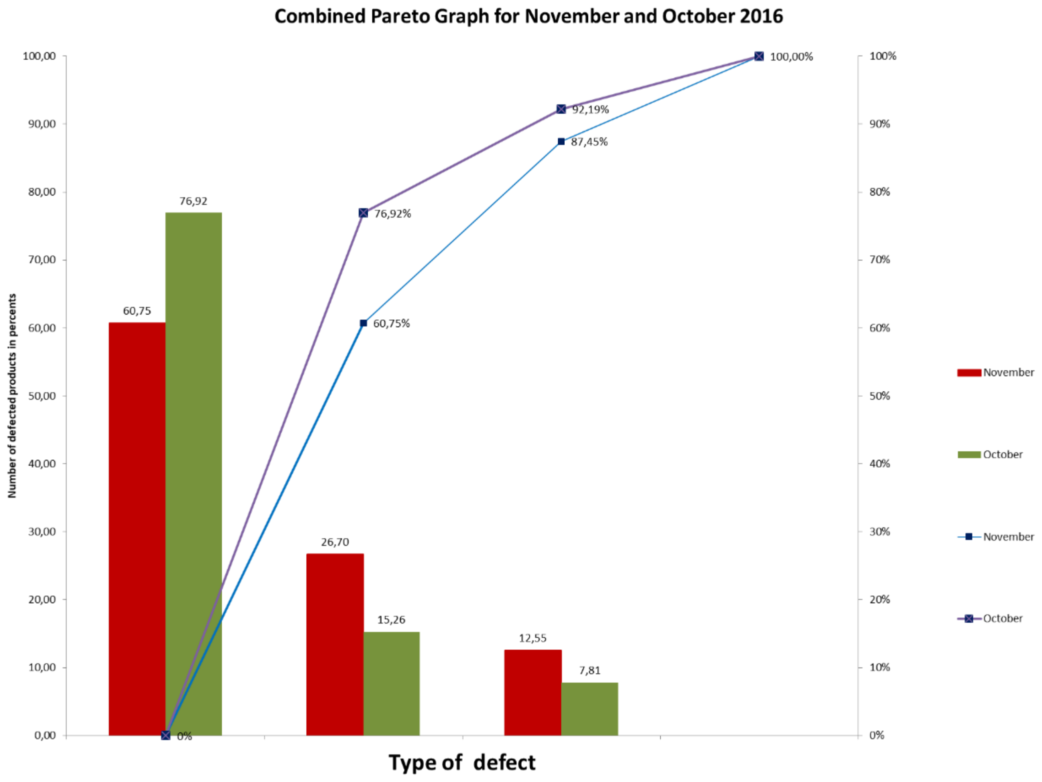


Figure No 12. Combined Pareto diagrams for November and October 2016

After implementation of this tool, the research can has even deeper conclusions. They are presented below.

1) From the Pareto diagram it can be seen that the number of defected product parts has decreased in November. This also needs to be checked.

2) The biggest number of defects comes from dents on the plastic tubes. Twice as less comes from the ends broken on the tubes. And then 4 times less come from the scraps on the plastic tubes.

Fishbone (Isikawa) diagram

In order to get the final conclusions, a detailed view on how the process goes is needed. In this case the Fishbone (Isikawa) diagram can help well as it gives the possibility to check and mention every part of the whole process where every part can effect on the number of defected products. The data presented in this diagram was acquired by both observation/interviews and quantitative analysis made above.

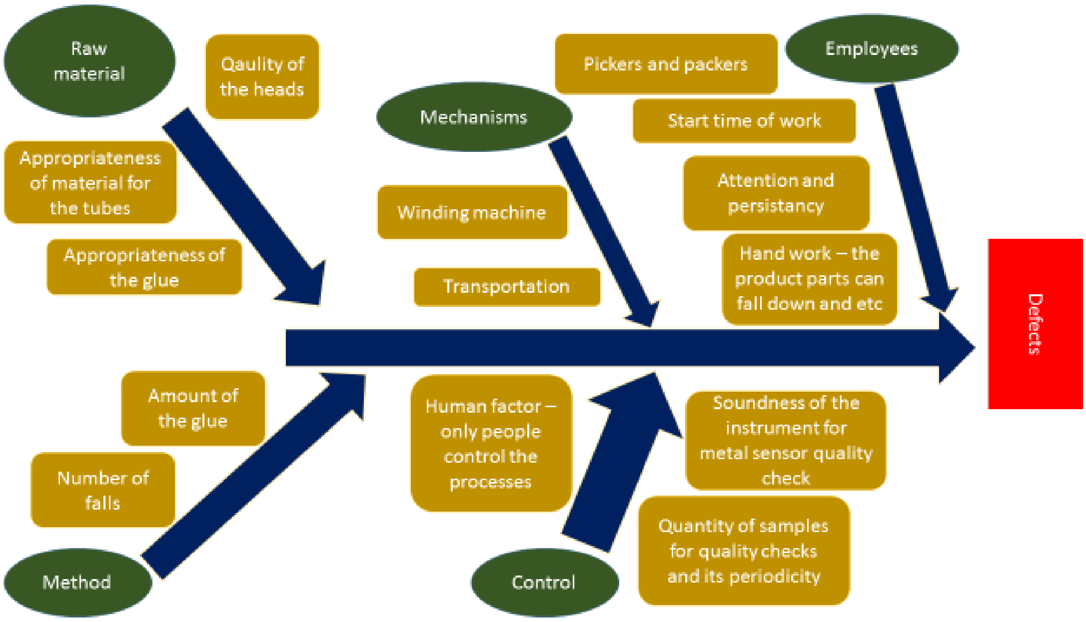


Figure No 13. Fishbone (Isikawa) diagram for the production line of study

Summarizing the Define, Measure and Analyze Phases from the quantitative side, the following conclusion can be made.

1) Transportation is the reason of almost 73% of the defected product parts. This happens because:

    a. Loading employees have to throw the tubes throughout the process: they throw them from the winding machine into the cell in which a batch of tubes is being delivered, they throw the tubes from the cells to the production lines and so on – this creates a situation when the tubes may fall and break;
    b. Loading employees load the tubes in the cells in such a way that each time 3 tubes at the bottom of the cell become defective – that is, those that lie at the bottom of the cell and on which the rest of the tubes lie – the problem is in the cell's construction and also in the way loading employees load and unload the cells.

2) Incorrect insertion of the metal sensor into the plastic tube leads to 27% of the defected products:
    a. This happens most probably because of the defective tube initially (due to a mistake of the winding machine or because of transportation mistake (as the winding machine workers said, it happens so that the washing of certain parts of the winding machine takes place later than necessary, and therefore the quality, for example, of the ends of the tubes occurs o be spoiled – the chips, scratches and dents arise),

This all can also be represented in a way of what shall be reduced, and what Sigma level will come then.

1) Decrease defected products by 60% (that is, remove all tubes that get dents) – in this case the Sigma level will be 4.68
2) Reduce by 13% (that is, remove all defective tubes with a broken surface) – the Sigma level will become 4.79
3) Reduce by 27% (that is, remove the causes of defective ends on the tubes) – the level will be ideal – 6 Sigma

Therefore, after making these conclusions as well as summarizing, categorizing and analyzing the data, the research can move to the next stage, which is to analyze how these findings gathered out of the numerical data correspond or correlate to the Manufacturing Strategy that the Chelyabinsk factory has.

4.4.2 Qualitative analysis

Observation and general communication with the management also gave ideas concerning what is the Manufacturing Strategy there. Below are the Manufacturing Strategy concepts applied to the factory in Chelyabinsk.

1) The Generic Competitive Strategy is a Cost Leadership one. It seems so because they try to do anything on order to be as cheap as possible. They do not invest in the new equipment as this would rise the costs eventually, while the market for their products is not stable enough. They do not make their services differentiated or anyhow special from the competitors, as the products themselves are very specialized ones as well as the customers, which are more or less the same.

2) Their Network Type is Domestic as they are solely on the Russian market for several metal producers.

3) Their main Manufacturing Outputs include Cost, Flexibility and Quality. Cost is because their sole idea of the business is just get the product sold so that they could survive and pay the salaries for their employees. Flexibility is because they need to be flexible in order to, again, survive. For example, they may easily turn the some production process to another equipment or ask another employee to do the task. This arises from the poverty of the production, of course, but that can also be seen as an output they follow all the time. Although they are in extremely harsh conditions, they still try to have quality products for their clients – but that is only because, in my opinion, they hold “Heraeus Electro-Nite” name and also because some of the managers’ personal traits. This is not a stable system, as I see it.

4) They also have a Cellular Layout, which is also Operator-paced at the same time. For the process of my study, the products are always moved in batches, though the flow is rather big. It could have been several times bigger if it was an Equipment-paced line flow with a true

Line layout. The Layout is not lined because they have to move batches from place to place, from the warehouse to equipment, from the equipment to the package point, and from package point to shelves. That makes the flow not regular, sometimes even with disruptions and idle times.

5) Judging the Manufacturing Levers, it can be said that they are mostly either don't exist there, or they are in a bad shape. Following each bullet point of the Table No 5 of this research, the following list can be created (see table below).

Table No 16. Manufacturing Levers in Heraeus Electro-Nite Chelyabinsk (adapted from Miltenburg 2005, 65-67)

Manufacturing Levers' spheres	Manufacturing Levers	Manufacturing Levers in Chelyabinsk
Human Resources	• Mix of skilled and unskilled employees • Number of job classifications • Whether employees are multiskilled • Amount of training • Level of supervision • Policy on layoffs • Promotion opportunities • Responsibility and decision making given to employees • Participation of employees in problem solving and improvement activities	• No • Low • No • Low • Bad • Bad • Low • No • No
Organization Structure and controls	• Whether the Production System is a cost or profit center • Whether the organization structure is flat or hierarchical • Whether the Production System is bureaucratic or entrepreneurial, centralized or decentralized • Relative importance of line and staff • Responsibility and authority at each level of the organization • Measures to evaluate performance of individuals and departments • Who is responsible for quality • How managers are selected • Use of teams	• Cost center • Hierarchical • Entrepreneurial, but centralized • Yes • Low • Low • Employees, but they are not motivated • By the higher managers only • Low
Sourcing	• Amount of vertical integration • Number of suppliers and distributors and their capabilities • Whether supplier and distributor relationships are adversarial or partnerships • Responsibility given to suppliers for design, cost, and quality • Procedure for deciding whether a product will be produced internally or obtained from a supplier	• Low • Low • Partners • No • No
Production planning and control	• Whether systems are centralized or decentralized • Whether a push or pull control system is used • Size of raw material, work-in-progress, and finished goods inventories • How information is gathered and used • When maintenance is done	• Centralized • Pull • Big • Not in a detailed enough way • Rarely, if not never

	• How to schedule design changes and new products into production	• It all is dependent solely on costs
Process technology	• Whether to develop technology internally or purchase it from external sources • Whether technology is new or old • Amount of automation • Whether machines are general purpose or specialized • Whether tooling is low or high volume • Factory layout • Whether layout and technology are static or continuously improving • Quality practices	• They develop technology internally, but it's very weak anyway • Old • Low • General purpose • Low • Cellular working as a line • Static • Once a day a person comes for a check
Facilities	• Whether facilities are large or small • Whether facilities are general purpose or specialized • Location of facilities • Capacity planning • Capabilities of production support departments	• Small • General purpose • Good enough • Limited by space and costs • Low

6) Finally, the Manufacturing Capabilities that the Chelyabinsk factory has, are also increasingly limited, thus the level of Capabilities is Infant.

Therefore, as it has already been mentioned in the Fishbone (Isikawa) Diagram, the process of producing the products of this study is a rather difficult one, which is being affected by many factors. This is the “echo” of the Manufacturing Strategy that was established at the company. The factors and their correlation with the Manufacturing Strategy are presented below.

Raw Materials factor. This factory is affected very much by the chosen Network type and the existing Manufacturing Capabilities at the Chelyabinsk factory. Their supply chain is not hierarchically integrated, the technologies are being only developed internally, though the equipment is only general type and very much constrained by the financial situation. This, in turn leads to a high dependency on the raw materials produced for tubes and metal sensors, which is, in turn, leading to the higher number of the defected products.

Mechanisms. This factor is mainly affected by the mixed Production System type that the company has. As it was already mentioned before, the Chelyabinsk factory only has Cellular Layout, but with Operator-paced line flow. This, in turn, leads to the problems in the transportation, dependency on the winding machine, and human factor mistakes.

Method. As it is possible to see this is being mostly affected by the Manufacturing Outputs that are followed in the company. Following only the Cost, Quality and Flexibility Outputs, the Chelyabinsk factory concentrates less on the defected products elimination and more on their chosen Outputs.

Control and Employees. This factor comes from the bad shape of Manufacturing Levers in the company and the aforementioned wrongly designed Production system. Production System leads to the human factor mistakes, and lack of the Levers for a developed quality Control (not just a sample of 5 products a day) leads to a further worsening of the situation.

Now there are some improvement suggestions that can be done after this analysis. They are discussed further.

4.5 Suggest phase

Following the Analyze phase of this research it becomes clear that, generally, the following actions should be taken in relation to the plastic tubes that are often defected.

1) Change the way plastic tubes and metal sensors get delivered to the factory (change the Network type),
2) Improve transportation of the plastic tubes (improve the Manufacturing Levers),
3) Or reduce the number of tubes' movements (change the Manufacturing Layout),
4) Or remove the need to move the tubes at all (change the Production System type).

This research will only concentrate on the 3 of the possible suggestions, excluding the first one based on the factory's management decision.

However before going further, it is important to see if anything has already been made in order to improve the situation. As management said, they have done the following things.

- Improved the drying process of the tubes on the winding machine during their production.
- The diameter of the tubes’ ends became smaller and thus more suitable for pressing at the winding machine.
- Upgraded the gluing table – tubes’ fasteners were added.

These changes, in turn, brought the following improvements.

- The total number of the defected products decreased by almost 25% (200 product parts) per month.
- With a help of tubes’ fasteners on the tables, the number of crumpled tubes decreased by almost 36% (220 tubes) per month.

These changes reflect what can actually be done. Therefore the suggestions that were raised by this research correspond to them in terms of easiness and financial constraints.

The first change suggestion is about improvement of the plastic tubes’ transportation or reducing the amount of movements (or improvement of the Manufacturing Levers and chaining the Manufacturing Layout at the factory).

The idea is that the forklift drivers could have had a signal board to know when the production tables need new batch of raw materials. The driver in the forklift could have had an electronic display, with which he could see which production table needs more tubes. There could be red, yellow and green colors, which could show the levels of necessity at different tables. Each table, in turn, could have had buttons that would let the driver know if they need tubes in 5, 10 or 15 minutes.

Another idea concerning the transportation of plastic tubes could be the changed schedule for forklift drivers. The thing here is that different tables need different time periods for complete info the work cycles. It could be scheduled so that one table starts at one time, another table starts at another. This will eliminate the situations when a one forklift needs to bring the raw materials to five tables in a row, it will create the forklift’s work more balanced.

These ideas about the transportation improvement arise because they have several advantages that can help a lot. First of all, it will reduce the number of forklifts needed – one instead of two – because the schedule will be more balanced and there will be no idle times for them. Moreover, this will reduce the need in the stock shelves on the first floor – this could improve the situation with idle times again, which arise from the necessity to move the products from the stock shelves to the warehouse.

The second change suggestion is about improvement of the production line (improvement of the Manufacturing Levers).

The problem here was that at the gluing table the tubes have often been falling from the cell to the conveyor where have often been broken. The idea here could be that a small strip is attached to the table as shown on the pictures below.

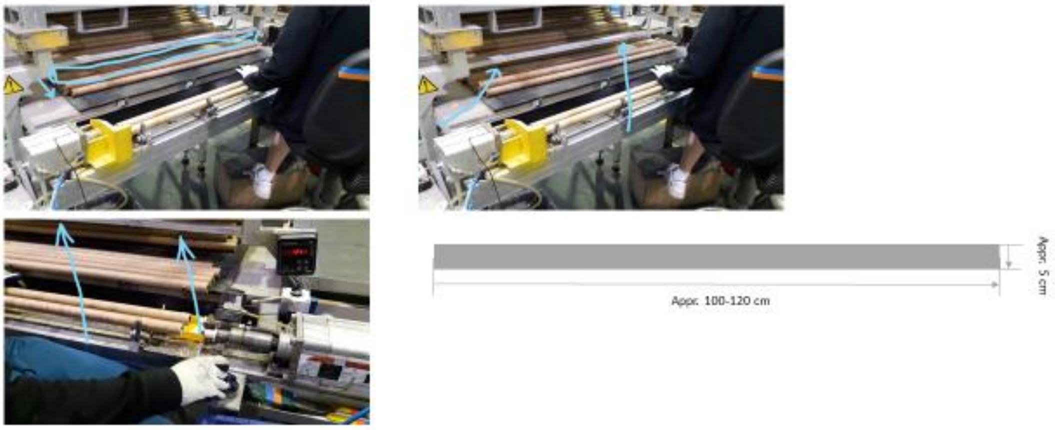
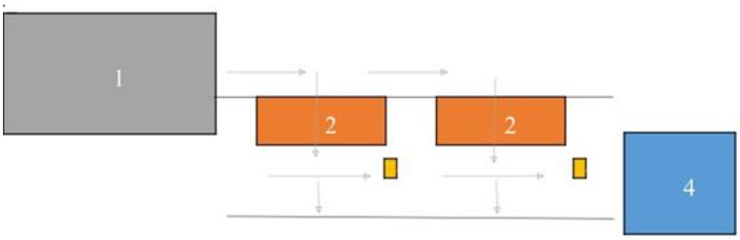


Figure No 14. Small strip attached to the table

This could both decrease the number of defected products and also the amount of idle times as when these tubes fall at the conveyor, an employee has to stop the process and take a long time to retrieve the tube from the conveyor. This is basically the minor change which is very simple and cheap.

The last change suggestion is to remove the need to move the tubes at all (changing the Production System type). This is the major change and might be costly, though very efficient.

The idea here is to create the automated line, which could Equipment-paced line flow with a true Line Layout. The picture is presented below.



Where 1 – Winding machine, 2 – sorting mechanism, 3 – metal sensors gluing mechanism, 4 – packaging line

Figure No 15. Scheme of the new possible automated line

The advantages of such a system is that it basically eliminates the need for transportation of the batches, this will also significantly reduce possibility for the human factor to affect the defect level. It can also significantly improve quality control and productivity rates.

There are also ideas that the current transportation type should be improved. It was revealed that many plastic tubes get broken while being loaded or unloaded in or from the cells by which they are delivered. This means that the cells forms should probably be changed to reduce the defect level of transportation.

These are all the changes suggestions that were raised by the research for “Heraeus Electro-Nite Chelyabinsk”. Unfortunately, as mentioned in the beginning of this thesis, the research is time-constraint, thus most of the change suggestions won’t be implemented. These ideas were judged as possible by the factory’s management, though they were not up to immediate implementation.

5 Conclusions

After trying the theory in practice on the study case, this research has showed that the ideated plan for Six Sigma statistical control implementation is actually working and giving the results. It does so by, firstly, making a framework in which the data shall be gathered and analyzed, secondly, by allowing a researcher to see the cohesive picture as well as a structured picture with different perspectives.

The plan helps to understand the root causes of statistical faults – the defected products. It also helps to understand the current levels of the defected products among all. Moreover, it gives a picture where to head next and how to perceive the today's situation in terms of the Manufacturing Strategy at a company. This plan also helps to see and create the roadmap to implementing changes in order to be compliant with ISO 13053.

In general, this research gave 3 main conclusions that are presented below.

1. This plan of Six Sigma implementation that was generated during this research helps to establish a proper statistical control with different graphs and diagrams at hand, which allow to visualize and follow the level of defected products for managers. Administrative managers can look at the Six Sigma level they have at the factory, look at their upper limit of defected products that shouldn't be crossed, see how far they are from the Six Sigma level, and thus decide how good or bad they are at the defectiveness rate. This checks can be done every month or so by just inputting the data in, for example, prepared Microsoft Excel file.

2. Implementation of this plan also allows to conduct a proper effectivity analysis and see what problems a specific process has, where are its bad sides and good sides. It also allows to see if its Manufacturing Strategy is defined and implemented correctly.

3. Having this DMAS cycle in place (or even DMAIC if there are enough resources and strength to change something at the factory), can help to see and create a roadmap of what to do in order to be compliant with ISO 13053. Being closer to this standard doesn't only give one more certification to a company, but it can actually decrease the level of defectiveness, thus increasing the profit, customer satisfaction, business sustainability.

Six Sigma isn't a “majestic stick” that will eliminate wastes at production. It only gives another perspective by which the problems can be enlightened and solved.

Therefore, this research also showed that perceiving the results of DMAS cycle is possible even without solid engineering background. Administrative managers can establish such kind of a statistical control themselves and see their own production site from a different, statistically proven and improvement-oriented angle.

6 Discussion

6.1 Meeting the research objectives and answering the questions

In the introduction part there were 3 research objectives and 3 corresponding research questions raised. Below are the explanations of how they were met throughout the research.

The first objective was mainly to uncover the concepts of Manufacturing Strategy. This objective was achieved mainly during the literature review part. All of the Manufacturing Strategy concepts were explained, described and analyzed. After that all of these Manufacturing Strategy concepts were also used during the empirical study.

The second objective was, in general, to elaborate on Six Sigma methodology and tools. This was achieved via explanations during the literature review part. Six Sigma methodology was fully described with the mathematical explanation of Six Sigma tool and additional elaboration on the tools that could be used with it. This Six Sigma methodology arose into the ideated DMAS plan (which is the next objective of the research work), and was also implemented during the empirical study along with the Six Sigma tools.

The last objective was to ideate the Six Sigma plan and see how it works in real circumstances. For achieving this, the DMAS plan was ideated and tried out during the empirical study. This objective was also reached by raising the suggestions for production changes for the study factory, as well as elaborating on what can be done after the implementation of the ideated Six Sigma plan.

All in all, the questions were answered quite fully, while the objectives of the research were achieved.

6.2 Assessment of research validity and reliability

The concept of research validity refers to whether the findings do mean what they are presented to be about, whether there is a causal relationship between two variables (Saunders et al. 2009, 156-161). Validity of the presented information in this research was ensured by a correctly built research design, triangulation of methods, solid supervision by the study company supervisors.

Research reliability is concerned with whether the data collection techniques and analysis procedures used in this research are able to yield consistent findings (Saunders et al. 2009, 156-161). The measures or the raw data acquired during the study process were transparently and understandably transferred to conclusions used for further analysis and calculations. However, the measures that were acquired during the study process concerning the number of defected products, concerning the number of products produced as well as observations concerning the study production line and the Manufacturing Strategy of the factory – these measures can change since the study factory may always be in the process of change, thus, getting the same results with may not be possible. At the same time, this only concerns the data and measures acquired, not the conclusions of this work. The same observations and conclusions may be reached by other observers too with the study held at the similar circumstances and conditions.

Subject or participant error and bias in giving information is minimized by triangulation of methods and splendid amount of analysis procedures (for example, after interviewing a middle manager, there will always be practical check of his/her words, as well additional interview of other employees concerning the subject).

Observer error and bias were minimized by a vast amount of literature sources and a thorough supervision of the study factory managers. Such supervision level was acquired by constant individual meetings and results presentations, as well as a big public results presentation in the end of the study.

The conclusions of the work are generalizable. The ideated Six Sigma plan can be applied to other study cases with different characteristics. At the same time, the Management Strategy concepts, as well as Six Sigma methodology tools discussed and applied in this research are also applicable to other study cases. This knowledge is rather general and adaptive.

6.3 Ideas for further research

There are many ideas on what could be done in the future. Some of them are presented below.

1. In this research only DMAS cycle was implanted. It would probably be very interesting to see, how the actual DMAIC cycle implementation would work (i.e. with the real changes and follow-up statistical control of the changes' success or failure).

2. It would be interesting to try this DMAS cycle on companies that work in other industries and that face some problems with imperfect work done by them. For example, logistics industry where a warehouse isn't able to provide the shipments in time, or maybe even loses the products during its own warehouse operations. That would be very interesting to see, if this DMAS cycle and Six Sigma statistical control apply to other industries as well, not just pure manufacturing.

3. It would also be interesting to see how a study company actually does achieve the official compliance with ISO 13053. What should it do, how are the processes built in such a company, how different is it from, for example, Heraeus Electro-Nite Chelyabinsk.

All in all, there are many ways to test and study this Six Sigma methodology. This research showed that it is an interesting manufacturing and supply chain concept.

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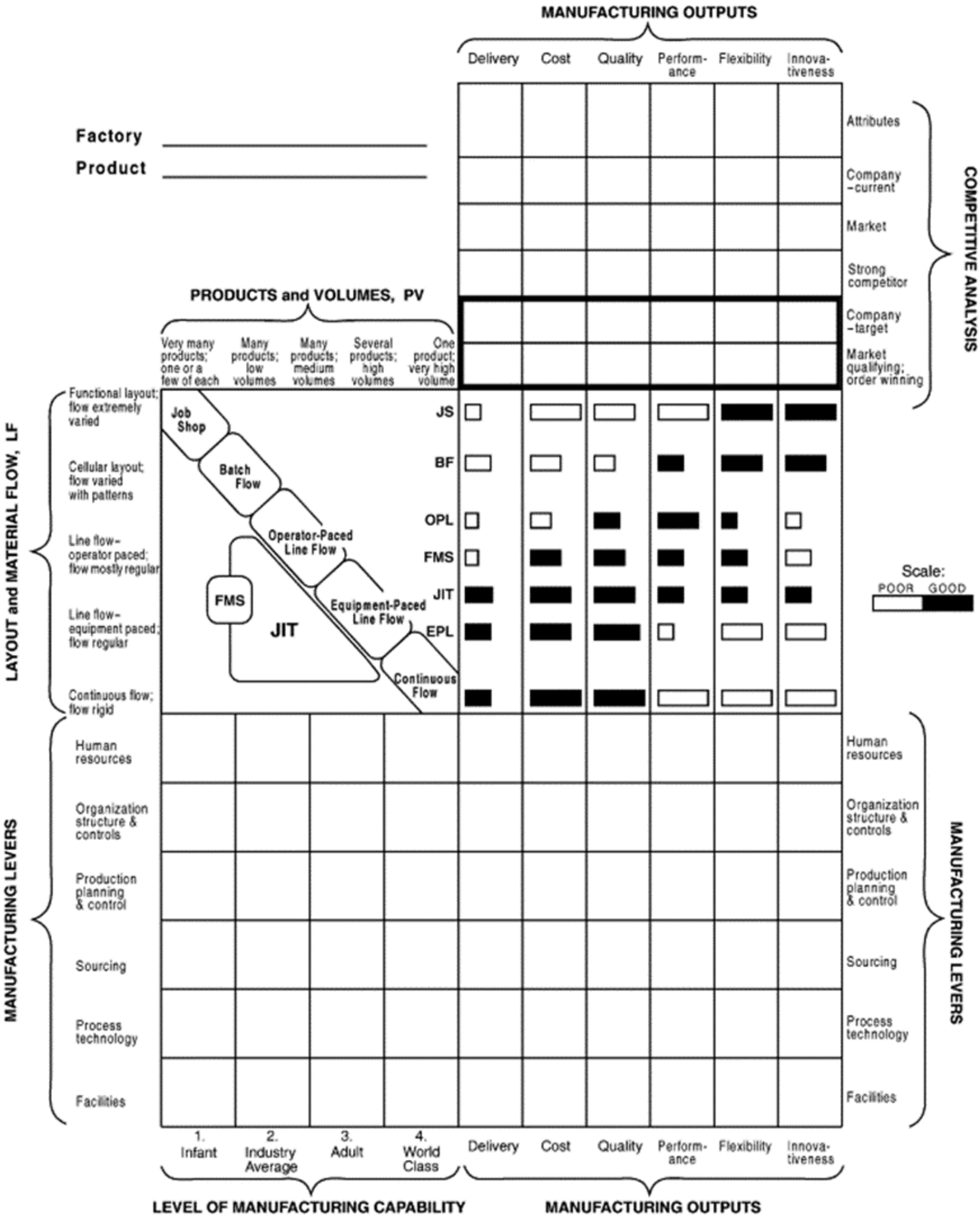
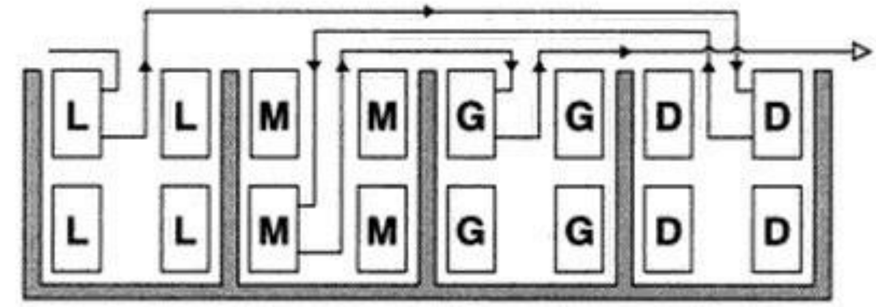
Appendices

Appendix 1. Manufacturing Strategy Worksheet (adapted from Miltenburg, 2005, 4)

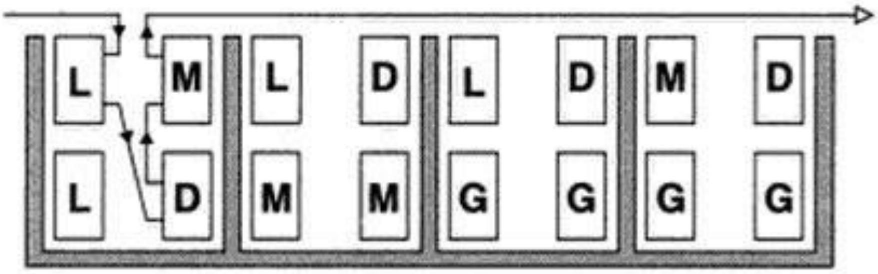


Appendix 2. Basic Factory Layouts (adapted from Miltenburg, 2005, 54)



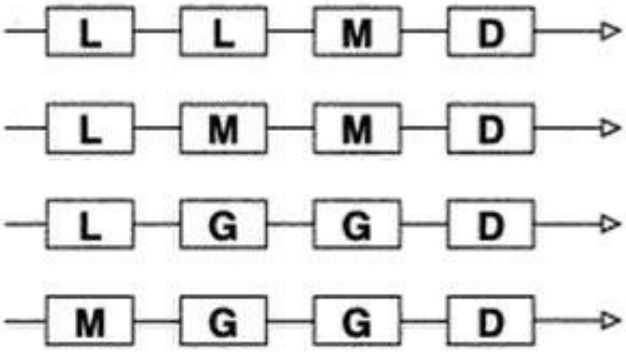
Functional Layout

- Similar equipment (L, M, G, D) is grouped together
- Flow is extremely varied for each product



Cellular Layout

- One cell for each product family
- Flow is regular for each product family, but is varied for each product within a family



Line Layout

- One line for each product or product family
- Flow is regular

Appendix 3. Extract of Data for November 2016

Defected Tubes Table Number 1

Worker's name		Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname
Date		01.11.2016	02.11.2016	03.11.2016	04.11.2016	05.11.2016	06.11.2016	09.11.2016	10.11.2016	11.11.2016	12.11.2016	13.11.2016	14.11.2016	15.11.2016	15.11.2016/ночь	16.11.2016	17.11.2016	18.11.2016
time when done	Start	7:50	8:00	8:00	8:00	8:10	7:45	7:55	7:55:00/15:45	8:00	8:00	8:40	7:50	8:00	19:45	8:00	7:40/15:50	7:45
	End	19:15	19:00	19:15	18:00	16:30	19:00	19:15	14:55:00/18:55	19:15	19:30	19:15	19:15	19:00	7:10	19:20	14:55/19:05	19:00
Number of products done per day		6260		7185	5380	3200	6850	5970	6200	7200	7350	6100	7500	6450	6600	8400	8300	8500
Product 1	Scraps																	
	Ends broken																	
	Dents																	
	Scraps																	
	Ends broken																	
	Dents																	
Product 2	Scraps		3								5		2	7			2	2
	Ends broken				1			5	3		3			2				
	Dents	1	4		8	1	12	5	6	5	4		6	4			1	9
	Scraps									10		1			2	10		
	Ends broken									1	2					3		
	Dents		2							3	12	3			8	12	5	7

Defected Tubes Table Number 2

Worker's name		Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname	Surname
Date		01.11.2016	02.11.2016	03.11.2016	04.11.2016	05.11.2016	06.11.2016	09.11.2016	10.11.2016	11.11.2016	11.11.2016	13.11.2016	14.11.2016	15.11.2016	15.11.2016/ночь	16.11.2016	17.11.2016	18.11.2016
time when done	Start	7:50	7:55	8:00	8:00	8:00	8:10	7:55	8:00	8:00	8:00	8:40	7:50	8:00	19:45	8:00	7:45	7:45
	End	19:15	18:55	19:15	18:00	19:10	19:00	19:15	19:00	19:15	19:30	19:15	19:15	19:00	7:10	19:20	19:15	19:15
Number of products done per day		7000	6700	7185	5380	6500	6850	5970	5800	7200	7350	6100	7500	6450	6600	8400	8300	8100
Product 1	Scraps																	
	Ends broken																	
	Dents																	
	Scraps																	
	Ends broken																	
	Dents																	
Product 2	Scraps	3	1								2		2	5				
	Ends broken	5	2	1						3				2				
	Dents	5	4	5		20	3	12	20	8	15		6	3				
	Scraps									12		3			3			6
	Ends broken				30					2	2						3	
	Dents		2		7		1			7	7	3			13			6
Summ of defected products per day		14	18	6	46	21	16	22	29	51	52	10	16	23	26	25	11	30

Appendix 4. Current Six Sigma level graph MSA for November 2016

Argument in absolute units	Argument in parts of σ	Ideal level meaning	Current level meaning	Upper limit of ideal level	Lower limit of ideal level	Upper limit of current level	Lower limit of current level
-59,9999966	-6,00	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-58,9999966	-5,90	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-57,9999966	-5,80	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-56,9999966	-5,70	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-55,9999966	-5,60	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-54,9999966	-5,50	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-53,9999966	-5,40	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-52,9999966	-5,30	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-51,9999966	-5,20	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-50,9999966	-5,10	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-49,9999966	-5,00	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-48,9999966	-4,90	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-47,9999966	-4,80	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-46,9999966	-4,70	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-45,9999966	-4,60	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-44,9999966	-4,50	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-43,9999966	-4,40	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-42,9999966	-4,30	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-41,9999966	-4,20	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-40,9999966	-4,10	0,00%	0,00%	3,00	-3,00	4,26	-1,74
-39,9999966	-4,00	0,00%	0,01%	3,00	-3,00	4,26	-1,74
-38,9999966	-3,90	0,00%	0,01%	3,00	-3,00	4,26	-1,74
-37,9999966	-3,80	0,00%	0,01%	3,00	-3,00	4,26	-1,74
-36,9999966	-3,70	0,00%	0,01%	3,00	-3,00	4,26	-1,74
-35,9999966	-3,60	0,01%	0,01%	3,00	-3,00	4,26	-1,74
-34,9999966	-3,50	0,01%	0,01%	3,00	-3,00	4,26	-1,74
-33,9999966	-3,40	0,01%	0,02%	3,00	-3,00	4,26	-1,74
-32,9999966	-3,30	0,02%	0,02%	3,00	-3,00	4,26	-1,74
-31,9999966	-3,20	0,02%	0,02%	3,00	-3,00	4,26	-1,74
-30,9999966	-3,10	0,03%	0,03%	3,00	-3,00	4,26	-1,74
-29,9999966	-3,00	0,04%	0,03%	3,00	-3,00	4,26	-1,74
-28,9999966	-2,90	0,06%	0,04%	3,00	-3,00	4,26	-1,74
-27,9999966	-2,80	0,08%	0,04%	3,00	-3,00	4,26	-1,74
-26,9999966	-2,70	0,10%	0,05%	3,00	-3,00	4,26	-1,74
-25,9999966	-2,60	0,14%	0,06%	3,00	-3,00	4,26	-1,74
-24,9999966	-2,50	0,18%	0,07%	3,00	-3,00	4,26	-1,74
-23,9999966	-2,40	0,22%	0,08%	3,00	-3,00	4,26	-1,74
-22,9999966	-2,30	0,28%	0,09%	3,00	-3,00	4,26	-1,74
-21,9999966	-2,20	0,35%	0,11%	3,00	-3,00	4,26	-1,74
-20,9999966	-2,10	0,44%	0,12%	3,00	-3,00	4,26	-1,74
-19,9999966	-2,00	0,54%	0,14%	3,00	-3,00	4,26	-1,74
-18,9999966	-1,90	0,66%	0,16%	3,00	-3,00	4,26	-1,74
-17,9999966	-1,80	0,79%	0,18%	3,00	-3,00	4,26	-1,74
-16,9999966	-1,70	0,94%	0,20%	3,00	-3,00	4,26	-1,74
-15,9999966	-1,60	1,11%	0,22%	3,00	-3,00	4,26	-1,74
-14,9999966	-1,50	1,30%	0,25%	3,00	-3,00	4,26	-1,74
-13,9999966	-1,40	1,50%	0,28%	3,00	-3,00	4,26	-1,74
-12,9999966	-1,30	1,71%	0,31%	3,00	-3,00	4,26	-1,74
-11,9999966	-1,20	1,94%	0,35%	3,00	-3,00	4,26	-1,74
-10,9999966	-1,10	2,18%	0,39%	3,00	-3,00	4,26	-1,74
-9,9999966	-1,00	2,42%	0,43%	3,00	-3,00	4,26	-1,74
-8,9999966	-0,90	2,66%	0,47%	3,00	-3,00	4,26	-1,74
-7,9999966	-0,80	2,90%	0,52%	3,00	-3,00	4,26	-1,74
-6,9999966	-0,70	3,12%	0,57%	3,00	-3,00	4,26	-1,74
-5,9999966	-0,60	3,33%	0,62%	3,00	-3,00	4,26	-1,74
-4,9999966	-0,50	3,52%	0,67%	3,00	-3,00	4,26	-1,74
-3,9999966	-0,40	3,68%	0,73%	3,00	-3,00	4,26	-1,74
-2,9999966	-0,30	3,81%	0,79%	3,00	-3,00	4,26	-1,74
-1,9999966	-0,20	3,91%	0,85%	3,00	-3,00	4,26	-1,74
-0,9999966	-0,10	3,97%	0,92%	3,00	-3,00	4,26	-1,74
0,0000034	0,00	3,99%	0,98%	3,00	-3,00	4,26	-1,74
1,0000034	0,10	3,97%	1,05%	3,00	-3,00	4,26	-1,74
2,0000034	0,20	3,91%	1,12%	3,00	-3,00	4,26	-1,74
3,0000034	0,30	3,81%	1,19%	3,00	-3,00	4,26	-1,74
4,0000034	0,40	3,68%	1,26%	3,00	-3,00	4,26	-1,74
5,0000034	0,50	3,52%	1,34%	3,00	-3,00	4,26	-1,74
6,0000034	0,60	3,33%	1,41%	3,00	-3,00	4,26	-1,74
7,0000034	0,70	3,12%	1,48%	3,00	-3,00	4,26	-1,74
8,0000034	0,80	2,90%	1,55%	3,00	-3,00	4,26	-1,74
9,0000034	0,90	2,66%	1,62%	3,00	-3,00	4,26	-1,74
10,0000034	1,00	2,42%	1,69%	3,00	-3,00	4,26	-1,74
11,0000034	1,10	2,18%	1,75%	3,00	-3,00	4,26	-1,74
12,0000034	1,20	1,94%	1,81%	3,00	-3,00	4,26	-1,74
13,0000034	1,30	1,71%	1,87%	3,00	-3,00	4,26	-1,74
14,0000034	1,40	1,50%	1,92%	3,00	-3,00	4,26	-1,74
15,0000034	1,50	1,30%	1,97%	3,00	-3,00	4,26	-1,74
16,0000034	1,60	1,11%	2,02%	3,00	-3,00	4,26	-1,74
17,0000034	1,70	0,94%	2,06%	3,00	-3,00	4,26	-1,74
18,0000034	1,80	0,79%	2,09%	3,00	-3,00	4,26	-1,74

19,0000034	1,90	0,66%	2,12%	3,00	-3,00	4,26	-1,74
20,0000034	2,00	0,54%	2,14%	3,00	-3,00	4,26	-1,74
21,0000034	2,10	0,44%	2,16%	3,00	-3,00	4,26	-1,74
22,0000034	2,20	0,35%	2,17%	3,00	-3,00	4,26	-1,74
23,0000034	2,30	0,28%	2,17%	3,00	-3,00	4,26	-1,74
24,0000034	2,40	0,22%	2,17%	3,00	-3,00	4,26	-1,74
25,0000034	2,50	0,18%	2,16%	3,00	-3,00	4,26	-1,74
26,0000034	2,60	0,14%	2,15%	3,00	-3,00	4,26	-1,74
27,0000034	2,70	0,10%	2,13%	3,00	-3,00	4,26	-1,74
28,0000034	2,80	0,08%	2,10%	3,00	-3,00	4,26	-1,74
29,0000034	2,90	0,06%	2,07%	3,00	-3,00	4,26	-1,74
30,0000034	3,00	0,04%	2,03%	3,00	-3,00	4,26	-1,74
31,0000034	3,10	0,03%	1,98%	3,00	-3,00	4,26	-1,74
32,0000034	3,20	0,02%	1,93%	3,00	-3,00	4,26	-1,74
33,0000034	3,30	0,02%	1,88%	3,00	-3,00	4,26	-1,74
34,0000034	3,40	0,01%	1,82%	3,00	-3,00	4,26	-1,74
35,0000034	3,50	0,01%	1,76%	3,00	-3,00	4,26	-1,74
36,0000034	3,60	0,01%	1,70%	3,00	-3,00	4,26	-1,74
37,0000034	3,70	0,00%	1,63%	3,00	-3,00	4,26	-1,74
38,0000034	3,80	0,00%	1,56%	3,00	-3,00	4,26	-1,74
39,0000034	3,90	0,00%	1,49%	3,00	-3,00	4,26	-1,74
40,0000034	4,00	0,00%	1,42%	3,00	-3,00	4,26	-1,74
41,0000034	4,10	0,00%	1,35%	3,00	-3,00	4,26	-1,74
42,0000034	4,20	0,00%	1,28%	3,00	-3,00	4,26	-1,74
43,0000034	4,30	0,00%	1,21%	3,00	-3,00	4,26	-1,74
44,0000034	4,40	0,00%	1,14%	3,00	-3,00	4,26	-1,74
45,0000034	4,50	0,00%	1,07%	3,00	-3,00	4,26	-1,74
46,0000034	4,60	0,00%	1,00%	3,00	-3,00	4,26	-1,74
47,0000034	4,70	0,00%	0,93%	3,00	-3,00	4,26	-1,74
48,0000034	4,80	0,00%	0,87%	3,00	-3,00	4,26	-1,74
49,0000034	4,90	0,00%	0,80%	3,00	-3,00	4,26	-1,74
50,0000034	5,00	0,00%	0,74%	3,00	-3,00	4,26	-1,74
51,0000034	5,10	0,00%	0,68%	3,00	-3,00	4,26	-1,74
52,0000034	5,20	0,00%	0,63%	3,00	-3,00	4,26	-1,74
53,0000034	5,30	0,00%	0,58%	3,00	-3,00	4,26	-1,74
54,0000034	5,40	0,00%	0,53%	3,00	-3,00	4,26	-1,74
55,0000034	5,50	0,00%	0,48%	3,00	-3,00	4,26	-1,74
56,0000034	5,60	0,00%	0,44%	3,00	-3,00	4,26	-1,74
57,0000034	5,70	0,00%	0,39%	3,00	-3,00	4,26	-1,74
58,0000034	5,80	0,00%	0,36%	3,00	-3,00	4,26	-1,74
59,0000034	5,90	0,00%	0,32%	3,00	-3,00	4,26	-1,74
60,0000034	6,00	0,00%	0,29%	3,00	-3,00	4,26	-1,74
61,0000034	6,10	0,00%	0,26%	3,00	-3,00	4,26	-1,74
62,0000034	6,20	0,00%	0,23%	3,00	-3,00	4,26	-1,74
63,0000034	6,30	0,00%	0,20%	3,00	-3,00	4,26	-1,74
64,0000034	6,40	0,00%	0,18%	3,00	-3,00	4,26	-1,74
65,0000034	6,50	0,00%	0,16%	3,00	-3,00	4,26	-1,74
66,0000034	6,60	0,00%	0,14%	3,00	-3,00	4,26	-1,74
67,0000034	6,70	0,00%	0,12%	3,00	-3,00	4,26	-1,74
68,0000034	6,80	0,00%	0,11%	3,00	-3,00	4,26	-1,74
69,0000034	6,90	0,00%	0,10%	3,00	-3,00	4,26	-1,74
70,0000034	7,00	0,00%	0,08%	3,00	-3,00	4,26	-1,74
71,0000034	7,10	0,00%	0,07%	3,00	-3,00	4,26	-1,74
72,0000034	7,20	0,00%	0,06%	3,00	-3,00	4,26	-1,74
73,0000034	7,30	0,00%	0,05%	3,00	-3,00	4,26	-1,74
74,0000034	7,40	0,00%	0,05%	3,00	-3,00	4,26	-1,74
75,0000034	7,50	0,00%	0,04%	3,00	-3,00	4,26	-1,74
76,0000034	7,60	0,00%	0,03%	3,00	-3,00	4,26	-1,74
77,0000034	7,70	0,00%	0,03%	3,00	-3,00	4,26	-1,74
78,0000034	7,80	0,00%	0,02%	3,00	-3,00	4,26	-1,74
79,0000034	7,90	0,00%	0,02%	3,00	-3,00	4,26	-1,74
80,0000034	8,00	0,00%	0,02%	3,00	-3,00	4,26	-1,74
81,0000034	8,10	0,00%	0,01%	3,00	-3,00	4,26	-1,74
82,0000034	8,20	0,00%	0,01%	3,00	-3,00	4,26	-1,74
83,0000034	8,30	0,00%	0,01%	3,00	-3,00	4,26	-1,74
84,0000034	8,40	0,00%	0,01%	3,00	-3,00	4,26	-1,74
85,0000034	8,50	0,00%	0,01%	3,00	-3,00	4,26	-1,74
86,0000034	8,60	0,00%	0,01%	3,00	-3,00	4,26	-1,74
87,0000034	8,70	0,00%	0,01%	3,00	-3,00	4,26	-1,74
88,0000034	8,80	0,00%	0,00%	3,00	-3,00	4,26	-1,74
89,0000034	8,90	0,00%	0,00%	3,00	-3,00	4,26	-1,74
90,0000034	9,00	0,00%	0,00%	3,00	-3,00	4,26	-1,74