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Machine Vision system to advance Quality Control

A case study of company M

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Abstract

Quality control is an essential tool for creating a high-quality product and thus essential for the success of the organization. One of the technologies still developing today in the field of quality control is machine vision, which can give the company a competitive advantage and provide a better product. For this reason, Company M wished to explore the possibility to incorporate machine vision technology in one or more of their production phases, as a defect detecting method. In order to explore this option, two research questions needed to be answered:

Can machine vision improve quality inspection?

How can we utilize machine vision in the inspection process of company M?

To answer these questions, there was a need to first research and understand in depth the concept of quality management, the different costs associated with it, the international standards for quality management ISO 9001:2015 and IATF 16949: 2016 and the quality tools that can be used in the process. It was important to find out what are the quality measuring and inspection tools that are used in the metal part production industry, and from that focus on applications of machine vision. At the same time, it was imperative to also understand the different technologies in company M and locate which process or processes will benefit most from applying the machine vision inspection.

After inspecting the different solutions machine vision system can offer in the field of quality control, it was found that the technology available can be used to improve the quality process of deep drawing and laser cutting technology, as well as aid in the washing process and part picking. While other processes can also benefit from this solution in the future, these processes, when improved, will advance quality control in the company. A table was composed to show the different defects and how they can be detected with the different technologies, also a list of important considerations was given for the process of choosing the technology supplier for a machine vision system.

Keywords/tags (subjects)

Machine vision system, quality control, Inspection, deep drawing, laser cutting.

Miscellaneous (Confidential information) ***Appendices 3,4,5,6,7,8 and 9 are confidential and they have been removed from the public thesis. Grounds for secrecy: Act on the Openness of Government Activities 621/1999, Section 24, 17: business or professional secret. Period of secrecy is five years and it ends 18.5.2025.***

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1 Introduction

Companies today must find and develop a competitive edge over others to acquire their share of the market. A competitive edge can be reached by different means, one of them being the quality of their products. The quality of a product can be influenced by many aspects, one of them being the level of quality inspections. The field of quality inspection, specifically utilizing machine vision, is constantly developing. Keeping up with the latest technological advances can promote a company's product, customer satisfaction, brand reputation and ultimately their total business results.

The topic of this research was proposed by company M, which believes in continuous development and improvement, was interested in exploring machine vision as a new technology to improve their product quality. The company wished to detect, and if possible, prevent any defects that might take place during the manufacturing process, reduce waste, and make sure the customer gets the best possible product.

The aim of the research was to review the different technologies in machine vision and assess which ones can benefit the company by improving their production and quality inspection process.

This research reviewed the concept of quality and the quality inspection process as it is practiced today, specifically by company M. The research explored the different technologies used by company M and the possible quality inspection points. The research also examined the technology of machine vision and how it is applied in the field of quality inspection, to find possible adequate solutions for the company. The research employed the use of literature review as well as field research of company M's technologies and quality failure data provided by company M.

2 Research methods

It is generally understood that research methods lie on a spectrum. On either end lies the quantitative and qualitative methods, and between them a spectrum of mixed methods. A common way of seeing the differences between the quantitative and qualitative methods is by defining the areas of research they employ- quantitative methods are used where measurements are made of quantifiable things, while qualitative methods are used in areas that require open-ended questions and answers. Another way to differentiate between the research methods would be to look at the basic assumptions of the research, the types of research strategies used and the specific methods employed. (Creswell 2018, 3-4.)

In selecting a research method, the researcher anticipates the type of data needed to respond to the research questions (Williams 2007, 65). If the research question requires numerical data, the quantitative method is selected; if textural or unquantifiable data is the one to provide the answers - the qualitative method is employed. The mixed method approach is used if the questions require both numerical and textural data.

2.1 Quantitative research method

Quantitative is an approach for testing theories and analyze variables that can be measured instrumentally. The data is used to objectively measure reality. Quantitative variables are defined by their amount. In case we have a quantitative independent variable, the researcher is usually interested in the nature of the function related to the variable. The usual methods of data gathering are surveys and experiments, which provide quantifiable data. (William 2007. 66; Myers, Well & Lorch 2010, 5.)

2.2 Qualitative research method

Qualitative is an approach for exploring and understanding the meaning individuals or groups ascribe to a social or human problem, and has its origins in anthropology, sociology and the humanities. Qualitative methods rely on text and image data. Qualitative variables involve the type of an action. In this case, the researcher in keen on the number of times a specific function was done and what are its outcomes. Examples for qualitative research methods are case studies, phenomenological research, grounded theory, ethnography and content analysis. It is important that researchers consider the worldview of the population as well as ethical issues that might arise from the research. This method usually involves observation and interviews. (Creswell 2018, 4,13-14; Brodsky, Buckingham, Scheibler & Mannarini 2016, 14-15; Myers, Well & Lorch 2010, 6.)

2.3 Mixed research method

As implied by the name, this method Involves collecting both quantitative and qualitative data. There are three main methods for mixed research method:

- Convergent mixed methods: qualitative and quantitative research done at the same time.
- Explanatory sequential mixed methods: quantitative research first, qualitative after to explain the data.
- Exploratory sequential mixed methods: the inverse of explanatory.

The core assumption is that integration of both types of data offers additional insights beyond what either of them alone would provide. The main tools used in mixed method research are closed-ended and open-ended questionnaires, interviews and observations. While the closed-ended questionnaires provide the quantitative data, the open-ended questionnaires, interviews and observations provide the qualitative data. (Creswell 2018, 14-15; Zohrabi 2013, 254.)

2.4 Methods of collecting data

Interview

An interview is a coordinated conversation aimed at obtaining desired information. The interviewer is face-to face with the interviewee, asking him questions. The interviewer comes with prepared questions but has some freedom to expand and ask for more detailed information as needed. The interviewer's role is to bring the respondent's full attention to the task and encourage him or her to answer honestly and yet make sure not to influence the response. There are two basic categories of interviews – Structured and unstructured:

- Structured interview: similar to a questionnaire, the questions are very direct and focused with not much room for deviation. This provides straight answers to all questions.
- Unstructured interview: allows to probe for additional information and uncover important data.

(Gubrium & Holstein 2001, 3, 51; Phillips & Stawarski 2008, 24.)

Observation

Observation is a is a method of collecting data, record of events, situations or experiences with the help of a recording instrument like a camera or a recorder. In Observation, the participants are being observed to record any change in their behavior. The observer can either be a staff member, or an external third-party observer, to give a more objective view. Observation must be planned and executed accordingly. It is important to know what info should be given in advance and what is not to the observed individual. Timing is also a parameter to consider, since different circumstances, such as stress, can produce different results. Observation should be done by a knowledgeable person who knows how to analyze the info and is also able to minimize their influence on the results. (Phillips & Stawarski, 2008. 28-30; Walliman 2010, 70.)

Literature review

In literature review we study the information available on the topic. It helps us determine if this is a viable research to follow and focus on the area to research. Literature review can be used either in the introduction, in a separate section as review in the study or used at the end as basis for analyzing the findings. Literature review can use a variety of sources such as specialized librarians, library catalogues, journals and newspapers, books and computerized databases such as Google Scholar and ProQuest. (Creswell 2018, 25-33; Walliman 2010, 54-55.)

Survey questionnaire

A survey studies a sample of a determined population. Surveys help answer three types of questions: descriptive questions, questions about the relationships between variables, and questions about predictive relationships between variables over time. In this form one has prepared questions similarly to an interview, though this can address a much bigger crowd without the presence of the interviewer. This method is very popular for collecting data due to the following advantages:

- Low cost
- Free from bias
- No time or distance limitation
- Can utilize large population in short amount of time and little effort

There are, however, some disadvantages for a survey lacking an interviewer

- Low rate of return
- Requires responder's cooperation
- No control over the process of answering them
- Inflexibility due to pre-drafted questions
- Unclear answers open for interpretation
- Reliability is unknown
- Slower than frontal interview

One should weigh the different questions and aspects of the questions very carefully to make sure they will deliver the required answers, are clear, and easy to transfer into workable information. (Creswell 2018, 147-148; Kothari, C.R. 2004, 100-101.)

Case study

A case study is a research strategy aimed to investigate the particularity of a single case. The case can be a person, an institution or a system. We need to know why we want to conduct this study and how. A case study seeks to answer research questions using different kinds of sources and evidence. Case study commonly adopts three methods such as interviews, observation and document analysis. (Simon 2009, 3-7; Gillham 2000, 1.)

3 Research questions

Company M has shown interest in combining the technology of machine vision in order to improve their quality assurance process and thus their business results. In order to focus the research, I have come up with the following questions which I would want to answer in this thesis.

1. Can machine vision improve quality inspection?
2. How can machine vision be utilized in the quality inspection of company M?

3.1 Limitations of the research

The research work will focus on different technologies that are in use by the company during its serial production phases. It will follow selected number of items to identify which are the possible defects in the manufacturing and in which production phases they occur.

The focus will be on one or two processes that are either more problematic or serve as a strategically important process. After inspecting which possible defects can occur in those stages, a research will be made into what modern machine vision technologies can detect those.

Furthermore, this research will not cover the cost aspect of the new technology but only give a rough estimation as to the cost of such systems.

3.2 Research hypothesis

Since this is a preliminary examination of the process of quality assurance in the factory, and since a new technology will not be tested yet at this point, it will be hard to have a good prediction as to how much the new technology can improve the process. It is, however, my hypothesis that there are applicable technologies out there that can greatly improve the process in the factory both from the quality aspect and from the aspect of time saving.

4 Quality management

Before discussing quality management, we need to first understand what quality is. Most definitions see quality as certain standards, and the way these are achieved, maintained and improved (Zairi 1991, 33). Juran and Godfrey (1998, 2.1-2.2) define quality in two ways:

1. Quality are the features of a product that meet customer needs and thus provide customer satisfaction. This definition focuses on the expected revenue. The better the quality, the better customer satisfaction and thus his willingness to pay more and buy more. Better quality however means a bigger monetary investment and must be checked for its cost effectiveness.
2. Quality means “freedom from deficiencies”, meaning that our product is done correctly without any flaws, need no rework and does not cause any customer dissatisfaction. This definition focuses on the cost of the product. Higher quality means less waste and thus means less monetary investment.

From the two definitions above, one can say they represent the difference between the cost of quality to the cost of poor quality (ibid., 8.2).

4.1 Quality costs

Detecting the point of failure is vital as soon as possible. As seen from Wood (2015, 11) the following figure (figure 1) shows the detection points as a function of the failure cost.

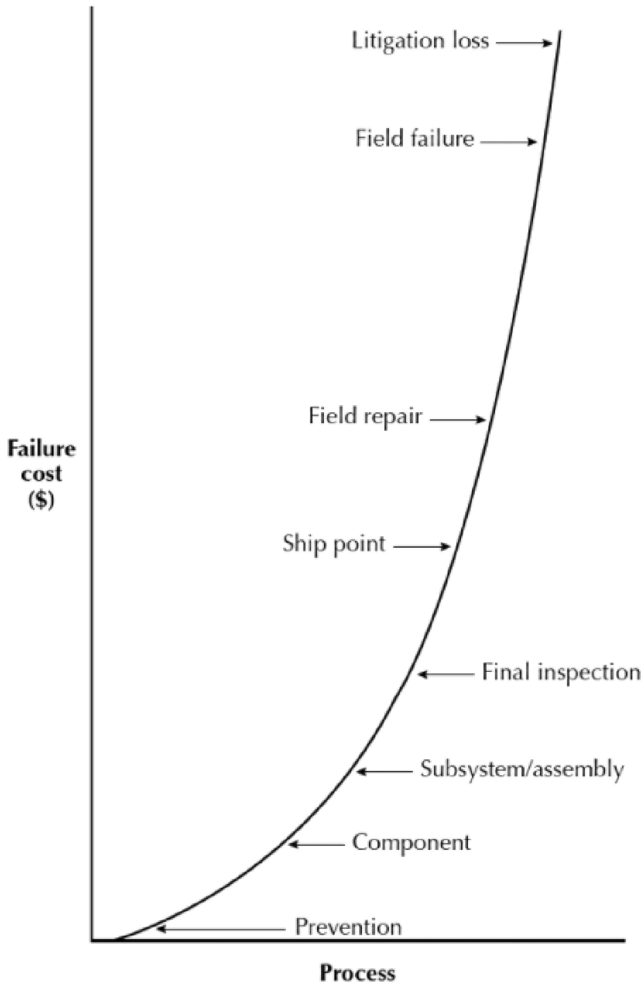


Figure 1. Failure cost as a function of detection point in a process (Wood 2015, 11)

We can see how much potential costs a part gathers the farther we are from the production stage. According to Mahmood and Kureshi (2015, 1), Mohandas and

Raman (2008) define cost of quality analysis as a tool for organizations to improve the outcome of business by identifying the needed measurements to take and eliminate the poor quality. When discussing the cost of poor quality, Mahmood and Kureshi (2015, 1) define those as all those costs that would not exist if the process was executed exactly as needed. They further quote (ibid. 2015, 9) Maycock and Shaw (1994) who found that the cost of poor quality, or failure, mostly falls between 20 to 40 percent of the company's total cost of sales. This indicates how critical the subject of poor quality is to a company's profitability.

Juran and Godfrey (1998, 8.4-8.8) divided the cost of good quality into appraisal costs and prevention costs, and the cost of poor quality into internal and external costs (Figure 2).

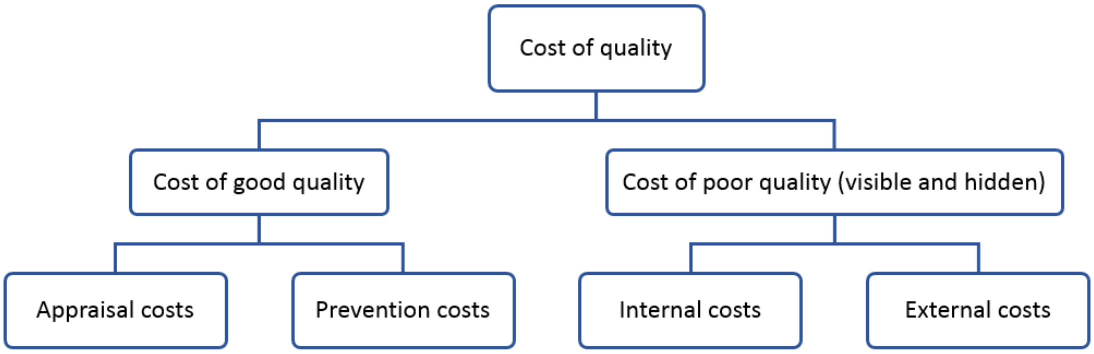


Figure 2. Quality costs. Adapted from Juran and Godfrey (1998, 8.4-8.8)

Prevention costs

Prevention costs are one of the types of good quality costs. Gupta and Campbell (1995, 43) explain, that those are costs spent by the company in advance, to prevent quality problems from occurring, including:

- Quality planning
- Quality control systems
- Quality reporting
- New product development review
- Supplier quality assurance

- Training and improvement programs

Juran and Godfrey (1998, 8.7) further mention the importance of quality audits and exclude from these costs' product design, process design and maintenance and customer service.

Appraisal costs

Appraisal costs are the second type of good quality costs. Gupta and Campbell (1995, 43) explain, that those are costs the company spend to check problems with the product, for it to meet the quality they set for it, including:

- Inspection of raw material
- Calibration and testing
- Work in progress assessment
- Inspection of final product

Juran and Godfrey (1998, 8.7) further mention the need to test the existing stock for degradation.

Cost of poor quality

Costs of poor quality can exceed 100 percent of the organization's total quality, so it is important that we know where the money is going and how we can avoid these losses (Harrington 1999, 221-230). Juran and Godfrey (1998, 3.10) divide poor quality by internal and external failure costs. The failures are those defects that are discovered in house, before the product is delivered. Amongst these failures they named:

- Scrap - defective products or raw material that cannot be economically reworked.
- Rework - defective products that can be repaired, though at a cost.
- Analysis - failure to detect the cause of the defects and so to prevent it from reoccurring.

- Waste - extra products that are created to compensate with expected defects in manufacturing due to bad performance. This can create extra product that goes to stock without use and waste of raw material.

External failure costs come from defects that are found after the customer receives the product. These include:

- Warranty - cost of defects to a product within its warranty period. These include repair or complete replacement of the product.
- Complaints and compensations - the cost of handling complaints and investigating their origin. Here we can also find compensation given for poor quality.
- Recalls / returns – Cost of retrieving defective products and replacing them, including paperwork, correcting billing and shipment.

Internal failure costs come from the internal customer – those within the production organization. External failure costs are associated with the external customer - purchaser, end user, merchant and even the suppliers. (Juran & Godfrey 1998, 3.10.)

Hidden costs of poor quality

While some of the factors causing poor quality are easy to distinguish such as waste, rework and recalls, others might be missed due to not being measured or associated with other activities. Juran and Godfrey (1998, P.8-9.11) name amongst the hidden costs of poor quality:

- Changes in product design due to poor quality
- Cost of Downtime or process change due to quality issues
- Lost sales or customers – company reputation is impacted
- Cost from supporting operations such as customer service

According to Mahmood and Kureshi (2015, 9) Petty (1997) found that the hidden cost of poor quality can be between three and ten times that of the visible costs, yet many companies make decisions according to the visible costs alone.

4.2 TQM and Quality Standards

Total quality management (TQM) is a management approach for organizations based on the participation of all its members, centred on quality, that aims for long-term success through customer satisfaction, and that benefits all in the organization and society. The goal of TQM is constant improvement and producing as little defects as possible. Quality standards are a tool to help achieve a unified standard, such as the quality of TQM, between different companies. (Youssef, El-Hofy & Ahmed, 779; Kalpakjian & Schmid 2010, 1023.)

4.2.1 ISO 9001:2015

ISO is an international organization for standardization, consisting of a worldwide federation of national standard bodies. The members, together with International organizations, governmental and non-governmental, work together with the ISO to promote the standardization. ISO9001:2015 is the updated version of the standard, and it specifies requirements for quality management systems when a company needs to demonstrate the ability to provide products that meet customer and legal requirements. It also aims to enhance customer satisfaction through constant improvement of the processes. (What is the ISO 9000 standard series? n.d.; ISO 9001:2015 Quality management systems – Requirements, 2015.)

Quality management principles

All the requirements of ISO 9001:2015 are generic and are intended to be applicable to any organization, regardless of its type or size, or the products and services it provides. The quality management principles are:

- Customer focus – quality management revolves around the customers. The organization must understand the customers’ current and future needs.
- Leadership – the top management is to work towards involvement of all those in the organization to achieve the organizations’ objectives.

- Engagement of people – it is vital that every part of the organization works properly and is fully involved for achieving the organization’s objectives.
- Process approach – all activities and resources need to be managed as part of a process. The organization should plan the processes and interactions.
- Improvement – continuous improvement should be the objective of the organization.
- Evidence-based decision making – organization must make different analyses and make decisions according to the data collected.
- Relationship management – it is mutually beneficial to maintain a good relationship with the suppliers.

The ISO 9001:2015 sees the process approach, mentioned above, as an added value activity, incorporating the Deming cycle of “Plan, Do, Check, Act” (figure 3):

- Plan: planning the processes and resources needed to deliver the wanted outcome
- Do: implement the plans
- Check: monitor and compare the results against the wanted outcome
- Act: Take action to improve performance if needed

One of the innovations of the ISO 9001:2015 is the division of the ISO by chapters, each characterizing a different step in the process, with the numbers appearing in the figure 3, are those of the corresponding chapters. (What is the ISO 9000 standard series? n.d.; ISO 9001:2015 Quality management systems – Requirements, 2015. Watkins & Orchiston 2016, chapter 5 & 6.)

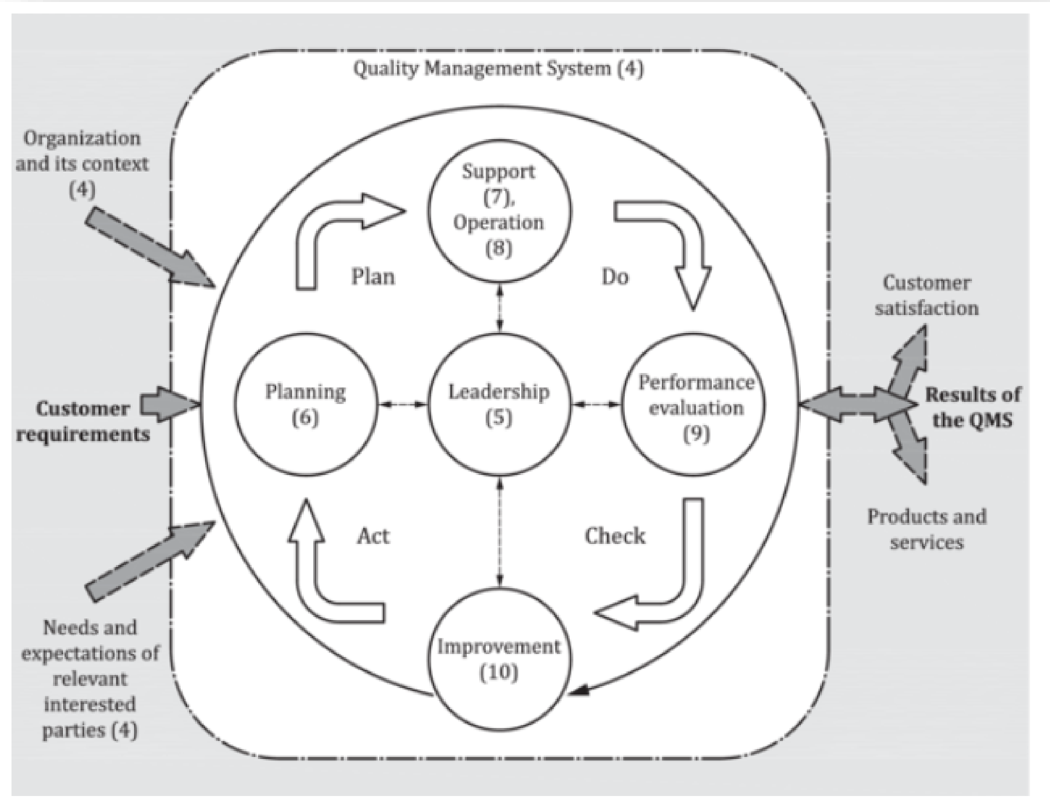


Figure 3. Process approach by Plan, Do, Check, Act (ISO 9001:2015 Quality management systems – Requirements, 2015)

Review of the benefits of ISO 9001 to companies

According to Tari, Molina-Azorin and Heras (2012, 298), Delmas (2001), Braun (2005) and others point out, ISO 9001 standard is not a performance standard to measure the quality of a product, but is a standard aimed to systemize, formalize and document processes. In their literature review of 82 studies, Tari, Molina-Azorin and Heras (2012, 298-303) found the following benefits of ISO9001:

- Improved Efficiency, profitability and systematization (documentation, work procedures, clarity of work)
- Improved customer satisfaction
- Improved employee results -motivation, satisfaction, teams, communication, knowledge and training.
- Increased market share, sales and exports

- Increased competitive advantage
- Improved product quality and image
- Improved relationships with suppliers, authorities and other stakeholders

The results were not identical for all companies, but the clearest benefits were those of improved internal performance and operations, customers and people's results (idib. 303). Regarding financial performance, However, there was no distinct connection found to ISO9001 (idib. 307, What is the ISO 9000 standard series? n.d.).

Risk-based thinking

A risk is the probability that a person is harmed if exposed to a hazard. The same can apply to property or equipment loss. When talking about manufacturing, we can divide those risks in the following way:

- Chemical: Physical and chemical properties, toxicity
- Ergonomic: Repetitive movements, improper workstation
- Physical: Radiation, magnetic fields, extreme pressure
- Psychological: Stress, violence
- Environmental: Air, water and soil pollution
- Safety: Slippery environment, no safety nets, no machine guarding, breakdowns

The ISO 9001:2015 presented new requirements regarding risk-based thinking, meaning that all risks must be identified, evaluated and controlled in all aspects of quality management systems- processes, functions and causes. All risks found will need to have some process to control and improve them. (Youssef, El-Hofy & Ahmed 2012, 843-844.)

In his survey, Chiarini (2017, 314) divided risk causes into 11 categories (table 1). The survey was sent to quality managers of different companies and found that the categories most regarded as vital to be addressed by the companies were internal production of poor-quality products, poorly trained employees lacking skills, poor raw material from suppliers and lack of risk-based assessment.

Table 1. Risk cause categories (Chiari 2017. 314)

Id risk	Risk source category
1	Lack of customer requirements and satisfaction analysis
2	Nonconforming technical results from new product design
3	Lack of risk-based assessment
4	Supplier nonconforming product/service
5	Supplier business continuity problems
6	Production planning and control mistakes
7	Production of nonconforming products
8	Information and communication technologies (ICT) failures
9	Machine and equipment failures
10	Workers badly trained, lack of skills and awareness
11	Acts of God

4.2.2 IATF 16949: 2016

IATF 16949 is an international standard for quality management systems in the automotive industry. The standard was developed by IATF - International Automotive Task Force, a group of automotive manufacturers and their trade associates. The standard is based on ISO 9001 and aims to improve the quality of products of the automotive industry, making it applicable to any manufacturer, assembler or supplier of parts. The principles of IATF 16949:2016:

- Context of the organization – the organization must assess internal and external influences in order to formulate and implement the quality management system. The influences can be anything from the customer to the law, political, cultural and social changes. The organization must understand the needs of stakeholders, determine the scope of the quality management system and ensure conformance with laws and regulations of all products and processes.
- Leadership – similarly to ISO 9001:2015, the top management is to work towards involving all the personnel in the organization to achieve the organizations' objectives.

- Planning – Risk analysis should extend to product recalls, audits, returns, repairs, complaints, scrap and rework, including a contingency plan for those.
- Support – emphasizes a multidisciplinary approach covering risk identification and mitigation. Lab units of the organization and those affiliated should have specific scope of expertise and ability to run needed checks and calibrations.
- Operation - Product and service design and development must apply to all stakeholders and include the suppliers' quality management system development and all product related software.
- Performance evaluation – should include an organization level audit for internal and external performance trends and process criticality.
- Improvement – The organization is required to work for continued improvement and problem-solving, including product software and warranty management system.

IATF 16949 specifies for companies the requirements for quality management system throughout the life cycle of a product - product design and software, production and logistics. The use of FMEA – Failure mode and effect analysis, will bring continued improvements and reduction of defects, variation and waste. Another important point brought upon the ISO 9001:2015 and implemented here, is the importance of documentation. This calls for a process flow layout, production and measuring system capacity. (About IATF, n.d.; Gruszka & Misztal 2017, 331-318.)

4.3 Quality tools

Since quality is so important to the company's product and overall results, different tools were developed to help monitor and manage the different quality aspects. There are different tools that can measure different things and be used in different ways to find the root cause of the quality problems.

4.3.1 Cause-and-effect diagram

The cause-and-effect diagram was developed for manufacturing problems but has since been used for all manners of problems. To create it – we write the effect on the arrow and then add the potential problems to it (figure 4).

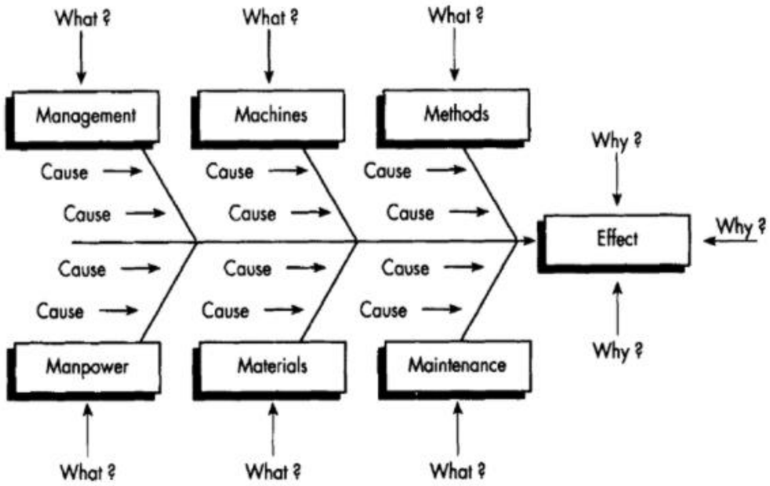


Figure 4. Cause and effect diagram (Zairi 1991)

The stages for building the diagram are: State the problem, Write the major causes in categories, add potential causes to each category and Prioritize the potential causes. We end up with a short list of major causes to which we should ask "why", leading us to the most probable cause. This mapping of the potential problems can help us find the root cause. (Juran & Godfrey 1998, 5.42; Zairi 1991, 103-104.)

4.3.2 Check sheet

A check sheet is a structured, prepared form to collect and analyze data, and by that solve a specific problem (figure 5). There are three types of check sheets: attributed, variable and defect location sheet.

- Attribute check sheet - meant to collect data of the number of defects in a process.

- Variable check sheet – meant to collect data on variables through a process of measurement.

- Defect location sheet – a sketch of a product where the operator can mark the location of the defect by using crosses.

Source of calls received	Monday 9 am- 5 pm	Tuesday 9 am- 5 pm	Wednesday 9 am- 5 pm	Thursday 9 am- 5 pm	Friday 9 am- 5 pm
Sales reps	𝍸 II	IIII	III	𝍸 II	𝍸 𝍸 I
Existing customers	III	𝍸 III	𝍸 𝍸		𝍸 II
General enquiries	𝍸 𝍸 III	IIII	𝍸 IIII	𝍸 𝍸 IIII	𝍸 IIII
Employee relations	IIII	II	𝍸 I	IIII	II
Total	27	18	28	26	29

Figure 5. Check sheet example for a switchboard call monitor (Zairi 1991, 106)

This tool can provide us with facts, so one must design them to collect the right type of information. We must know what data we are searching for, is it going to be an attributed data, meaning binary data that can be counted, or variable data that is to be collected on a continuous scale. An example for a check sheet can be seen in figure 6. (Zairi 1991, 104-106; The 7 basic quality tools for process improvement n.d.)

4.3.3 Control chart

A control chart consists of a graph used to study the changes in a process over time. A stable process should give us a stable distribution with a normal shape bell curve (figure 7) where we can estimate the mean μ and standard deviation σ:

- 68.3% of the variable values will be within $\mu \pm \sigma$

- 95.4% of the variable values will be within $\mu \pm 2\sigma$ or probability of 5%

- 99.7% of the variable values will be within $\mu \pm 3\sigma$ or probability of 0.26%

Comparing the current data with historical data, can give an indication if the process variation is consistent (in control) or is unpredictable (not controlled - special causes of variation). A control chart serves as a tool for stabilizing a process and make on-line adjustments. (Zairi 1991, 114-116; The 7 basic quality tools for process improvement n.d.)

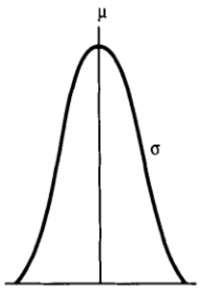


Figure 6. Natural distribution of a continuous variable (Zairi 1991, 114)

4.3.4 Histogram

A histogram is a graph used for showing frequency of distributions, how often a value in a set of data occurs. The data is subject to variation, and different causes show different patterns of variation – the distribution. There are various types of histograms (figure 7) representing different variations, from each we can conclude different things.

- Bell shaped – represents normal distribution.
- Double peaked – two normal distributions indicating two processes.
- Plateau – No distinct peak suggesting there is more than one distribution.
- Comb – alternating peaks showing possible error.
- Skewed – asymmetrical shape reflecting limit in specification on one end.
- Truncated – Asymmetrical shape with peak at the end indicating a part of a normal distribution.
- Isolated peak – two normal distribution suggesting two processes at the same time.
- Edge peaked – Error in data recording.

In case of errors, we can use the different shapes to surmise what is the problem or error in our data. (Zairi 1991, 111-112; The 7 basic quality tools for process improvement n.d.)

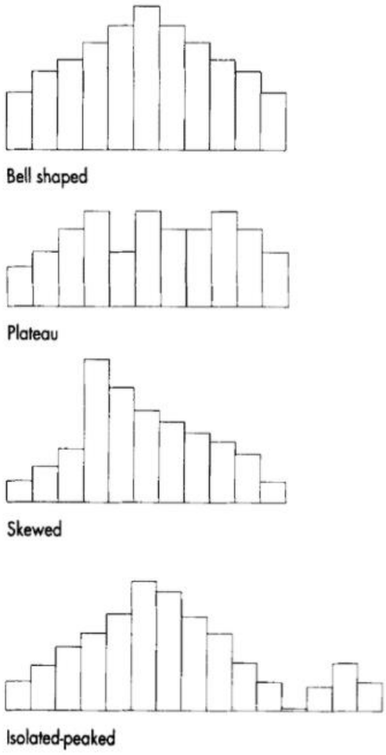


Figure 7. Different types of histogram shapes (Zairi 1991, 111)

4.3.5 Pareto chart

Pareto chart is a tool meant for prioritizing our problem solving. The principle states that in any population that contributes to a common effect, there are the vital few that are responsible for the bulk of that effect. This gave rise to the ABC categorization principle in inventory management and control, in which 20% of materials consist 80% of the total cost. Similarly, in production we can say 20% of all types of errors, responsible for 80% of manufacturing defects. Using the Pareto for analysis, we can divide the different contributing effects into “vital few” and “useful many”. As can be seen from figure 8, Pareto diagram includes three basic elements: the contributors to the effect, ranked by magnitude of contribution (1), numerical expression of the magnitude of each contributor (2) and a cumulative percent of total effect (3). (Zairi 1991, 109-111; Juran & Godfrey 1998, 5.21 & AV.9-11.)

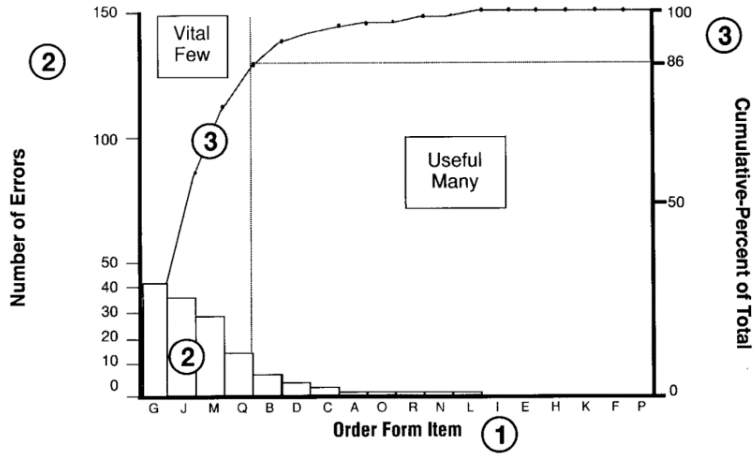


Figure 8. Pareto diagram basic elements (Juran & Godfrey 1998; AV.10)

4.3.6 Flow chart

A flow chart is a pictorial representation of a process. The flow chart must be based on collection of data and information and not include uncertainties. The questions asked must reflect the process by using who, where, what, why. A flow chart is aimed at simplifying terminology and instructions. Can easily be used for specific projects or to define different circumstances. The flow chart uses different symbols that represent a process, operation, input, decision, flowline, start and end. Flowchart is to be drawn from top to bottom, left to right (figure 9). (Zairi 1991, 101-103; Pries & Quigley 2012, 56-57.)

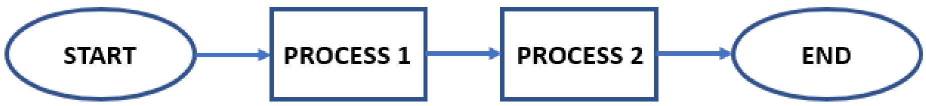


Figure 9. Example of a process chart

4.3.7 Scatter diagram

Scatter diagram is an investigative tool aimed at finding a correlation between two variables. This tool is useful for situations with many variables at the same time. The correlation can be strong and show tight connection between the variables, weak and show weaker connection, or no correlation at all (figure 10). Correlation can be either positive or negative. The relationship indicates correlation alone and not necessarily causation. (Zairi 1991, 112-113; Pries & Quigley 2012, 46-47.)

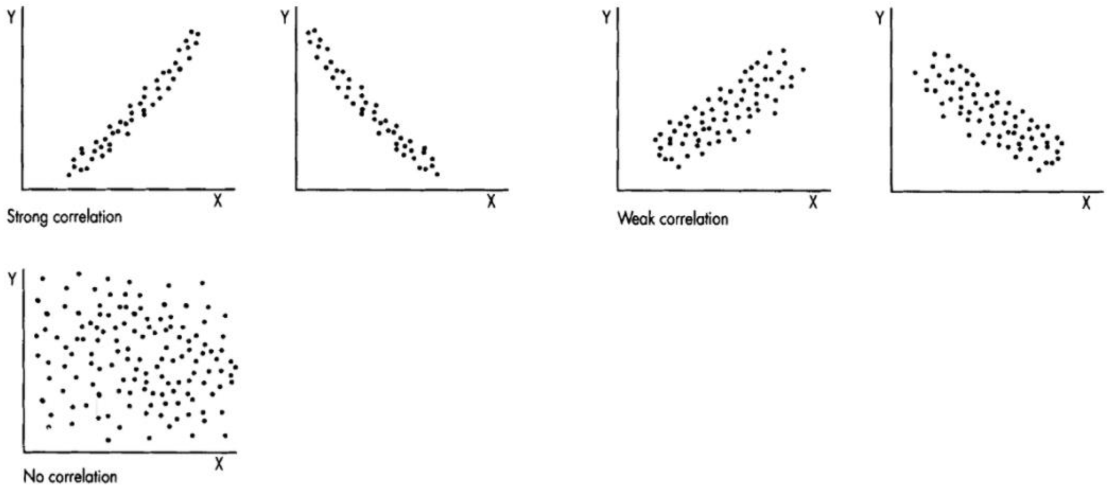


Figure 10. Scatter diagrams (zairi 1991, 113)

4.3.8 8D document

The 8D method is a process of introducing improvements and eliminating problems and errors, and can be used for products, systems and processes. In their book, Zarghami and Benbow (2017, 1.1-1.3) name the different steps:

- D0 Initiation - This stage is the one where the customer or management identify a problem that needs resolving, define it by creating a system of quality alerts and determine the prerequisites. Then a decision is made if this problem requires and 8D team.

- D1 Team approach - One must select and establish a team of people with the relevant knowledge and experience and assign a team leader. The team could be composed of people from different departments, depending on what issues the problem involves, with each offering their perspective. Documentation is an important part of this process and allows for a clear follow-up.

- D2 Define and explain the problem -The team needs to detail specifically what the problem is. The tool used in this is 5W&2H:

    - Who is complaining?
    - What are they complaining about?
    - When did it start?
    - Where is the problem occurring?
    - Why is the problem occurring?
    - How did this problem occur?
    - How many problems are there (measurable and magnitude)?

  It is important that the problem is described in a quantifiable way, so that we can monitor the improvement.

- D3 Interim containment action - At this stage we need to isolate the problem from the customer and contain all problematic parts. This means we might need to make 100% inspection of the part in-house and of the inventory the customer already received. This is only a temporary measure until the root of the problem is solved.

- D4 Root cause analysis - This is the most challenging stage of the D8, in which we must identify all applicable causes and identify why was it not noticed before. For the analysis we will use hard and soft problem-solving tools. Hard tools involve statistical analysis, while soft tools include team brainstorming, five why process, flow chart, checklist, check sheet and cause-and-effect diagram.

- D5 Develop permanent correction action - Once we identify the root cause of the problems, we should decide on the needed corrections. We should use preproduction programs to confirm that these corrections will solve the problems.

- D6 Implement permanent correction action - At this point we need to implement the corrective actions. When implementing the changes in the production itself, the team must make sure that there are no new problems arising from the change, and that everyone is aware and trained for those changes.

- D7 Prevent future recurrences - The team should keep monitoring that the improved process achieves its goal and has no negative affect. We must modify all systems, practices, and procedures to prevent recurrence of the problems.

- D8 Congratulate the team - Recognize the team’s collective effort officially by the organization.

The problem solving is done on an 8D form, is team oriented and has its own supervisor. It is vital that all the steps are properly recorded so that they can be used as an aid for other process improvements. (Zarghami & Benbow 2017, 1.1-1.3; What are the eight disciplines (8D)? n.d.; Krajnc 2012, 118-123.)

4.3.9 A3 report

The A3 report is based on the Deming cycle of Plan-Do-Check-Act. The report is used to define and clarify problems, suggest solutions, record the results and offer improvements. The report itself is divided into a right and left sections (figure 11) with a total of 7 sections:

1. Theme/ title - stating the problem in one to two sentences. Should focus on the problem and not offer solutions.

2. Background needed to understand the problem. No need to add the way the problem was discovered or why it’s important.

3. Current condition using a flow chart documenting the different steps including quantities and setup time. Chart should be easy to read and understand.

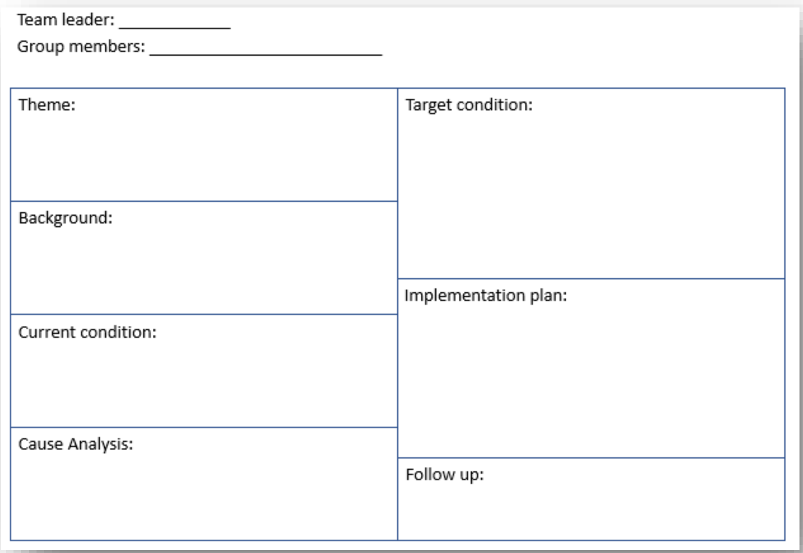
4. Cause analysis – it is critical to have a deep understanding of the root cause of the problem, to make sure to tackle it and prevent it from reoccurring.

5. Target condition – Now that we know the current situation and the root cause, we can offer ways of how to improve and suggest counter measurements.

6. Implementation plan – identify the steps needed to improve the situation and outline them in a plan.

7. Follow up – We need to have a plan to follow the changes and measure how much was the situation improved. It should include some prediction as to how the new system will perform.

The idea of a report of such size is to limit the space and by that eliminate irrelevant information. The focus is to remain on the problem and solution. (A3 Report. n.d.; Sobek & Jimmerson, 2004.)


Team leader: ____________
Group members: ________________________

Theme:	Target condition:
Background:	
Current condition:	Implementation plan:
Cause Analysis:	Follow up:

Figure 11. A3 Report template

4.3.10 Benchmarking

Benchmarking is a continuous process of measuring products, services, and practices against the organization's biggest competitors and the industry leaders. This means that a company keeps comparing themselves to those in the field, to identify those internal practices that need to be improved. The benchmarking process requires learning, leading and then benchmarking (figure 12), and is divided into stages:

1. Benchmarking Planning: Company needs to recognize the need for benchmarking process, decide whom and what to benchmark, choose processes or products, and with which companies.

2. Data Collection, Validation and Normalization: We should plan how to conduct the investigation and collect the data. Establishing a professional help desk for the data collection could make the process more efficient. One must put also emphasis on the data validity to avoid inaccurate data from leading to misguided conclusions. Normalization is also a critical point, since without it, it would be very difficult to compare benchmarked subjects from different sources.

3. Analysis and Reporting: once we have all the information, we must analyze it in an impartial and objective manner. We must have a full understanding of the internal processes and only then compare them to the normalized information we have from other companies. This provides us a basis on which we determine what needs to be done. Once the analysis is concluded it should be reported to the participants. Confidentiality is a big factor, since with higher level of confidentiality, the lower the learning potential.

4. Identifying leading practices: The benchmarking process requires transferring the knowledge gathered from the practitioners to the other benchmarks. Only by transferring the knowledge can we maximize the effectiveness of the process and achieve higher success. To achieve it, one can hold internal forums in the company, one-to-one benchmarking in a group to explore issues in greater detail, and lead practice sharing forums, to share information between top performing companies, to the benefit of all.

5. Understanding performance gap: After the benchmarking findings we will need to evaluate the performance gap found, prioritize improvement in the areas needed, allocate resources to fix problems and bridge the gap, and lastly plan controls to supervise the changes.

6. Implementing improvement projects: The company must now implement those plans while monitoring the progress.

7. Evaluating outcomes and replicating learning: Benchmarking is a continuous process, meaning that the process and outcome should be evaluated and refined before repeating.

It is important to remember the legal and ethical aspect of benchmarking. Benchmarking means sharing knowledge and information while remembering to control its use, since intellectual property can be exposed in the process. (Juran & Godfrey 1998, 12.2; De Feo 2017, 524-532.)

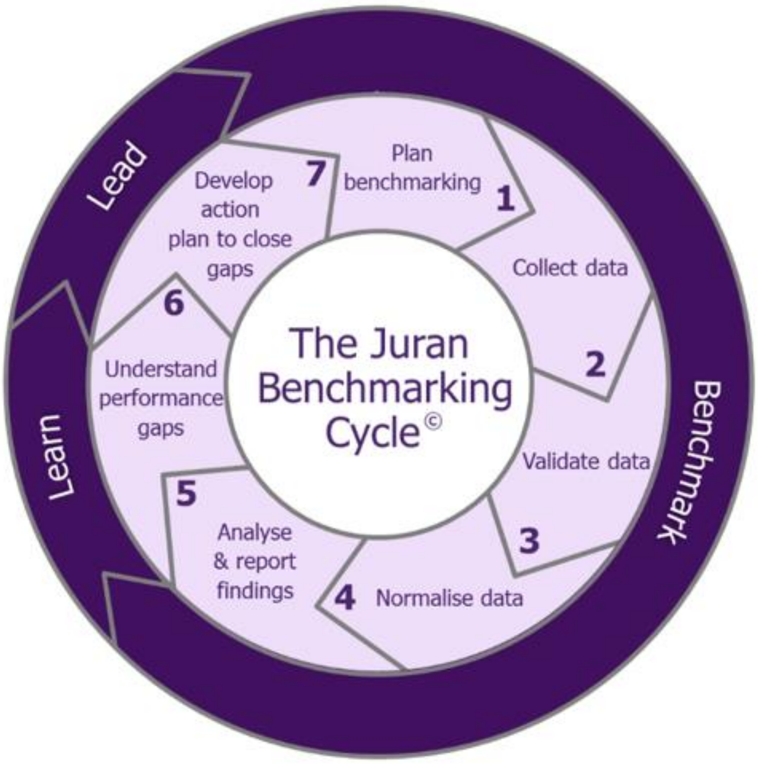


Figure 12. Benchmarking process (Juran Benchmarking - Our approach n.d.)

4.3.11 Customer satisfaction survey

Customer satisfaction is a measurement of how content customers are with a company's products, services, and capabilities. When we discuss customer satisfaction it is important first to clarify who is the customer and what is a deficiency. Customer is defined as anyone who is affected by the product or production, meaning they can be external or internal. A deficiency can be any fault that impairs the product's quality, by either definition, or its process. Understanding these two concepts enables us to discuss what is customer satisfaction and dissatisfaction:

- Customer satisfaction: the customer feels their expectations from the product were met.
- Customer dissatisfaction: the customer feels their expectations from the product were not met. This can be a matter of quality problems such as defects but can also be simply an attribute the product lacks.

Customer satisfaction surveys can help the company to determine where and how to improve. (Juran & Godfrey 1998, 2.3; What is customer satisfaction? n.d.)

4.4 Quality measuring and inspection tools

Inspection is an organized examination or formal evaluation. The inspection involves measurements, tests and gages aimed to check the characteristics and function of an object. The result is compared to the specific requirements and standards the object must comply with. In production some deviation can always occur, so some deviation in dimensions is acceptable - this is called the tolerance of the parts. Tolerance is the amount of variation in size that a part can tolerate. It can be the maximum or minimum size limit, or other variation depending on the work grade needed. Working tolerance can be bilateral or unilateral (figure 13). The deviation from the basic dimension at the edge of the tolerance zone are called upper and lower deviation while their average called mean deviation:

- Bilateral – when tolerance can be on both directions of the desired size.

- Unilateral – when tolerance can be only on one direction of the desired size (zero tolerance on the other size).
- Mean deviation – the average between the upper and lower deviations of any size of the part and the basic size.
- Upper deviation – the difference between two maximum limits of any size and the corresponding basic size.
- Lower deviation – the difference between the minimum limit of any size and the corresponding basic size.

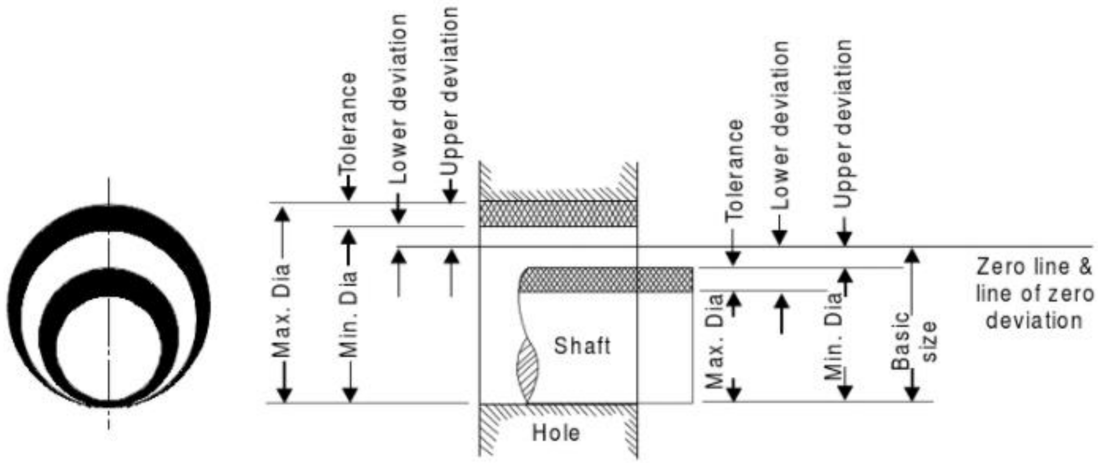


Figure 13. Upper and lower deviations for a shaft and the hole (Singh 2006, 468)

There are further fittings that need to be checked when discussing assembled parts such as clearance fit, interference fit and transition fit. Surface finish is another requirement that has become essential for product quality, not only for esthetic reasons but also functional such as when a protective coating surface is needed to extend the product life. (Campbell 2013, 1-2; Singh 2006, 467-471.)

4.4.1 Quality inspection methods

There are many different tests and inspection tools to check the metals after production. The different methods check different properties such as physical, chemical, thermal, electrical, magnetic, optical and mechanical properties:

- Hardness test – Method used to predict strength of metals. All heat-treated steels are subjected to hardness testing to verify the heat produced the wanted hardness, which in turn indicated the metals' strength.

- Tensile test – Method used to evaluate the mechanical properties of the material. During this test the part is destroyed since the part is checked for its yield and failing stress and for that uses samples from a batch.

- Chemical analysis – Method used to determine the composition of metals and alloys using x-ray fluorescence and optical emission spectroscopy.

- Metallography – Method aimed at determining the material structure at the surface or a cross section of a sample. It helps to detect possible problems rising from casting, welding and fabrication imperfections.

- Liquid penetration inspection - Non-destructive test aimed to find flaws of solid surfaces such as cracks, laps, porosity and shrinkage.

- Magnetic particle inspection – aimed at inspecting discontinuities in ferromagnetic materials, which might cause magnetic discontinuities in case of magnetizing the material.

- Eddy current inspection – aimed at identifying differences in conductivity of ferromagnetic and nonferromagnetic metals.

- Radiography inspection – test using the radiation absorption of different materials and compositions to test the consistency of a test piece by measuring the radiation that can pass through it.

- Ultrasonic inspection – test using high frequency acoustic energy to detect surface and subsurface flaws, test thickness of materials and depth of flaws.

Some of these test methods are non-destructive, meaning they are used on the parts without causing any hard to them, such as hardness test. Other tests are destructive meaning the sample parts tested are destroyed in the process, such as tensile strength test. (Campbell 2013, 5-19; Singh 2006, 122-127.)

4.4.2 Visual inspection and CMM

Visual inspection is a method enabling us to detect a variety of surface flaws such as corrosion, contamination, cracks, surface finish, quality of welds and seals. Visual inspection is the most common method of detecting flaws that can cause structural failure. Visual inspection uses different tools such as magnifying devices, special lighting, measuring devices and recording tools. Coordinate measuring machines (CMM) are machines used to inspect finished products using probes and moving arms that provide measuring input with or without the involvement of an operator. The CMM measures individual points in space and computes them. It can measure many features including position of features related to part coordinates, distances between features, size, forms (flatness, circularity, cylindricity) and perpendicularity. The CMM probes are mounted on the articulated arms to measure the position once the probe contacts a surface. A computer makes calculations based on the information from the CMM and comparing it with the wanted measurements. CMM is also used to control manufacturing processes and reverse engineer designs from part to a computer rendered imagine such as CAD. The machines can include contact and non-contact probes that allow for different measurements. The machines can be accompanied by an analysis software that interpret the measurements to keep up with the production. These developments gave rise to machine vision technology, as discussed in the next chapter. (Campbell 2013, 1-3 & 21-44; Hocken & Pereira 2012, 30; Coordinate Measuring Machines. n.d.)

5 Machine vision technology

Machine vision is a constantly developing field of industrial inspection and quality control and is widely used in the automotive and electronics industry. Machine vision's capabilities include shape identification, measuring distance and range, gage size and dimensions, determine part orientation and surface shading. The machine vision system consists of a host computer that controls the process, an image acquisition tool (camera), a light source and machine vision software (figure 14).

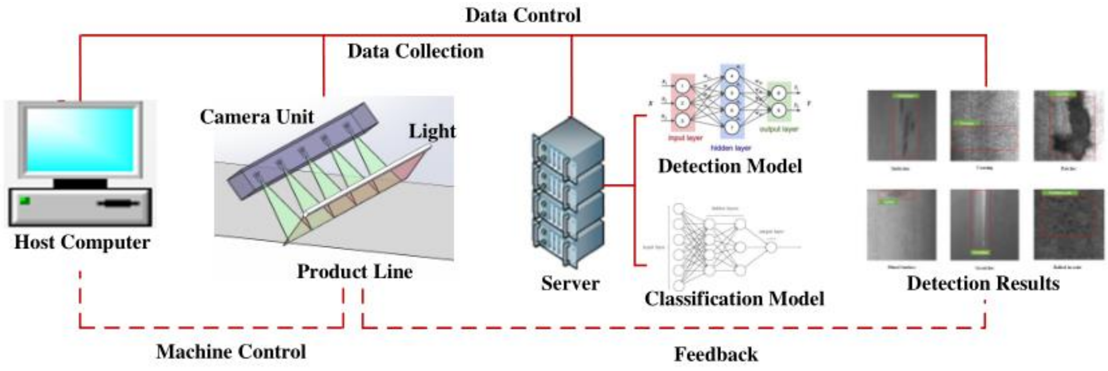


Figure 14. Machine vision system (Lv, Duan, Jiang, Fu & Gan, 2020)

The software in turn can use online datasets for detection and classification. To choose the different technology of the machine vision system we need, we must consider different aspects like cost, what part we are inspecting, the performance required of the of the system, such as accuracy and speed, the interface, the environment in which it is performed and the available space to put it. Related to the chosen part, there are different aspects we need to take into consideration:

- Single part or continuous material (such as a metal sheet)
- Minimum and maximum dimensions
- Change in shape
- Shading
- Part orientation detection
- Must have full description of the features required
- Variation of the different errors that can be (in a form of dataset of defects)
- Surface finish, colour, corrosion, oil residue
- Changes due to handling – labels, fingerprints

Other than that, we need to take cost into consideration - the return on investment. The performance of the system must be accurate and fit a time limitation such as processing time and cycle time. The environment of the system needs to be checked for factors that can affect the image acquisition, such as lighting, dirt or dust, vibrations and temperature. (Campbell 2013, 3-4, 64; Davies 2005, Xxi; Tang, Kong, Wang & Chen 2009, 359; Hornberg 2017, 33-35.)

5.1 Benefits and challenges of machine vision

Machine vision has many benefits, such as:

- Providing 100% inspection of production with the full speed of the production line.
- Immediate detection and classification of defects saves valuable time and production to reduce possibility of defects.
- Improving real-time process control, high productivity and reliability, reduced waste.
- Inexpensive and safe (no human involvement) inspection.

As for the challenges of machine vision, wrong calibration or placement of the parts can cause problems in image acquisition, such as: motion of the camera, poor or wrongly placed illumination, variations in sensor response, lack of proper contrast, deformed letters on labels and similar overlapping parts. (Tang, Kong, Wang & Chen 2009, 359; Campbell 2013, 72-74.)

5.2 Camera type and image acquisition

The first step in the machine vision process is acquiring the image of the work piece we want to inspect. It is fundamental we choose the correct design of camera, or sensor, for our machine vision system, since it influences the choice of the hardware and image we acquire. We will need to choose between area camera and line camera (figure 15).

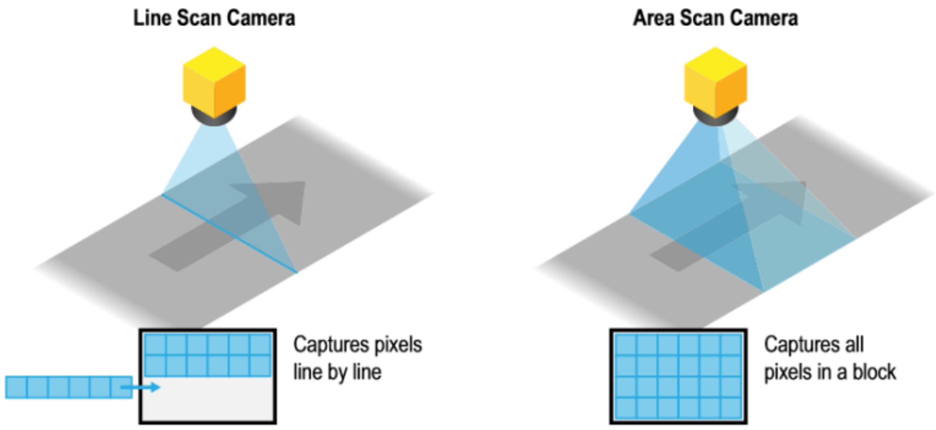


Figure 15. Comparison between Area and Line scan cameras. (metrology n.d.)

- Line camera – Suitable for moving parts like a surface of a cylinder or a continuous metal sheet. Acquires a line of pixel at a time. Adjusting is complex. More expensive than area cameras. Since the image is continuous, this allows higher resolutions than area cameras in both 2D and 3D.

- Area camera - common in automation. Acquires an area of pixels. Setup is relatively easy. Cheaper than line cameras. Since they are more general purpose, they are used in most machine vision systems.

Other considerations pertaining to image acquisition is the field of view. When capturing an image, it is important to consider not only the optimal size of the item, but the size needed to capture the image if it is off set (figure 16). (Hornberg, 2017, 36; Line-scan vs. area-scan cameras: What is right for your machine vision application, 2017)

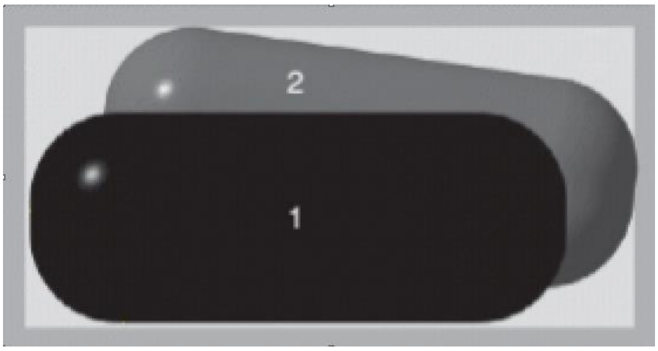


Figure 16. Field of view (adapted from Hornberg, 2017, 37)

5.3 Choice of Camera, frame grabber and hardware platform

For the choice of camera that will provide for the image we need, we will need to take into consideration different requirements such as colour sensor, interface technology, packaging size, price and availability. There are different types of image sensor cameras such as vidicon cameras, charge-coupled device (CCD) image sensor and solid-state cameras. The choice of frame grabber, the electronic part that captures the frame or video stream, needs to be compatible with the camera of choice. Pixel rate is the speed of imaging received as pixel per second for line camera, and for area cameras, is the vertical resolution times the horizontal resolution times the frame rate, and all that in addition to overhead of about 10-20%. Resolution is also an important aspect when choosing a camera, since different cameras can provide different resolutions which are essentially the number of columns and rows of pixels and the size of a pixel. The more pixels, the higher the resolution – the details – that are in a single picture, and the greater chance to find the irregularities in the part. The frame grabber needs to also take into consideration: compatibility with the pixel rate and software library, the number of cameras used, available on time processing, price and availability. When discussing the hardware platform, we will need to decide between a smart camera, compact vision system or PC-based system. Choosing between these takes into consideration the operation system, compatibility of the different parts, used friendly interface, memory and packaging price. (Hornberg 2017, 38-41; Campbell 2013, 63 & 68-70.)

5.4 Illumination

The placement of the light source is a consideration to take, since it effects the contrast of the image acquired. There are many optional types and settings for the illumination (figure 17):

- Backlight - maximised the image contrast and is adequate if we want to have a silhouette of the part (such as with part recognition).
- Frontal light will give us the features of the surface of the part.
- Side/ structured light - When a 3D image of the item is required.
- Diffused light - when the light is provided from all angles.
- Direct light – light is provided from a range of angles.
- Confocal front light – light comes from the direction of the camera's optical axis.
- Bright field – Direct light that is reflected by the part's surface. Areas that do not reflect will appear dark.
- Dark field – direct light. The reflected light is directed away from the camera – irregular parts will reflect and appear bright.

There are also different types of light sources, such as fluorescent lights, Halogens, Xenon lamps, LED and laser. (Hornberg A. 2017, 45-46; Campbell 2013, 68-69.)

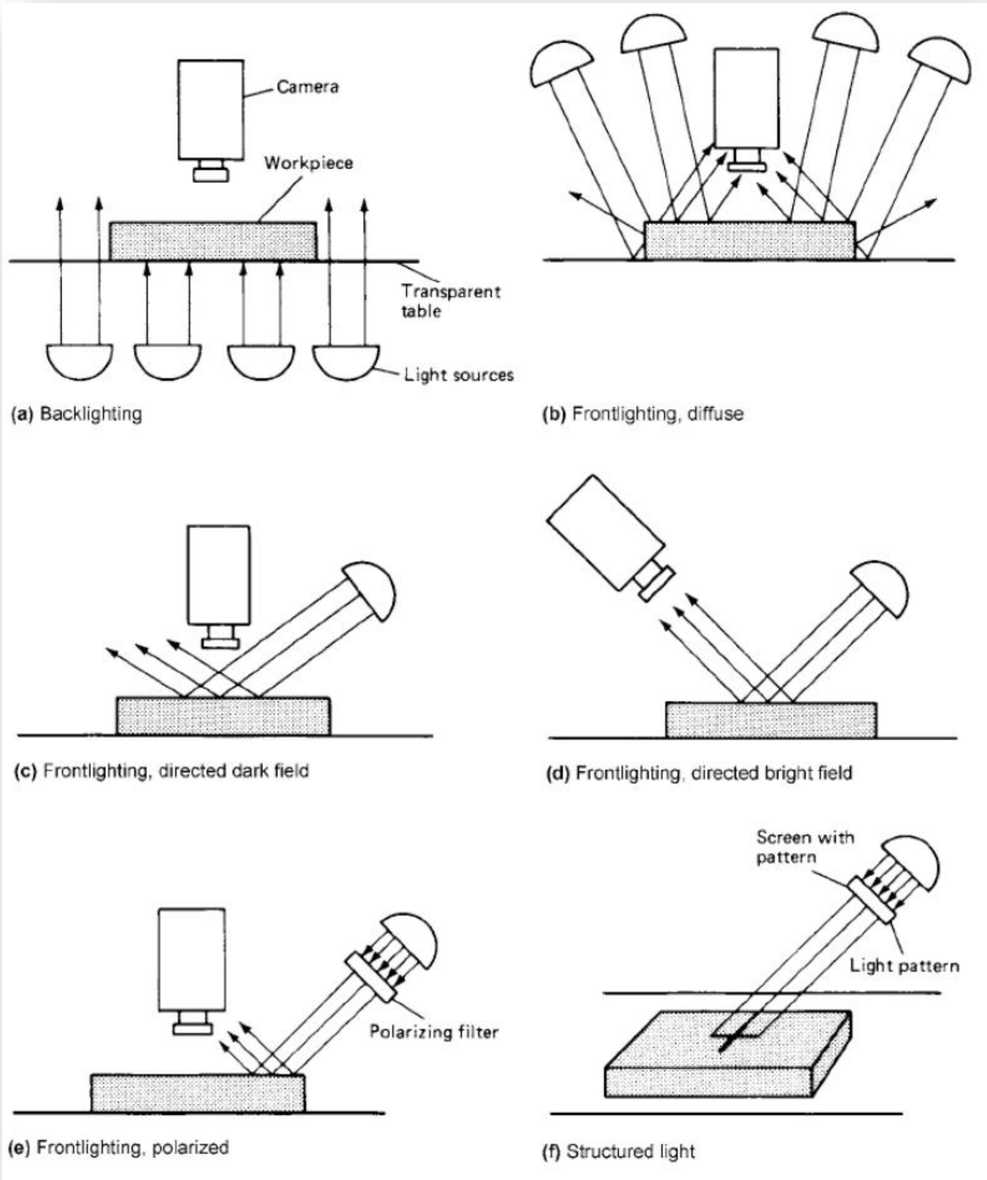


Figure 17. Illumination techniques for machine vision systems (Campbell 2013, 69)

5.5 Software and Deep Learning

After acquiring the image, we will need a software to extract the information from the digital image. The software needs to recognize the part, locate the specific features, calculate measurements and compare them to the model specifications. The system uses different algorithms to evaluate the components. In many cases there is use of software libraries, featuring different algorithms (table 2). In complex situations such as factory automation in manufacturing, it might be needed to use algorithm-based learning tools, that utilizes datasets. A dataset is a collection of data, in the case of machine vision. It will include algorithms and a database of digital photos that developers use to test, train and evaluate the performance of the algorithms. Detecting defects in metallic surfaces can be problematic, since it is influenced by the illumination, light reflection, and the type of metal used. There is a high variation of defects, requiring vast datasets. An example of datasets can be seen in table 3.

Table 2. Machine-vision system-supplier software library (Campbell 2013, 80)

Tool	Function	Applications
Search	Locates complex objects and features	Fine alignment, inspection, gaging, guidance
Auto-train	Automatically selects alignment targets	Wafer and PCB alignment without operator involvement
Scene angle finder	Measures angle of dominant linear patterns	Coarse object alignment, measuring code angle for reading
Polar coordinate vision	Measures angle; handles circular images	Locating unoriented parts, inspecting and reading circular parts
Inspect	Performs Standford Research Institute (SRI) feature extraction (blob analysis)	Locating unoriented parts, defect analysis, sorting, inspection
Histograms	Calculates intensity profile	Presence/absence detection, simple inspection
Projection tools	Collapses 2-dimensional images into 1-dimensional images	Simple gaging and object finding
Character recognition	Reads and verifies alphanumeric codes	Part tracking, date/lot code verification
Image processing library	Filters and transforms images	Image enhancement, rotation, background filtering
V compiler	Compiles C language functions incrementally	All
Programming utilities	Handles errors, aids debugging	All
System utilities	Acquires images, outputs results, draws graphics	All
C library	Performs mathematics, creates reports and menus	All

There are deep learning tools that use artificial intelligence and can be employed in manufacturing to automate and scale complex part location, verify assemblies, detect defects and perform classification. (Hornberg A. 2017, 46-48; Introduction to machine vision - Cognex n.d., 16; Campbell 2013, 77-81; Malevé 2019.)

Table 3. Example of datasets for defect detection

Dataset	Images	Categories	Defect Type categories
NEU-DET	1800	6	rolled-in scale, patches, crazing, pitted surface, inclusion, scratches
GC10-DET	3570	10	punching, weld line, crescent gap, water spot, oil spot, silk spot, inclusion, rolled pit, crease, waist
Steel Plates Faults	1941	7	Pastry, Z scratch, K scratch, stains, dirtiness, bumps, other faults

5.6 Costs

A major consideration with every new technology is the issue of cost. Many companies do not offer specific information and online pricings, and due to the huge variety of hardware, software and specialized requirements, it is very difficult to have a good estimation. To get some information and measure of the cost, the help of a teacher from JAMK, who has experience with purchasing such systems, was needed. The email includes the following communication and can be found in appendix 10. Mr Riekkinen’s opinion is that the system costs for these applications greatly depend on the accuracy and area requirements. The accuracy can vary between +-1mm, +-0.1mm and +-0.01mm, and the cost rises with the accuracy needed. If the need is just for a certain pattern or an existing property, the check will be much simpler and needs less accuracy. The size of the scanned area is also a factor in the cost. Machine vision systems cost from a few hundreds to tens of thousands of euros. While it is possible to get all component costs at around 1000€ including camera and cheap lightning, most of the systems, that include components and some designing and programming, will cost a minimum of 10k€. If no other specifications are available, it would be wise to make a budget of 20k€ for this kind of application. (Riekkinen 2020.)

6 Case study – Company M

Company M is a company specializes in metal component manufacturing for different industries, including the automotive industry. The company has over 2000 customers and employs over 250 professionals. Due to the high number of customers there is a big variation of components. The components are produced mostly in-house according to lean manufacturing- from metal sheet to assembly, excluding painting and coating. The company has several branches specialized in different technologies. The factory inspected uses different types of steel – mainly DCO4 and DCO6 that are both deep drawing steel that are good for formability. DCO4 is cheaper but the material ages and formability decreases after approximately 6 months. DCO6 is more expensive but has no aging effect. The factory also uses DX53 and DX54, that have deep drawing quality as base material, and other types of metals, in lesser quantities.

6.1 Quality in Company M

The company's KPIs include Quality performance of over 99%, on time deliveries of over 98%, zero injuries at work and personnel trust index of 68. Company uses SIM, Short Interval Meeting with visual management tools, in all operations. They put great importance in customer satisfaction and as mentioned, have high standards for their quality. Company M follows ISO 9001 quality standard and since they manufacture components also for the automotive industry, they also have an IATF 16949 automotive quality certificate.

6.2 Technologies in Company M

Metal forming can be defined as a process in which we obtain a desired size and shape through metal deformation by using specified instruments and applying force. Metal forming is wasteless, highly accurate, gives easy formability and desired metallurgical properties. The processes are based on plastic deformation of the metal. Elastic deformation is the ability to get back to the original shape once the stress of the load is removed. Plastic deformation means the material undergoes permanent deformation, without failure, so it retains the new shape upon removing the load. (Singh & Dwivedi 2009, 63-64.)

The core business of company M is manufacturing metal components using different metal forming methods. The company uses CMT (cold metal transfer) welding technology which is best for sheet metal parts since it does not cause deformation. (Group quality manager in Company M, 2020.)

6.2.1 Blanking

Production starts from cutting blank metal sheets to size and adding guiding holes in preparation for deep drawing (figure 18). Metal sheets are usually delivered as large coils or sheets. They need to be cut fit the needed size and pierce guiding holes. (Hu, Marciniak & Duncan 2002, xiii.)

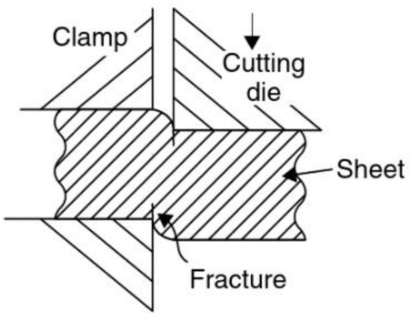


Figure 18. Basic cutting process (Hu, Marciniak & Duncan 2002, xiii)

Blanking can also be used to cut from a metal sheet a piece, which will serve as our work piece, using a process very similar to punching (figure 19). The difference between this blanking and punching, is that the product in this case is the piece we cut out. The process is most likely to make the material at the edges hardened locally. (Singh & Dwivedi 2009, 94.)

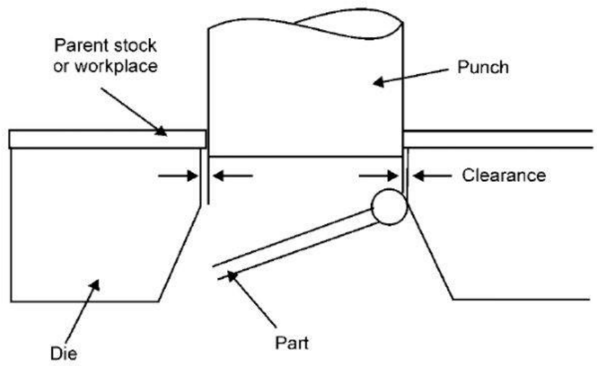


Figure 19. Blanking (Singh & Dwivedi 2009, 94)

6.2.2 Punching

Punching is a term for cutting an opening, in a part or metal sheet, to create holes and slots. Punching is a similar process to blanking, only here during the punching, the piece produced - the slug, is scrap. The diameter of the hole depends on the punch diameter (figure 20). (Singh & Dwivedi 2009, 94-95; Kalpakjian & Schmid 2010, 385.)

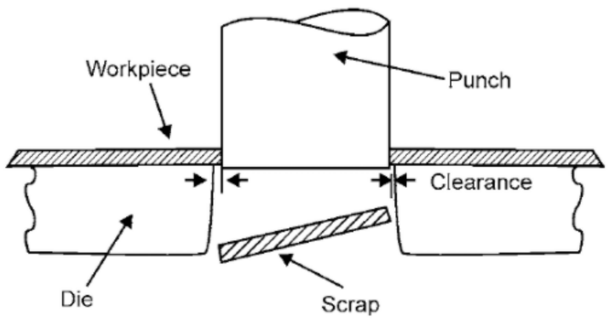


Figure 20. Two-dimensional look of a punching process (Singh & Dwivedi 2009, 95)

6.2.3 Stamping / Pressing

Stamping process can be defined as a plastic deformation process of reshaping a metal sheet blank to form shallow parts in the metal surface. During the Stamping process, as can be seen in figure 21, the blank is clamped (a), stretched by the punch (b) and the further stretched from the counterpart (c). Stamping process consists of a punch, a draw ring and a blank holder. The shape is obtained by using a die and if needed, a counterpunch. (Hu, Marciniak & Duncan 2002, 45-46; Omar 2011, 15.)

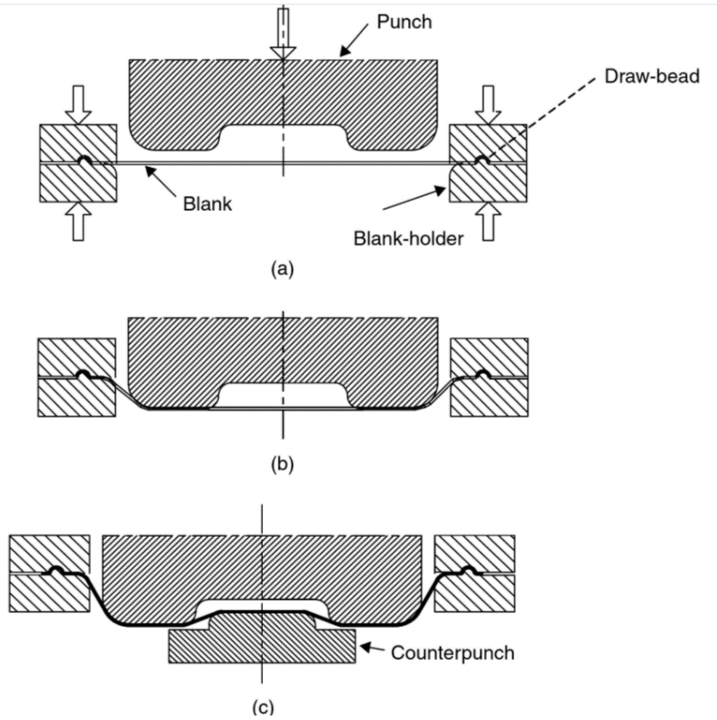


Figure 21. Stamping process (Hu, Marciniak & Duncan 2002, 45)

6.2.4 Deep drawing

When discussing deep drawing, Hu, Marciniak and Duncan (2002, xvi-xvii) claim, that there is a limitation to how much a metal sheet can be stretched before tearing. For this reason, in the process of stamping, the parts are shallow. To form deeper parts, we must pull more material inward, claiming the name deep drawing.

Deep drawing is a process of plastic deformation taking place inside a hydraulic or mechanical press. In the process, a metal plate is pressed to form into a recessed three-dimensional part with a depth much thicker than that of the metal. The figure below (figure 22) shows us the process of deep drawing. The center part is pressed into the die opening while the corners are held in place by the binder ring. The binder ring is exerting force to hold the blank in place, and another one to punch the metal into shape. It is important to have the surface lubricated to reduce the friction and allow the blank to stretch over the punch. Also, there is some radii clearance between the punch and die, and curved sides, to prevent the part from tearing. (Singh & Dwivedi 2009, 99-101.)

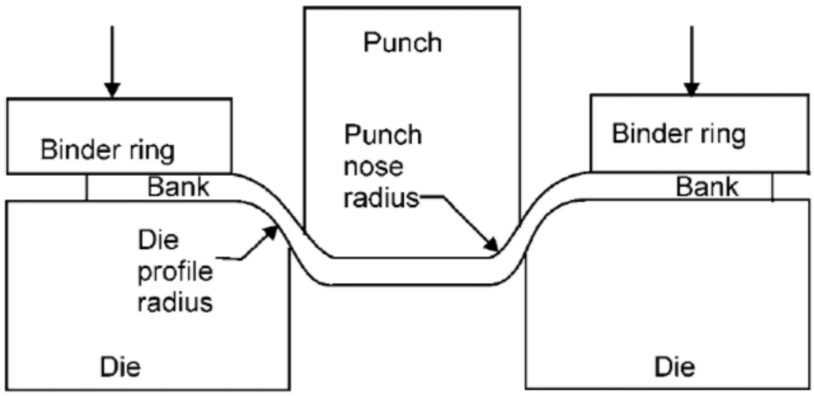


Figure 22. Method of deep drawing (Singh & Dwivedi 2009, 100)

Defects of deep drawing

In his article, Zaid (2016, 7-8) names the following defects that can occur during the deep drawing process

- Thinning due to ironing – Reduction in the wall thickness of the part. There is always reduction to a certain point, but it needs to be within a given range.
- Galling / scratches - surface damage to the part in which some of the material transfers from the product to the surrounding die (figure 23a).
- Orange peeling – occurs when the sheet metal has big grain size that, when stretched, creates an uneven surface resembling orange peel (figure 23b).
- Earing – formation of ears or ruffles around the top of the drawn piece. This results from directional difference in the plasticity of rolled metal with the different directions of rolling (figure 23c).

- Tearing/ fracture – Can happen when the rim holding the blank stops it from sliding and bending over the die profile to be able to draw deeper (figure 23d).

- Buckling/wrinkling – Uncontrolled deformation of the surface causing a bend, kink or other wavy condition of the part. It can also be called puckering depending on the position of the deformation (figure 23d).

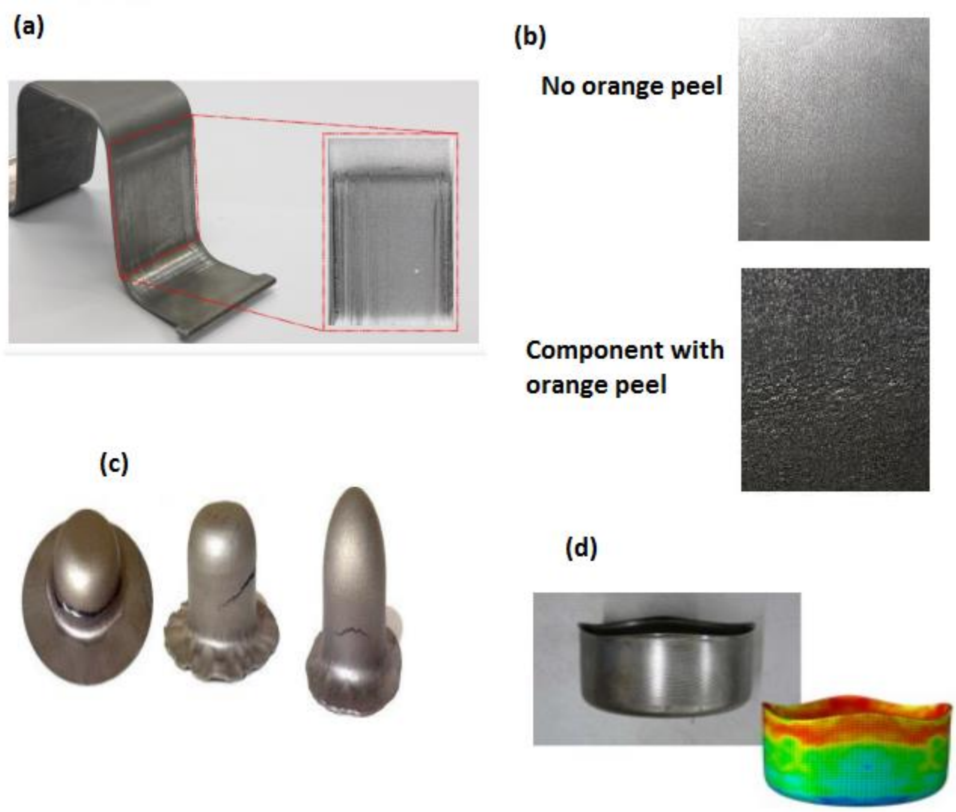


Figure 23. Deep drawing defects (Voss B. 2018; Industrial metallurgists LLC n.d.; Zaid 2016)

According to Hu et al. (2002, xvi-xvii) some of the problems in deep drawing occur due to lack of proper lubrication, use of wrong, untreated or damaged raw material or a too hard of a grip.

6.2.5 Laser cutting

Laser cutting is a thermal cutting process used to cut a variety of shapes, in a variety of thicknesses. The laser heat is concentrated on the workpiece until the metal reaches a liquid or vapor state, and then removed with gas-pressure flow. Different metals require different heat for the process. Use of oxygen as an assist-gas can increase the heat of the cutting process. (Caristan 2004, 17.)

The laser cutting process is fast and results in low deformation with a narrow heat affected zone due to the focus of the beam. The high-power density allows for a high cutting speed and with it a high edge quality, meaning that it can minimize material waste to the point of making the cut itself as the border of adjacent patterns, with no waste of material between. It is also environmentally friendly being quiet and easily to isolate for ventilation purposes. (Ion 2005, 35.)

Company M uses a laser mounted on a robotic arm, allowing it to perform 3D laser cutting. The 3D technology allows for cutting in different places and angles. The laser is also used to bore holes and create exact borders to the different parts that are manufactured. There is no use of visual input in this process. For the cutting to be accurate, the part is mounted on a rig in a pre-decided manner, to match the programming of the laser cutting robot.

Defects of Laser cutting

In their quality inspection, company M named a few key defects that rose from the process:

- Dirty tool – the rig or surrounding stained the part.
- Dents - due to wrong positioning or handling.
- Holes too close to the edge – misalignment of the parts in the rig.
- Asymmetrical pieces – Can occur from misalignment of the parts or wrong calibration.

- Unfinished cutting or missing holes - failure of the laser machine or the programming.

- Burr – during the cutting there is a lot of heat put into the process. Depending on the gas used, it is possible the heat in the process is increased, making more material melt, and if the air pressure is not high enough, the material will become solid again before it is blown off by the air pressure. The material left at the edges creates a dripping pattern on the edge (figure 24). As mentioned, this can happen due to low air pressure, but also due to wrong operation of the laser, too high feed rate, or too high focus.

We can see that some of the problems are due to human error, while others are due to wrong calibration of the machine or program.

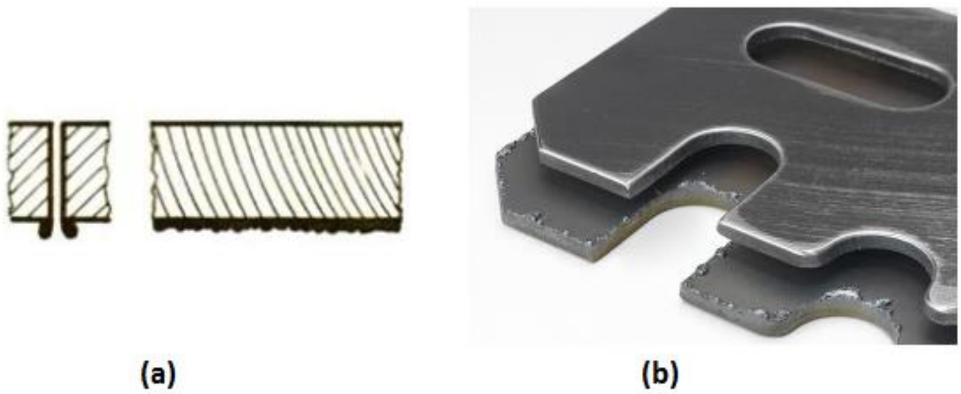


Figure 24. (a) Cross section of a burr (b) An example of a piece with and without burrs. (Yang 2017; Velling 2019)

6.2.6 Welding

Welding is a process of joining two metals with the help of heat, pressure or other means. Welding is cost effective and fast, when compared to other joining processes. Welding creates a strong joint, making it widely used in manufacturing of machine tools and auto parts. A welded structure is normally lighter than riveted or bolted structure and alterations to it can be easily made. Welding can be done either by forging /applying pressure, without the addition of filler material, or can be done by fusion using additional filler material. Welding is done both by machine and by hand. The welding robot uses CMT (Cold Metal Transfusion) technology, a welding method that fits best for machine part manufacturing since it causes no deformation. The robot welding is directed by a program that has no visual input, similar to laser cutting. The part is mounted on a rig to match the programming. A mounting error will produce a defective part, since the laser machine has no machine vision by itself, and follows the location pre-set by the program. (Singh & Dwivedi 2009, 167-168; Group quality manager - Company M, 2020.)

6.2.7 Grinding

Grinding is a metal cutting process utilizing an abrasive tool called grinding wheel. The wheel is made from hard and heat resistant abrasive grains. The size of the grain depends on the amount of material to be removed, the desired finish and the hardness of the material worked on. The process is used as a finishing step giving an accurate good surface finish. Depending on the desired finish, the grinding machine can allow us to perform different operations such as polishing, buffing, lapping, honing and super finishing. This process is only not needed for all parts. It is mainly important to remove sharp edges and scratches for safety and esthetic reasons accordingly. Company M uses a grinding robot which is faster and has higher precision than manual grinding. (Singh & Dwivedi 2009, 158-163; Kalpakjian & Schmid 2010, 746-748.)

6.2.8 Washing

Surface cleaning is important for the manufacturing process since it removes solids, semisolids or liquid contaminants from the surface of the metal. The type of cleaning process depends on the different residue existing on the metal. Washing can be done with an electrolyte solution, chemical cleaning including different detergents, cleaning fluids such as alkaline solutions, solvents, acids and salts. In company M, the washing process is performed at the end of manufacturing to remove any dirt or oils from the parts using special solutions. They are then ready for shipping, assembly, or if needed, transferred to a third party to be coated or painted. (Kalpakjian & Schmid 2010, 991-993; Youssef, El-Hofy & Ahmed 2012, 651-653.)

6.2.9 Assembly

At the assembly stage individual parts and components are assembled into a finished or semi-finished product. Assembly costs can vary between 25-50% of the total cost of manufacturing. With manual assembly being slow and expensive, a need rose to automate the process. Automation has many advantages such as increased productivity, a product with higher reliability, removal of human factor from hazardous situations and opportunity to reconsider the product design. When we consider cost, automation can be either an advantage or a disadvantage. Fast yet expensive technology for assembly could be worthwhile for big volume of work, but for small lots such an investment might not be economically profitable. The choice of the assembly method varies and depends on batch size, production rate, product life cycle, availability of labor and cost. Assembly can be divided into three types: manual, high-speed automatic and robotic:

- Manual – used simple tools, economic for small lots and can easily assemble even complex parts.
- High speed automatic – uses transfer mechanism, meaning the station is designed to direct the parts to their place and then assembled on the spot. Faster than manual but limited in its orientation.
- Robotic arm assembly – this option has the most sophisticated mechanism, allowing assembly in different axes. This option is faster than manual and its speed depends on the complexity.

Company M incorporates both manual and automatic assembly. Manual assembly is usually done for small quantities and multistage assembly. The automatic assembly allows a simultaneous production and assembly of the components. Other methods of combining the parts is available with screws, staples or welding. (Kalpakjian & Schmid 2010, 1083-1089; Boothroyd 2005, 6.)

7 Data, Analysis and conclusion

7.1 Methods of collecting data

In order to gather information for this thesis, I employed several different methods of collecting data:

- Observation – before beginning the thesis investigation, I went for a visit in company M’s facility to observe the different technologies in the factory, take notes and talk to the people in order to get some initial information as to the needs of the company.

- Literature review – In order to investigate the process of quality in the company, and understand their needs for a machine vision solution, I conducted a literature review to gather information about the meaning and process of quality, and of the technology of machine vision. The literature review included books, e-books and scholarly articles, as well as some professional websites. To find these I employed the JAMK library webpage and search engines such as ProQuest search engine, Google Scholar and IEEExplore.

- Questionnaire –following the factory visit and after processing the initial information, I wrote the first survey. The survey had very general questions to gain a basic understanding on how quality inspection is dealt in company M and allow us to further examine and prepare more direct/exact questions. The questionnaire aimed at clarifying also some information that was given during the visit. Following the information given by the first survey, a second one was conducted in order to refine the information given and gather some information on their inspection times.

- Case study – Company M was taken as a case study, in order to view their real-time needs and get specific information in order to offer them a specific solution to match their needs.

7.2 Quality control in company M

Company M conducts quality control using mainly manual inspection and employs advanced quality control tools such as D8 and A4. They hold daily meetings to assess and supervise the situation in the factory concerning the KPI's and the work in progress to make sure they meet their targets. Since manual inspection is a time-consuming process and has the possibility of human error, the company wished to explore the use of machine vision to make the process faster and more reliable. The company has a quality standard certificate and works according to the ISO 9001:2015 and the IATF 16949:2016, since they produce parts also for the automotive sector.

7.3 Process chosen for Analysis

In order to decide where best to implement the machine vision quality inspection for company M, the first step is to identify the quality control points (figure 26).

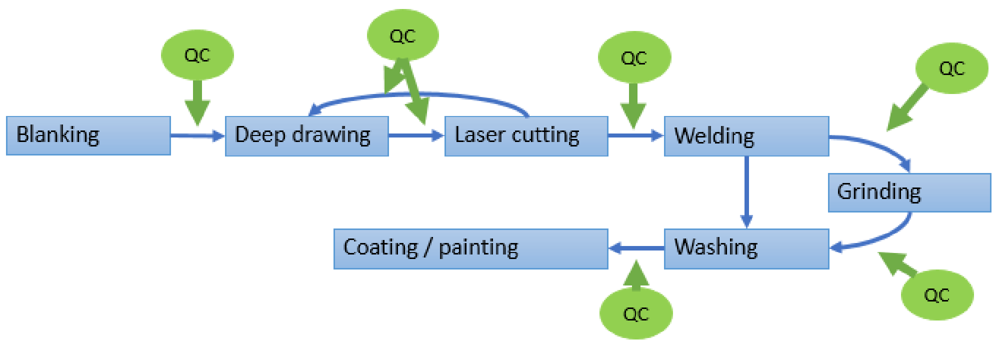


Figure 25. Quality control points in company M's process.

Next it was time to check the internal WIP error report. The company started to follow those since September 2020, so the report has limited information (figure 27). We can see that most of the non-quality costs come from 3 main technologies – deep drawing, laser and robotic welding. With robotic welding, most of the problems originated from one single part, while the other processes, deep drawing and laser cutting, have different defects under them.

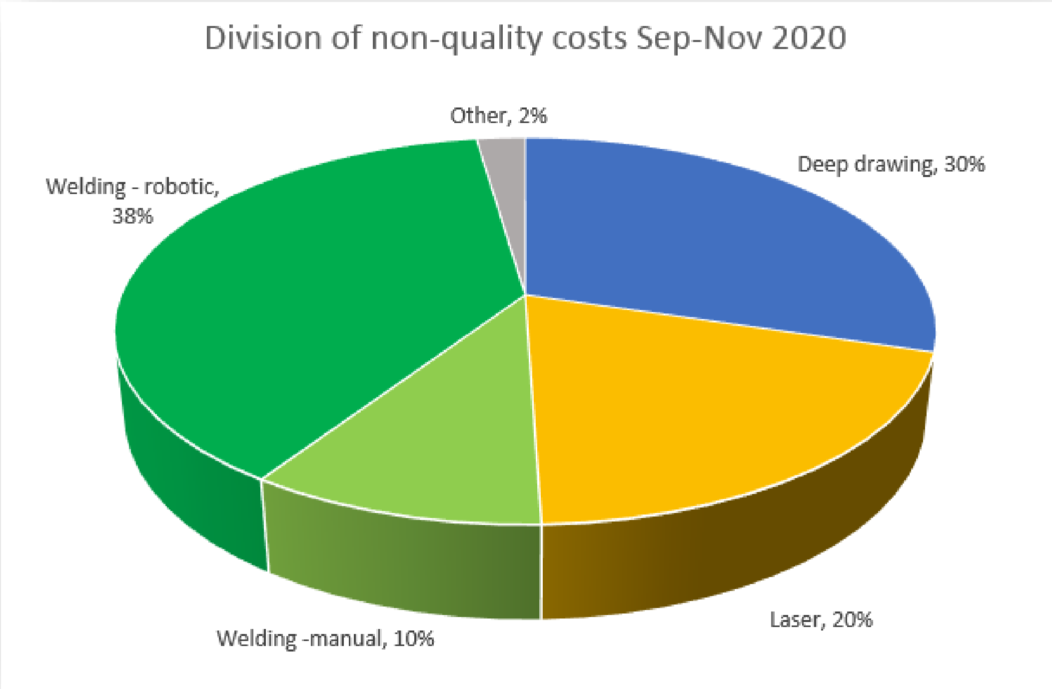


Figure 26. Division of non-quality costs Sep-Nov 2020

After exploring the WIP, the company's reclamation report was utilized to learn of the manufacturing defects that were not detected prior to being sent to the customers. The next chart shows us all the different reclamations by category during 2019-2020 (figure 28): detected prior to being sent to the customers. There are many categories, some originated from technological manufacturing reason and other causes. To see the extent of the problems that originate from the technological reasons, the following chart was devised (figure 29). We can see that over 53% of reclamations are manufacturing related. If we look at only technology-related reclamations, we get the following picture (figure 30). We can see that deep drawing and laser cutting are responsible for most of the reclamations received in the company.

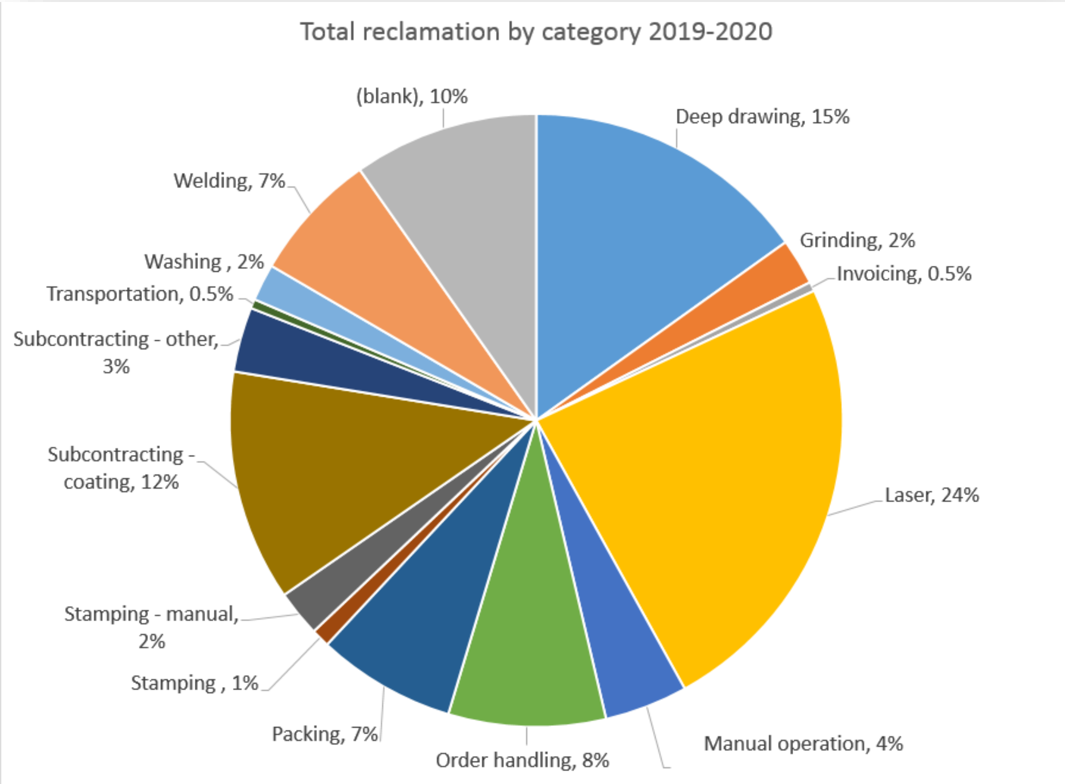


Figure 27. Total reclamation adapted from Company M's reclamation report

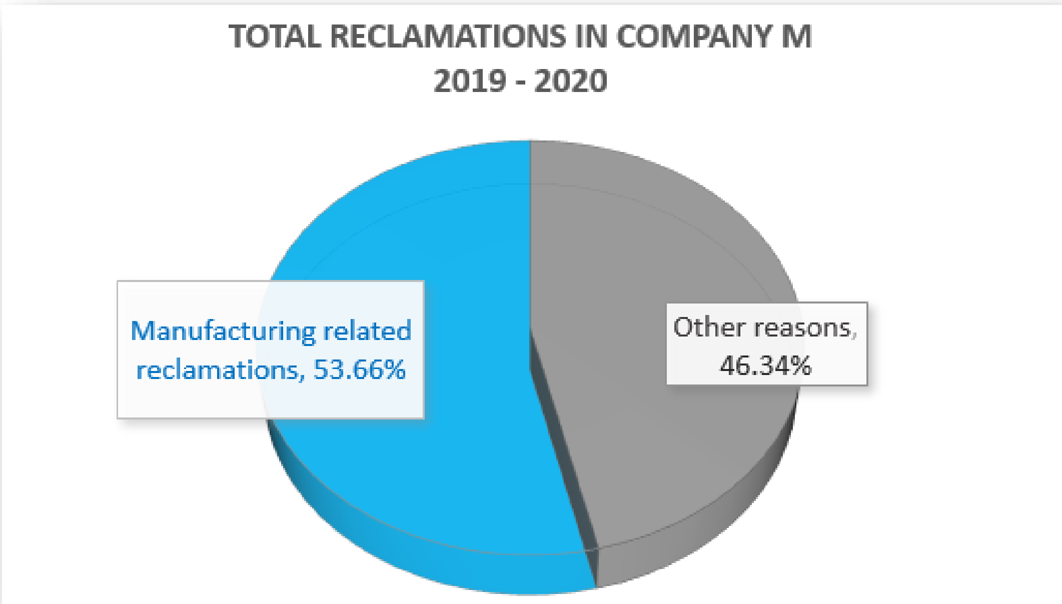


Figure 28. Division to manufacturing related reclamations and other reasons.

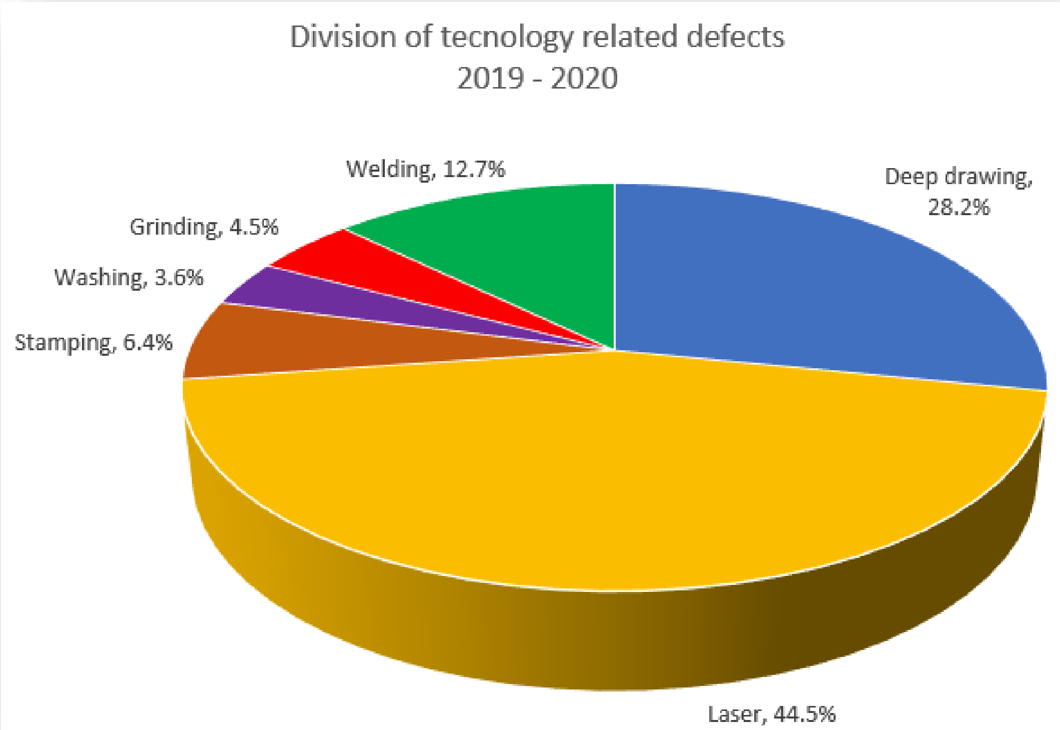


Figure 29. Division of Technology related defects from reclamations of 2019-2020

Considering the reclamations and the internal WIP defects led to choosing deep drawing and laser cutting as the two processes to focus on with machine vision solution. After further inspection of the available technologies, it was decided to offer the solution for the washing process, and to a non-technology related error - wrong item sent to the customer. There is available technology for recognition of parts and thus combining this in the product picking process can eliminate this problem.

7.4 Steel defect detection

To check for existing technologies that can detect the different defects in deep drawing and laser cutting, the defects were extracted from the reclamation reports, WIP defects and company M’s worker manual. The following table (table 4) shows the different defects and if there is an available machine vision solution for them.

Table 4. Deep drawing and Laser cutting defects according to reclamation report 2019-2020

Deep drawing	**machine vision detection**
Defective blank	+
Dents	+
Scratches	+
Dirty tool	+
Wrong part	+
Wrong positioning	+
Missed in inspection	+
Lubrication problem	-
wrong calibration of machine	-

Laser	**Machine Vision Detection**
Defective blank	+
Wrong blank	+
Burrs	+
Dents	+
Scratches	+
Incomplete cut	+
Missing cut / Hole	+
Wrong positioning on rig	+
Dirty Tool	+
Tool - other problems	Need clarification

Wrong part

For us to be able to detect if we are in fact using the correct piece, we can again use machine learning and teach it the parts that are supposed to be used in the process (and avoid using wrong blanks or shipping the wrong item). We can also use different industrial datasets that are meant to detect 3D objects that exist in the database. There are many different parts that differ in their surface reflection, symmetry, complexity, flatness, details compactness and size. (Drost, Ulrich, Bergmann, Härtinger & Steger 2017.)

We can teach the system about the shape and positioning of the part using geometric pattern matching (figure 32). We will need to utilize deep learning and use geometric pattern matching. These tools can tolerate large variation in contrast and light, and different orientation of the part. It will be able to recognize if the part is in different lighting, distancing, scaling and positioning, and detect if these do not match the required position for the laser cutting. (Van Baer 2018, 12; Introduction to machine vision - Cognex n.d., 7-8.)

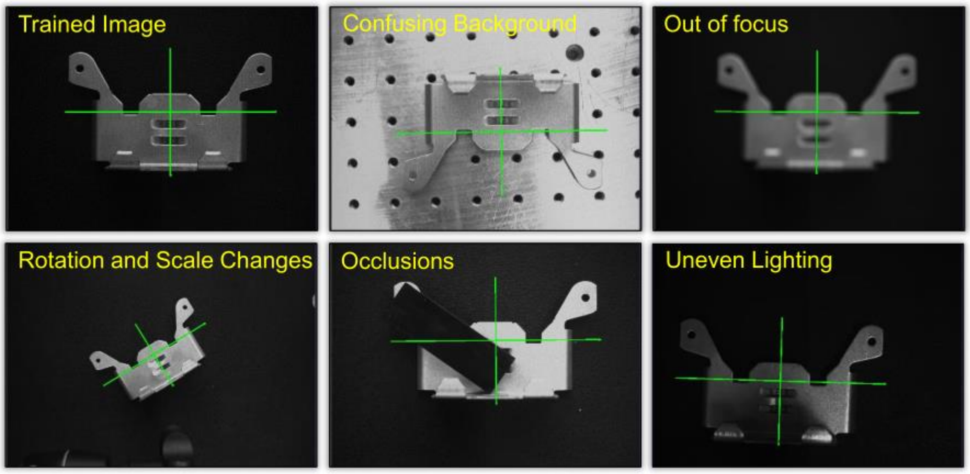


Figure 30. Geometric pattern matching (Van Baer 2018, 13)

Jig positioning

One of the major origins of defects was the positioning of the part on the jig for laser cutting. The pieces need to be put in the exact position since the laser machine is “blind”, it works using pre-determined coordinates and cannot detect the position of the part by itself. To solve this issue, a detection point pre-cutting phase is offered. The positioning of each part on their respective jig can be fed into the machine vision system and teach it what is the exact position allowed. In case of a big part that might deform while placed on the jig, due to its size, machine vision can also help.

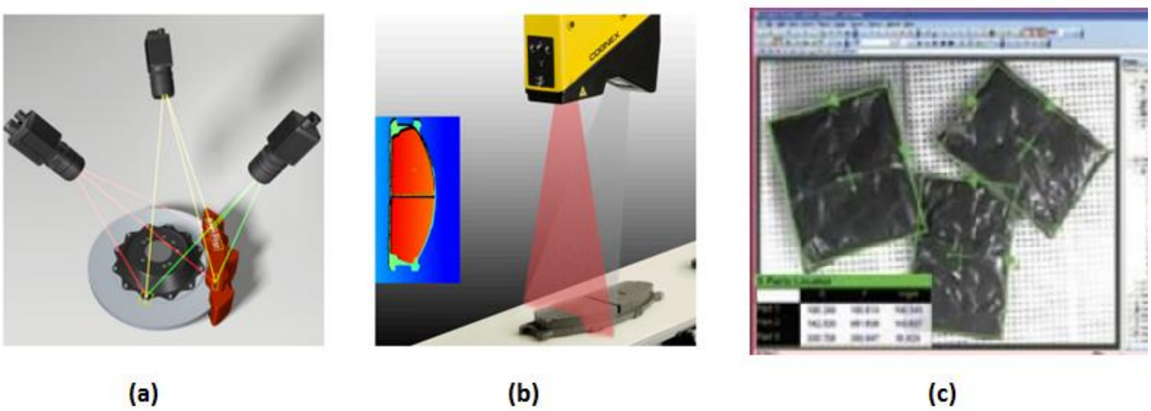


Figure 31. 3D machine vision system image capturing (Introduction to machine vision - Cognex n.d, 20; Van Baer 2018, 12)

In order to make sure the part is in the position required; we will require 3D imaging (figure 31). We can see an example if the use of multiple cameras (a), a single scan camera (b) and geometric pattern matching. Using side light, or structured light, and single or multiple cameras, can give us the current picture (c). This can be compared with the control images of the program and found if it is correct, and by that practically eliminate this defect. (Introduction to machine vision - Cognex n.d, 20; Van Baer 2018, 12)

Defected blank, scratches, dents, dirt

A defected blank means there were existing defects even before we started processing our metal sheet. Machine vision can detect defects that appear on the blank, as well as many that occur later after processing. Amongst the defects (seen on figure 33) we can name crazing, inclusion, patches, pitted surface and scratches. In this example, taken from a research released in 2020, the machine vision system used datasets (see Table 3 for dataset example) containing a variety of defects used for comparison by different mathematical models. The article notes the lack of available datasets and contributed one of their making. Examples of the defects can be seen in figure 34 and 35. Figure 34 shows us defects including: inclusion, crazing, patches, pitted surface, scratches and rolled in scale. Figure 35 has defects including: crescent gap, welding line, water spot, silk spot, inclusion, oil spot, crease, punching, waist folding and rolled pit. (Lv, Duan, Jiang, Fu & Gan, 2020.)

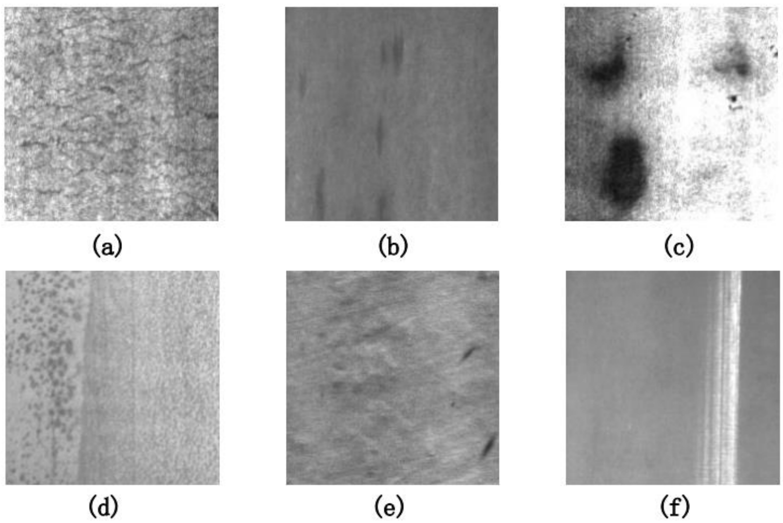


Figure 32. Metallic Surface defects (Lv et al. 2020)

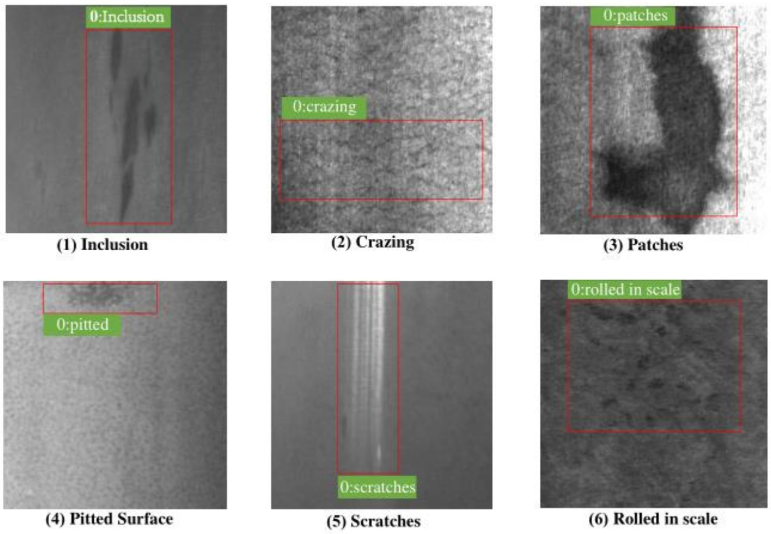


Figure 33. Different defects detected using NEU-DET (Lv et al. 2020)

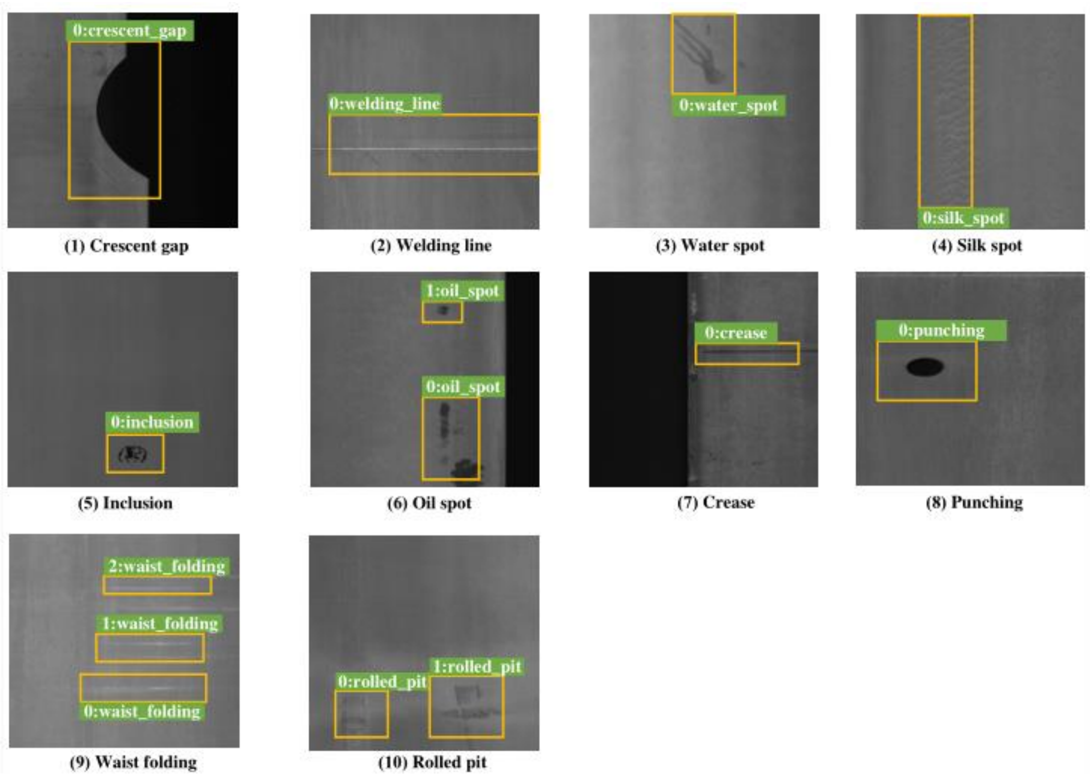


Figure 34. Different defects detected using GC10-DET dataset (Lv et al. 2020)

Burr detection or incomplete cut

In their article, Zeiler, Steinboeck, Vincze, Jochum and Kugi (2019) showed how detection of burrs and fractures can be visible in the trimmed edges of steel plates. The following image (figure 36) shows the process of detection. Zeiler et al. used different techniques to try and detect the defects. The figure shows (a) the original image where the burr is visible (b) processing the image with different techniques and (c) the image after noise reduction.

We can see that the burr is visible before the processing of the image (figure 36a), but after applying different techniques such as thresholding, smoothing, segmented burnished area and applying boundaries, the burr is almost not visible (figure 36b). The algorithm needs to check if the suspected burr is in fact a burr or just a small deviation that is accepted.

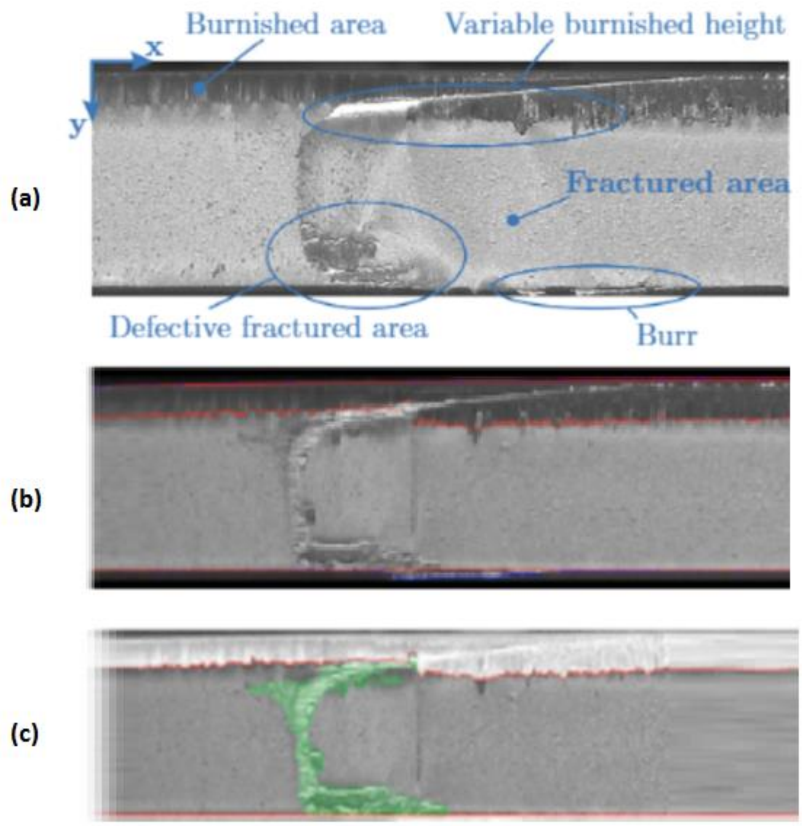


Figure 35. Inspection of trimmed steel (Zeiler et al. 2019)

The height of the burr is calculated and checked if it exceeds the pre-defined threshold level to be considered as a burr. In the next image (figure 36c), after applying noise suppression and highlighting the defective area, the burr seems undetectable. It is possible that with different processing and another threshold for the burr, it would have been seen at this point. This is an example of how advanced the technology is in the field, but how it can still miss things by using different processing of the image. Also, this experiment was done on edges that were trimmed, it is possible we would get a better picture from the laser cutting, since it is a cleaner and more precise process.

There is also option to detect burrs in holes that were cut, as present from an article by Cho and Chi (2015). By using an inexpensive vision system and processing methods, they managed to detect unwanted burrs in parts manufactured by CNC machines (figure 37). In case we have missing holes, or unfinished cut-outs clinging to the part, the machine can compare the defective part to the correct looking part in the system's database, and indicate it is defective (Van Baer 2018, 4.)

The different defects and detection methods were gathered into tables referring to company M's own defect categorization. The tables are divided by processes and their respective defects, and can be seen in Appendices 6, 7 and 8. An installation recommendation for the system, for detecting the different defects, is also attached in appendix 9.

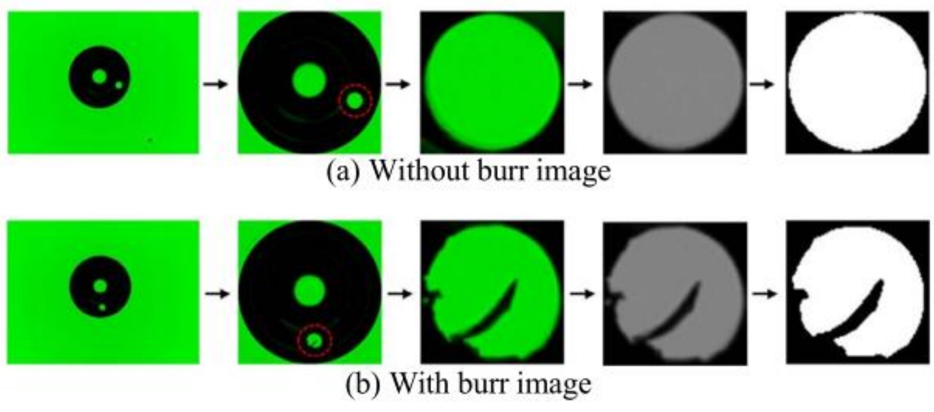


Figure 36. Processed image (a) without burr (b) with burr (Cho & Chi 2015)

7.5 Prevention Vs. Inspection after manufacturing

The cost of non-quality can be taken from both the WIP and from the reclamation processes. Reclamation is very expensive as can be seen in hidden costs above. WIP can also be quite expensive, in that if the error is not discovered in time you need to calibrate the machine again. Machine vision can help as preventative measure and not just defect discovery. From table 4 we saw that there are different defects, and those can be divided to ones that can be prevented, and those inspected after-the-fact. It will be beneficial to invest in prevention, that might decrease and even eliminate many of the defects that occur. When consulting with company M, it was apparent that there is no one clear way to perform the inspection. There is a wide variety of parts, some will need inspection before the process, some after and some both. Because of this issue, it is important to consider both aspects of inspection – the prevention and the one after the process (Survey with Quality engineer from company M, 2020).

7.6 Investment consideration

As mentioned previously (see 5.6 costs), it is very difficult to give an exact estimation of the different visible and hidden costs, fixed or variable, of machine vision systems. The variety is wide, and companies are not keen on putting their prices on the market for display. There are, however, some guidelines we can take into consideration:

- Infrastructure – we might need to build a surrounding for the devices to support and install them. It will be good to check if the company can provide installation guidance. In here we can also include specific electrical needs of the system such as rewiring for the camera and lighting placements.

- Maintenance costs for hardware and software both – How often maintenance is done, will the costs remain constant, what is the extent of them in the warranty and do they include part costs.

- Common spare part listing including prices and availability – since we are acquiring a new technology, we cannot know in advance what will be our needs for maintenance. We can request from the company a listing of their parts so we can check their availability, and if that fits our needs for when spare parts are required.

- Licensing – is the software purchased from the company bought for unlimited use, or does it require monthly/yearly payments for licensing.

- What are the warranty limitations – length, what parts and services are included, can it be extended.

- Would be important to check if the software support connection to ERP system for analysis of information.

- Durability – what is the expected lifespan of the system, its estimated work time.

- Implementation – Teaching the staff of the system and providing on-time assistance later. Will it be charged by the hour or included in the price – the preferred method is “key in hand”, meaning the company gets the full pack of support included in the price.

- Personnel training – other than the implementation of teaching the staff, we need to take into consideration that while the staff is being trained to use the system, they will not be manning the floor. It will be good to decide on a project leader that will compose the first group that is to be trained, decide on when it will be the right time for the training considering the work load, when a refresher course will be needed and when additional groups will be trained. Important to note, that the government supports up to 60% of the cost of education for new technologies.

In calculating the investment costs, we need to take the benefits we gain from the system into consideration, that can be translated into efficiency and quality. As discussed earlier, machine vision technology will reduce the number of personnel needed for inspection, and free them to work in other positions. Better inspection also means better quality product. Another important aspect is the Marketing edge – by advertising that the company is using advanced technology, the company is seen as offering a higher quality product, and this will give a competitive advantage to those who do not use it.

7.7 Thesis process

The idea for the thesis was brought forward by company M, wishing to inspect the option of adding machine vision technology to their quality control process. Following are the steps of the thesis and process of work:

- A meeting was help online to introduce the company and the relevant personnel representing the company. Following the meeting, a brainstorming was done, and a mind map was composed covering the main topics of interest (see appendix 1). This brainstorming became the basis for the chapters of the thesis.
- The brainstorm map was introduced to the supervising teachers and the subjects were agreed upon.
- A thesis proposal was composed. The chapters taken from the mind map. research questions and a timeframe for the thesis was set. Work began on the literature review.
- Limitations were decided for the thesis. The cost of technology scope was agreed to be addressed, but not fully investigated. Third party processes were also omitted since the focus was put on the company's own processes. Also, due to confidentiality reasons, some topics were moved to the appendix to keep the company's internal practices confidential. Technologies that are not relevant to the thesis were not explored.
- A visit took place to the factory of company M. The visit included meeting the relevant contact personnel, observing the different processes taking place in the factory and discussing them with the workers on the floor, to understand

their own aspect on the matter of inspection and defects. Since the company serves as a case study for this research, notes were taken during the visit.

- The different processes were mapped in order to recognize the different quality control points that were found during the visit to the factory. This step was the 1st step toward the analysis of the research, aimed at understanding the different processes taking place, and can be seen in the thesis path below (figure 25).

- A survey was sent via email to the contact person in company M (see appendices 2 and 3), to clarify and get more in-depth information following the visit.

- One of the research questions “How machine vision is better than visual inspection, and how is it not?” was moved to the analysis part, since I expected the technology to be better, but cannot make it as a research question, to retain neutrality.

- Further information was received from the company relating to their WIP errors and their reclamations. These were the 2nd and 3rd step in the research analysis (figure 25), those defects found internally, and those reported externally by the customers.

- Upon deeper analysis, it was found that four processes can be promoted using machine vision:

    - Deep drawing - 1st survey found that 31% of all complaints are due to deep drawing

    - Laser cutting - it being an important strategic process for company M

    - Washing

    - Order picking

The focus was decided to be on deep drawing and laser cutting defects, with recommendation to apply them also for order picking and washing. This step was the 4th step in the research analysis (figure 25).

- A 2nd survey was sent to the company to get better understanding on some issues related to inspection duration, that were not included in the 1st survey. The 2nd survey can be found in appendices 4 and 5.

- Due to the high variation in the manufacturing of company M parts, there was no definite answer as to the average or relative duration of the quality inspections, so this subject was not addressed.

- Upon further analysis of the defect information from the company, and the potential inspection points found, a distinction needed to be between two approaches: Prevention of errors, and the detection of errors once those are made. This step, the 5th in the analysis (figure 25), aimed at collecting the results and possibilities of the different defects, and involved the comparison of the defects, and the machine vision technology that could detect them.

- In order to receive an estimated price for such a system, a member of JAMK staff, Juho Riekkinen, was contacted. Mr. Riekkinen was involved in purchasing such a system and was able to give information on the existing systems and a rough estimation for the cost. This step was the 6th and final step in the analysis.

- The original aim was to find one part which was the most problematic, with the most claims or WIP errors, and analyze according to it. Upon analyzing the information concerning the claims of the past several years, it was found there is not one part that can be the problem, but more of several processes with their respective defects. Using their categorization of the claims, I have managed to collect different claims that could have been prevented using machine vision inspection, and suggestions were given accordingly.

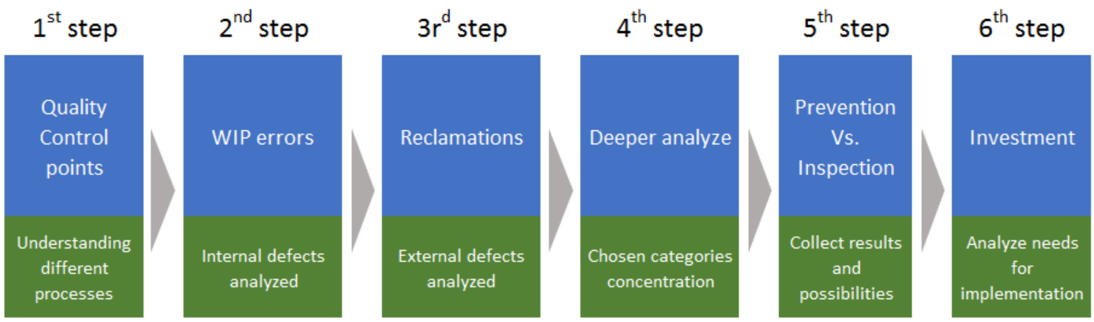


Figure 37. thesis path

7.8 Conclusions

The thesis path gave 6 steps of the analysis that were discussed and analyzed. As for the conclusion, they were each concentrated in the figure below (figure 38) respectively to their analysis step.

1. Most suitable places to place the quality control points were either before or after the processes, in order to detect the problems as early as possible and prevent waste of time and material.

2. According to WIP, machine vision could benefit the manufacturing by detecting different errors while the parts are still in-house. The option is also to collect the measurements and analyze them statistically with different quality tools, such as scatter diagram. This can allow us to see what problems need to be addressed faster, or what processes or parts end up with the most defects, and of what type.

3. The reclamation process gave us problems that were not detected before shipping the parts to the customer. We can use these occurrences as a learning tool for our own machine vision needs. In cases the parts are not shipped back, or shipment can take a prolonged time, it would be beneficial to request photos documenting the defects and see if they can be used for the detection learning tool.

4. The deeper analysis found many types of different defects in the different stages in deep drawing and laser cutting - defected or wrong blank, dents, scratches, dirty tool, wrong positioning, burrs and incomplete or missing cuts. To be able to answer to these defects, a research was conducted and found a few sources including researches and manufacturer of machine vision technologies, that portray the possibility to detect these defects using machine vision systems.

5. Here came then the aspect of prevention versus inspection – as mentioned, prevention is always the better option since if we want to work by lean management, we must decrease our waste. To decide where it would be better to begin with machine vision inspection I suggest categorizing the different defects by ABC categorization, while giving the most critical issues A category, to be implemented as soon as possible, category B in range of months, and category C for the next year. In my opinion, prevention is a critical measure, so I would suggest to start with putting the inspection of blank and part positioning in deep drawing and in the laser cutting jig as the first to be implemented, as a measure to decrease the total number of possible defects.

6. The investment assessment stage gave a rough estimation to the price, but for considering the investment, it will be important to know what we are looking for. A list of guidelines was given to help with the consideration and choice of the technology that will be needed.

Considering the information gathered and the many possibilities offered by the new technology, I believe that machine vision is a great solution for company M to pursue.

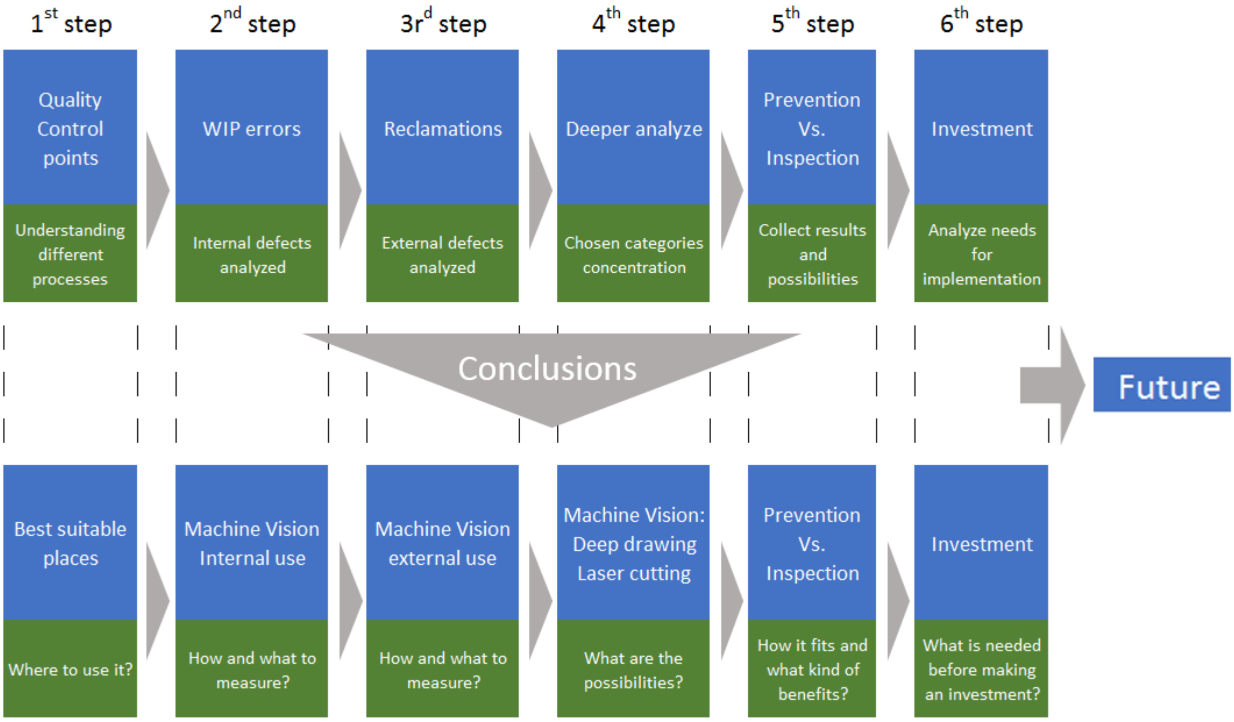


Figure 38. Thesis conclusion

Benefits Versus disadvantages

Machine vision is a well-established and developing technology that can detect a variety of faults in a matter of seconds, reduce waste, save resources, increase product quality and customer service and overall improve the company's abilities and competitive advantage. There are many leading manufacturers in the different steel manufacturing industry such as machines and vehicles, that employ machine vision systems to their own benefit, and because of that – it might become even a standard in the future.

If we considering the benefits versus the disadvantages, I have presented in the thesis the importance of quality and the many possibilities machine vision can give us to detect faults so that we can have a high-quality defect-free product. Even if we consider that we have well trained personnel that can do the inspection, using this system can eliminate human error, or even the human factor altogether, and free those specialized personnel to proceed with other aspects of the work. I have mentioned the benefits of such a system – it is fast, precise, always learning and evolving and can improve customer experience, the product quality and give a competitive advantage.

The only disadvantage I could find was the cost issue. To counter that, I have added a brief investment assessment, and while I could not give a specific number for a price, I did provide a list of important considerations that can be used for benchmarking when choosing the provider for the machine vision system. I have focused on information retrieved from Cognex, but there are other companies worth considering such as: Beckhoff, Movetec Oy, Stemmer imaging and Vision systems. Considering the information gathered and the many possibilities offered by the new technology, I believe that machine vision is a great solution for company M to pursue.

7.9 Criticality evaluation

The information gathered in this thesis was taken from textbooks, published articles, trusted websites and machine vision manufacturing website. The information was also gathered specifically from company M to understand their needs and see what can be found to address their needs. I am sure that with further research one can find more information about the different subjects given more time and resources. With the information regarding the WIP being from only the last 3 months, it is hard to calculate the financial aspect. For that, further information needs to be gathered and analyzed.

Since the WIP information was limited, it would have been a good idea to try and get more information by interviewing the workers themselves at the different processes. Due to COVID-19 situation, visits to the factory were limited, so such interviews were not conducted.

It is also important to check exactly how the different solutions can fit the company in real life conditions. How many adjustments are needed, how work will be influenced, before investment is possible.

In search of a company offering the solution of machine vision systems, a focus was put on the information available by Cognex. There were however other companies that it would be worth checking as to their solution such as Beckhoff, Movetec Oy, Stemmer imaging, Vision systems (Finnish company). There are other companies out there, but these are the ones I found that had visible relevance to the subject on their website.

Since no machine vision system was able for trial, it was not possible to conduct any tests on existing parts and check the reliability of the machine vision system. It would be preferred to have a live case study including parts that can be tested against a candidate machine vision system.

7.10 Discussion of research questions

1. Can machine vision improve quality inspection?

   As seen from the thesis, machine vision can offer many different solutions in the field of quality inspection, both from the preventative aspect, and from the after-production defect detection. It is used today in many industries and is a developing field.

2. How can we utilize machine vision in the inspection process of company M?

   I have presented the different defects detection options that can answer those defects presented by company M in appendices 6, 7 and 8 and have offered also installation ideas in appendix 9.

7.11 Discussion of research hypotheses

My hypotheses were that it will be hard to have a good prediction as to how much machine vision systems can improve the quality process of company M, but that there is a technology out there that can offer improvements.

I have found that there are many options out there that can fit the needs of company M, and while I might not be able to give an estimation as to the time or money that can be saved in the process, I can say that it will for sure offer improved quality inspection results and will offer many benefits beyond just defect detection.

7.12 Suggestions for the future

After researching the processes in the company, and the available solutions machine vision presents, I have a few suggestions for company M to pursue in the future:

1. The process of WIP non-quality cost should be followed, since I believe it is vital to collect the information at this stage, detect the problems, and address them. These conclusions can help in the process of applying the machine vision technology, and that in turn will reduce the WIP defects.

2. The information that can be gathered from the machine vision system can be applied to the different statistic models of quality tools such as control chart. Control chart studies the changes in a process over time and give us a clear picture of the benefit of introducing the machine vision technology. The use of a histogram can show frequency of distributions for different errors or adjustments needed.

3. Another suggestion would be to use ABC categorization to divide the machine vision implementation by their implementation need, giving the most critical issues A category, to be implemented as soon as possible, category B in range of months, and category C for the next year, as mentioned before.

4. I would suggest making live case tests with real company parts to check how the machine vision system function in detecting defects.

5. I would also suggest collecting figures about inspection times and compare those to the automation inspection. This will further automation in the company which can increase profitability and speed and eliminate the human factor from inspection.

6. It would be wise to check, how the use of machine vision in the company can give it a marketing advantage and increase the reliability of the brand.

7. In investment consideration it would be important to keep in mind the different pointers given, in order to have a clear picture of the immediate and long-term costs of such a system.

Acknowledgement

I would like to, firstly, thank my husband for his unlimited support throughout all my studies and specifically at the stages or writing this thesis. He has given me all the space needed and I would not be able to endure all the obstacles without him. Next, I would like to thank my supervisors Jarmo Räisänen and Juha Sipilä, who were there for me from beginning till end, encouraging me, supporting me, always there with a kind word and a push forward. I would also like to thank the employees of company M, who were eager to provide the needed information, either in person, online chats or emails, and were more than willing to support this introduction to a new technology.

Thank you everyone.

Nataly Feder

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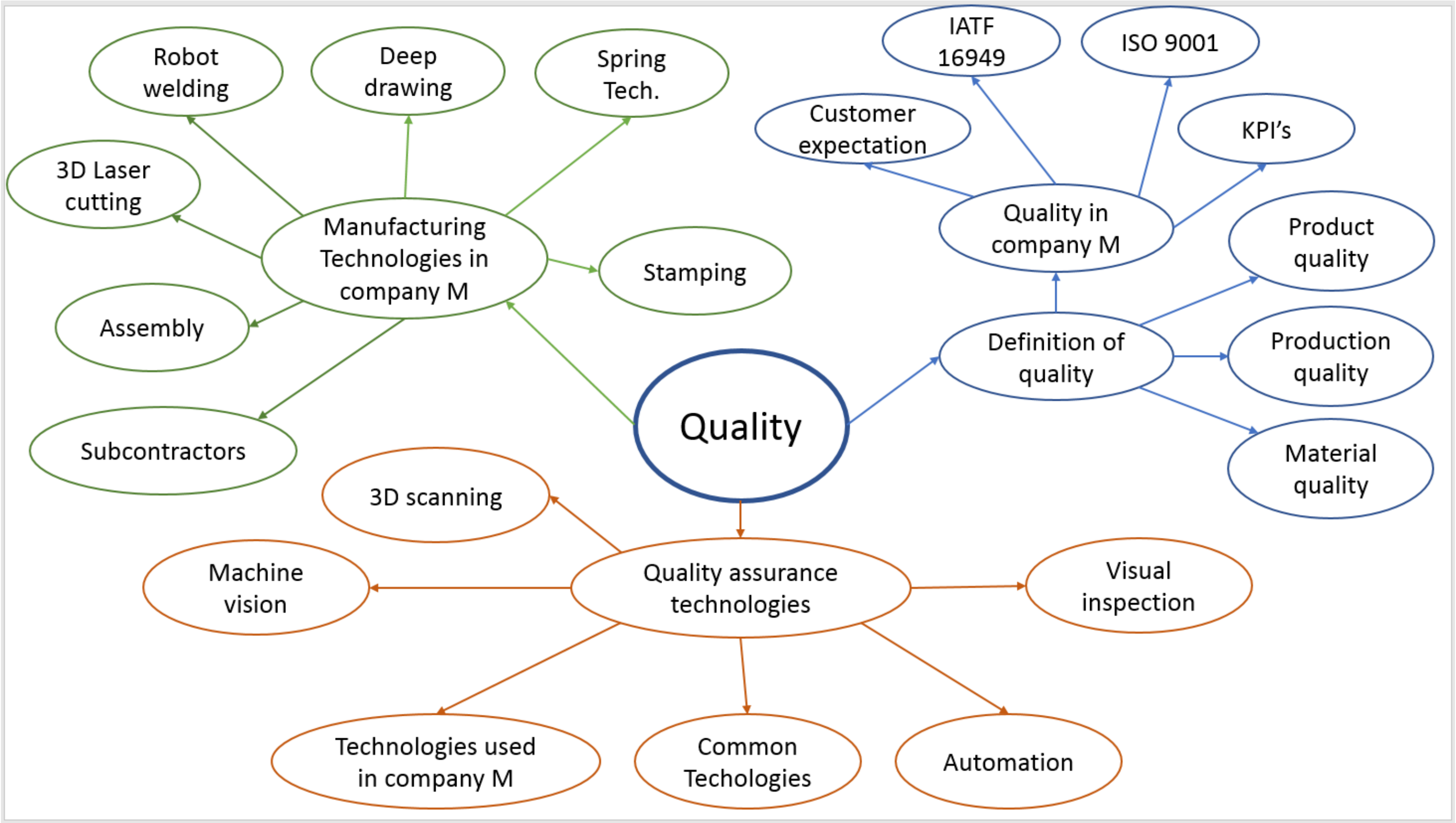
Appendices

Appendix 1. Brainstorming mind map



Appendix 2. Survey 1 for Company M

1st Survey

General information

1. Do you have any daily/weekly/monthly follow-up on the number of defects or customer reclamation? do you have it by parts?

2. if so, is your defects or reclamations classified under severity of malfunction (from aesthetic reason to danger of use)

3. Do you generally categorize your items by the ABC classification? do these parts fall under one of these classifications or scattered.

Aspect of company needs:

1. what part/s that are made in biggest quantities (economically important)
2. What parts have the longest/most complicated process time (costly)

Aspect of quality:

1) Total number of defects/claims a day/week.
2) Parts that have the most reclaims/defects (in the span of a week/month/6 months)
3) what are the most common quality problems in each manufacturing process?
4) How are these quality problems discovered? what process of quality checks are done. what tools.

Appendix 10. Email communication with Mr. Juho Riekkinen

Feder Nataly
Tue 10/27/2020 14:39
To:

- Riekkinen Juho

Hello Juho,

I don't know if you remember me, you taught me in one of my logistics courses.
I am currently doing my thesis about machine vision and my instructors Juha Sipilä and Jarmo Räisänen suggested I contact you about the cost issue that such a system can require.

I have made an overview of requirements for quality check for deep drawing, laser cutting and cleanliness of surfaces, using an area camera. Do you have a rough estimation as to how much a system could cost for either of those processes?

Regards,

Feder Nataly

Riekkinen Juho
Tue 10/27/2020 17:03

To:

- Feder Nataly

Hi Nataly!

Of course I remember you. Nice to hear that your studies are improving and closing to end.

System costs for these kind of applications are greatly depending on the accuracy and area requirements. What kind of quality check is it about? Do they have to measure something accurately (+-1mm, +-0.1mm, +-0.01mm?) or just check if a pattern or property exists? What is the size of the area to be scanned?

Machine vision systems cost from hundreds of euros to tens of thousands of euros. Component costs could start from 1000€ including camera and cheap lightning. Still, most of the systems cost 10k€ minimum. This could include components and also a bit of designing/programming.

As you see, it is not so easy to give price for a general machine vision system. If no other specs are available, I would make a 20k€ budget for this kind of application. Still it might be quite far from reality (depending on the requirements)..

-Juho