Set up quality control policies for incoming goods at Bomech B.V.

Bachelor Thesis

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This thesis is the final step in completing my Bachelor's degree in Industrial Engineering and Management at the University of Twente. Thank you for reading this thesis.

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Management summary

This research aims to increase the production capacity of Bomech B.V., a manufacturer of high-quality trailing shoe spreaders used for fertilizer distribution on farmland. The company's production facility and offices are based in Albergen, from where machines are distributed across Europe.

Bomech is currently experiencing a problem regarding the production capacity, as the company seeks to manufacture more machines than its current output allows. We analyzed the production process and identified the absence of quality control for incoming goods as the primary issue. This deficiency leads to reduced labor productivity, thereby constraining overall production capacity.

The production process at Bomech consists of five stages, each playing a crucial role. The goods handling process is divided into three stages. Currently, incoming goods are not subjected to quality control, allowing defective parts to enter the production process. Additionally, the lack of systematic counting prevents accurate verification of delivered quantities against receipts.

Defective parts often go unnoticed until later stages of assembly. Partial disassembly to replace them is then required. This rework consumes valuable time that could otherwise be allocated to increasing machine output. Implementing inspection protocols for incoming goods is proposed as a solution to mitigate this issue.

To quantify the impact of productivity loss, we collected data on time lost due to defect replacement and the total time required to manufacture machines. With these data, we calculated the productivity loss, which lies between 2.6% and 3.9% of working hours.

We then conducted a literature review to identify optimal methods for addressing this inefficiency. The review focusses on three key areas: counting methods for incoming goods, sample size determination techniques for setting representative acceptance and rejection limits, and sampling methods for selecting items from a lot. Each section presents multiple methods and ends with an overview of the discussed methods.

Stakeholder meetings played a crucial role in determining the requirements that selected methods must comply with. Each stakeholder contributed essential criteria for establishing quality standards and norms for incoming products. These requirements informed the selection process for the most appropriate quality control measures.

To determine the appropriate Acceptance Quality Limit (AQL), we conduct an analysis on the impact of various AQL levels. While Bomech aims for a 1% defect rate, a range of values around this target are examined. The findings indicate that stricter AQL levels could lead to labor productivity improvements between 2.3% and 3.4%, whereas more lenient AQL levels could yield improvements between 1.5% and 2.4%.

Beyond productivity gains, implementing quality control introduces additional inspection time. The impact of different AQL levels on inspection duration was assessed and compared to the reduction in time lost within the production process. The results suggest significant benefits: all in all, when offsetting the inspection costs to the reduction in time-loss, adopting the strictest AQL level analyzed could reduce labor costs by 46%, while the least strict AQL level could achieve a 23% reduction.

Future research should investigate the potential correlation between assembled machines with undetected defects and subsequent service or part replacements within the warranty period. If such a relationship exists, associated costs could be incorporated into the findings to reevaluate AQL

selection. Additionally, further research is needed to accurately calculate inspection times and costs for various item types. Due to data limitations, assumptions were made in the current analysis. Future studies could enhance the accuracy of cost-benefit evaluations and lead to more precise AQL decisions.

We recommend a phased implementation strategy, including a pilot phase, to introduce the proposed quality control measures. A detailed implementation plan has been developed, outlining the necessary steps, associated risks, and mitigation strategies to ensure a successful transition.

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1 Introduction

This chapter provides an introduction to this Bachelor of Science (BSc) thesis. The research is conducted at Bomech B.V, located in Albergen, the Netherlands. Bomech is a leading manufacturer of high-quality trailing shoe spreaders, machines used for the precise spreading of fertilizers on agricultural land. This technology enables farmers to use fertilizers efficiently and in an environmentally friendly way, which contributes to sustainable agricultural management. Bomech trailing shoe spreaders are known worldwide for their quality, precision and reliability. However, to guarantee this high quality standard, an efficient production process is crucial.

This chapter consist of four sections. Section 1.1 describes the problem and contains the problem cluster with proper explanations and motivations on the core problem. Section 1.2 states the research aim which describes what the solution will look like and a target goal. Section 1.3 provides the research questions and the methods used to answer these research questions. Lastly, section 1.4 provides the scope and limitations of this bachelor thesis. This scope describes what is included in this research and what is not.

1.1 Problem description

Bomech is looking to increase the efficiency in the production department. Due to several problems, the production capacity is not meeting Bomech's expectations. In other words, Bomech cannot manufacture as many machines as they would like to. The result is an overfull production planning that is subject to severe delays if the smallest things go wrong. These delays result in dissatisfied customers who see their purchase be delivered too late. In order to tackle the problem, we formulate the action problem as follows: production capacity is too low. We define production capacity in this case as the number of machines actually assembled.

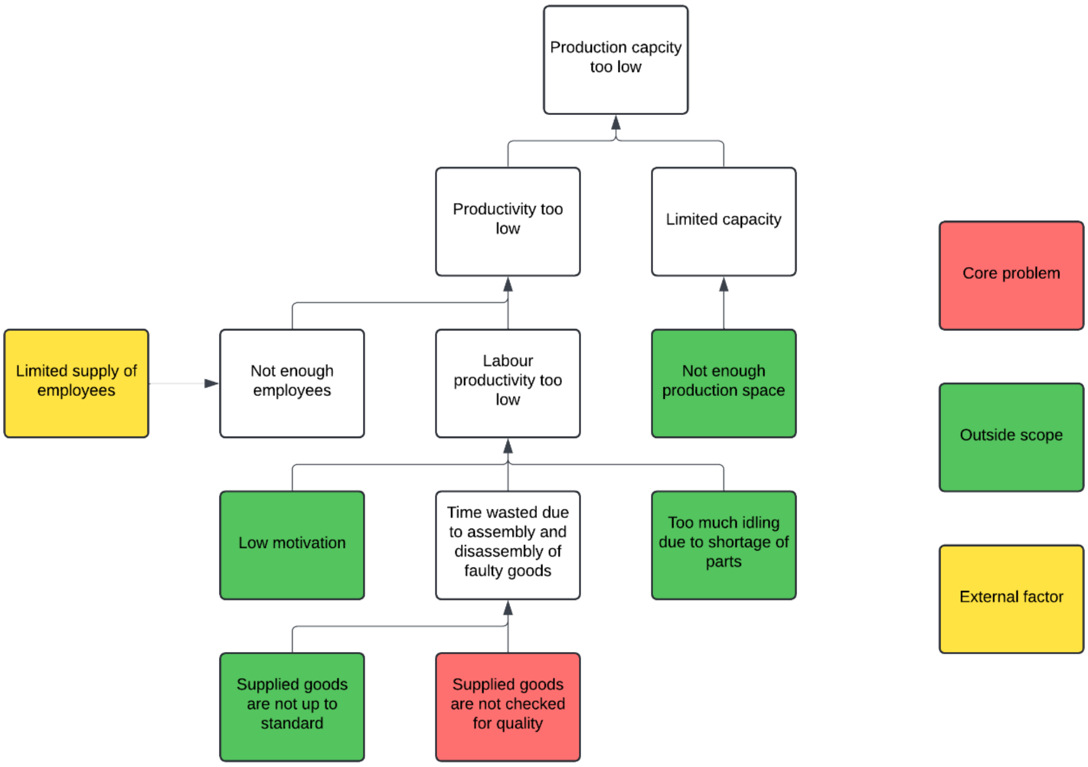

Figure 1 Problem cluster

Figure 1 shows that two problems create the action problem: A too low productivity and limited capacity. These problems consist of multiple other problems. A description of the problems is provided below.

Limited capacity

Not enough production space

The problem of limited capacity is caused by a lack of production space. This physical limitation means that there is no unused production space left to expand into to increase the production and with that the production capacity. Since Bomech is already planning to expand next year, this is a problem that will be solved shortly and this problem is therefore outside the scope of this research.

Productivity too low

Not enough employees

One reason for low productivity is a shortage of employees. Bomech is constantly trying to attract new employees to be able to create more production capacity. However, good employees are scarce. In 2024, 71% of Dutch employers faced a shortage of staff (Centraal Bureau voor de Statistiek, 2024). Since this problem is not going to disappear anytime soon, it is considered an external factor.

Labor productivity too low

Low motivation

Low labor productivity directly results in low productivity. One of the causes of low labor productivity is low motivation among employees. Low motivation can have a tremendous impact on labor productivity. Motivated employees can be up to 31% more productive than unmotivated employees and are up to 87% less likely to quit their job (Bradberry, 2016). While it can significantly benefit the organization if their employees are motivated, it is a very complex problem. Marital satisfaction, for example, is positively correlated with job performance (Sun, Mao, & Zhou, 2022). In other words, marital problems lead to worse job performance. Additionally, the level of pressure and stress in the home situation is a predictor of job satisfaction. Higher levels of pressure and stress predict reduced job satisfaction and therefore job performance (Kalliath & Kalliath, 2013). Due to the wide variety of problems causing low motivation, combined with the fact that there is a good possibility these problems are caused by problems in the home situation, the low motivation problem is considered out of scope.

Too much idling due to shortage of parts

Other causes of low labor productivity include idling time due to parts shortages. On regular occasions, one or more parts are out of stock. When parts are out of stock, machines cannot be built. When this happens, a decision has to be made on how to proceed. This often results in building other types of machines that can be built. While this certainly costs valuable time, there are other, more pressing problems that potentially have a greater impact on improving the labor productivity. Additionally, solving one of these problems will partially solve the problem of idling time due to parts shortages as well. This is the reason why this problem is considered out of scope.

Time wasted due to assembly and disassembly of defect goods

Supplied goods are not up to standard

Time waste due to faulty parts is a problem that causes low labor productivity. This time waste is created by defect parts entering the production process. Every time a defect part is found to be assembled on a machine, it needs to be disassembled and replaced by a good part. Occasionally, a defect is not noticed until (near) completion of a machine. Replace this defective part then requires a lot of disassembly and assembly again. This costs a great deal of time and could have been avoided if the part had been up to standard. Forcing suppliers to improve their production process could be helpful in reducing the number of defects, but this number will never be zero. By doing this, Bomech would still be dependent on the willingness of suppliers to actually improve. Additionally, since no quality inspections are performed on parts, the improvement cannot be confirmed. This dependence is not desired and therefore, this problem is considered out of scope.

Supplied goods are not checked for quality
Currently, supplied goods are not checked for compliance with quality norms and compliance with parts drawings. This means that there is no knowledge on what the quality is of products that enter the production process. This allows for defects enter the production process unhindered. Additionally, having bad batches in storage gives a false sense of having stock, since these bad batches can create parts shortages when the defects are eventually noted. Since defects will not be used, this false sense of having inventory can implode really quickly, revealing dangerously low inventory levels. Therefore, setting up a quality inspection can (partially) solve multiple problems at once. Due to the large impact of this problem on the entire production process, it is considered the core problem and will be subject to further investigation in this research.

1.2 Research aim

The goal of this research is to design a quality control solution made to fit Bomech's production requirements. Currently, the lack of having quality control measures in place results in lower than desired production capacity. In this research, we describe several ways to conduct quality checks on incoming items in detail, which should lower the rate of defect parts getting through inspection and therefore increase labor productivity. The target is to realize a 3-5% increase in labor productivity.

1.3 Research questions

In order to solve the problem, we formulate several research questions to collect the information needed to design a solution. Each research question is answered in a separate chapter to keep information separated and structured. Eventually, with the information collected to answer each research question, we can provide a clear, functional and implement ready solution.

Chapter 2 describes the current situation at Bomech. The research question to answer in this chapter is: *What do the work processes at Bomech look like and how does the presence of defect goods affect the labor productivity?* In order to answer this research question, a series of sub-questions are answered:

- What does the production process look like at Bomech?
- What does the incoming goods handling process look like?
- What is the time spent on machines at the different production stages and in total?
- How much time-loss do employees experience due to defective parts entering the production process and how does this affect the labor productivity?

To get the required information on what methods and protocols are used in incoming goods checking, we conduct a literature review which reviews methods to help design a solution to the. This literature review can be found in Chapter 3. The research question answered is: *What quality control methods and inspection protocols have been effective in incoming goods checking?* To be able to answer this question, the following sub-questions are answered first:

- What methods and protocols are commonly used in incoming goods checking?
- What are the benefits and drawbacks of these respective methods and protocols?

In order to get the information needed on what inspection methods to use and what the user requirements are, we conduct stakeholder meetings. The goal of these meetings is to set boundaries between which the design of the incoming goods inspection has to operate. The meetings are very important, as the results of these meetings determine what measures will be chosen to use in the incoming goods inspection. With this information and the information gathered in Chapter 3, we are able to compare quality control measures to each other and pick the best solution. The research question we answer in Chapter 5 is: *Which quality control system offers the best balance between cost, accuracy, fit to lot characteristics and training/integration requirements whilst adhering to criteria and requirements from stakeholders?*

1.4 Scope and limitations

The scope is limited to analyzing Bomech's incoming goods quality control needs and proposing a practical solution that answers these needs. This practical solution includes an implementation plan. This plan provides the steps that have to be taken and the risks involved with the implementation of every step, but it will not assign tasks to employees or allocate resources. This is up to Bomech to decide. The research will not be about the full implementation or evaluation of the recommended system due to a lack of time. The focus is on delivering a theoretically solid and operationally viable quality control design.

2 Current situation

This chapter answers the following research question: *What do the work processes at Bomech look like and how does the presence of defect goods affect the labor productivity?* Section 2.1 addresses the production process and what stages are part of the production process. Section 2.2 provides a look at the incoming goods handling process. Section 2.3 gives an overview of the time spent on the machines at the different stages in the production process. Section 2.4 provides an overview of the time-loss due to the presence of defective parts in the production process and this will provide the information to quantify the effect of defective parts on the labor productivity. Section 2.5 is a brief summary of the answers to the sub-questions as specified in Section 1.3 and it will also answer the research question.

Defects occur among a lot of different parts. From bend arms and mounting frames with welding errors to leaking cylinders used to fold the arms. In this research, it serves no particular purpose to dive into the different defects found, since this research focuses on designing a solution to improve labor productivity by lowering the number of defects ending up in the production. The goal is not to explore the variety of defects found. For this reason, we do not discuss the type of defects further.

Figure 2 Bomech Farmer

Figure 3 Bomech Speedy

Figure 4 Bomech Multi

2.1 Overview of the production process

At Bomech, 3 main lines of machines are built. These are the Farmer (Figure 2), Speedy (Figure 3) and Multi (Figure 4). Other lines of machines are built as well, however these are low volume lines that represent a small minority of the total production. For that reason, we will not include these lines in the research. Every machine at Bomech has two parts that form the backbone of the machine: the middle part and the arms. The middle part consists of two separate frames: a mounting frame and a middle frame. The middle part and arms are different for each machine.

Figure 5 shows the mounting frame of a Farmer. Figure 6 shows the middle frame of a Farmer. These two frames together form the middle part of the Farmer. Figure 7 shows the right arm of the Farmer. The left arm is a mirrored version of the right arm.

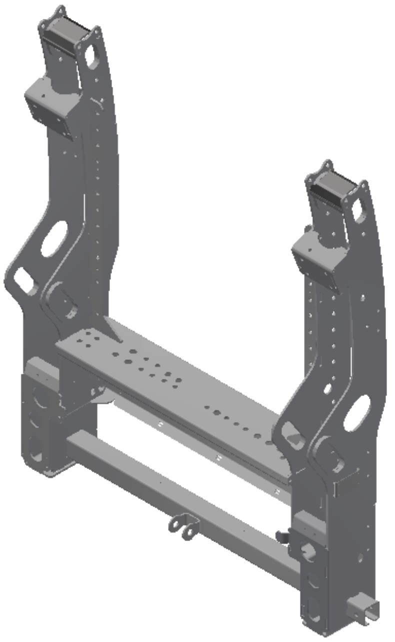

Figure 6: Farmer mounting frame

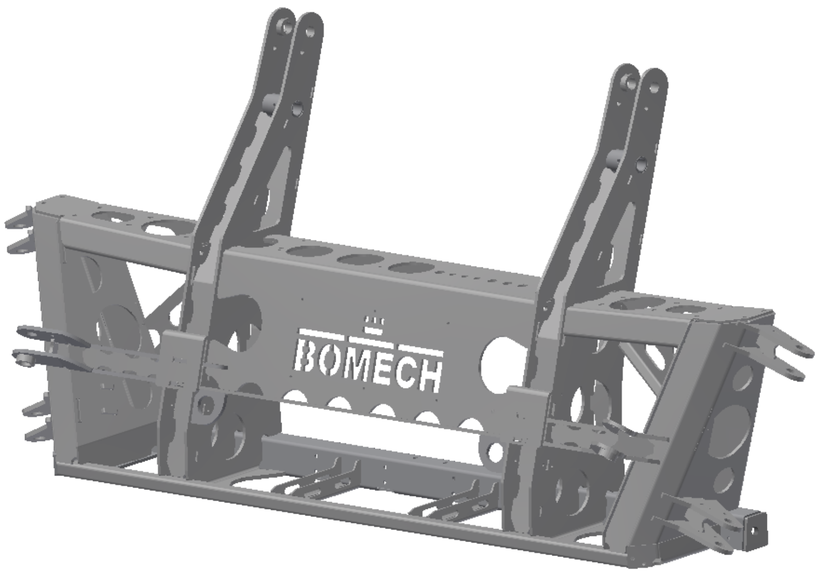

Figure 5: Farmer middle frame

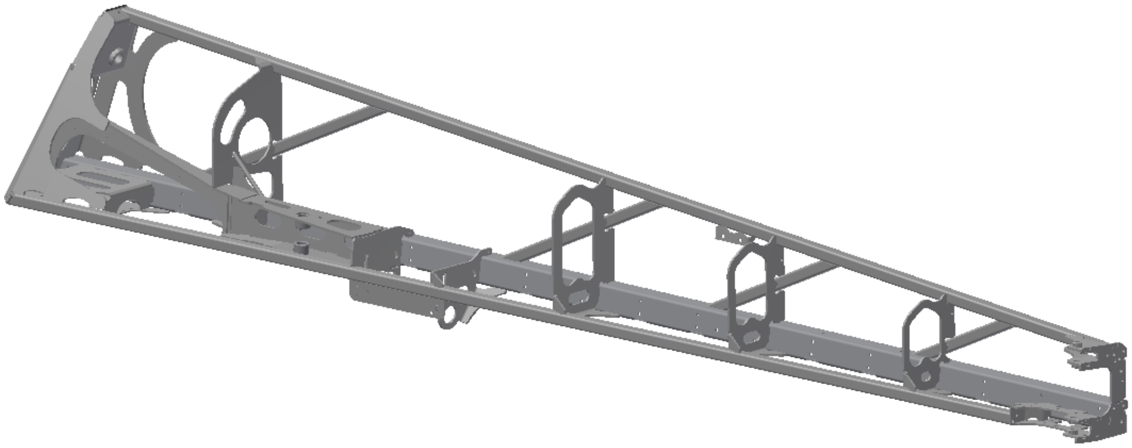

Figure 7: Farmer arm

In the production process, there are 5 stages a machine and its parts pass through. The first and third stage are preparation stages. The first stage is the preparation of the middle part. The middle part consists of the two frames mentioned before that are prepared. Preparation does not consist of manufacturing these parts, this is outsourced to companies specialized in this kind of work.

Each machine has the same basic functions and if desired, several options can be ordered. To be able to operate the basic functions and selected options of the machines, hydraulics and occasionally pneumatics are required. The second stage is the assembly of all hydraulics and pneumatics in the middle part and connecting the two frames of the middle part.

The third stage is the preparation of the arms that will be mounted to the middle part later in the process.

The fourth stage is the mounting of the arms to the middle part and connecting the hydraulics and hoses between the arms and the middle frame. In this stage, the green hoses, which can be seen in Figures 2, 3 and 4, are also put in place. The green hoses are used to spread the slurry evenly onto the land.

The last stage is the testing of the completely assembled machine to make sure it is adjusted properly and there are no mistakes made in previous stages. Figure 8 shows a flowchart of this process.

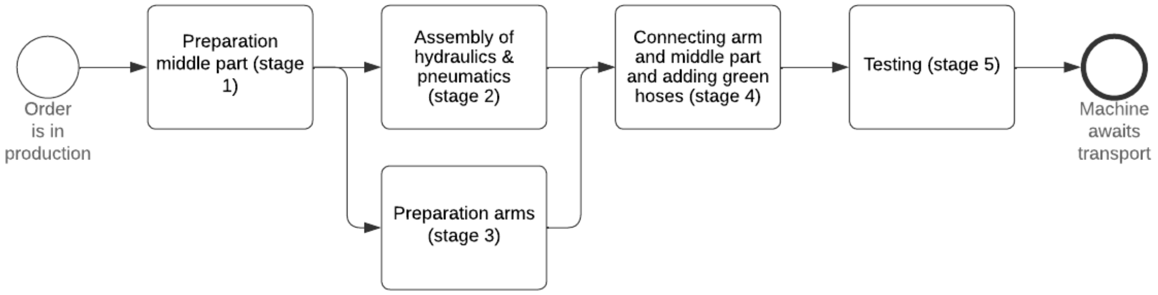

Figure 8: Production process

Figure 9 shows a lay-out of the production plant. The plant is around 4250 m^2 big and has one floor. It consists of two buildings, the first building is where the Multi and Farmer and 3 stage 4 areas are located. The second building is where the arms are prepared (stage 3), the Speedy is located and the machines are tested (stage 5). It also consists of the receiving area and 2 stage 4 areas. Except from a wall between the two buildings, the plant is fully open and there are no walls. Necessary separations are created by storage racks.

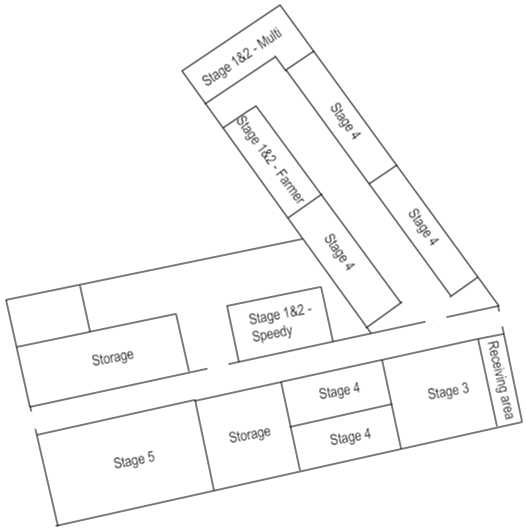

Figure 9: Production plant lay-out

2.2 Overview of the incoming goods handling process

The incoming goods handling process consists of 3 stages. The first stage is the unloading of a truck/van with supplies by the staff handling incoming goods.

The second stage is checking the incoming goods. It is checked if the right parts are in the pallet/box, which cannot always be done properly due to faults in the delivery notes from some of Bomech's suppliers. In order to be able to visualize the part numbers on the delivery notes, parts drawings or models are necessary. Since the employees handling the goods do not have access to parts drawings and models, they do not know if the products in the pallet/box actually are the products stated on the delivery note. This is especially the case for items that are not delivered often and for new parts. Parts with regular delivery are usually remembered by heart. Further, the employees handling the incoming goods cannot assess the product quality due to a lack of drawings, 3D models and tooling to do so.

Sometimes, the quantity of products in a pallet/box is counted. This is not nearly always done since a lot of goods arrive in non-transparent packaging which makes it hard to check the quantity of goods inside without it costing a lot of time. Currently, there are no tools present to aid the counting of products, so when there are a lot of items in a pallet/box, the staff assumes that the quantity is right. In case the wrong products are delivered or the quantity of goods in a box that is counted are not the same as what is mentioned on the delivery note, the found error is noted. The logistics manager, who is responsible for the handling of the incoming goods, is then notified of the error and this person will contact the suppliers to work out how to solve the problem.

The third stage is the placing of the incoming goods in storage where they await their use in the production process. Figure 10 shows an overview of the process.

Currently, there is nothing present to check the quality of incoming goods. Everything is checked by eye. This can result in two problems; batches that do not meet quality standards enter the production process and the wrong number of incoming goods are added to the inventory system, which can lead to early stockouts or a higher than desired stock level.

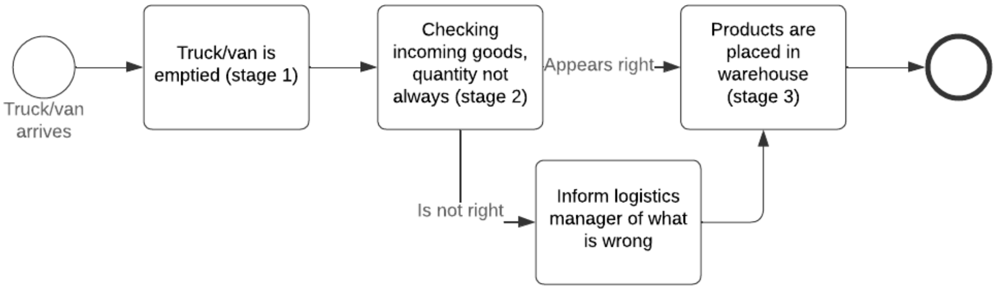

Figure 10: Incoming goods handling process

2.3 Time spent on building machines

Since there were no accurate records for the time spent on machines, we obtained the data used for the calculations by asking employees who work on the machines how much time they spent on manufacturing these machines. This may not give the most accurate results, but at least gives a very decent indication of time spent on building machines.

Each of the three machines (Speedy, Farmer and Multi) is offered with varying working widths. Table 1 shows an overview. Choosing for a wider working width does not necessarily result in extra work. Time spent on Farmer 12 and 15, for example, is the same. On the other hand, for the Multi, generally speaking, the bigger the working width, the more time is spent on the machine. For an overview of the effect of working widths on hours spent on a machine, see Appendix A.1 for Farmer and Appendix A.3 for Multi. Additionally, Table 1 shows that the Speedy line is divided into three machines. These machines, despite their differences, have a lot of similarities. That is why they are ultimately grouped as one machine type. Since the Speedy One is considerably smaller, it requires less time to be built then a Speedy or Speedy Small, which require about the same building time, assuming all other specifications are the same. See Appendix A.2 for a more detailed overview.

Speedy			Farmer	Multi
Speedy	Speedy Small	Speedy One		
12 & 15 meter	12 & 15 meter	7.5, 9 & 10.5 meter	12 & 15 meter	12, 15, 18, 21 & 24 meter

Table 1: Overview of working widths per machine

Some of the machines produced currently were not in production at the start of the data collection period, which is 2021 (the 18 meter Farmer as an example, from which the first prototype was made in 2023 and the production started in the second half of 2024). Due to a lack of sufficient accurate data, we will not include these machines.

Between the Farmer, Speedy and Multi, different hydraulic configurations (3DW, I-Control and E-Control) and various hydraulic/pneumatic options are available. These configurations and options influence time spent on a machine. A Farmer E-control, for example, costs significantly more time to build in stage 2 than a Farmer 3DW. However, far more Farmer 3DW configurations are sold than Farmer E-Control configurations. We used proportions of built configurations to create weighted time averages. This is done for every machine and for every stage. For a calculation on how we determined the numbers in the Table 2, see Appendix A.

Table 2 shows the hours spent by production employees on each machine for every stage of the production process.

Average working hours spent	**Farmer**	**Speedy**	**Multi**
Preparation middle part (stage 1)	1.5 hours	0.75 hours	1.75 hours
Assembly of hydraulics & pneumatics (stage 2)	4 hours	7 hours	17.5 hours
Preparation arms (stage 3)	1.5 hours	1.25 hours	4.5 hours
Connecting arm and middle frame and green hoses (stage 4)	7 hours	7.5 hours	22.25 hours
Testing (stage 5)	1 hour	1 hour	2.25 hours
Total	**15 hours**	**17.5 hours**	**48.25 hours**

Table 2: Hours spent on building machines

2.4 Experienced time-loss and effect on labor productivity

To be able to quantify the productivity loss, the time-loss has to be known. We have asked employees working on the machines to provide the time-loss due to defective parts per fte (full-time employee) per week. Fte in Bomech's case means 38 hours per week. Questioning employees revealed two interesting points:

1. Defects are almost never recognized in stage 1, 3 and 5, but nearly always in stage 2 and 4. That explains why Tables 3-5 do not show stages 1, 3 and 5, as they barely experience time loss due to defective products.
2. Because crews in stage 4 build every type of machine and not solely one type, they were not able to accurately categorize time loss per machine type. That is why in Table 3-5 for stage 4, the values are noted among all machines.

In Table 3, the time-loss is shown. The time-loss is expressed as hours per week per fte.

Time loss per week per fte	Farmer	Speedy	Multi
Stage 2	1 hour	1 hour	1.5 hours
Stage 4	1.5 hours		

Table 3: Time loss per week per fte

To calculate productivity loss per week per fte, we need the time loss per week per fte and the number of hours a fte works per week. The time loss per week per fte can be found in Table 3 and as mentioned before, a fte works 38 hours per week. The productivity loss in time per week per fte can be found in table 4. It is calculated by dividing the time-loss by the 38 hours a fte works per week.

Productivity loss (time) per week per fte	Farmer	Speedy	Multi
Stage 2	2.6%	2.6%	3.9%
Stage 4	3.9%		

Table 4: Productivity loss (time) per week per fte

To be able to convert the productivity loss in time per week per fte to productivity loss per machine, we assume that the number of machines made is proportional to the time worked. This means a linear correlation, which is a valid assumption since there are no setup times or other fixed times connected the process of dealing with disassembly and reassembly. Based on this assumption, the productivity loss in time per week per fte is the same as productivity loss per machine. This means that the values in table 4 are also the productivity losses per machine for the respective stages.

To calculate the productivity loss in machines per year per fte, we need the labor productivity in machines per week per fte. To calculate this, the hours per week a fte works are required as well as the amount of hours spent on a machine. A fte works 38 hours per week and the number of hours spent on a machine can be found in Table 2. In order to be able to calculate the labor productivity for stage 4, the proportion of each type of machine built has to be known. The proportions are multiplied with the hours on average required to build the machines. A calculation to find the proportions can be found in Appendix A.4.

With the productivity loss per machine and the labor productivity in machines per week per fte, we can calculate the productivity loss in machines per week per fte. This is done by dividing the productivity loss per machine by the labor productivity in machines per week per fte.

One fte works 45 weeks per year. Multiplying the labor productivity loss in machines per week per fte with the amount of weeks a fte works per year yields the results in Table 5 of productivity loss in machines per year per fte.

Productivity loss (machines) per year per fte	Farmer	Speedy	Multi
Stage 2	11.3	6.3	4.1
Stage 4	8.6		

Table 5: Productivity loss (machines) per year per fte

2.5 Conclusion

To conclude the chapter, we first answer the sub-questions.

What does the production process look like at Bomech?
The production consists of five stages: two preparation stages, two assembly stages and a testing stage. Figure 5 shows a flowchart of the production process at Bomech.

What does the incoming goods handling process look like?
The incoming goods handling process consists of three stages: unloading the truck/van, checking goods and placing the goods in the warehouse. Figure 6 provides a flowchart of this process.

What is the time spent on machines at the different production stages and in total?
Employees in the production process have provided estimates of how long they spent working on each type of machine and also what the effect of having to fit each option is on the time spent on the

machines. Then the proportions of each type of machine and the proportion of which machines were fit with what options were used to calculate weighted averages which were then combined to reveal the total average time spent on each type of machine. This number ranges from 15 to 48.25 hours per machine, depending on the type of machine. Table 2 shows a detailed description.

How much time-loss do employees experience due to defective parts entering the production process and how does this affect the labor productivity?
Asking employees revealed that nearly all errors are found in stages 2 and 4. In these stages, 1 to 1.5 hours of time-loss is experienced every week. 2.6% to 3.9% of production time is wasted on dealing with defect parts which translates to 4.1 to 11.3 machines per year per fte that could be built extra if no defects were to enter the production process.

Using the answers to the sub-questions, we can answer the research question which is as follows:
What do the work processes at Bomech look like and how does the presence of defect goods affect the labor productivity?
The work processes (production process and incoming goods handling process) are multi-stage processes with each stage having a significant role in their respective process. Further, labor productivity in several parts of the production process is negatively affected by the presence of defect goods, with 2.6 to 3.9% of the production time being wasted on having to deal with defect goods.

3 Literature review

In this chapter, we review literature regarding quality control measures in order to be able to answer the research question: *What quality control methods and inspection protocols have been effective in incoming goods checking?* Section 3.1 explores several methods to count the quantity of goods delivered, which is necessary to be able to confirm the delivery note. Section 3.2 focuses on a variety of sampling plans, which are used to determine a statistically sized sample of items to inspect. Sampling plans are often used since 100% inspection is very time-consuming and often unnecessary. Further, Section 3.3 reviews three sampling methods that can be used to select a predetermined number of samples from an incoming lot. At the end of every section, we provide an overview of each method reviewed in that section.

3.1 Counting methods

One of the first things done when goods arrive, is checking if the delivery note is accurate. This means checking if the correct parts are delivered as well as checking if the specified quantity on the delivery note matches the quantity in the delivered pallet/box. It is important to count the number of incoming goods, since a difference between the quantity in the pallet/box and the quantity specified on the delivery order will cause incorrect levels of inventory in the company's software system. This can potentially lead to early stockouts, which causes all sorts of problems. It can also cause overstocking, which causes holding costs to increase. In Sections 3.1.1-3.1.4, a selection of methods to count goods is described. These are manual counting, weight-based counting, counting by scanning barcodes and counting using RFID technology (Liu, Han, Bretz, Wan, & Yang, 2016) (Nakbua, 2014).

3.1.1 Manual counting

The most basic and primitive way to count the number of goods in a pallet/box, is manual counting. This is a very simple way to confirm the delivery note. It is easy to implement and requires no investment in expensive technology (Shahikian, 2024). Any material type can be counted as well. In case of small businesses with limited inventories, counting by hand will work fine. However, when quantities increase and the company grows, counting by hand turns into an inaccurate event, due to the human error involved. On top of that, it is a very time-consuming and labor-intensive counting method (Liu, Han, Bretz, Wan, & Yang, 2016). Training and knowledge requirements for manual counting are very basic. Being knowledgeable about the items coming in is very important.

3.1.2 Weight-based counting

Weight-based counting is a method that relies on the use of highly accurate scales to determine the number of items in a batch by weighing them. This technique works under the assumption that all items in the batch are uniform in weight. By dividing the total measured weight of the batch by the weight of a sample of items, the number of incoming goods can be calculated. A sample of items is used to reduce the effect of the scale error. For example, a 1000 kg scale may have display increments of 0.5 kg. For an item that weighs 2.2 kg, the scale would display 2 kg, and the error would be 10%. If 4 items are placed on the scale, the weight is 8.8 kg and the scale would display 9 kg. This time, the error is only 2.22%. Generally speaking, the bigger the sample of items weighted, the lower the error (Steiner & MacKay, 2004). Another way to reduce the error, is to get a scale with better sensitivity.

This method is particularly suited for counting bulk items, where individual counting would be time-consuming. The key to accurate weight-based counting lies in ensuring that the weight of a single item is precisely known and consistent. Variations in the weight of individual items, due to for example manufacturing tolerances or damage, can introduce errors into the counting process (Steiner

& MacKay, 2004). Further, weight-based counting does not pose any limits regarding product materials.

In order to obtain higher accuracy, one could get a scale of lower capacity, but with higher sensitivity, to measure samples of lightweight pieces as these lower capacity scales are more precise than the higher capacity scales (Woodward, 2021). This can reduce the errors further, when weighing the entire batch.

The upfront investment in weight-based systems is quite low. Scales capable of precise measurement are generally affordable and easy to operate, with minimal infrastructure requirements. Advanced systems may integrate scales with software solutions to automate the counting process and directly update inventory levels. This reduces human error and increases efficiency.

However, weight-based counting has limitations. If incoming goods contain mixed items or items with inconsistent weights, the system cannot differentiate between them, leading to inaccurate counts. Additionally, humidity, vibrations and other environmental factors can affect the accuracy of the scales, requiring regular calibration and maintenance (Kopczynski & Ness, 2001).

Weight-based counting is in principle an easy to use method which does not require difficult training. The employee handling the counting should be able to understand and calculate how to select a sample of products to minimize scale inaccuracies to a desired level and how to calculate the lot size from the lot weight and sample size and sample weight. Apart from that, there is not much more to weight-based counting.

Despite its drawbacks, weight-based counting offers a fast and cost-effective solution for counting incoming goods, especially for industries handling uniform, lightweight items. When implemented correctly, this method can significantly reduce processing time and labor costs, making it an attractive option for many supply chain operations.

3.1.3 Counting by scanning barcodes

Barcode systems work by converting data into a series of vertical bars and spaces of varying widths. Different barcodes are often assigned to different types of products, to be able to distinguish between different types of products.

A big advantage of using barcode systems is that the scanners are very accurate. The scanners only make one mistake in every 70 million scans, compared to the human error of one in every 100 characters typed (Woodford, 2022). Also, barcode scanning works for any type of material. It does not matter if the product is made from metal, plastic, ceramics etc. Another advantage of using barcode systems to count incoming items is that the technology is relatively low cost. The barcode tags are very cheap and the scanners are low-cost as well (Thanapal, Prabhu, & Jakhar, 2017). Additionally, barcode scanning systems allow for high speed data entry and data reading (Burke & Ewing, 2014). Since most barcode technology comes with software that can be connected to a company's ERP system, this means that scanned barcodes are immediately uploaded in the ERP system, and the total amount of entries can be quickly seen after scanning all codes. This prevents the above mentioned human error in entering data into the ERP.

Barcode scanning systems of course also have disadvantages. Arguably the biggest problem is that in order to be able to scan a barcode, the scanner needs a direct line of sight (Hinz, 2012). This means that it is impossible to count stacked items without unstacking the items. Having to do this obviously costs a lot of time. Further, if tags get damaged or are missing entirely, scanning becomes problematic (White, Gardiner, Prabhakar, & Abd Razak, 2007).

To lower the risk of rejecting good lots because damaged tags resulted in an inaccurate count, manual counting or weight-based counting can be used to recount and reevaluate decisions. This results in time-loss, but lowers the risk of unjustified lot rejections.

Barcode scanners are cheap and can be obtained for a few hundred euros. Tags also are cheap, costing a few cents at most. The suppliers will have to add the tags to their products, which is not a large amount of work. This means that while the price for items will increase, it will not be significant.

To be able to properly operate barcode based counting, there is some training and knowledge required. First off, employees handling the count should be trained on how to properly use the barcode scanner and how the scanner functions. Additionally, since barcode scanning systems are connected to software, the employees should receive training that focuses on how to operate the software. This also presents the challenge of making the software work with existing ERP software within the company, which can be a costly process. Further, some knowledge on how to proceed in case of problems (broken barcode stickers for example) is necessary. Lastly, the employee executing the count should be able to do a recount if necessary.

Overall, barcode scanning technology offers a low-cost way to improve the counting accuracy. It will also shave some time from the counting process. However, it does pose limitations regarding scanning stacked items and damaged barcode tags.

3.1.4 Counting using RFID technology

Radio Frequency Identification (RFID) works by sending radio waves between two objects: a reader and a tag. RFID technology provides the opportunity to quickly detect and track objects in a reliable way (Kgobe & Ozor, 2021). There are two types of tags, active and passive. Active tags make use of a battery which powers them and enables them to function as a transmitter that can store and transmit information. Passive tags have no onboard battery and function on radiated energy from the reader to transfer information from the tag to the reader (Chawla & Ha, 2007).

Passive tags are considerably cheaper than active tags and are the most used type of tag. The price is dependent on the frequency bands the tags operate on. Low frequency tags are generally more expensive than high and ultra-high frequency tags. The reading range is dependent on the frequency. The higher the frequency, the bigger the reading range. There are also dedicated RFID tags that work better work in metal-rich environments, called on-metal tags. On-metal tags are often low frequency tags due to metal interfering with radio waves, which low-frequency signals can navigate around better. On-metal tags are more expensive than regular tags (Halstead, 2020) and the reading range for on-metal tags is low, often being only a few centimeters. The use of on-metal tags poses significant problems since the reading range for on-metal tags is only a few centimeters and the presence of a large quantity of metal will still interfere with the signals. Therefore, big companies do not equip metal parts with RFID tags.

Overall starting investments will be high, as the infrastructure for the passive RFID technology is expensive (Dhabliya, et al., 2024). The readers require significant investment, as well as the infrastructure around it needed to make the technology work. And then there are the tags. One tag is not expensive, but if one needs thousands of them, it can get expensive. On-metal tags start around a euro per tag for read only tags (these tags only transmit information and cannot be programmed by end-users). These tags are often considered single-use due to the inability to reprogram them. Read and write tags are more expensive, but are reusable and can be reprogrammed to store different information.

The use of RFID technology can speed up the counting of incoming goods dramatically. An RFID reader can pick up the tag's signals in a matter of seconds. In other words, if every part is equipped with an RFID tag, the number of parts in a pallet/box is known within seconds. There is nothing that can match this speed. The downside to this is that suppliers have to attach a tag to every product they ship. If using read and write tags, tags have to be programmed as well, to transfer the specific information belonging to the product it is attached to, like a part number, part description and production date/batch number for example. This will result in extra work for the supplier and this will lead to an increase in costs for the supplier, especially if they also have to invest in RFID printers. This will result in higher product costs. Additionally, there is a risk of damaged tags being present in the lot. As a result, the tags will not transmit information anymore and be useless (Hawrylak, Mickle, & Cain, 2008). Therefore, counts will be off.

Just like with barcode counting, manual counting or weight-based counting can be used to recount and retake decisions to counter the risk of rejecting lots because one or more damaged tags resulted in an inaccurate count. This again results in time-loss, but lowers the risk of unjustified lot rejections.

RFID counting requires some training and knowledge. A lot of the requirements are shared with barcode counting. The employee doing the count should be trained on how to use the RFID reader and how the reader works. Just like with barcode technology, RFID technology is connected to software and the employee should know how to operate this software. Also, the software has to be coupled to the ERP software in place. Further, having knowledge on how to proceed in case of damaged tags and possible recounts is required.

Overall, RFID technology offers a way to quickly count incoming goods. The initial set-up costs are high, but the counting time and labor costs associated with this can be greatly reduced when the system is up and running.

3.1.5 Overview

Table 6 shows an overview of the different counting techniques. + and - symbols are used to indicate how the methods perform in each category. + and ++ symbols are used when the performance is good and excellent respectively. - and -- symbols are used when the performance is bad and terrible respectively. +- is used when the performance is mediocre.

	Manual counting	Weight-based counting	Barcode counting	RFID counting
Investment costs (this includes tags)	++	+-	+	--
Labor costs	--	+	-	++
Accuracy	--	+ (depends on sample relative to scale accuracy)	-	++ (depends on material, for metal --)
Suited for heterogeneous lots	Yes	No	Yes	Yes
Suited for metal parts	Yes	Yes	Yes	No
Training/knowledge requirements	+	+	-	-

Table 6: Overview counting methods

3.2 Sample size determination methods

In Sections 3.2.1, 3.2.2 and 3.2.3, three ways to determine sample size and acceptance/rejection limits are reviewed. Choosing the right sampling size determination method is very important, since some sampling size determination methods require more knowledge and use different sample sizes for similar lot sizes.

3.2.1 Sample size determination: ISO 2859-1 – Single sampling plan

ISO 2859-1 is part 1 in the standardized sampling procedures from the ISO organization. Part 1 is named: *Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection* (ISO, sd). As it names suggests, ISO 2859-1 contains sampling schemes which provide sampling sizes for given Acceptance Quality Limits (AQL). Additionally, it provides acceptance and rejection limits to determine whether to accept or reject an incoming lot. Sampling tables specify the exact number of items to inspect based on lot size and desired inspection level. The sampling tables can be found in Appendix B.

- **Inspection levels**: Levels I, II, and III vary in inspection rigor. For first time inspection of new goods or new suppliers, level II is often chosen. For reliable suppliers with historically good quality, level I is often chosen (In Touch, 2019). For suppliers with known quality problems in recent times, level III if often chosen (In Touch, 2019). Generally speaking, the higher the inspection level, the bigger the sample, the higher the labor cost concerned with sample inspection.
    - Level I: Reduced inspection for reliable suppliers. Requires smaller sample sizes
    - Level II: Normal inspection for routine shipments. Requires average sample sizes
    - Level III: Tightened inspection for high-risk or previously defective suppliers. Requires bigger sample sizes
- **Decision criteria**: Acceptance/rejection tables define limits for defects. Based on sample size and set acceptable quality limits, acceptance and rejection limits are provided

By incorporating statistical methods, single sampling plans protect customers by minimizing the risk of accepting bad lots and minimizing the risk of rejecting good lots (Harrington, 1990). For suppliers, knowing that clients use sampling methods, it is important to be sure of good quality products. Suppliers do not like to see rejected batches get returned and clients may search for new suppliers when too many quality problems occur. This indirectly increases quality (Gomes, 2011).

Training requirements for single sampling plans depend on the amount of knowledge the employee already has on sampling. With a little background in sampling, single sampling plans are easy to use. For a known lot size, inspection level and AQL, sample sizes can be retrieved from the ISO 2859-1 tables. If not familiar with sampling, a little training on the basics of sampling can be helpful. Familiarity of the sampling tables is helpful to reduce the risk of misreading the tables.

While minimizing the risk of rejecting a good lot (type 1 error) and minimizing the risk of accepting a bad lot (type 2 error), the risk is not fully eliminated (Banovac, Pavlović, & Vistica, 2012). This means that good batches may be rejected due to an unrepresentative sample, or that bad batches may be accepted due to an unrepresentative sample. Additionally, quality control personnel has to get familiar with sampling tables and quality standards and this can be tricky.

3.2.2 Sample size determination: ISO 2859 – Double sampling plan

When using the principles of the double sampling plan, an initial sample is inspected and if results are inconclusive, a second sample is inspected to determine lot acceptance or rejection. The double sampling plan largely works the same way as the single sampling plan, with the same inspection levels and decision criteria. Sampling tables can be found in Appendix C.

- **Process**: An initial sample is inspected. If the number of defects is lower than the limit for the first sample, the batch is accepted. If the number of defects is higher than the limit for the two samples combined, the batch is rejected. If the number of defects is higher than the limit for the first sample, but lower than the limit for the two combined samples, a second sample in inspected. After, the results from both samples are combined to make the final decision (Agricultural Marketing Service & Department of Agriculture, 2024).

One of the advantages of the double sampling plan is that it can result in lower overall inspection costs while maintaining accuracy, just as is the case with single sampling plans. In comparison with the single sampling plan, double sampling plans offer the same statistical protection while potentially having a smaller average sampling size (Six Sigma, 2024). In addition, if the first sample is inconclusive, it allows for a second chance to identify defects (NIST/SEMATECH), reducing the risk of rejecting good lots or accepting bad ones. Further, just as is the case with single sampling plans, the presence of the double sampling plan, indirectly increases quality from the producer (Gomes, 2011).

Since double sampling largely works the same as single sampling, the training requirements are the same as well. Some basics on sampling are relevant as well as familiarity with the sampling tables.

All of the disadvantages from single sampling plans apply to double sampling plans as well, albeit that the risk of accepting bad lots, for example, is lower. A disadvantage compared to single sampling plans is that with wildly varying quality, it can increase the average sample size, which will result in more time spent on checking samples.

3.2.3 Sample size determination: Cochran’s sample size formula

When one is looking for proportions across populations or lots (in this case the proportion of defects), the following formula (Cochran’s sample size formula) can be used to calculate the sample size (Ahmed, 2024):

$$n = \frac{Z^2 * p * (1 - p)}{E^2}$$

Equation 1: Cochran's sample size formula

Where:
n=required sample size,
Z=z-value associated with the desired confidence level (e.g., 1.96 for 95 % confidence),
p=estimated proportion of errors (p=0.5 is used if proportion of errors is unknown to minimize risk),
E=margin of error (consumer risk: probability a bad lot gets accepted by customer)

Cochran’s sample size formula assumes a very big population. In case a population is not that big, the sample size can be a bit smaller. The adjustment is done with Finite Population Correction (FPC). This is valid to do since a given sample size says more about a small population than a large population (Israel, 1992). The formula used for this is:

$$n_{adj} = \frac{n}{1 + \frac{n - 1}{N}}$$

Equation 2: Finite Population Correction (FPC) formula

Where:
n_{adj}=adjusted sample size,
n =initial sample size from Cochran’s formula or the other formulas,
N=total lot size

Combining these two formulas yields the following formula for calculating a sample size that is adjusted for a finite population:

$$n = \frac{N \cdot Z^2 \cdot p \cdot (1-p)}{E^2 \cdot (N-1) + Z^2 \cdot p \cdot (1-p)}$$

Equation 3: Cochran's sample size formula adjusted with FPC

Where:
n=required sample size,
Z=z-value associated with the desired confidence level (e.g., 1.96 for 95 % confidence),
p=estimated lot proportion of errors (use p=0.5 if unknown to maximize variability),
E=margin of error (consumer risk: probability a bad lot gets accepted by customer)
N=lot size

When the sample size is calculated, an acceptance quality limit (AQL) has to be determined. With sample size and AQL, one can calculate the acceptance and rejection limits. The acceptance limit is found by calculating the upper bound of the confidence interval. The formula for this is:

$$Upper\ bound = \mu + z \cdot \sigma$$
$$\mu = n * p$$
$$\sigma = \sqrt{n * p * (1-p)}$$

Equation 4: Upper bound of confidence interval formula

Where
μ=expected defective items in sample
z=z-value associated with the desired confidence level (e.g., 1.96 for 95 % confidence)
σ=standard deviation
n=sample size
p=desired error rate (AQL)

- **Decision criteria:** The number provided by the upper bound calculation has to be rounded, the value that follows from this is the acceptance limit. One or more items over the acceptance limit is rejection of the lot.

Cochran’s sample size formula is typically used in a different setting than ISO 2859-1. ISO 2859-1 is typically used in quality control settings and Cochran’s formula is often used in survey research (Ahmed, 2024). However, that does not mean Cochran’s formula cannot be used in quality control settings. The advantage of Cochran’s formula is that it offers more flexibility, for example in terms of desired consumer risk (ISO 2859-1 uses 10%, while it can be higher or lower in Cochran’s formula) or desired confidence levels (ISO 2859-1 uses 95%, but it can be higher or lower in Cochran's formula). In this way, risk can be mitigated with bigger sample sizes, or inspection costs can be lowered by choosing a lower confidence level, which results in a smaller sample size.

A disadvantage of using Cochran’s sample size formula, is that is difficult to differentiate sampling based on risk. High-risk suppliers will generally be sampled the same as low-risk suppliers, unless consumer risk and confidence levels are continuously monitored and altered for every supplier based on sample results from the past. This can lead to sampling errors and additional time and resources spent on sampling (Noor, Tajik, & Golzar, 2022). Additionally, for smaller lots, the sample size is relatively high. This makes it more time-consuming and therefore more expensive to execute on smaller lots.

3.2.4 Overview

Table 7 shows an overview of the sample size determination methods. + and - symbols are used to indicate how the methods perform in each category. The + symbol is used when the performance is good. The - symbol is used when the performance is bad.

	Single sampling plan	Double sampling plan	Cochran’s formula
Sample based on supplier risk	Yes	Yes	No
Statistical knowledge required	+	+	-
Training/knowledge requirements	+	+	-

Table 7: Overview sample size determination methods

3.3 Sampling methods

Sampling methods are critical tools in quality control, particularly when inspecting large shipments of incoming goods. They allow organizations to evaluate a representative portion of a lot rather than each individual item, saving time and cost. One of the biggest advantages of sampling is that it reduces the inspections costs significantly due to only limited sized samples being inspected (Schilling, 1998). The most used probability sampling methods, simple random sampling, systematic sampling and stratified sampling are explained (Panacek & Thompson, 2007).

3.3.1 Simple random sampling

Simple random sampling is a sampling method where items are randomly chosen from a large lot for a sample. (Horton, 2024). Simple random sampling is often used where lots are large and homogeneous to obtain a sample that is representative of the entire lot (Noor, Tajik, & Golzar, 2022). This means that the assumption is made that the defect rate across the lot is consistent.

- **Process:** The sample size and acceptance/rejection limits can be determined by using any method mentioned in Sections 3.2.1, 3.2.2 or 3.2.3. Then, random items are drawn from the lot until the required number of samples is drawn.
- **Decision criteria**: The acceptance/rejection limits are to be used to decide whether to accept or reject the lot.

An advantage of simple random sampling is that there is no bias involved in the sample selection process. And since there is no selection bias, the results of the sample inspection are often precisely generalizable to the entire lot (Noor, Tajik, & Golzar, 2022). Simple random sampling is also an easy to implement sampling plan (Newcastle University, sd).

Executing simple random sampling is rather simple. Not much training is required to be able to understand and apply this sampling plan. Assuming the employee handling the sampling knows how to determine the sample size and acceptance/rejection limits, the only additional knowledge required is how to choose samples in a way that no selection bias arises.

3.3.2 Systematic sampling

Systematic sampling is a simple sampling method in the sense that there are no difficult statistical measures are to be used. Every k^{th} item is sampled (Kalton, 2017). A random number generator is often used to determine an unbiased first item between item number 1 and k. Systematic sampling works best in homogeneous lots.

Sample interval determination:
At first, the total sample size is determined. Either method mentioned in Sections 3.2.1, 3.2.2 or 3.2.3, can be used for this. The number of k can be calculated as follows (Siegle, sd):

$$k = \frac{n}{N}$$

Equation 5: Sample interval formula

Where:
k=sample interval
n=sample size
N=lot size

- **Process**: Determine the sample size and retrieve acceptance/rejection limits with any method mentioned in Sections 3.2.1, 3.2.2 or 3.2.3. Calculate k and select a random item between 1 and k. Then, every k^{th} item after the first one is inspected to confirm it is according to specifications.
- **Decision criteria**: The acceptance/rejection limits are to be used to decide whether to accept or reject the lot.

Systematic sampling is easy to implement and offers excellent dispersion of sample items throughout the lot (Mishra, Wanjari, Gangele, & Rawa, 2023). Additionally, every item in a lot has the same chance of being selected for the sample.

A disadvantage of systematic sampling is that selection bias can arise if there is an defect pattern in the population that coincides with the sampling interval (Ahmed, 2024). As an example, if for some reason, every 5th item produced has an error, k is 15 and the first checked item is item 10, every sampled item will be a faulty one while in reality, only one in five is a defect. So, in most cases, either the found number of defects is too high, or too low. In other words, if patterns can be or are present, it is best not to use systematic sampling (Sharma, 2017).

As is the case with simple random sampling, systematic sampling does not require much training to be properly executed. The employee conducting the sampling should know how to randomly choose a starting number between 1 and k.

3.3.3 Stratified sampling

According to the principles of stratified sampling, items from incoming lots are placed into subgroups (strata) based on factors like supplier, batch etc. with samples taken from each stratum (Qian, 2010). Larger lots require more strata and a bigger total sample size to be representative. Stratified sampling is most suited to create accurate acceptance/rejection decisions when lots are heterogeneous. The more distinct the strata are, the more accurate the sampling will be (Mishra, Wanjari, Gangele, & Rawa, 2023). To check the samples from each stratum, either simple random sampling or systematic sampling can be used.

Strata size determination:
To calculate the sample size for each stratum, a sample size for the entire lot is calculated first. This can be done with the methods mentioned section 3.2.1, 3.2.2 or 3.2.3. When the total sample size is determined, each individual stratum gets its own sample size based on the proportion of the lot size of each stratum within the entire lot. The formula for this is as follows (Ahmed, 2024):

$$n_h = \frac{N_h}{N} * n$$

Equation 6: Stratum sample size formula

Where:
n_h = sample size for stratum h,
N_h = population size for stratum h,

N = total population size,
n = overall sample size.

- **Process:** Strata are inspected independently to ensure quality consistency across all strata.
- **Decision Criteria:** Results from all subgroups are combined to make an acceptance/rejection decision for the entire lot.

The biggest advantage of stratified sampling is that since the variability within strata is reduced, the stratification normally provides more accurate estimates in heterogeneous lots compared to non-stratified sampling methods (Singh & Mangat, 1996). It is also more reliable compared to other sampling techniques in case of heterogeneity since the variability is decreased between strata, when using stratified sampling (Ahmed, 2024).

A disadvantage of stratified sampling is that it is more complex to carry out than other sampling methods (Ahmed, 2024). First, products have to be divided into clear, non-overlapping strata and it requires time and precise product knowledge to be able to do this. Another disadvantage is that stratified smalling is useless in homogeneous lots, since these lots cannot be divided into strata based on product characteristics as the product characteristics across all items are the same.

Stratified sampling requires more training than simple random sampling and systematic sampling. The employee sampling items has to be able to divide products into strata based on product characteristics. This means the employee has to be familiar with different suppliers and product characteristics. If this information is not present, the employee cannot accurately place items into strata. The strata samples are inspected with either simple random sampling or systematic sampling. The training requirements for these sampling methods can be found in their respective sections.

3.3.4 Overview

Table 8 shows an overview of the sampling methods discussed. We use + and - symbols to indicate how the methods perform in each category. We use the + symbol when the performance is good and we use the - symbol when the performance is bad.

	Simple random sampling	Systematic sampling	Stratified sampling
Bias	+	+ when defects random, - when errors possibly follow pattern	Depends on what sampling used within strata
Heterogeneous lot	No	No	Yes
Complexity	+	+	-
Training/knowledge requirements	+	+	-

Table 8: Overview sampling methods

4 Choosing best QC measures

This chapter gives a detailed overview of the different QC measures described in Chapter 3. Additionally, we choose the best QC measures. There are requirements and criteria from stakeholders that affect the choice for QC measures. These requirements and criteria are the result of stakeholder meetings we conduct. Since the results affect the choice, we mention these first. Section 4.1 lists the criteria to which products have to adhere. Section 4.2 describes the wishes concerning inspection methods, tools etc. Section 4.3 contains a list of requirements set by each stakeholder with which the quality control measures should comply .Section 4.4 offers a comparison of counting methods, Section 4.5 offers a comparison of sample size determination methods, Section 4.6 offers a comparison of sampling methods and Section 4.7 offers a conclusion that mentions the results of the comparisons that answers the research question from Chapter 4: *Which quality control system offers the best balance between cost, accuracy, fit to lot characteristics and training/integration requirements whilst adhering to criteria and requirements from stakeholders?*.

4.1 List of criteria

In collaboration with the engineering department, we set up a list of general criteria. This forms the basis for the quality inspection. Incoming goods will be inspected against these criteria and the standards set for these criteria. The list is grouped as follows:

Physical characteristics
- Appearance: Check for visual defects (scratches, dents, discoloration).
- Dimensions and tolerances: Verify measurements against specifications (length, width, height, diameter, etc.).
- Weight: Confirm weight matches expected values.
- Surface finish: Assess for smoothness, coating uniformity, or any required treatments like hardening (which leaves visible marks) or different surface treatments (different zinc treatments have different appearances for example)

Documentation and Identification
- Labeling and barcodes: Confirm labels match the purchase order and specifications.
- Accompanying documents: Check for required certificates.

Packaging
- Packaging integrity: Inspect for damage, adequate sealing, and proper materials.
- Labeling accuracy: Ensure packaging labels are correct and legible.
- Protective measures: Confirm appropriate cushioning or protection for the goods if necessary.

Quantity and Completeness
- Count/quantity: Verify the number of items received matches the purchase order.
- Completeness: Ensure all parts, components, or accessories are included.

4.2 Inspection methods

When selecting tools for goods handling employees, it is very important to prioritize simplicity where possible. The employees involved in these tasks do not have advanced technical expertise or specialized knowledge of complex tools. Therefore, it is crucial for management to invest in straightforward, user-friendly instruments that can be easily understood and effectively operated with minimal training.

For example, basic tools such as scales, calipers, and measuring tapes are excellent choices. These tools are simple, reliable, and familiar to most people, making them ideal for tasks like weighing packages, measuring dimensions, or checking tolerances. Their simplicity not only makes sure the measurements are accurate but also allows employees to work efficiently without the need for time-consuming instructions or prior experience.

Additionally, it is important to avoid implementing statistical sampling methods that are complex or require advanced mathematical knowledge. While statistical sampling can be useful for quality control, relying on methods that are too complex may lead to errors, inefficiencies, or frustration among the staff. Instead, choose simplified approaches or pre-configured tools that automate the most challenging parts of these processes, ensuring they remain accessible to all employees.

4.3 Requirements from stakeholders

We have asked all stakeholders connected to the implementation and use of the incoming goods inspection (goods handling employees, engineering and management) about their requirements for the design of the system to make sure it will function properly after implementation. Table 9 presents the list of requirements.

Requirements	
Goods handling employees	Access to (a limited version of) the ERP software to be able to check the delivery notes against the order in the ERP software
Goods handling employees	Laptop/powerful tablet that can run 3D software so that model drawings can be accessed in order to compare delivered products against the drawings
Goods handling employees	With every order, a set of drawings with the main and most important dimensions should be attached to be able to verify these dimensions
Goods handling employees	Tools to actually be able to verify product dimensions
Engineering	A way to be able to be extra strict on checking new suppliers, since these cause more problems than known suppliers
Engineering	Photo's added of each confirmed delivery, so that orders can be (re)checked for completeness if problems arise later on
Engineering	Since delivery notes from some suppliers more often than not are incorrect, goods handling employees really need to be able to accurately check deliveries against the delivery notes and the delivery notes against the order that is in the ERP software.
Engineering	Person who does the checks, needs to sign off the checks, so that possible errors can be traced back to this person. This also prevents problems where personnel will be less strict as they are not held accountable and the problem is not traceable to them.
Management	Floorplan + space requirement to be able to efficiently set up the new receiving area with integrated quality control area
Management	List of investments to do for the new quality control measures to work effectively

Table 9: User requirements

Some of these requirements will have impact on this research. Some requirements do not impact this research, but are to be considered in the implementation of the quality control measures in the future. An example is: “With every order, a set of drawings with the main and most important dimensions should be attached to be able to verify these dimensions.” This requirement is not affecting this research, but is important in the preparation stages of the implementation. One requirement that does affect this research is: “A way to be able to be extra strict on checking new suppliers, since these cause more problems than known suppliers”. This is directly related to the choice of sample size and acceptance/rejection limit determination.

4.4 Comparison of counting methods

Table 10 shows an overview of the different counting techniques. It is the same table as Table 6 (Section 3.1.5). We use + and - symbols to indicate how the methods perform in each category. We use + and ++ symbols when the performance is good and excellent respectively. We use - and -- symbols when the performance is bad and terrible respectively. We use +- when the performance is mediocre.

	Manual counting	Weight-based counting	Barcode counting	RFID counting
Investment costs (this includes tags)	++	+-	+	--
Labor costs	--	+	-	++
Accuracy	--	+ (depends on sample relative to scale accuracy)	-	++ (depends on material, for metal --)
Suited for heterogeneous lots	Yes	No	Yes	Yes
Suited for metal parts	Yes	Yes	Yes	No
Training/knowledge requirements	+	+	-	-

Table 10: Comparison of counting methods

Based on table 10, we can pick the best counting method. RFID counting is the first method we drop due to its inability to work properly in metal dense environments. Since nearly every product at Bomech is made from metal, RFID counting would be really unsuited for counting incoming items. Next, we drop manual counting. Manual counting has terrible accuracy compared to barcode counting and weight-based counting. Additionally, it is very time consuming and therefore, the labor costs are very high. This makes manual counting unfeasible to use for counting incoming items.

Weight-based counting and barcode counting remain as options. Both are able to work in metal-dense environments and both provide more accurate counts than manual counting. When using weight-based counting, it is not possible to count heterogeneous lots. However, this is not a major concern, as the vast majority of incoming items is delivered in homogeneous lots. The few lots that are heterogeneous only have a few items per item type which can easily be counted by hand.

While weight-based counting requires a slightly bigger investment compared to barcode counting, it will offset this in the long run with lower labor costs. Especially in larger lots, using weight-based counting will result in significantly lower labor costs. Additionally, a little less knowledge and training is required in order to use weight-based counting, albeit that the difference is small. That leaves the decision to accuracy. Assuming the sample size is determined with scale accuracy in mind, it is more accurate than barcode counting. This means that the best counting method in Bomech's case is weight-based counting.

4.5 Comparison of sampling size determination methods

Table 11 shows an overview of the sample size determination methods. It is the same table as Table 7 (Section 3.2.4). We use the + and - symbols to indicate how the methods perform in each category. We use the + symbol when the performance is good and we use the - symbol when the performance is bad.

	Single sampling plan	Double sampling plan	Cochran's formula
Sample size	+	++ when constant quality, - when varying quality	-
Sample based on supplier risk	Yes	Yes	No
Statistical knowledge	+	+	-
Training/knowledge requirements	+	+	-

Table 11: Comparison of sample size determination methods

Based on table 11, we discard Cochran's sample size formula immediately, since it is inferior to single and double sampling in every regard and does not really offer the possibility to sampling based on supplier risk. This is a requirement from the engineering department. This leaves single and double sampling. These two plans can be differentiated on sample size. Currently, there is little to no knowledge available on how product failure and variance in quality are distributed. This means that the quality can be either constant or varying. In this case, it is best to choose the middle of the road solution, which is single sampling. The sample size is slightly bigger compared to using double sampling when the quality is constant, but slightly smaller compared to using double sampling when the quality is varying.

4.6 Comparison of sampling plans

Table 12 shows an overview of the sampling methods discussed. It is the same table as Table 8 (Section 3.3.4) We use + and – symbols to indicate how the methods perform in each category. We use the + symbol when the performance is good and we use the - symbol when the performance is bad.

	Simple random sampling	Systematic sampling	Stratified sampling
Bias	+	+ when defects random, - when errors possibly follow pattern	Depends on what sampling used within strata
Heterogeneous lot	No	No	Yes
Complexity	+	+	-
Training/knowledge requirements	+	+	-

Table 12: Comparison of sampling methods

Based on table 12 and the fact that heterogeneous lots are nearly absent, we will not consider stratified sampling as the best sampling method. It is unnecessarily complicated and has no purpose in homogeneous lots. Between simple random sampling and systematic sampling, both are rather simple and require limited training. Since it is often not known if defects are random or follow a pattern, we choose simple random sampling as the best sampling plan because it offers the least amount of bias all-round.

4.7 Conclusion

Together with the engineering department, we created a list of criteria that will be used for the quality inspection. Incoming items will be checked for compliance with these criteria and the standards set for these criteria. The list can be found in Section 4.1.

With the stakeholders involved, we decided it to keep the methods and tools to be used as simple as possible in order to avoid overcomplicating the quality inspection process. The employees that are going to be tasked with this additional new process do not possess advanced knowledge of sampling and technical difficult tools. To avoid errors, simplicity is key.

Together with all stakeholders, we drafted up a list of requirements with which the measures to be used should comply. These requirements range from access to parts drawings to be able to check incoming items against these drawings to more widespread use of the ERP functionalities in place already. The complete list of requirements can be found in Section 4.3. The requirements do not necessarily all have an impact on this research, but should be kept in mind with the implementation of the solution provided in this research.

In conclusion, we choose to use weight-based counting for verifying lot sizes since it is a relatively low-cost method with good accuracy which does not take much time to execute. It does not require much training to be able to properly operate and execute scales and item counting. We pick the single sampling plan to use for determining the sample sizes. This means adhering to the ISO 2859-1 standard. We choose this because it is a widely adopted method that offers relatively small sample sizes whilst still being accurate. Additionally, it satisfies the requirement of being able to sample based on risk and training and knowledge requirements are limited. Lastly, we choose simple random sampling as the best sampling method in Bomech’s case since it offers the least amount of bias in the selection of items all-round and is simple to implement. Due to its incomplexity, it does not require much training and knowledge.

5 Analyzing the effect of the solution

In this chapter, we analyze the effect of the proposed solution on the productivity and inspection costs. At the end, we provide an overview of the total labor costs reduction. These analyses are done for multiple acceptance quality levels (AQL). Bomech would like to aim for an AQL of 1 percent. That said, they asked to provide an overview of some acceptance levels around the 1 percent mark. Section 5.1 provides an analysis of the inspection times for different AQL levels. Section 5.2 provides an analysis to show how time-loss in the production process is reduced and it compares this reduction to the time needed to inspect parts. Section 5.3 will display a scenario in which the effect of inspecting extra critical parts only is analyzed. Section 5.4 gives the conclusion of this chapter.

5.1 Inspection times

In Table 13, the percentage of the sample size relative to the lot size is calculated for the ISO 2859-1 single sampling plan - level II table. Level II is displayed as it is the middle ground. The sample sizes for the ISO 2859-1 single sampling plan are sourced from the ISO 2859-1 tables found in Appendix C. To be able to calculate the percentage of the sample size relative to the lot size, a fixed lot size has to be used in each lot size step. The choice has been made to use the median in that case. This means that for the 91 to 150 range, the lot size number used in that case is 120. These numbers can be seen in brackets behind the lot size range. Lot sizes of up to 1200 products are displayed, as there are no products that arrive in larger lots. There is therefore no purpose to show these larger lot size ranges.

	ISO 2859-1 – Level II		
Lot size	**AQL = 0.65**	**AQL = 1**	**AQL = 1.5**
2 to 8 (5)	100.00%	100.00%	100.00%
9 to 15 (12)	100.00%	100.00%	66.67%
16 to 25 (20)	100.00%	65.00%	40.00%
26 to 50 (38)	52.63%	34.21%	21.05%
51 to 90 (70)	28.57%	18.57%	11.43%
91 to 150 (120)	16.67%	10.83%	26.67%
151 to 280 (215)	9.30%	23.26%	14.88%
281 to 500 (390)	20.51%	12.82%	12.82%
501 to 1200 (850)	9.41%	9.41%	9.41%

Table 13: Sample size as proportion of lot size

Table 13 shows that across the different lot sizes, generally speaking, a bigger lot size means a percentual smaller sample size. However, this is in some cases not true. This anomaly occurs due to the fact that the sampling tables are standardized. The number of lot size ranges and sample sizes are limited. Lot ranges have a code letter attached to it. This letter comes back in the sampling tables and show how many samples to pick. Moving up in lot size range often means moving up in sample size code letter as well. Sometimes, the increase in sample size when moving to a bigger lot size is proportionally bigger than the increase in this lot size. This is when the anomalies as observed occur. It is a known characteristic of sampling tables.

To analyze the inspection costs, several assumptions have to be made. We assume that of all parts fitted to a machine, a third is considered critical and extra critical. These parts are called critical and extra critical parts as these parts are responsible for basically all time-loss since these require significant disassembly and reassembly. A Farmer and Speedy have roughly 180 parts per machine on average, so 60 parts are critical and extra critical. A Multi consists of roughly 230 parts, which means 77 are critical and extra critical. Further, there are 4 extra critical parts take considerably more time to replace than the critical parts. These four parts are the mounting frame, middle frame and arms. This means a Farmer and Speedy have 56 critical parts and a Multi has 73 critical parts, while both have 4 extra critical parts.

Further, It is assumed that that it will take around 1.5 minutes to inspect one extra critical part, while it is assumed that inspection of the other parts will take 15 seconds per part on average.

For regular critical parts, since different lot sizes come with different sample sizes, a distribution on the size of incoming lots is needed. Table 14 shows this distribution for the different lot size ranges from ISO 2859-1.

Lot size	Distribution of incoming lot sizes
26 to 50 (38)	0.35
51 to 90 (70)	0.35
91 to 150 (120)	0.15
151 to 280 (215)	0.05
281 to 500 (390)	0.05
501 to 1200 (850)	0.05

Table 14: Distribution on the size of incoming lots

Combining the numbers from table 14, the assumption on inspection times per part, the assumptions on the number of critical parts per machine and the ISO-2859-1 tables, we can calculate the inspection times of critical parts per machine for different AQL levels. Since a Multi has more critical parts, it requires more inspection time than a Farmer or Speedy. But as fewer Multis are sold, the numbers are corrected with production numbers. Table 15 shows these numbers. Since the inspection times are an assumption, there are also two rows that show for 25% more and less inspection time needed per part, to see if the conclusion changes when the inspection times turn out to be different.

	AQL = 0.65%	AQL = 1%	AQL = 1.5%
Assuming 15 seconds inspection per part	2.8 minutes	2.2 minutes	2 minutes
25% more time required	3.5 minutes	2.7 minutes	2.5 minutes
25% less time required	2.3 minutes	1.7 minutes	1.6 minutes

Table 15: Inspection times per machine for critical parts

It turns out that using an AQL of 0.65% means 31% more inspection time per machine is required for critical parts compared to an AQL of 1%. Using an AQL of 1.5% means 7% less inspection time per machine is required for critical parts compared to an AQL of 1%.

We assume that extra critical parts come in lots of on average 8 pieces. This assumption stems from the fact that the extra critical parts are big and take up a lot of space in a lorry trailer. From this assumption follows that these lots will always be subject to 100% inspection for the analyzed AQL levels. This means that each machine will have about 6 minutes inspection time for just the more time-consuming to replace parts. Table 16 shows the total inspection time, again with a row for 25% more time required and a row for 25% less time required.

	AQL = 0.65%	AQL = 1%	AQL = 1.5%
Assumption	8.8 minutes	8.2 minutes	8 minutes
25% more time required	11 minutes	10.2 minutes	10 minutes
25% less time required	7 minutes	6.6 minutes	6.4 minutes

Table 16: Total inspection time per machine

5.2 Effect on productivity

To measure the effect of the proposed solution on productivity, we have to gain insight in how the defects per machine change when using different AQL levels. That is why we have set up a Monte-

Carlo simulation that will predict the number of defects that are assembled to a machine. In order to do a Monte-Carlo simulation to simulate the defects in a machine, two types of information are necessary: the number of parts in a machine (more parts means more defects assuming the same defect rate) and the defect rate. Then, every part is simulated for failure. If a machine consists of 100 parts, 100 individual experiments are done to simulate the number of failures per machine. This is done for a large number of machines to get a representative average.

Several assumptions have been made by Bomech in order for the researcher to be able to do the Monte-Carlo simulation. The first being the current defect rate, which is estimated to be around 2.5%.

To represent the current situation, for a Farmer and Speedy, 60 experiments per machine will be done and for a Multi, 77 experiments per machine are done. These are the number of critical and extra critical parts per machine. To represent the situations with the to analyze AQL levels, respectively 56 and 73 experiments per machine are done. This correction is applied since inspecting extra critical parts results in 100% inspection for these parts (see Section 5.1). The four extra critical parts therefor do not have to be simulated as defects assembled to a machine, as all errors should be filtered out with the 100% inspection. For all three machine types, 1000 machines are simulated.

We made the assumption that the chosen AQL is the defect rate. An AQL of 1% means that the defect rate is in any case lower than or equal to 1%. We made this assumption since suppliers will likely try to be as close to the 1% defect rate as possible. Producing with better rates simply is more expensive.

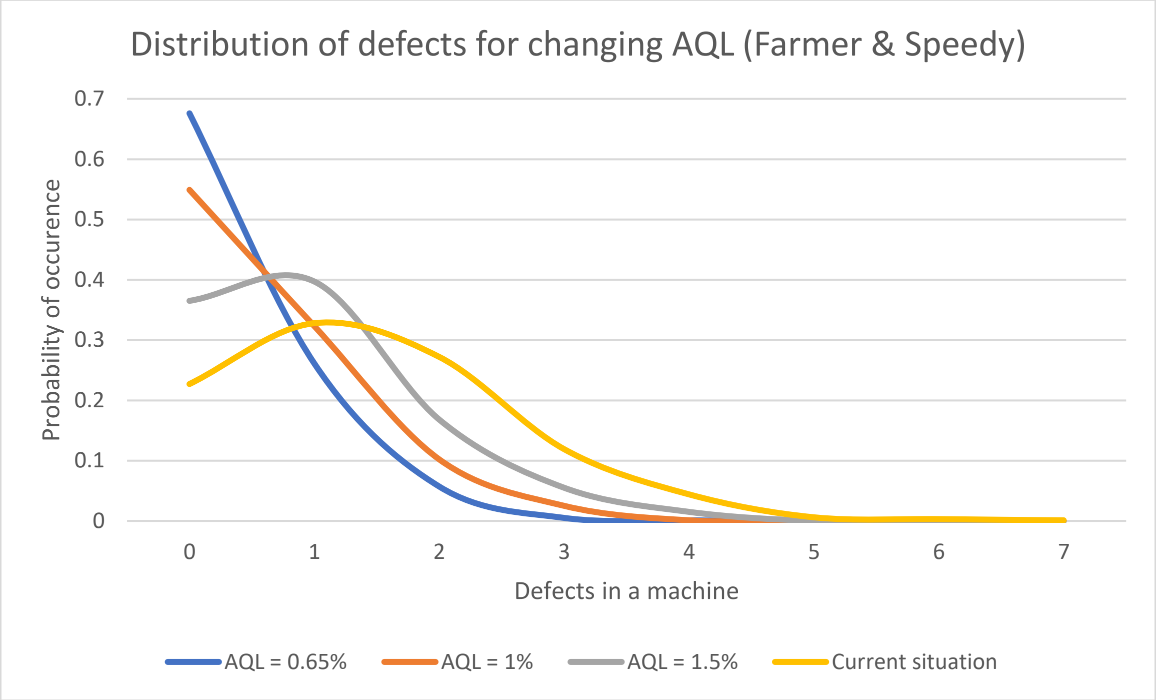

Figure 11: Distribution of defects for changing AQL (Farmer & Speedy)

Figure 11 shows the defects per machine for the Farmer and Speedy for different AQL levels and the current situation. It shows that having a stricter AQL leads to a bigger chance of having zero defects per machine. Additionally, the higher the AQL, the more the graph skews out to the right, indicating more defects on average per machine. Table 17 shows the average number of defects in a machine for different AQL levels for the Farmer and Speedy.

AQL = 0.65%	AQL = 1%	AQL = 1.5%	Current
0.32	0.55	0.86	1.46

Table 17: Average number of defects per machine for changing AQL (Farmer & Speedy)

The third assumption made by Bomech is that currently, around 50% of the critical and extra critical failures are found in production and replaced. This means that currently, 0.73 critical and extra critical errors per Farmer/Speedy leave unnoticed. From the 60 critical and extra critical parts, this means that on average 1.2% of these parts on delivered machines are defective.

AQL = 0.65%	AQL = 1%	AQL = 1.5%	Current
0.42	0.71	1.13	1.87

Table 18: Average number of defects per machine for changing AQL (Multi)

Table 18, together with the assumption that 50% of the critical errors are noticed, shows that currently 0.935 critical and extra critical errors are present per delivered Multi. This is 1.2% of the 77 critical and extra critical parts found on the Multi, which is exactly the same percentage compared to the Farmer and Speedy.

Tables 19 shows the percentual difference in the average number of critical and extra critical defects per machine compared to an AQL of 2.5%. Adopting an AQL of 1.5% means having 40% less critical and extra critical defects per machine compared to the current situation, while adopting an AQL of 1% results in having 62% less critical and extra critical defects per machine compared to the current situation. Finally, an AQL of 0.65% will result in a reduction of 78% compared to the current situation.

AQL = 0.65%	AQL = 1%	AQL = 1.5%
-78%	-62%	-40%

Table 19: Percentual difference in the average number of critical and extra critical defects per machine compared to the current situation

Table 20 shows the percentual difference between the average number of critical defects per machine for AQL = 0.65% and AQL = 1.5% compared to AQL = 1%.

AQL = 0.65%	AQL = 1.5%
-42%	+58%

Table 20: Percentual difference in the average number of critical and extra critical defects per machine compared to an AQL of 1%

On average, 4 hours are needed to replace a defect of extra critical parts. For the other parts, it costs on average 15 minutes to replace a defect one. With these numbers, the time-loss per machine due to defects can be calculated for the current situation and for the different AQL levels (where no extra critical defects should be present in the production process anymore). Table 21 shows the results.

Current	AQL = 0.65%	AQL = 1%	AQL = 1.5%
22.8 minutes	2.3 minutes (20.5 minutes)	4 minutes (18.8 minutes)	6.3 minutes (16.5 minutes)

Table 21: Time-loss per machine due to defects with reduction in brackets

Table 22 shows the percentual difference between the AQL levels analyzed and the current situation.

AQL = 0.65%	AQL = 1%	AQL = 1.5%
-90%	-82%	-72%

Table 22: Percentual difference in the time-loss per machine compared to the current situation

With all the information from the analysis, the improvement in labor productivity can be calculated. Table 23 shows the current productivity loss due to defect parts.

Productivity loss	Farmer	Speedy	Multi
Stage 2	2.6%	2.6%	3.9%
Stage 4	3.9%		

Table 23: Productivity loss due to defect parts

Table 24 shows the productivity improvement for each AQL level. The data we use to calculate these numbers comes from table 14 and table 17. The following equation is an example of how the improvement is calculated. It is done for the Farmer in stage 2 and an AQL of 0.65%

$$\frac{(100 - 2.6 * (1 - 0.90)) - (100 - 2.6)}{(100 - 2.6)} * 100 \approx 2.4\%$$

All other calculations are similar, but use different values since the values in the tables are different.

Productivity improvement	AQL = 0.65%			AQL = 1%			AQL = 1.5%		
	Farmer	Speedy	Multi	Farmer	Speedy	Multi	Farmer	Speedy	Multi
Stage 2	2.4%	2.4%	3.7%	2.2%	2.2%	3.3%	1.9%	1.9%	2.9%
Stage 4	3.7%			3.3%			2.9%		

Table 24: Productivity improvement due to reduction of defects in production process

Finally, it can be calculated how much labor costs can be saved by implementing quality control measures. This is done by using the data from Table 16 and Table 21. We add the time-loss per machine in the production process for the different AQL levels to the inspection times per machine for the different AQL levels. We compare this sum to the current time-loss per machine in the production process. The results are shown in Table 25.

AQL = 0.65%	AQL = 1%	AQL = 1.5%
-51%	-46%	-37%

Table 25: Labor costs savings

5.3 Scenario

While the general overview already shows the significant effect of implementing quality control measures, more detailed separations can be made in the results.

Below is an overview of three scenarios with again the assumption that 50% of defects that do enter the production process are found:

- Scenario 1: Average time-loss per machine with 2.5% defect rate for both types of parts.
- Scenario 2: Average time-loss per machine with 1% defect rate for extra critical parts and 2.5% defect rate for the other parts
- Scenario 3: Average time-loss per machine with 1% defect rate for both types of parts

Scenario 1	Scenario 2	Scenario 3
22.8 minutes	10.6 minutes	4 minutes

Table 26: Time-loss per machine for different scenarios

Table 26 shows the results from the different scenarios. It shows the impact of the 4 extra critical defects to fix on the total average time-loss per machine. From the 18.8 minutes reduction in time-loss per machine, 12.2 minutes come from checking extra critical parts alone. The other parts account for 6.6 minutes of time reduction. When taking into account the inspection costs as well, checking the extra critical parts alone would reduce the labor costs in total with 27% and checking the other parts would reduce labor costs by 19%. When checking all parts, a reduction of 46% in labor costs is possible.

5.4 Validation

While the results are really promising, there are some nuances that have to be made. We assume in this paper that the inspection is 100% effective, meaning that every defect sample picked is also marked as a defect part. This is of course not realistic. Inspection accuracy is very much dependent on the inspector, the products to be inspected and the environment in which inspections are performed. It is therefore hard to determine what the accuracy will be, especially since there are varying types of products to be inspected. According to See (2015), trained inspectors can correctly reject 85% of defective items in case of precision manufactured goods. She also mentions that the industry average is 80%. Since Bomech is not in the precision manufacturing field, we will use the industry average of 80% as the inspection accuracy. This means that 20% of inspected samples will be marked as good while in reality, these are not. This means that the average amount of defects per machine will be 20% higher than what is displayed in table 17 and 18. Combining all of the information above, we can calculate the adjusted results. Table 27 and 28 show these results.

Productivity improvement	AQL = 0.65%			AQL = 1%			AQL = 1.5%		
	Farmer	Speedy	Multi	Farmer	Speedy	Multi	Farmer	Speedy	Multi
Stage 2	2.3%	2.3%	3.4%	2%	2%	3%	1.5%	1.5%	2.4%
Stage 4	3.4%			3%			2.4%		

Table 27: Adjusted productivity improvement due to reduction of defects in production process

AQL = 0.65%	AQL = 1%	AQL = 1.5%
-46%	-38%	-23%

Table 28: Adjusted labor costs savings

After validating the results, the solution still offers strong improvement of the current situation. In case the inspection accuracy is above industry average, this can result in even stronger improvement.

5.5 Conclusion

To conclude, we found that using QC measures can tremendously lower labor costs connected to the current time-loss. The analyzed scenario shows that checking the extra critical parts only can cause the most reduction in labor costs. Overall, in the best case, labor costs can be lowered by nearly 50%. Additionally, significant labor productivity improvements are possible. The target is not going to be met completely, but with 2.3 to 3.4% improvement in the best case, it still means significant improvement. From the analysis, adopting the strictest AQL level analyzed seems like the best option.

6 Conclusions and recommendations

This chapter gives a summary of the conclusions from each chapter. Additionally, some recommendations will be provided regarding potential future research. Section 6.1 provides the answers to the research questions and Section 6.2 discusses the recommendations.

6.1 Conclusions

To summarize, we showed that the production process and incoming goods handling process are multi-stage processes. Labor productivity in several parts of the production process is negatively affected by having to deal with defect parts. 2.6 to 3.9% of the production time is lost to dealing with defect parts.

After reviewing quality control measures that are used often, we drew up lists of criteria and requirements with shareholders. These lists contain information that aided in the process of selecting the best quality control measures for Bomech.

In the end, we chose to select weight-based counting for counting incoming goods. This method was chosen due to its simplicity and high accuracy combined with low costs. In order to determine sample sizes and associated acceptance and rejection limits, we showed that using the ISO 2859-1 single sampling plan is the best option for Bomech. This sampling plan is widely used in the world of quality control and offers great statistical protection against accepting bad batches of parts whilst keeping the sample sizes small. Simple random sampling is the best choice for selecting samples as it is simple to implement and offers a virtually bias free selection of samples.

After finalizing the choices, we analyzed the effect of the chosen solution on the production process. This was done for several AQL levels. It turns out that implementing the proposed solution can have a significant impact on labor costs. Including inspection costs and costs associated with time-loss due to defects, the implementation of the strictest AQL level can reduce labor costs with 46%. The more least strict AQL level analyzed can reduce labor costs with 23%. Productivity also can be significantly improved. The least strict AQL level can improve labor productivity with 1.5 to 2.4%, while the strictest AQL level can improve labor productivity with 2.3 to 3.4%. This does not fully meet the target of 3 to 5% improvement, but is a significant improvement nonetheless.

6.2 Recommendations

When confronted with the fact that currently, 1.2% of critical parts on a machine are delivered with a defect (see Section 5.2), employees from Bomech mentioned that around 1% of newly delivered machines need service on or replacement of critical parts within the warranty period. While this does not prove a correlation between the numbers, the fact that they are close to each other certainly raises the question if they possibly are correlated.

This is very much relevant, because failure of critical parts within the warranty period means that the parts have to be replaced by Bomech. This is done in either of two ways: Bomech employees drive to the customer with parts and replace them or Bomech sends the parts to the customer who then replaces these themselves if they are prepared to do so. Either way, it is expensive and costs a lot of time to handle, especially if some of Bomech's employees have to drive to these customers since the customers generally live far away. Replacing parts is for that reason often multiple days of work.

It could be interesting to conduct more research into this to see if a correlation can be found between the percentage of critical errors per machine and the percentage of newly delivered machine that need parts service of replacement within the warranty period. If so, this would show that altering quality norms will lead to more or less newly delivered machines needing parts service or replacement within the warranty period. The data and costs that follow if this correlation turns out to be true could then be incorporated into the results from this research to reevaluate the adopted quality level.

Further, Bomech should conduct research into what inspection times, and with that inspection costs, are to be expected for inspecting different products. In this research, rough estimates were used. However, significant differences may have a significant effect on the ultimate results and for that reason, more research should be conducted. These results can than be incorporated into the results from this research for more accurate results.

Lastly, Table 13 shows that having a bigger lot size generally means that the proportion of samples becomes smaller. However, table 14 shows that the vast majority of lots are quite small. Therefore, some research could be conducted into analyzing whether it is possible to combine multiple smaller lots of products into bigger lots. This will decrease the inspection time per product and therefore decrease inspection costs overall. Larger lots require more storage space and therefore cause higher storage costs, but it could be interesting to find out if they offset each other and if ordering larger lots in the long run can save costs.

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Appendices

Appendix A: Calculations of average labor productivity

Due to fierce competition in the sector Bomech operates in, they are reluctant about sharing actual production numbers and related information. That is why the numbers are shown in percentages.

Appendix A.1: Calculations of average labor productivity Farmer

Proportion between Farmer versions over 3 years

2023	
3DW	76%
I-Control	22%
E-Control (plus)	2%

Total = 26.1%

2022	
3DW	84%
I-Control	14%
E-Control (plus)	2%

Total = 34.1%

2021	
3DW	81%
I-Control	17%
E-Control (plus)	2%

Total = 39.8%

Weighted average over 3 years

3DW	81%
I-Control	17%
E-Control & plus	2%

Proportion between options fitted to Farmer machines over 3 years

	2023	2022	2021
Section control	44%	37%	39%
ASC	2%	1%	1%
Lighting	83%	84%	98%

Weighted average over 3 years

Section control	40%
ASC	1%
Verlichting	89%

Hours spent at stage 1

Farmer	
Mounting frame (per 6)	4 hours

Middle frame (per 5)	2 hours
Middle frame + lighting (per 5)	4 hours

$$Average\colon \frac{4}{6} + \frac{2}{5} * (1 - 0.89) + \frac{4}{5} * 0.89 \approx 1\frac{1}{2} \text{ hours}$$

Hours spent at stage 2

Farmer	
Arms	1.5 hours

Hours spent at stage 3

Farmer	**3DW**	**I-Control**	**E-control (plus)**
12 & 15	3 hours	5 hours	12 hours (12 hours)
Section control	+1 hour		
ASC	+ 4 hours		

$$Average\colon 0.81 * 3 \ + \ 0.17 * 5 \ + \ 0.02 * 12 \ + \ 0.4 * 1 \ + \ 0.01 * 4 \ \approx \ 4\,hours$$

Hours spent at stage 4

Farmer	
12 & 15	7 hours
ASC	+ 8 hours

$$Average\colon 7 + 0.01 * 8 \approx 7\,hours$$

Hours spent at stage 5

Farmer	
12 & 15	1 hour

$$Total\ average\colon 1\frac{1}{2} + 1\frac{1}{2} + 4 + 7 + 1 = 15\,hours$$

Appendix A.2: Calculations of average labor productivity Speedy

Proportion between Speedy, Speedy Small and Speedy One over 3 years

2023	
Speedy	56%
One	32%
Small	12%

Total = 34.7%

2022	
Speedy	52%
One	31%
Small	17%

Total = 30.6%

2021	
Speedy	54%
One	30%
Small	16%

Total = 34.6%

Weighted average over 3 years

Speedy	54%
One	31%
Small	15%

Proportion between Speedy versions over 3 years

2023	
3DW	21%
I-Control	58%
E-Control (from which plus)	21% (57%)

Total = 34.7%

2022	
3DW	29%
I-Control	50%
E-Control (from which plus)	21% (53%)

Total = 30.6%

2021	
3DW	23%
I-Control	57%
E-Control (from which plus)	20% (37%)

Total = 34.6%

Weighted average over 3 years

3DW	24%
I-Control	55%
E-Control (from which plus)	21% (48%)

Proportion between options fitted to Speedy machines over 3 years

	2023	**2022**	**2021**
Section control	17%	15%	16%

Weighted average over 3 years

Section control	16%

Hours spent at stage 1

Speedy	
Mounting frame (per 6)	4.5 hours

$$Total: \frac{4.5}{6} = \frac{3}{4}\ hours$$

Hours spent at stage 2

Speedy/Small	1.5 hours
One	0.5 hours

$$Average: (1 - 0.31) * 1\frac{1}{2} + 0.31 * \frac{1}{2} \approx 1\frac{1}{4}\ hours$$

Hours spent at stage 3

Speedy	**3DW**	**I-Control**	**E-Control (plus)**
One/Small/Speedy	5 hours	6.5 hours	7 hours (10 hours)
Section control	+ 1.5 hours		

$$Average: 0.24 * 5 + 0.55 * 6.5 + 0.21 * (0.48 * 10 + 0.52 * 7) + 0.16 * 1.5 \approx 7\ hours$$

Hours spent at stage 4

Speedy/Small	7 hours
One	8 hours

$$Average: (1 - 0.31) * 7 + 0.31 * 8 \approx 7\frac{1}{2} hours$$

Hours spent at stage 5

Speedy/Small/One	1 hour

$$Total\ average: \frac{3}{4} + 1\frac{1}{4} + 7 + 7\frac{1}{2} + 1 = 17\frac{1}{2}\ hours$$

Appendix A.3: Calculations of average labor productivity Multi

Proportions between Multi versions over 3 years

2023	
3DW	95%
I-Control	5%

Total = 30.0%

2022	
3DW	96%
I-Control	4%

Total = 28.2%

2021	
3DW	95%
I-Control	5%

Total = 41.8%

Weighted average over 3 years

3DW	95%
I-Control	5%

Proportions between Multi sizes over 3 years

2023	
12 & 15	28%
18	37%
21-24	35%

Total = 30.0%

2022	
12 & 15	20%
18	40%
21 & 24	40%

Total = 28.2%

2021	
12 & 15	25%
18	37%
21 & 24	38%

Total = 41.8%

Weighted average over 3 years

12 &15	24%
18	38%
21 & 24	38%

Proportion between options fitted on Multi machines

	2023	2022	2021
Hydraulic folding arm extension	46%	58%	52%
ASC (without air tank)	10%	8%	8%
ASC (with air tank)	2%	4%	3%

Weighted average over 3 years

Hydraulic folding arm extension	52%
ASC (without air tank)	9%
ASC (with air tank)	3%

Hours spent at stage 1

Mounting frame (per 4)	4 hours
Middle frame (per 4)	3 hours

$$Total: \frac{4}{4} + \frac{3}{4} = 1\frac{3}{4}\ hours$$

Hours spent at stage 2

12 & 15	1.5 hours
18	2.5 hours
21 & 24	8 hours

$$Average: 0.24 * 1\frac{1}{2} + 0.38 * 2\frac{1}{2} + 0.38 * 8 \approx 4\frac{1}{2}\ hours$$

Hours spent at stage 3

Multi	**3DW**	**I-Control**
12, 15, 18, 21 & 24	16 hours	28 hours
Hydraulic folding arm extension	+ 1 hour	
ASC (without air tank)	+ 3 hours	
ASC (with air tank)	+ 4 hours	

$$Average: 0.95 * 16 + 0.05 * 28 + 0.52 * 1 + 0.09 * 3 + 0.03 * 4 \approx 17\frac{1}{2}\ hours$$

Hours spent at stage 4

12 &15	10 hours
18	16 hours
21 & 24	32 hours
Hydraulic folding arm extension	+ 2 hours
ASC (without air tank)	+ 4 hours
ASC (with air tank)	+ 8 hours

$$Average: 0.24 * 10 + 0.38 * 16 + 0.38 * 32 + 0.52 * 2 + 0.09 * 4 + 0.03 * 8 \approx 22\frac{1}{4}\ hours$$

Hours spent at stage 5

12 & 15	1 hour
18	2 hours
21 & 24	3 hours

$$Average: 0.24 * 1 + 0.38 * 2 + 0.38 * 3 \approx 2\frac{1}{4}\ hours$$

$$Total\ average: 1\frac{3}{4} + 4\frac{1}{2} + 17\frac{1}{2} + 22\ \frac{1}{4} + 2\frac{1}{4} = 48\frac{1}{4}\ hours$$

Appendix A.4: Calculating proportion of each machine type

	Farmer	Speedy	Multi
2021 = 38%	50%	35%	15%
2022 = 32%	51%	37%	12%
2023 = 30%	41%	45%	14%

$$Average\ Farmer: 0.38 * 50 + 0.32 * 51 + 0.3 * 41 \approx 47.6\%$$
$$Average\ Speedy: 0.38 * 35 + 0.32 * 37 + 0.3 * 45 \approx 38.6\%$$
$$Average\ Multi: 0.38 * 15 + 0.32 * 12 + 0.3 * 14 \approx 13.7\%$$

	Farmer	Speedy	Multi
Average over 2021-2023	47.6%	38.6%	13.7%

Appendix B: Sampling tables ISO 2859 - single sampling plan

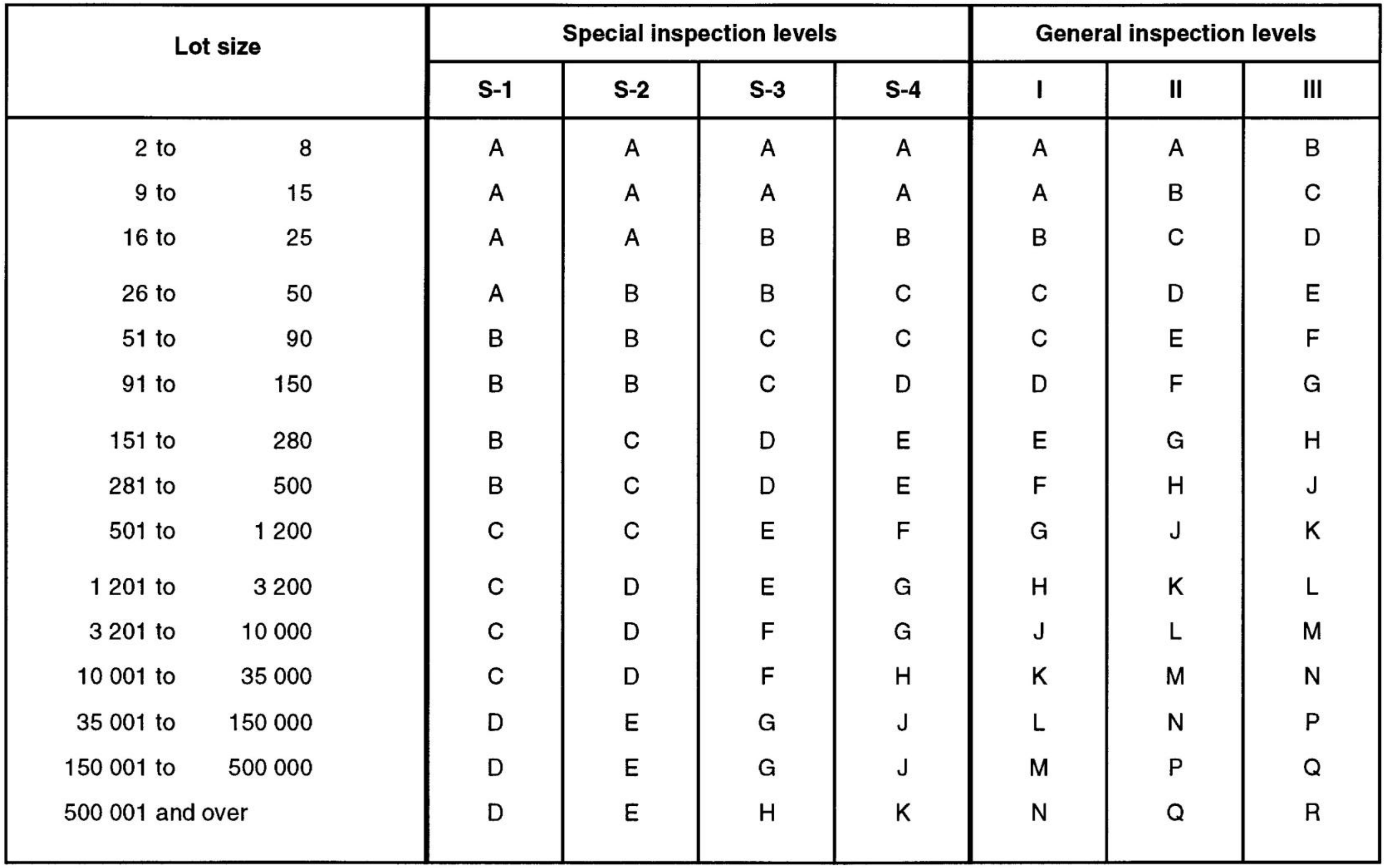

Table 1 - Sample size code letters (see 10.1 and 10.2)

Lot size	Special inspection levels				General inspection levels		
	S-1	S-2	S-3	S-4	I	II	III
2 to 8	A	A	A	A	A	A	B
9 to 15	A	A	A	A	A	B	C
16 to 25	A	A	B	B	B	C	D
26 to 50	A	B	B	C	C	D	E
51 to 90	B	B	C	C	C	E	F
91 to 150	B	B	C	D	D	F	G
151 to 280	B	C	D	E	E	G	H
281 to 500	B	C	D	E	F	H	J
501 to 1 200	C	C	E	F	G	J	K
1 201 to 3 200	C	D	E	G	H	K	L
3 201 to 10 000	C	D	F	G	J	L	M
10 001 to 35 000	C	D	F	H	K	M	N
35 001 to 150 000	D	E	G	J	L	N	P
150 001 to 500 000	D	E	G	J	M	P	Q
500 001 and over	D	E	H	K	N	Q	R

Table 2-A — Single sampling plans for normal inspection (Master table)

Sample size code letter	Sample size	Acceptance quality limit, AQL, in percent nonconforming items and nonconformities per 100 items (normal inspection)																									
		0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	3	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45
C	5	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	⇧
D	8	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	⇧	⇧
E	13	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	⇧	⇧	⇧
F	20	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧
G	32	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧
H	50	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
J	80	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
K	125	⇩	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
L	200	⇩	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
M	315	⇩	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
N	500	⇩	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
P	800	⇩	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
Q	1 250	0 1	⇧	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
R	2 000	⇧	⇧	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧

⇩ = Use the first sampling plan below the arrow. If sample size equals, or exceeds, lot size, carry out 100 % inspection.

⇧ = Use the first sampling plan above the arrow.

Ac = Acceptance number

Re = Rejection number

Table 2-B — Single sampling plans for tightened inspection (Master table)

Sample size code letter	Sample size	Acceptance quality limit, AQL, in percent nonconforming items and nonconformities per 100 items (tightened inspection)																									
		0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28
B	3	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	41 42
C	5	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	41 42	⇧
D	8	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	41 42	⇧	⇧
E	13	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	27 28	41 42	⇧	⇧	⇧
F	20	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧
G	32	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧
H	50	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
J	80	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
K	125	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
L	200	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
M	315	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
N	500	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
P	800	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
Q	1 250	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
R	2 000	0 1	⇧	⇩	1 2	2 3	3 4	5 6	8 9	12 13	18 19	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
S	3 150			1 2																							

⇩ = Use the first sampling plan below the arrow. If sample size equals, or exceeds, lot size, carry out 100 % inspection.

⇧ = Use the first sampling plan above the arrow.

Ac = Acceptance number

Re = Rejection number

Table 2-C — Single sampling plans for reduced inspection (Master table)

Sample size code letter	Sample size	Acceptance quality limit, AQL, in percent nonconforming items and nonconformities per 100 items (reduced inspection)																									
		0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
C	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	14 15	21 22	↑
D	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	14 15	21 22	↑	↑
E	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	14 15	21 22	↑	↑	↑
F	8	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑
G	13	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑
H	20	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑
J	32	↓	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑
K	50	↓	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
L	80	↓	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
M	125	↓	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
N	200	↓	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
P	315	↓	0 1	↑	↓	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Q	500	0 1	↑	↑	↓	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
R	800	↑	↑	↑	1 2	2 3	3 4	5 6	6 7	8 9	10 11	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

↓ = Use the first sampling plan below the arrow. If sample size equals, or exceeds, lot size, carry out 100 % inspection.

↑ = Use the first sampling plan above the arrow.

Ac = Acceptance number

Re = Rejection number

Appendix C: Sampling tables ISO 2859 - Double sampling plan

Table 1 - Sample size code letters (see 10.1 and 10.2)

Lot size	Special inspection levels				General inspection levels		
	S-1	S-2	S-3	S-4	I	II	III
2 to 8	A	A	A	A	A	A	B
9 to 15	A	A	A	A	A	B	C
16 to 25	A	A	B	B	B	C	D
26 to 50	A	B	B	C	C	D	E
51 to 90	B	B	C	C	C	E	F
91 to 150	B	B	C	D	D	F	G
151 to 280	B	C	D	E	E	G	H
281 to 500	B	C	D	E	F	H	J
501 to 1 200	C	C	E	F	G	J	K
1 201 to 3 200	C	D	E	G	H	K	L
3 201 to 10 000	C	D	F	G	J	L	M
10 001 to 35 000	C	D	F	H	K	M	N
35 001 to 150 000	D	E	G	J	L	N	P
150 001 to 500 000	D	E	G	J	M	P	Q
500 001 and over	D	E	H	K	N	Q	R

Table 3-A — Double sampling plans for normal inspection (Master table)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptance quality limit, AQL, in percent nonconforming items and nonconformities per 100 items (normal inspection)																									
				0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
				Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A				⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇩	⇩	*	*	*	*	*	*	*	*	*
B	First	2	2	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	17 22	25 31
	Second	2	4																	1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27	37 38	56 57
C	First	3	3	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	17 22	25 31	⇧
	Second	3	6																1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27	37 38	56 57	
D	First	5	5	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	17 22	25 31	⇧	⇧
	Second	5	10														1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27	37 38	56 57		
E	First	8	8	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	17 22	25 31	⇧	⇧	⇧
	Second	8	16													1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27	37 38	56 57			
F	First	13	13	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧
	Second	13	26												1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27						
G	First	20	20	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	20	40											1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27							
H	First	32	32	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	32	64										1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27								
J	First	50	50	⇩	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	50	100									1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27									
K	First	80	80	⇩	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	80	160								1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27										
L	First	125	125	⇩	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	125	250								1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27											
M	First	200	200	⇩	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	200	400							1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27												
N	First	315	315	⇩	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	315	630						1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27													
P	First	500	500	⇩	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	500	1 000					1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27														
Q	First	800	800	*	⇧	⇩	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	800	1 600				1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27															
R	First	1 250	1 250	⇧	⇧	0 2	0 3	1 3	2 5	3 6	5 9	7 11	11 16	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	Second	1 250	2 500			1 2	3 4	4 5	6 7	9 10	12 13	18 19	26 27																

⇩ = Use the first sampling plan below the arrow. If sample size equals, or exceeds, lot size, carry out 100 % inspection.

⇧ = Use the first sampling plan above the arrow.

Ac = Acceptance number

Re = Rejection number

* = Use the corresponding single sampling plan (or alternatively use the double sampling plan below, where available).

Table 3-B — Double sampling plans for tightened inspection (Master table)

Sample size code letter	Sample	Sample size	Cumu-lative sample size	Acceptance quality limit, AQL, in percent nonconforming items and nonconformities per 100 items (tightened inspection)																									
				0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
				Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A				⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	*	*	*	*	*	*	*
B	First	2	2															*			0 2	0 3	1 3	2 5	4 7	6 10	9 14	15 20	23 29
	Second	2	4																		1 2	3 4	4 5	6 7	10 11	15 16	23 24	34 35	52 53
C	First	3	3														*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	15 20	23 29	⇧
	Second	3	6																	1 2	3 4	4 5	6 7	10 11	15 16	23 24	34 35	52 53	
D	First	5	5													*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	15 20	23 29	⇧	
	Second	5	10																1 2	3 4	4 5	6 7	10 11	15 16	23 24	34 35	52 53		
E	First	8	8												*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	15 20	23 29	⇧		
	Second	8	16															1 2	3 4	4 5	6 7	10 11	15 16	23 24	34 35	52 53			
F	First	13	13											*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧	⇧	⇧			
	Second	13	26														1 2	3 4	4 5	6 7	10 11	15 16	23 24						
G	First	20	20										*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧						
	Second	20	40													1 2	3 4	4 5	6 7	10 11	15 16	23 24							
H	First	32	32									*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧							
	Second	32	64												1 2	3 4	4 5	6 7	10 11	15 16	23 24								
J	First	50	50								*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧								
	Second	50	100											1 2	3 4	4 5	6 7	10 11	15 16	23 24									
K	First	80	80							*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧									
	Second	80	160										1 2	3 4	4 5	6 7	10 11	15 16	23 24										
L	First	125	125						*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧										
	Second	125	250									1 2	3 4	4 5	6 7	10 11	15 16	23 24											
M	First	200	200					*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧											
	Second	200	400								1 2	3 4	4 5	6 7	10 11	15 16	23 24												
N	First	315	315				*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧												
	Second	315	630							1 2	3 4	4 5	6 7	10 11	15 16	23 24													
P	First	500	500			*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧													
	Second	500	1 000						1 2	3 4	4 5	6 7	10 11	15 16	23 24														
Q	First	800	800		*	⇩		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧														
	Second	800	1 600					1 2	3 4	4 5	6 7	10 11	15 16	23 24															
R	First	1 250	1 250	*	⇧		0 2	0 3	1 3	2 5	4 7	6 10	9 14	⇧															
	Second	1 250	2 500				1 2	3 4	4 5	6 7	10 11	15 16	23 24																
S	First	2 000	2 000			0 2																							
	Second	2 000	4 000			1 2																							

⇩ = Use the first sampling plan below the arrow. If sample size equals, or exceeds, lot size, carry out 100 % inspection.

⇧ = Use the first sampling plan above the arrow.

Ac = Acceptance number

Re = Rejection number

* = Use the corresponding single sampling plan (or alternatively use the double sampling plan below, where available).

Table 3-C — Double sampling plans for reduced inspection (Master table)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptance quality limit, AQL, in percent nonconforming items and nonconformities per 100 items (reduced inspection)																									
				0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
				Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A				⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	⇩	⇩	*	*	*	*	*	*	*	*	*
B																	*	⇧			*	*	*	*	*	*	*	*	*
C																*	⇧	⇩		*	*	*	*	*	*	*	*	*	⇧
D	First Second	2 2	2 4												*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	7 11 18 19	11 16 26 27	⇧	
E	First Second	3 3	3 6											*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	7 11 18 19	11 16 26 27	⇧		
F	First Second	5 5	5 10										*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧	⇧	⇧			
G	First Second	8 8	8 16									*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧						
H	First Second	13 13	13 26								*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧							
J	First Second	20 20	20 40							*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧								
K	First Second	32 32	32 64						*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧									
L	First Second	50 50	50 100					*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧										
M	First Second	80 80	80 160				*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧											
N	First Second	125 125	125 250			*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧												
P	First Second	200 200	200 400		*	⇧	⇩		0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧													
Q	First Second	315 315	315 630	*	⇧			0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧														
R	First Second	500 500	500 1 000	⇧			0 2 1 2	0 3 3 4	1 3 4 5	2 4 5 6	3 6 7 8	4 7 10 11	5 9 12 13	⇧															

⇩ = Use the first sampling plan below the arrow. If sample size equals, or exceeds, lot size, carry out 100 % inspection.

⇧ = Use the first sampling plan above the arrow.

Ac = Acceptance number

Re = Rejection number

* = Use the corresponding single sampling plan (or alternatively use the double sampling plan below, where available).

Appendix D: Monte-Carlo simulation on AQL- script

```
Sub calcDefects()
   Dim i As Integer, j As Integer, k As Integer, l As Integer, m As Integer, n As Integer
   Dim NrDefects As Integer
   Dim DefectRate(1 To 4) As Double

   DefectRate(1) = 0.0065
   DefectRate(2) = 0.01
   DefectRate(3) = 0.015
   DefectRate(4) = 0.05

   For i = 1 to 4
           For j = 1 To 1000 ' Simulate 1,000 machines
           NrDefects = 0 ' Reset defect counter for each machine

           For n = 1 To 56 ' Check all critical parts in the machine Farmer & Speedy
                     If Rnd < DefectRate(i) Then
                     NrDefects = NrDefects + 1 ' Part failure
                     End If
          Next n
          Sheet1.Cells(j + 1, 1 + 2*(i-1)).Value = NrDefects 'Number of defective parts for this machine
          Sheet1.Cells(1, 1 + 2*(i-1)).Value = "AQL = " & DefectRate(i)
          Next j
   Next i
   For k = 1 to 4
           For l = 1 To 1000 ' Simulate 1,000 machines
           NrDefects = 0 ' Reset defect counter for each machine

           For m = 1 To 73 ' Check all critical parts in the machine Multi
                     If Rnd < DefectRate(i) Then
                     NrDefects = NrDefects + 1 ' Part failure
                     End If
          Next m
          Sheet1.Cells(l + 1, 9 + 2*(k-1)).Value = NrDefects 'Number of defective parts for this machine
          Sheet1.Cells(1, 9 + 2*(k-1)).Value = "AQL = " & DefectRate(i)
          Next l
   Next k
End sub
```

Appendix E: Implementation plan

This implementation plan outlines the steps to establish an effective quality control system for incoming goods at Bomech B.V. The plan aims to address inefficiencies caused by defective parts entering the production process. This plan integrates research findings and practical measures to create a system adjusted to Bomech's needs.

Phase 1: Preliminary steps

Stakeholder engagement

- Action: Organize initial meetings with stakeholders
- Goal: Finalize user requirements, inspection criteria, and desired acceptance levels.
- Outcome: A unified understanding of objectives and needs.
- Risks:
  - Misalignment of stakeholder expectations, leading to delayed approvals.
  - Resistance to change from employees unfamiliar with quality control measures.
- Risk mitigation: Clearly communicate objectives, benefits, and involve all relevant parties in decision-making.

Training and resources

- Action: Train staff on inspection techniques, sampling methods, and new tools (e.g., ERP software, scales).
- Resources needed:
  - Training materials for weight-based counting, ISO 2859-1 sampling plans and simple random sampling.
  - Access to ERP system and tools for incoming goods inspection.
- Outcome: A skilled workforce capable of executing the quality control plan effectively.
- Risk: Insufficient training may lead to errors during implementation.
- Risk mitigation: Allocate extra time for training sessions

Phase 2: Infrastructure setup

Inspection area design

- Action: Allocate space for a dedicated incoming goods inspection area.
- Goal: Ensure efficient workflow and compliance with inspection requirements.
- Outcome: Floorplan for the inspection area integrated into the current facility layout.
- Risks:
  - Limited space in the facility may lead to suboptimal workflow design.
  - Unexpected construction or setup delays.
- Mitigation: Perform a detailed space analysis early and use modular designs that can adapt to constraints.

Tool and equipment procurement

- Action:
  - Purchase high-precision scales for weight-based counting.
  - Provide laptops or tablets for accessing 3D models and drawings.
  - Procure basic tools like calipers and measuring tapes for dimension checks.
- Outcome: Fully equipped inspection area ready for use.
- Risks:
  - Delivery delays for key equipment.
  - Selection of tools that don't fully meet quality inspection requirements.
- Mitigation: Source equipment from multiple vendors and conduct detailed requirements analysis beforehand.

Phase 3: Implementation of inspection procedures

Standard Operating Procedures (SOPs)

- Action: Develop SOPs for:
    - Goods handling and quality checks.
    - Weight-based counting and sampling.
    - Documentation and defect reporting.
- Outcome: Clear guidelines for consistent and accurate inspections.
- Risks:
    - SOPs may be too complex for the staff to follow, leading to non-compliance.
    - Frequent updates to SOPs can create confusion.
- Mitigation: Keep SOPs simple, involve end-users in development, and conduct regular reviews.

Integration with ERP

- Action: Configure ERP to be able to:
    - Track incoming goods against purchase orders.
    - Document inspection results and who performed inspection.
- Outcome: Improved traceability and accountability in the inspection process.
- Risks:
    - Compatibility issues between ERP systems and new processes.
    - High reliance on IT support, which may not be directly available.
- Mitigation: Perform a detailed compatibility check and ensure IT support is available during integration.

Phase 4: Testing and calibration

Pilot phase

- Action: Conduct a pilot program to test:
    - Weight-based counting.
    - ISO 2859-1 single sampling plan.
    - ERP functionality
- Duration: 1 month.
- Outcome: Identify and resolve potential challenges.
- Risks:
    - Pilot results may not fully reflect production realities.
    - Resistance to testing new processes due to workload concerns.
- Mitigation: Run pilots under realistic conditions and schedule them during periods of lower production activity.

Feedback and adjustments

- Action: Collect feedback from employees on ease of use, efficiency, and accuracy.
- Outcome: Refined procedures and updated training as necessary.
- Risks:
    - Incomplete or biased feedback may lead to insufficient improvements.
    - Time constraints might limit the scope of adjustments.
- Mitigation: Use structured feedback mechanisms and prioritize critical issues.

Phase 5: Full-scale implementation

- Action:
    - Scale the inspection system across all incoming goods.
    - Monitor compliance with defined acceptance levels.
- Outcome: Full quality control across incoming goods.
- Risks:
    - Initial implementation may disrupt existing workflows.
    - Higher defect rejection rates initially could lead to supplier relationship challenges.

- Mitigation: Shock rollout and communicate expectations clearly and early to suppliers.

Monitoring and evaluation

- Action:
    - Implement key performance indicators (KPIs) such as defect rates and inspection time.
    - Conduct periodic audits to ensure adherence to SOPs.
- Outcome: Continuous improvement in quality control measures.
- Risks:
    - Inadequate data collection may hinder effective monitoring.
    - KPIs may not be well-defined or actionable.
- Mitigation: Define KPIs early and automate data collection where possible.

Timeline and milestones

- Month 1-2: Stakeholder meetings, training, and resource procurement.
- Month 3: Infrastructure setup and SOP finalization.
- Month 4: Pilot phase and adjustments.
- Month 5: Full-scale rollout and monitoring.

This implementation plan provides a structured guide to implement a quality control system for incoming goods at Bomech B.V. By addressing inefficiencies and implementing solutions that fit , the plan aims to improve productivity and reduce the defect rate.